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

By

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Scale 1:24,000

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EXECUTIVE SUMMARY

The Navajo Peak quadrangle is located in the Chama Basin of north-central New Mexico. The Rio Chama and the Chama River Canyon Wilderness bisect the map area. The eastern edge of the Gallina Mountain dome, where Permian to Cretaceous rocks dip 20–60° east, forms the western boundary of the quadrangle. For the most part, the Triassic to Cretaceous sedimentary rocks in the area to the east of the dome are gently deformed by broad folds 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 downcutting of the Rio Chama.

One discovery made during the creation of the geologic map of the Navajo Peak quadrangle was the identification of rounded lag gravels that discontinuously cap the highest surfaces on mesas adjacent to the Rio Chama. In general, these deposits include clasts of Proterozoic quartzite, metaconglomerate, granite, gneiss, schist, and pegmatite that are 1 to 30 cm in diameter. One deposit on a point overlooking the Rio Chama, 335 m (1100 ft) above the river between Dark Canyon and Mine Canyon, contains andesitic and basaltic clasts. Locating the source of these lag gravels is an ongoing research topic with implications for understanding Quaternary landscape evolution along the Rio Chama.

The regional-scale correlation of the red rock unit, which lies between the top of the Jurassic Todilto Formation and the Westwater Canyon Member of the Jurassic 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 Formation and Bluff Sandstone, which are exposed in Utah. *Allosaurus* tracks are preserved in this red unit in Dark Canyon. Notably, this red unit consists of well-cemented, stacked channel sandstones along the northern edge of the quadrangle and becomes progressively siltier with weakly cemented sandstones to the south. This north–south facies change may represent a transition from the sandy, megafan Salt Wash Member of the Morrison Formation to the north and the floodplain Recapture Member of the Morrison to the south. This facies change may impact the productivity of groundwater aquifers in this unit.

The cover photo was taken looking south (down the Rio Chama) from the top of the Cretaceous Burro Canyon Formation cliffs just south of Dark Canyon.

Introduction
This report accompanies the *Geologic Map of the Navajo Peak 7.5-minute Quadrangle, Rio Arriba County, New Mexico* (Goughnour et al., 2025; 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 30’x60’ map sheet at a 1:100,000 scale. An appendix with a full description of map units is presented at the end of this report.

Location and Geologic Setting
The Navajo Peak quadrangle in Rio Arriba County is located about 40 km (25 mi) northwest of Abiquiu and is about 20 km (12.5 mi) from Ghost Ranch, NM. The map area covers the northern portion of the Chama River Canyon Wilderness. Two major rivers drain the map area: the south-flowing Rio Chama and the southeast-flowing Rio Gallina, which is a tributary of the Rio Chama. There are several smaller, intermittent, east-west drainages and slot canyons that flow into the Rio Chama, including Dark Canyon, Mine Canyon, Huckbay Canyon, and the Rio Cebolla, which we use as geographic reference points throughout the report. Other prominent landmarks used as references throughout this report include (from north to south) the Hogback, Navajo Peak, Poso Spring, Mesa Golondrina, and Mesa de las Viejos (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. The north end of the Gallina-Archuleta anticlinorium, a northward extension of the Sierra Nacimiento Laramide highland, forms the western border of the quadrangle and separates the Chama Basin from the San Juan Basin (Woodward, 1974). Sedimentary bedrock in the map area ranges in age from Permian 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.

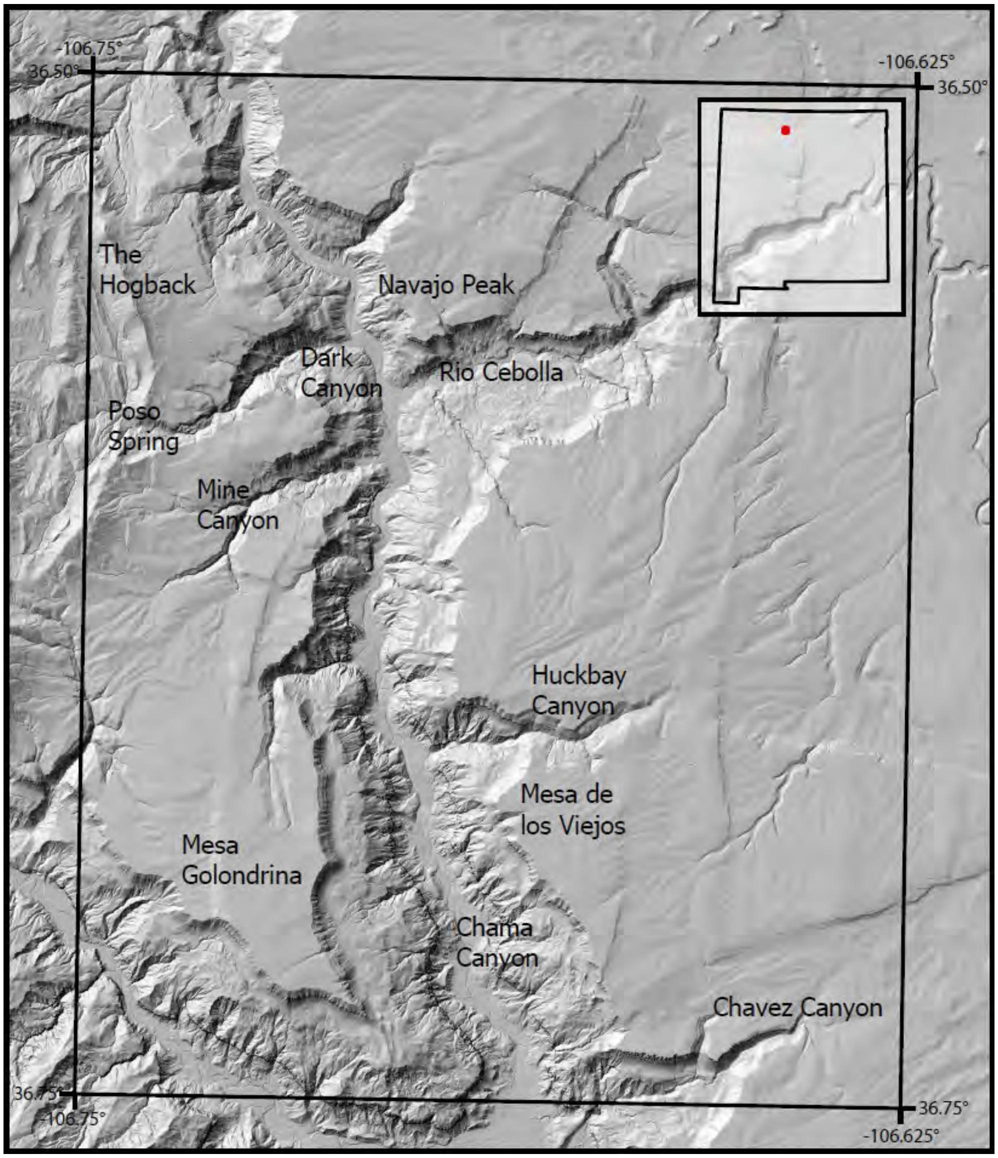

Figure 1. Geographic location map of the Navajo Peak quadrangle. The red box in the inset map shows the regional location of the quadrangle.

PREVIOUS WORK

The mapped area is included on the regional-scale geologic maps of Bingler (1968; scale 1:126,720) and Manley et al. (1987; scale 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 (scale 1:48,000) of the Chama River Canyon Wilderness that covers most of the Rio Chama and Gallina Canyon portions of the quadrangle. Ridgley et al. (1988) assessed mineral resources of the Rio Chama Wilderness Study area in the northern part of the quadrangle, north of Cebolla Canyon and east of the Rio Chama. 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 are, 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 unit just above the Todilto Formation called the Wanakah Formation that is composed of yellow to white sandstone, black shale, and limestone. The Wanakah Formation 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. Lucas et al. (2005) apply these names to Jurassic rocks below the Brushy Basin Member of the Morrison Formation and above the Todilto Formation exposed in the vicinity of Ghost Ranch. The Westwater Canyon Sandstone is not exposed at Ghost Ranch. The stratigraphic chart of Lupe (1983) shows that both the Bluff Sandstone and the Summerville Formation 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 call the red unit above the Todilto Formation the Recapture Member of the Morrison Formation. Like Ridgley and Light (1983), we recognize a significant facies change from north to south across the quadrangle in this lowest member of the Morrison Formation. Along the northern boundary of the quadrangle, the lowest unit is dominated by stacked pink sandstones with little floodplain material. Sandstone with some mudstone forms the section down to a latitude that is about 1 km north of Huckbay Canyon (Fig. 1). South of that point, maroon and red floodplain mudstone is intercalated 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 Member megafan grades laterally southward into the Recapture Member (Fig. 3).

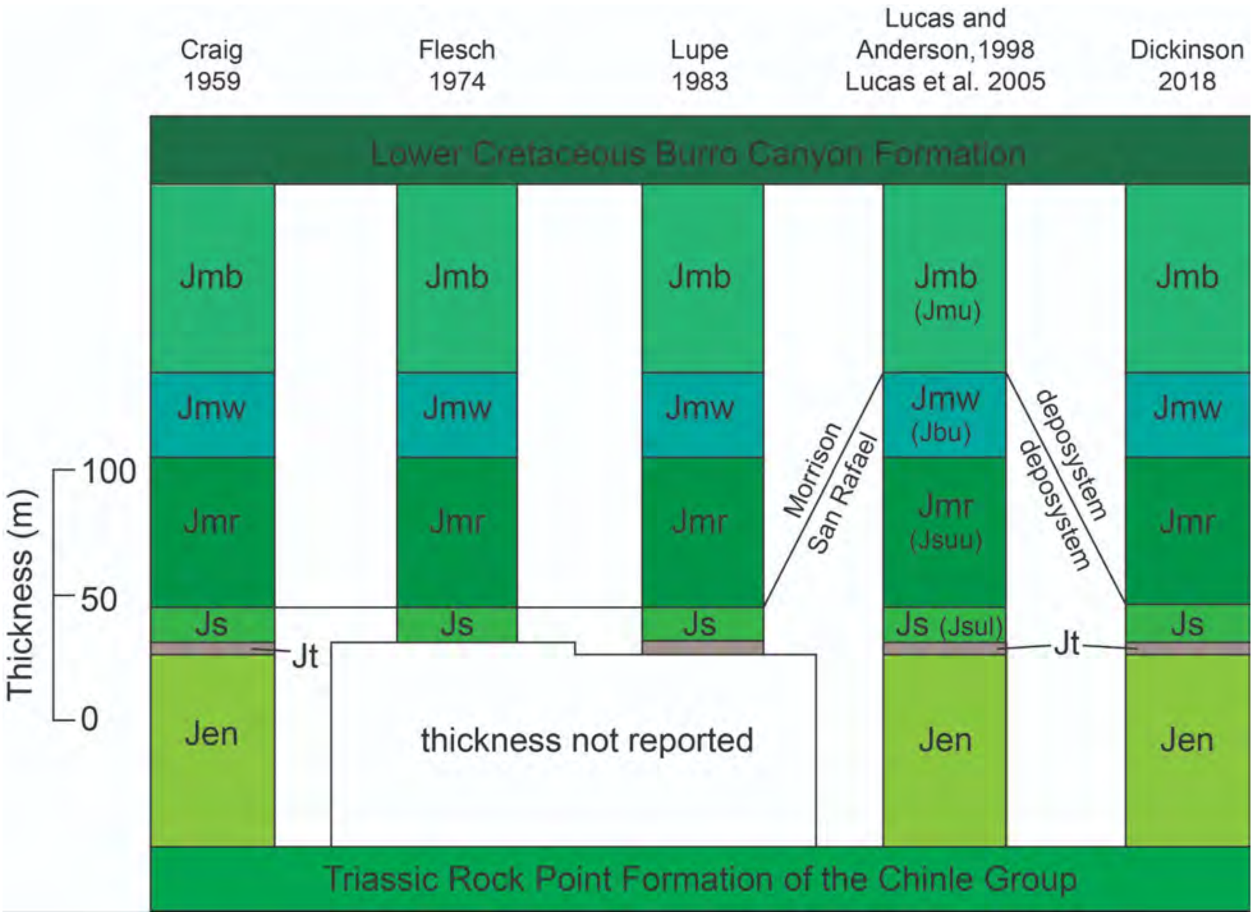

Figure 2. Correlation chart of the Jurassic section exposed at Ghost Ranch, which is located about 15 km (9 mi) east of the quadrangle (modified from Dickinson, 2018). The abbreviations in parentheses are based on the terminology used by Lucas and Anderson (1998). Jen= Entrada Sandstone; Jt=Todilto Formation, Js=Summerville Formation; Jsul=lower Summerville Formation; Jsuu=upper Summerville Formation; Jmr=Recapture Member and Morrison Formation; Jmw=Westwater Canyon Member and Morrison Formation; Jbu=Bluff Sandstone; Jmu=undifferentiated Morrison; Jmb=Brushy Basin Member and Morrison Formation.

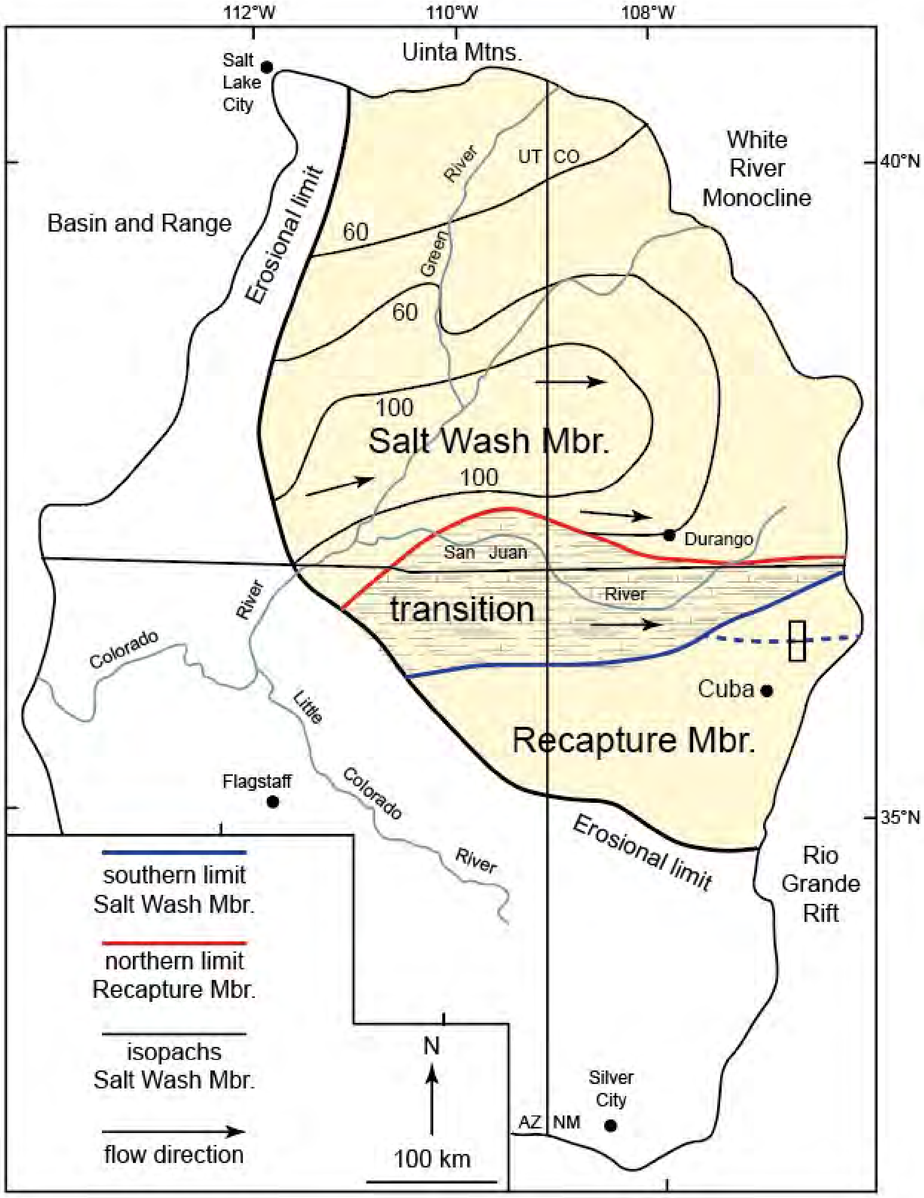

Figure 3. Paleogeographic reconstruction of the depositional environments during early Morrison time (modified from Dickinson, 2018). The rectangle shows the location of our study area (Navajo Peak [north] and Laguna Peak [south] quadrangles) and the dashed line shows the proposed adjustment of the southern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

MAPPING METHODS

The Burro Canyon Formation and the Entrada Sandstone cliffs were major obstacles to accessing the Chama River Canyon Wilderness on foot within much of the quadrangle; therefore, rafts were used to map the main river corridor. 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 (NAIP) in May 2022. In the field, locations of geologic-point data were primarily obtained using a handheld GPS unit or by referring to contours on a topographic map. Contacts and faults were drawn onto base maps that showed topography using contour lines and hill shading. 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 Navajo Peak 7.5-minute quadrangle are presented in the appendix at the end of the report.

Permian Period

Permian strata in the map area consist of basal, reddish, poorly sorted, arkosic sandstones/conglomerates and upper, red siltstones of the Cutler Formation (Fig. 4). Prior to the Permian period, a shallow sea covered the map area and deposited limestones that are not exposed in the quadrangle (the limestone is exposed 700 m west of the western boundary). Starting around 300 Ma, the shoreline of this sea retreated southward and the Cutler Formation was deposited by a south-flowing network of rivers. The lower part of the Cutler Formation contains cobbles and pebbles of Proterozoic quartzite and granite that were likely derived from the Ancestral Rocky Mountain Uncompahgre uplift to the northeast. As the climate started to dry during the early Permian, siltstone was deposited in the upper Cutler Formation.

Figure 4. Conglomeratic sandstone of the Permian Cutler Formation.

Triassic

An unconformity spanning 47 million years is present between the Cutler Formation and the Late Triassic Chinle Group, which consists of a thick package of red siltstone and mudstone, as well as white to tan sandstones. Rocks of the Chinle Group 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 Agua Zarca Sandstone marks the beginning of Chinle Group deposition and is characterized by a white, poorly sorted, coarse-grained quartz sandstone that locally contains abundant quartzite pebbles and cobbles. The Agua Zarca Sandstone is thin (<2 m) to absent in the Llaves 15-minute quadrangle to the west of the map area and is not exposed in the Navajo Peak quadrangle due to faulting. The upper contact of the Agua Zarca Sandstone is conformable with the green-gray and maroon shale and sandstone of the overlying Salitral Formation, which is poorly exposed in the vicinity of Poso Spring.

The Poleo Formation overlies, and often scours, the Salitral Formation and consists of yellowish-gray, micaceous sandstone with conglomeratic lenses of intrabasinal siltstone and calcrete clasts. The Poleo Formation is only exposed in the map area west of the Hogback, near Poso Spring. The unit grades into the overlying Petrified Forest Formation, which contains two members: 1) a lower, transitional, discontinuous, thinly bedded sandstone of the Mesa Montosa Member, and 2) a thick red to reddish-brown mudstone of the Painted Desert Member. The overlying Rock Point Formation (Lucas et al., 2005) is the youngest unit within the Chinle Group and primarily contains levee and floodplain deposits of red siltstones (Fig. 5). The Rock Point Formation and the Petrified Forest Formation make up the combined upper Chinle Group unit (**TRcu**) within the Chama Canyon in the southern portion of the quadrangle.

Figure 5. Photo of Chama Wall. The upper part of the Painted Desert Member of the Petrified Forest Formation is exposed just above the river. The lower and upper contacts of the Rock Point Formation are shown as white lines.

Jurassic Period

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 Entrada Sandstone was deposited (Imlay, 1980; Lucas et al., 1985). The Entrada Sandstone forms prominent red, yellow, and white cliffs along the Rio Chama (Figs. 5 and 6) and within the Hogback along the western edge of the map area. 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, toward the south to southwest (Tanner, 1965).

Cliffs of the Entrada Sandstone are capped by the Todilto Formation (Fig. 6), which consists of a basal limestone and shale unit (the Luciano Mesa Member) and, in places, up to 60 m (197 ft) of gypsum (the Tonque Arroyo Member). The Todilto Formation was likely deposited in a coastal body of saline water that was separated from the Jurassic-aged 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 is a thinly laminated kerogenic limestone. As evaporation within the closed Todilto basin continued, the system transitioned from calcium-carbonate to calcium-sulfate precipitation, leading to the deposition of the gypsiferous Tonque Arroyo Member (Anderson and Kirkland, 1960). Fossil evidence suggests that the Todilto Formation was deposited during the early to middle Callovian (Lucas et al., 1985).

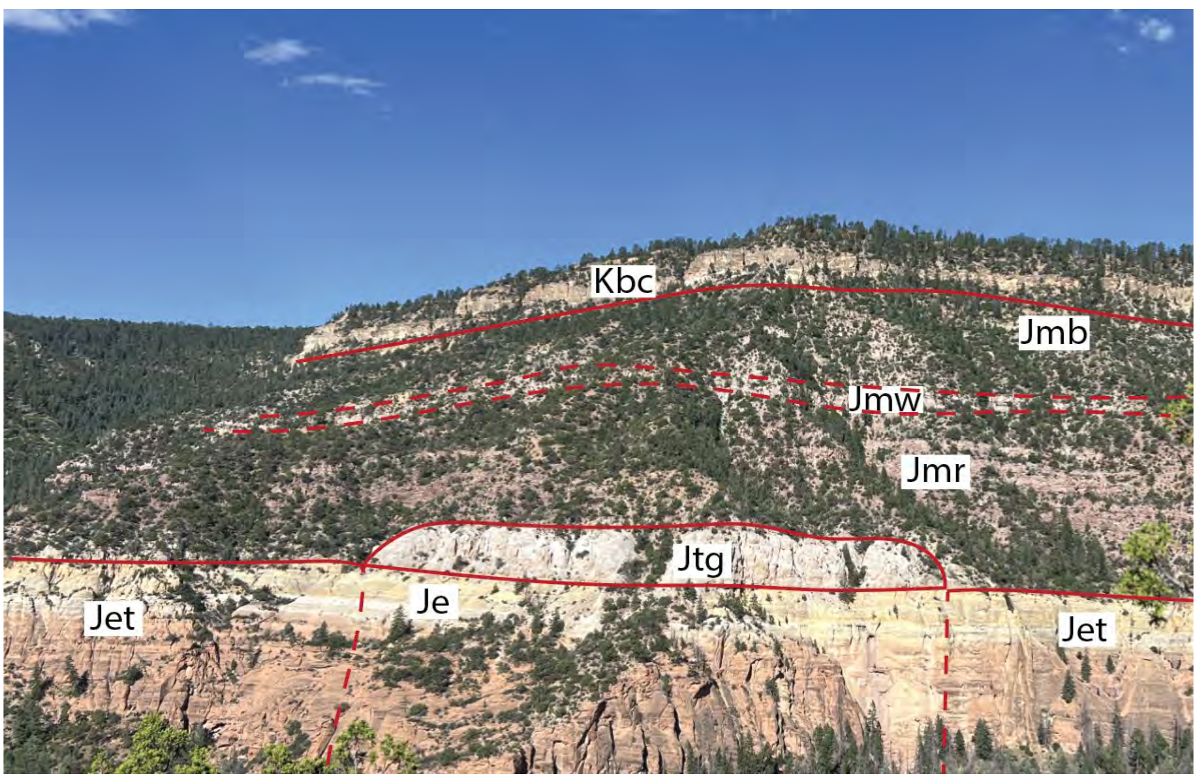

Figure 6. An annotated photograph of Jurassic and Cretaceous strata in the canyon carved by the Rio Chama. Note the discontinuous nature of the gypsiferous Tonque Arroyo Member of the Todilto Formation (unit Jtg). The Todilto Formation and Entrada Sandstone are mapped as Je, Jet, and Jtg depending on the presence and mappability of the gypsum unit; where gypsum is absent, the Todilto Formation and Entrada Sandstone are mapped as one unit (Jet).

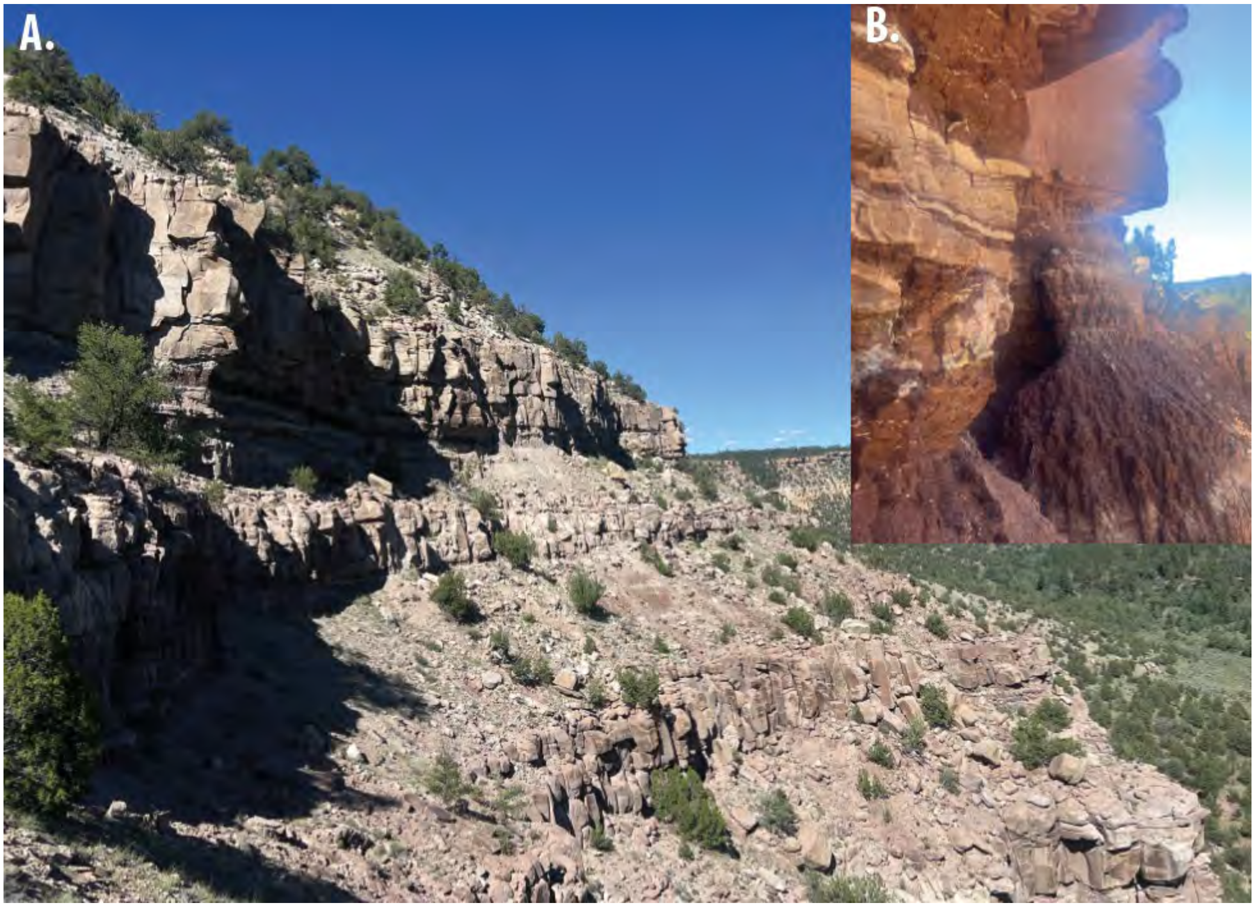

Figure 7. A) Resistant sandstone benches and slope-forming mudstone intervals within the Recapture Member of the Morrison Formation. B) Close-up view of the distinctly reddish-pink mudstones, siltstones, and sandstones that make up the Recapture Member. Photos taken looking north from Dark Canyon.

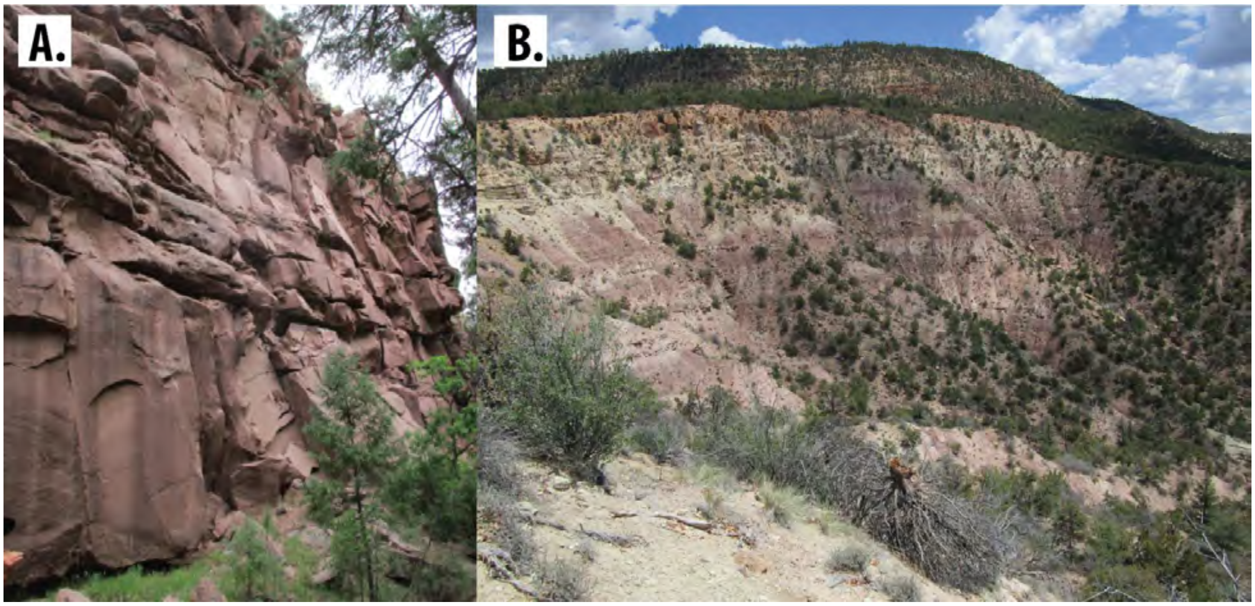

Figure 8. (A) Stacked channels in the Recapture Member of the Morrison Formation. Photo taken in Mine Canyon, in the northern part of the quadrangle. (B) Silty and poorly cemented sandstone in the Recapture Member. Photo taken above the Rio Gallina, along the southern edge of the quadrangle.

Deposition of the Morrison Formation marks a time of major plate tectonic reorganization in the southwestern United States, as well as a shift from an arid to a more humid climate in the region (Lucas and Anderson, 1998). At the start of Morrison Formation deposition, the area that is now northwestern New Mexico was at latitudes between 35° N and 38° N, which triggered arid conditions and contributed to eolian deposition in the Recapture Member (Figs. 7 and 8). In the Navajo Peak quadrangle, the Recapture Member consists of red, maroon, and white sandstone with little mudstone, and becomes more mudstone-dominated south of Huckbay Canyon (Fig. 8; see 'Previous Work' for a more in-depth discussion on facies changes within the Recapture Member). South of Huckbay Canyon, maroon and red floodplain mudstone is intercalated 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). Later, the Westwater Canyon and Brushy Basin members were deposited in more humid conditions at latitudes between 45° N and 48° N. 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. 6 and 9). The Westwater Canyon Member is overlain by the Brushy Basin Member, which consists of pistachio-green and pink mudstone with interbedded tan sandstone beds (Fig. 6 and 10). 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 the Recapture and Brushy Basin members, most of the Quaternary landslide failures originate from these units within the map area (Chesnutt et al., 2019)

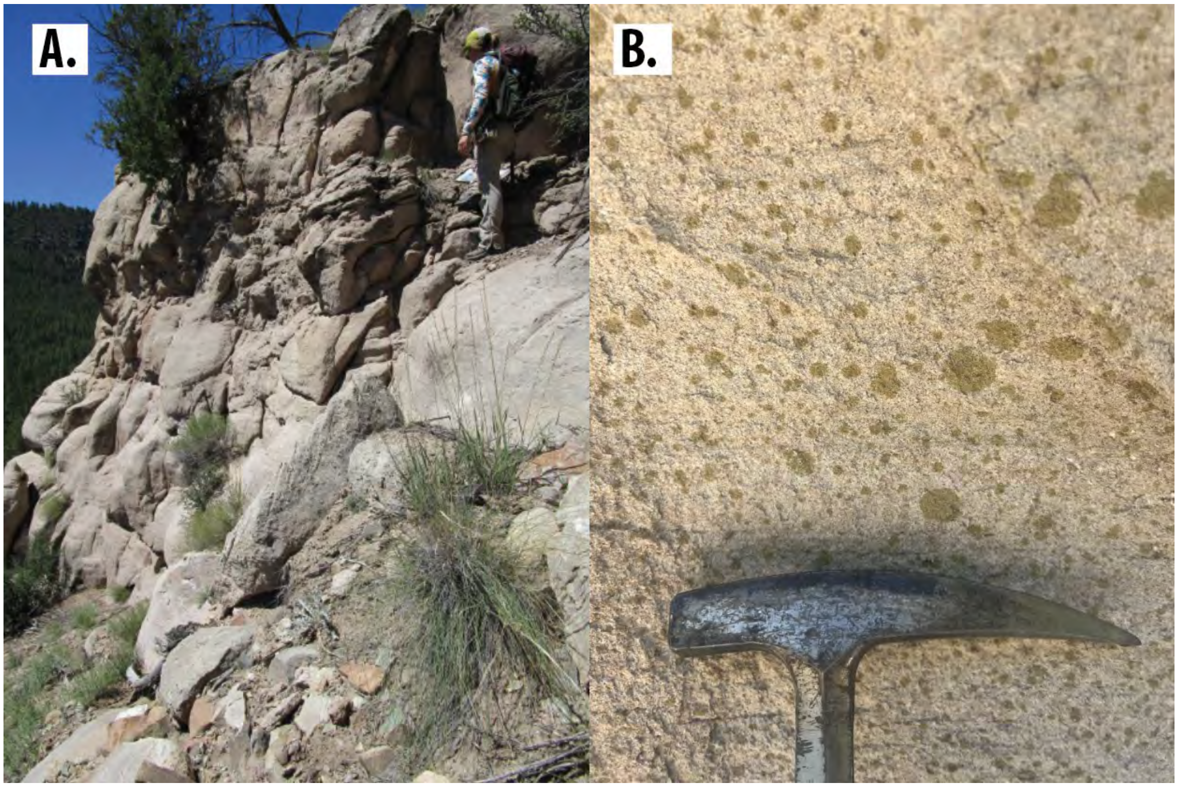

Figure 9. A) Outcrop of the Westwater Canyon Member of the Morrison Formation. B) Close up view of the Westwater Canyon Member. Note the distinctive yellowish-green splotches on the sandstone. Photos taken in the north part of the map area on the west side of the Chama Canyon.

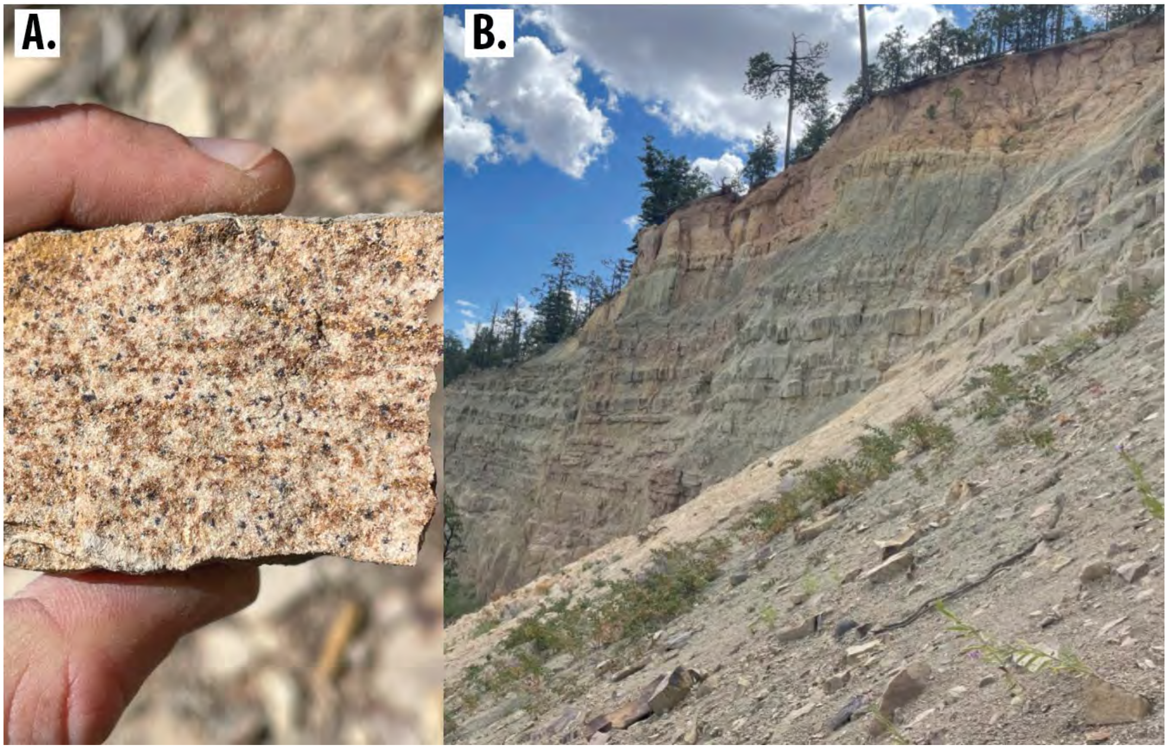

Figure 10. A) Close up view of a sandstone within the Brushy Basin Member of the Morrison Formation. Note the distinctive red-orange oxidized speckles. B) Brushy Basin Member exposed in a cliffy landslide scarp south of Navajo Peak quadrangle in the adjacent Laguna Peak quadrangle.

Cretaceous Period

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. The Burro Canyon Formation (Fig. 11) 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).

Figure 11. Outcrop of the Burro Canyon Formation. Note the light-tan to white color of the sandstone and the distinctive low-angle cross-beds.

The overlying Dakota Sandstone consists of interbedded tan to yellow-brown sandstone and dark-gray carbonaceous shale and siltstone and represents an overall marine transgression (relative sea-level rise) and expansion of the Western Interior Seaway (Varney, 2005). The lowest most Encinal Canyon Member of the Dakota Sandstone (Fig. 12) represents a transition from terrestrial facies to shallow, tide-dominated and open-marine, wave-dominated marine environments (Varney, 2005). Carbonaceous plant debris is preserved in the Encinal Canyon Member. Symmetric ripples are common throughout the Dakota Sandstone (Fig. 13), and asymmetric ripples are present in the Encinal Canyon Member. Outcrops of the overlying Cubero Tongue and Paguate Tongue sandstone outcrops are locally cross-bedded and commonly bioturbated (Fig. 14). Both the Clay Mesa Tongue of the Mancos and Paguate Member of the Dakota thin southward in the Chama region (Owen et al., 2005), particularly in the poorly exposed areas near the boundary between the Navajo Peak and El Vado quadrangles.

Toward the top of the Dakota Sandstone, sandstone members are separated by thin tongues of Mancos Formation shale. These intervening beds transition into the more substantial Graneros Shale of the Mancos Formation above the Dakota Sandstone and represent the start of a major marine transgression. The overlying Greenhorn Limestone was deposited around 93 Ma and represents sea-level peak (Nummedal, 2004).

Figure 12. Outcrop of the Encinal Canyon Member of the Dakota Sandstone. Note the thin interbeds of light-gray shale and mudstone. Photo taken at the southern tip of Mesa Golondrina.

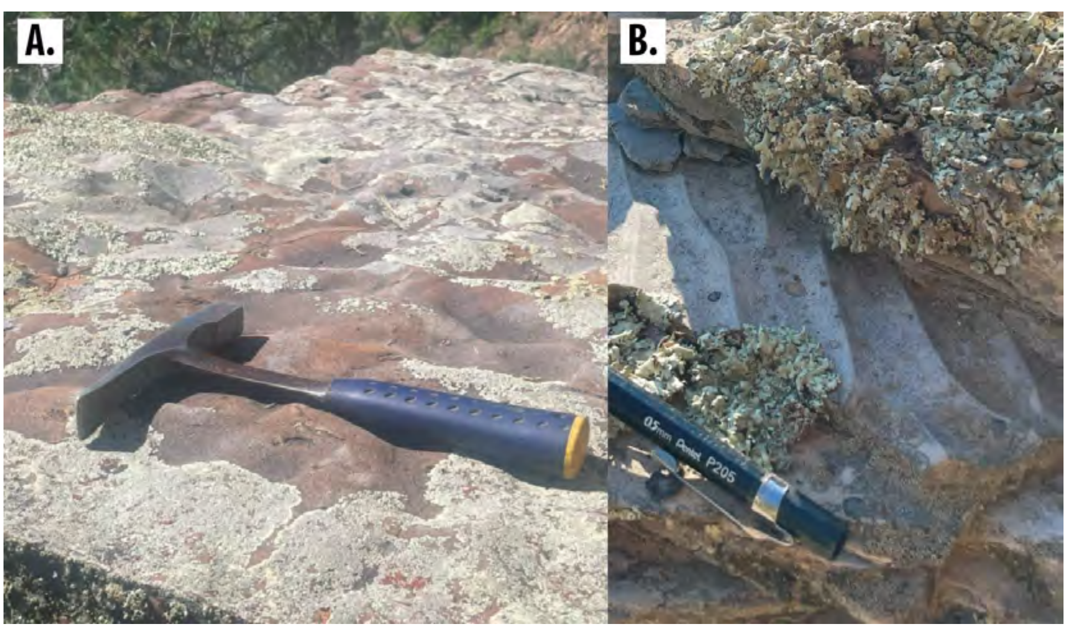

Figure 13. Examples of symmetrical ripples in the Dakota Sandstone. A) “Tadpole nest” interference ripples in an upper Dakota Sandstone member. B) Linear, symmetric, wave-formed ripples in the Encinal Canyon Member.

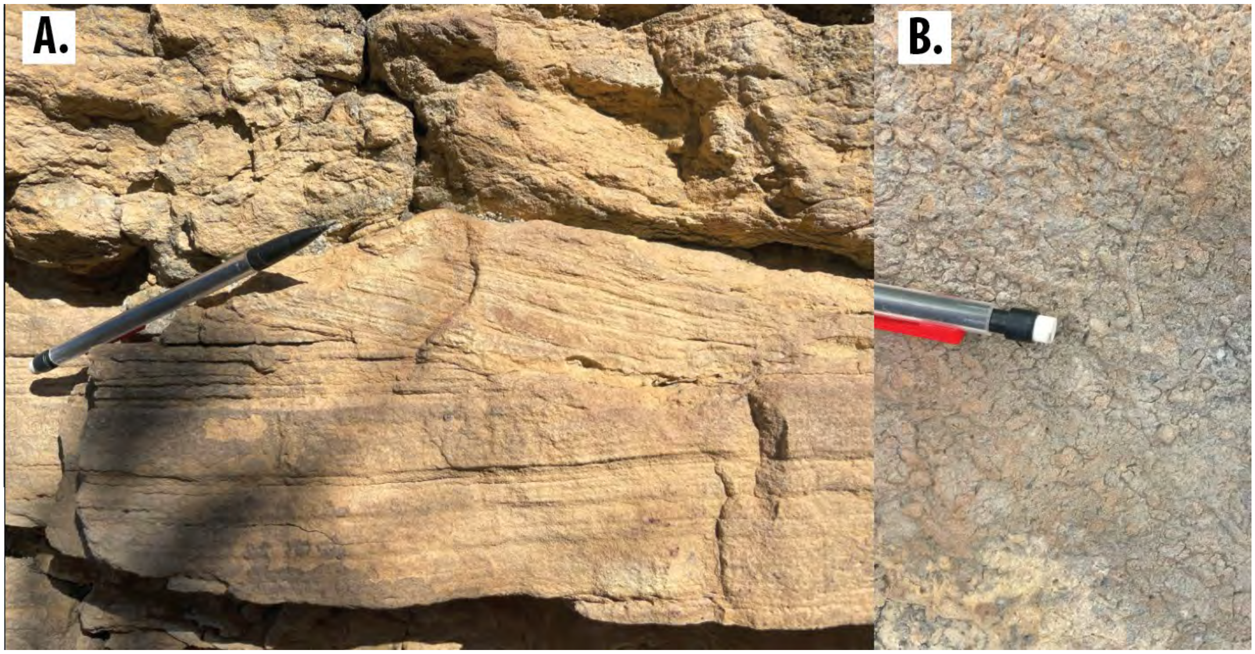

Figure 14. A) Example of cross-bedding in the Dakota Sandstone. B) Example of bioturbation in the Dakota Sandstone.

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. The 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 from an aggradational 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 brief periods of stability during a period of overall incision. Along the Rio Gallina, older and intermediate terraces (Qao and Qai) are 5–15 m (16–50 ft) above the modern grade. Terraces along the Rio Chama are not well-preserved in the map area due to the narrow, rocky nature of this section of the Rio Chama canyon. We map 2.5–4.5 m terraces as younger (**Qay**), and an approximately 9 m terrace in the northern portion of the canyon as intermediate (**Qai**). 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 canyon's response to rapid incision and oversteepening.

GEOLOGIC STRUCTURES

The Navajo Peak quadrangle is situated on the eastern limb of the Gallina-Archuleta anticlinorium, which consists of three structural domes. The west side of the quadrangle is characterized by strata dipping steeply to the east (35–47°) on the east flank of the northernmost Gallina Peak dome. East of this structure, toward the center of the map area, these strata flatten out and generally dip more shallowly, except where perturbed by local faulting. The fault responsible for the deformation, the Tierra Montañosa fault (Fig. 15), is exposed on the adjacent Llaves 15-minute quadrangle (Kelley et al., 2024). Two faults that are related to the folding of the Gallina Peak dome cut the rim of the dome. One NE-striking fault near Poso Spring juxtaposes the Poleo Sandstone and Mesa Montosa Member of the

Petrified Forest Formation of the Chinle Group against Entrada Sandstone. Also, near Poso Spring, a second small-displacement, NW-striking fault offsets the top of the Entrada Sandstone down to the north.

To the east of the dome, faulting is distributed across the entirety of the map area and is kinematically normal, strike-slip, or oblique-slip. One grouping of faults is approximately N-striking (0–30°) and another grouping is either ESE-striking or ENE-striking (65–120°; see the geologic map). Examples of ESE-striking faults are shown in Figure 16. In most instances, the N-striking faults seem to terminate the E-striking faults, although this relationship is sometimes cryptic. Based on this general cross-cutting relationship, it is likely that the approximately E-striking faults are older and associated with the formation of the Gallina-Archuleta anticlinorium during Laramide compression. The N-striking faults formed later and are likely associated with a tectonic shift from Laramide compression to overall extension in the late Oligocene to early Miocene. Both fault-sets locally perturb regional dips and create small-scale folds in some areas, such as the anticline in the northeast portion of the quadrangle.

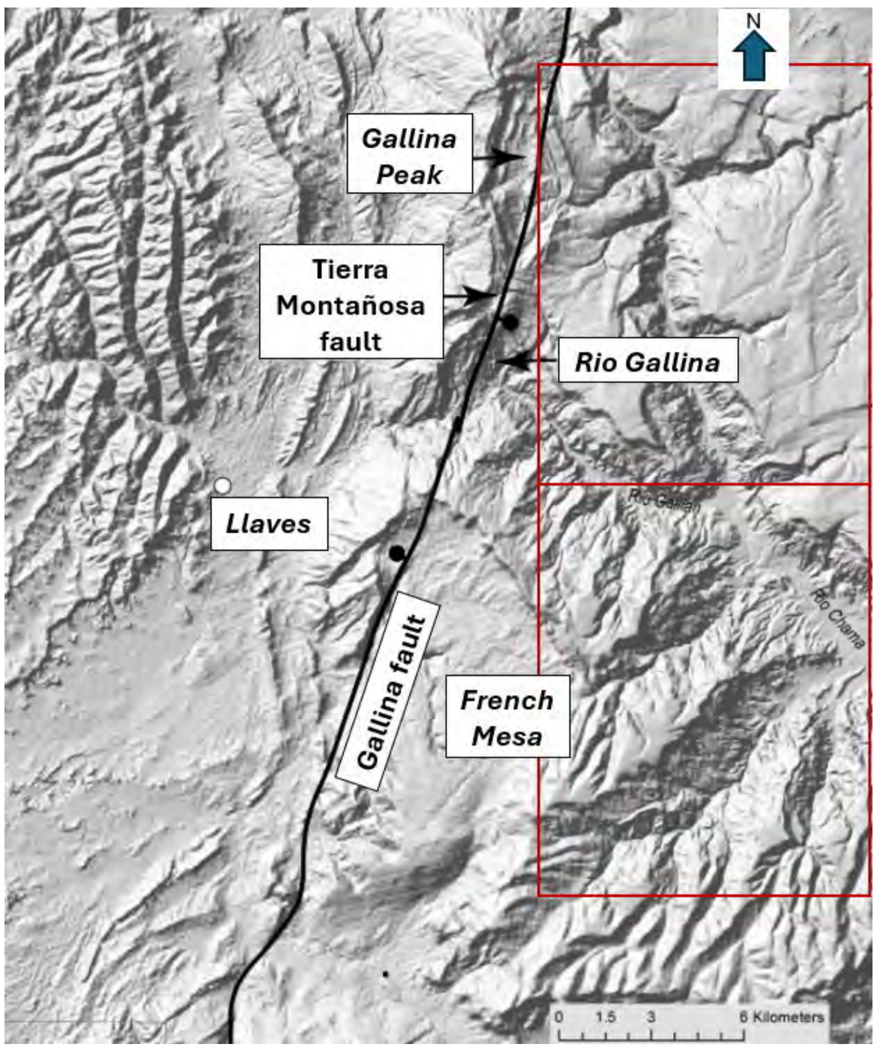

Figure 15. Hillshade map showing the location of the Tierra Montañosa fault, which runs along the very northeast boundary of the Navajo Peak quadrangle (northern quadrangle).

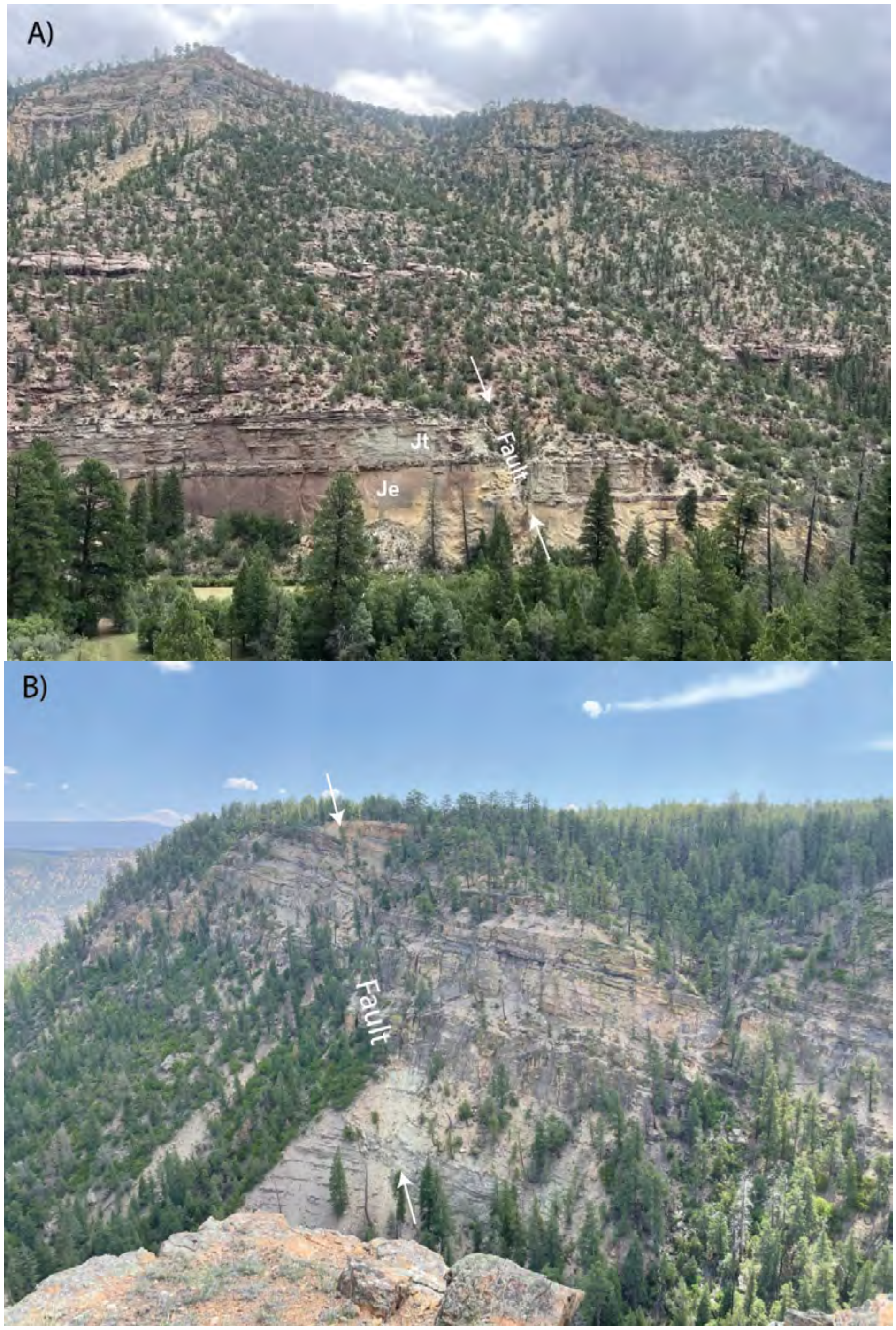

Figure 16. A) Annotated photograph of fault-terminated beds of Entrada Sandstone (**Je**) and Todilto Formation (**Jt**) in the northern portion of the Navajo Peak quadrangle. This fault is E-striking and bounds the north side of Navajo Peak. The photograph was taken looking east across the Rio Chama. B) Annotated photograph of an E-striking fault terminating beds of Cretaceous and Jurassic strata. The photo was taken looking south across Dark Canyon.

QUATERNARY-NEOGENE TERRACE GRAVELS

Lag deposits of Quaternary-Neogene terrace gravels (unit **QNg**) are found across the map area, specifically on the eastern and western edges of the Rio Chama canyon. Unit **QNg** consists of concentrated pebble- to small-boulder-gravels (Fig. 17). Similar lag deposits have been identified further to the west near the Rio Gallina and its tributaries (Kelley et al., 2024). Gravel clasts are primarily quartzites, volcanics, and metaconglomerates, with lesser granites, schists, and gneisses. Deposits are found up to 330 m (1,080 ft) above the modern Rio Chama grade, and matching deposits on either side of the river suggest previous continuity.

Quartzite and metaconglomerate clasts are likely sourced as recycled clasts from the Eocene El Rito Formation in the Tusas Mountains, approximately 40 km (25 mi) east of the map area. Volcanic clasts are primarily andesite-basalt lithologies and may be sourced from the Brazos lava flows (approximately 250 ka [Lipman and Mehnert, 1979]; approximately 200 ka [Zimmerer, 2024]), but further analyses are needed to confirm the source of these clasts.

Figure 17. Quaternary terrace lag deposit on Mesa Golondrina.

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Appendix

NAVAJO PEAK DMU
CENOZOIC
QUATERNARY

Anthropogenic

daf Disturbed and artificial fill—
Unconsolidated clay, silt, and fine sand associated with agriculture at the Monastery. The unit contains alluvial, eolian, and slope wash input. The unit is estimated to be 2–3 m thick.

Alluvial Deposits

Qar Recent alluvium—
Unconsolidated clay, silt, sand, gravel, and cobbles in active channels and floodplains. The unit also includes the lowest terraces, which are found 0–2 m above modern channel grade. The unit is approximately 1–2 m thick.

Qay Younger alluvium—
Unconsolidated clay, silt, sand, gravel, and cobbles that form an inactive alluvial terrace surface 2.5–4.5 m above channel grade. The unit is approximately 2–4 m thick.

Qai Intermediate alluvium—
Unconsolidated clay, silt, sand, gravel, and cobbles that form an inactive alluvial terrace surface 4–7 m above channel grade. The unit is approximately 4–7 m thick.

Qao Older alluvium—
Unconsolidated clay, silt, sand, gravel, and cobbles that form an inactive alluvial terrace surface greater than 8 meters above channel grade. The unit is at least 8 m thick.

Qaf Alluvial fan—
Unconsolidated clay, silt, sand, pebbles, cobbles, and boulders deposited by debris-flow events and sheetwash. The unit forms fan shapes at the bases of steep channels. Deposits grade into and interfinger with adjacent Quaternary deposits. Occasionally incised by active channels. Deposits are approximately 3 m thick.

QNg Terrace gravel—
Short
Unconsolidated lag deposit of pebble- to cobble-gravel that discontinuously caps the highest surfaces on mesas bounding the Rio Chama. Clasts are subrounded to subangular and 1–30 cm (mostly 10–20 cm). Clast lithologies include quartzite (primary), metaconglomerate, granite, gneiss, schist, and pegmatite; andesite occurs in some deposits.
Long
Unconsolidated lag deposit of pebble- to cobble-gravel that discontinuously caps the highest surfaces on mesas bounding the Rio Chama. Clasts are subrounded to subangular and 1–30 cm (mostly 10–20 cm). Clast lithologies include quartzite (primary), metaconglomerate, granite, gneiss, schist, and pegmatite. Andesitic clasts make up 24% of the clast population on a point overlooking the

Rio Chama 335 m (1,100 ft) above the river between Dark Canyon and Mine Canyon. The andesite clasts are crystal-rich with about 25% plagioclase phenocrysts 1–3 mm long and about 3% altered pyroxene 3–5 mm long in a black, aphanitic matrix. A few clasts of aphanitic basalt were also observed. The basalt near the Brazos cliffs to the east in the Tusas Range could be a source for the gravels observed in the map area. Lag deposits are generally less than one meter thick. In the northwest part of the quadrangle (section 15, T. 26 N., R. 2 E.) the gravel is at least 12 m thick.

Slope Wash, Alluvial, and Eolian Deposits

Qas Alluvium and slope wash—

Unconsolidated clay, silt, sand, and gravel deposited by alluvial channels and minor slope wash into valley bottoms. The unit sometimes includes eolian and colluvial deposits and is commonly adjacent to and interfingering with **Qsa**. The unit is estimated to be 1–5 m thick.

Qsa Slope wash and alluvium—

Unconsolidated clay, silt, sand, and gravel deposited by slope wash and minor alluvial channels into small basins and on hillslopes. The unit forms smooth, sloped topography with nonexistent to shallowly incised channels and sometimes includes eolian and colluvial deposits. The unit is estimated to be 1–5 m thick.

Qse Slope wash and eolian—

Short

Unconsolidated clay, silt, and sand deposited in small depressions on landslide features. Unit contains sheet-flow sediments sourced from hillslopes as well as windblown sediments. Eolian transportation is indicated by either subdued dune forms, or a thin veneer of well-sorted, silt to very fine-grained sand deposited at the surface. Unit exhibits a bumpy texture in lidar imagery. Unit is up to 3 m thick.

Long

Unconsolidated clay, silt, and sand deposited in small depressions on landslide features. The unit contains sheet-flow sediments sourced from hillslopes as well as windblown sediments. Eolian transportation is indicated by either subdued dune forms or a thin veneer of well-sorted, silt to very fine-grained sand deposited at the surface. The unit exhibits a bumpy texture in lidar imagery. The unit is up to 3 m thick.

Mass-wasting Deposits

Qc Colluvium—

Unconsolidated boulders, cobbles, pebbles, sand, silt, and clay that form 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. The unit is approximately 1–20 m thick.

Qls Landslides, undivided—

Short

Unconsolidated sand, silt, clay, pebbles, cobbles, and boulders deposited by rock falls, earth and debris flows, and rotational and translational landslides. The unit commonly displays landslide scarps, lateral margins, and toes. Deposits contain jumbled, locally derived rock types and lack obvious relative-age relationships. Estimated to be up to 45 m thick.

Long

Unconsolidated sand, silt, clay, pebbles, cobbles, and boulders deposited by rock falls, earth and debris flows, and rotational and translational landslides. The unit contains minor colluvial, slope wash, and alluvial input. The unit commonly displays landslide scarps, lateral margins, and landslide toes. Deposits contain jumbled, locally derived rock types and lack obvious relative-age relationships. The unit is estimated to be up to 45 m thick.

Qlsy Younger landslides—

Short

Unconsolidated sand, silt, clay, pebbles, cobbles, and boulders deposited by mass-wasting events. Contains jumbled, locally derived rock types and displays fresh morphological features, including scarps, lateral margins, and landslide toes. Topography is moderately to very hummocky. Commonly not incised or minorly incised. Commonly cuts across **Qlsi** and **Qlso**. Estimated to be up to 45 m thick.

Long

Unconsolidated sand, silt, clay, pebbles, cobbles, and boulders deposited by rock falls, earth and debris flows, and rotational and translational landslides. The unit has been somewhat reworked by alluvial and colluvial processes and contains jumbled, locally derived rock types. The unit displays fresh morphological features, including scarps, lateral margins, and landslide toes. Topography is moderately to very hummocky. Deposits are commonly not incised or minorly incised. **Qlsy** commonly cuts across **Qlsi** and **Qlso**. The unit is estimated to be up to 45 m thick.

Qlsi Intermediate-age landslides—

Short

Unconsolidated sand, silt, clay, pebbles, cobbles, and boulders deposited by mass-wasting. Muted morphological features, including scarps, lateral margins, and landslide toes. Deposits contain jumbled, locally derived rock types. Topography is moderately to very hummocky. Commonly not incised or minorly incised. Commonly crosscuts **Qlso** but is cross-cut by **Qlsy**. Up to 45 m thick.

Long

Unconsolidated sand, silt, clay, pebbles, cobbles, and boulders deposited by rock falls, earth and debris flows, and rotational and translational landslides. The unit has been somewhat reworked by alluvial and colluvial processes and contains jumbled, locally derived rock types. The unit displays muted landslide morphological features, including scarps, lateral margins, and landslide toes. Topography is moderately to very hummocky. Deposits are commonly not incised or minorly incised. **Qlsi** commonly crosscuts **Qlso** and is crosscut by **Qlsy**. The unit is estimated to be up to 45 m thick.

Qlso Older landslides—

Short

Unconsolidated sand, silt, clay, pebbles, cobbles, and boulders deposited by mass-wasting. Unit has subtle morphological features, with poorly defined scarps and gradational lateral margins.

Topography is smooth to moderately hummocky. Contains jumbled, locally derived rock types. Deposits are commonly disconnected from the source area. Commonly crosscut by **Qlsy** and **Qlsi**. Up to 45 m thick.

Long

Unconsolidated sand, silt, clay, pebbles, cobbles, and boulders deposited by mass-wasting. The unit is commonly reworked by alluvial and colluvial processes. The unit displays subtle morphological features, with poorly defined scarps and gradational lateral margins. Topography is smooth to moderately hummocky. Deposits contain jumbled, locally derived rock types. Deposits of **Qlso** are commonly disconnected from the landslide source area. **Qlso** is commonly covered by **Qlsy** and **Qlsi**. The unit is estimated to be up to 45 m thick.

MESOZOIC SEDIMENTARY ROCKS

CRETACEOUS

Mancos Shale Formation (Late Cretaceous)—

Kmgh Greenhorn Limestone Member (Late Cretaceous) —

Light-gray to white, finely crystalline limestone, often interbedded with shale. Limestone is very thin- to medium-bedded, dense, and sparsely fossiliferous. Fossils consist largely of broken prisms of *Inoceramus* species (Landis and Dane, 1967). The unit is 5–10 m thick.

Kmg Graneros Shale Member (Late Cretaceous) —

Short

Gray to black, occasionally calcareous, slope-forming shale. Unit is platy to laminated, sparsely fossiliferous, and occasionally contains concretions, including distinctive 0.8–1 m donut-shaped, quasi-septarian concretions near the base of the unit. Includes the Whitewater Arroyo Shale Tongue of the Mancos Shale and the Twowells Sandstone Tongue of the Dakota Sandstone. The unit is 40–50 m thick.

Long

Gray to black, occasionally calcareous, slope-forming shale. The unit is platy to laminated, sparsely fossiliferous, and occasionally contains concretions, including distinctive 0.8–1 m donut-shaped, quasi-septarian concretions near the base of the unit. Unit **Kmg** includes the Whitewater Arroyo Shale Tongue of the Mancos Shale and the Twowells Sandstone Tongue of the Dakota Sandstone (Owen et al., 2005). The unit is 40–50 m thick (Aby et al., 2016).

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 grains are subrounded to subangular. Symmetric and asymmetric ripple marks are common. The sandstone is interbedded with tongues of Mancos Shale. The unit is up to 50 m thick.

Long

(includes the Encinal Canyon, the Oak Canyon, Cubero, and Paguate Members and the Clay Mesa Member 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 subrounded to subangular. Symmetric and asymmetric ripple marks are common. This sandstone contains fossil wood and carbonaceous plant impressions are common near the base. The Oak Canyon Member is primarily a shale with a persistent medial sandstone bed observed throughout the Chama Basin (Ridgley, 1987). The Cubero Member is fine- to medium-grained and well-sorted. This sandstone has thin to medium tabular bedding and is usually bioturbated. The Paguate Member is fine- to medium-grained, well-sorted, thin to medium tabular-bedded, and commonly bioturbated. The Paguate Member has common 0.5–1 mm brown-orange iron oxidation spots, occasional herringbone cross-beds, occasional symmetrical ripple marks, and occasional calcium-carbonate cement. The uppermost sandstone on the Navajo Peak quadrangle is typically friable and less well-exposed. 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 that forms impressive cliffs intercalated with mudstone. Sandstone is fine- to medium-grained, quartzose, and kaolinitic with low-angle cross-bedding. Small-scale trough-crossbedding in conglomeratic channels. Conglomerate clasts (<2.5 cm long) are mostly chalky, white chert and varicolored quartzite. The unit is 30–40 m thick.

Long

White, light-yellow, orange, and buff conglomeratic sandstone that forms impressive cliffs intercalated with thin lenses of green or, more rarely, red mudstone (Saucier, 1974). The sandstone is fine- to medium-grained, quartzose, and kaolinitic, and is characterized by low-angle cross-bedding. 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 are subangular to subrounded. The base of the unit is typically more conglomeratic, while the top of the unit is sandier. 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 calcium-carbonate cemented. The basal contact of the unit is disconformable and displays significant paleotopography. The unit is 30–40 m thick and thins toward the southern part of the map area.

JURASSIC

Morrison Formation (Late Jurassic)—

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. The unit is 70–120 m thick.

Long

The Brushy Basin Member of the Morrison Formation 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. The 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. 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 abundant 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 a pitted texture where the feldspars have completely weathered. 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 to the south-southeast. The basal contact is conformable. The upper contact is abrupt, but conformable, with the overlying Brushy Basin Member of the Morrison Formation. Where present. the unit is up to 50 m thick.

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 nodules and thin (<1 m) beds of limestone and mud rip-up clasts. Siltstones are red, green, and white with variable clay and sand content. Thickness is 75–170 m, thickening towards the north.

Long

The Recapture Member 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 calcium-carbonate 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 contain nodules and thin beds of limestone near the base of the unit. 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 base of the unit is sandier toward the northern edge of the quadrangle and the unit is white-yellow at its base, right above the Todilto Formation. The thick sandstone interval at the base of the unit in the northern part of the quadrangle may correlate to the Salt Wash Member of the Morrison Formation (Dickinson, 2018). Samples were collected for detrital-sanidine analysis to test this correlation, but the dates are not available at the time of this writing. The unit thickens to the north. The unit is 75–170 m thick.

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

Short

Consists of a 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 formed by dissolution of the Tonque Arroyo gypsum 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, 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 wide and formed from eolian dune-forming processes. The top of the unit is conformable with the Luciano Mesa Member of the Todilto Formation, and the base of the unit is unconformable with the Rock Point Formation of the Chinle Group. The unit is 55–75 m thick.

Jet Todilto Formation and Entrada Sandstone (Middle Jurassic)—

Contains both the Entrada Sandstone and the limestone-dominated Luciano Mesa Member of the Todilto Formation, which caps the Entrada Sandstone. The Luciano Mesa Member consists of gray, laminated, kerogenic limestone and calcareous shale. The 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

TRcu 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 exposed thickness of this combined unit is 80 m.

Long

The upper Chinle Group includes mudstones, siltstones, and sandstones of the Rock Point and Petrified Forest formations. These units are combined because the Rock Point generally is preserved in a cliff just below the Entrada Sandstone cliffs, and thus is difficult to show on the map. This unit is exposed in the southern part of the quadrangle. The uppermost Rock Point Formation consists of 10–30 m of reddish-brown, and grayish-red beds of siltstone and fine sandstone. The top of the Rock Point Formation is marked by a sharp, unconformable contact with the Entrada Sandstone (the J-2 unconformity of Pipiringos and O'Sullivan [1978]), and the bottom of the unit is disconformable with the underlying Petrified Forest Formation. Only the top 70–80 m of the Painted Desert Member of the Petrified Forest Formation is exposed on the quadrangle. This member is a reddish-brown, bentonitic mudstone with thin ledges and lenses of ripple-laminated or cross-bedded sandstone. Petrified wood is common throughout the unit. The exposed thickness of this combined unit is 80 m.

TRcl Lower Chinle Group (Late Triassic)—

Short

The lower Chinle Group contains the Mesa Montosa Member of the Petrified Forest Formation, Poleo Formation, and Salitral Formation which is exposed on an east-dipping ridge adjacent to a fault zone. The Mesa Montosa Member is a red, ripple-laminated sandstone. The Poleo Formation is a white sandstone with minor conglomerate. The Salitral Formation is a red shale. Exposed thickness is about 100 m.

Long:

The lower Chinle Group contains the Mesa Montosa Member of the Petrified Forest Formation, the Poleo Formation, and the Salitral Formation, all of which are exposed on an east-dipping ridge adjacent to the Tierra Montañosa fault zone. The Mesa Montosa Member is a red, ripple-laminated, fine-grained sandstone. The Poleo Formation consists of white and red sandstone, with minor conglomerate. The sandstone is fine- to medium-grained, with angular to subangular grains. The sandstone contains abundant mica, feldspar, and lithic grains. Conglomeratic intervals contain clasts of siltstone, nodular calcrete, chert, and quartzite. Plant fossils were observed in the Poleo Formation where Dark Canyon intersects with the Tierra Montañosa fault. The Salitral Formation consists of 6–10 m of poorly exposed, red to maroon shale and siltstone. The Agua Zarca Sandstone, which consists of 1–2 m of white, quartz-rich, coarse-grained sandstone beds with quartz pebbles on the adjacent Llaves 15-minute map to the west, is not exposed on this quadrangle. The total exposed thickness of the lower Chinle Group is approximately 100 m.

PALEOZOIC SEDIMENTARY ROCKS

PERMIAN

Pc Cutler Formation (Early Permian)—

Short

Red, maroon, and white siltstones, sandstones, and conglomerates. Sandstones are arkosic, calcium-carbonate cemented, medium- to very coarse-grained, and angular to subangular. Conglomerates contain well-rounded, pebble- to cobble-sized clasts of chert, Proterozoic granitic rocks, and quartzite. Siltstones contain calcrete nodules and are interbedded with thin sandstones. The unit is 100–440 m thick.

Long

The Cutler Formation contains red, maroon, and white siltstones, arkosic sandstones and minor intraformational and extraformational conglomerates. The sandstones are mottled-white and orange-red to maroon, calcium-carbonate cemented, medium- to very coarse-grained, and angular to subangular. Flattened, green mud rip-ups are found at the base of channels. The unit occasionally displays soft sediment deformation. Conglomerates contain well-rounded, pebble- to cobble-sized clasts of chert, Proterozoic granitic rocks, and quartzite. Thick, slope-forming siltstones contain abundant calcrete nodules and are interbedded with thin sandstone sheets that are massive to trough-cross-bedded. The unit is 100–440 m thick (Fitter, 1958; Lookingbill, 1953).

CROSS SECTION ONLY

IPm Madera Formation (Pennsylvanian)—

Arkosic sandstone, sandstone, and limestone.

pCu Proterozoic rocks (Proterozoic)—

Igneous and metamorphic rocks ranging from 1.7 to 1.4 Ga.