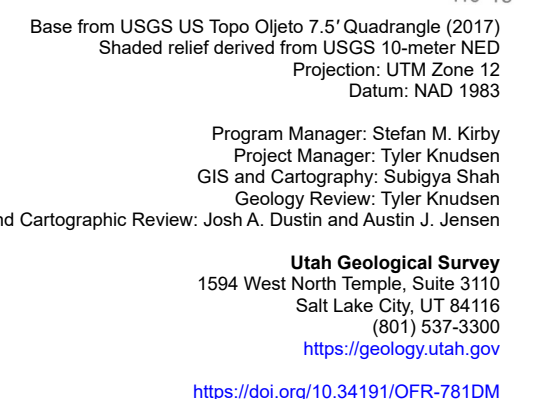


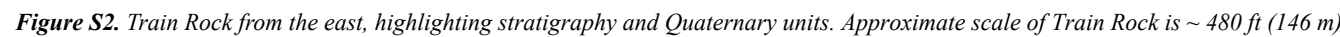


This geologic map was funded by the Utah Geological Survey and the U.S. Geological Survey, National Cooperative Geologic Mapping Program, through USGS STATEMAP award number G24AC00342 (2024–2026). The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

1	2	3
4		5
6	7	8

1. Monitor Butte
2. Oljeto NE
3. Goulding NW
4. Jacobs Monument
5. Goulding
6. Big Point
7. Boot Mesa
8. Mystery Valley

ADJOINING 7.5' QUADRANGLE NAMES



INTERIM GEOLOGIC MAP OF THE OLJETO QUADRANGLE, SAN JUAN COUNTY, UTAH

by

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INTRODUCTION

The Oljeto 7.5' quadrangle is in the southeastern corner of Utah, in southern San Juan County. The quadrangle is named after the Dinè (Navajo) community of Oljato. In the Dinè language, Oljato means “Moonlight on the Water.” It is presumed to describe moonlight reflecting on the waters of Oljato Spring. Note there is a spelling mismatch between the Geographic Names Information System (U.S. Geological Survey, 2022) and the local spelling. Throughout this report, we refer to the community of Oljato and the Oljeto quadrangle or map.

The Oljeto quadrangle is within the Colorado Plateau physiographic province (Fenneman and Johnson, 1946) and is part of the broader region of Monument Valley. The quadrangle ranges in elevation from 6680 ft to approximately 4650 ft (2036–1417 m) with the highest elevations in the southern part of the quadrangle, and lowest elevations in incised canyons in the northern margins of the map area. The Monument Valley Navajo Tribal Park, located southeast of the quadrangle, hosts about 250,000 annual visitors (Navajo Nation Office of the President and Vice President, 2025).

U.S. Highway 163 runs north-south just east of the quadrangle. The central part of the quadrangle is defined by Oljato Wash. This alluvial channel bisects the quadrangle, flowing from south to north. The perennial Oljato Spring emerges from an unnamed eastern tributary of Oljato Wash southeast of the community of Oljato. Two named tributaries to Oljato Wash are Mitchell Butte Wash, between Oljeto Mesa and Train Rock, and Train Rock Wash just north of Train Rock. In this report, we use the informal name Oljato Spring wash to describe the unnamed southeast-trending tributary to Oljato Wash that contains Oljato Spring. Until 2009, Oljato was host to a historical regional trading post, which first opened in 1921 (Miller, 2021; Monument Valley Tribal Park, 2021; Som, 2021).

All lands in the Oljeto quadrangle are managed by the Navajo Nation and held in Federal Trust by the United States Government. The population of Oljato in the 2020 census was 682, with many more families living in dispersed housing in the surrounding area. Most residents live on or near the main road that goes through Oljato Wash or along a secondary road that extends west from the main road and then north along the crest of the Organ Rock anticline near the western edge of the quadrangle. There is currently no irrigated agriculture in the quadrangle. The residents commonly graze a mix of cattle, sheep, and goats on open ranges throughout the map area. A single paved road wraps north around Oljeto Mesa, linking Oljato to nearby Gouldings in the adjacent Goulding quadrangle. The Oljato Chapter House in Oljato is the regional seat of government.

The primary goal of this mapping effort is to provide up-to-date information on the geology in and around the community of Oljato. Furthermore, we developed this map with a specific focus on the groundwater resources in the area. The hydrogeology section of this booklet provides a more extensive analysis of hydrogeologic resources than is typically included with UGS geologic maps. No modern geologic maps of the area at any scale have been published prior to this study.

PREVIOUS WORK

The region has been explored by different surveyors and geologists since the mid-1800s. An earlier period of Spanish expeditions from Santa Fe includes the 1775 mission led by Juan Antonio Maria de Rivera that passed north and east of Oljato, and the 1776–1777 Dominguez-Escalante party (Gregory, 1938). Federal government surveys led by Captain John N. Macomb in 1859 and Ferdinand V. Hayden in 1872 came near Oljato and may have seen Monument Valley—both groups passed east of the Oljeto quadrangle.

For more than a century, resource assessment has been the primary focus of geologic research in this region. Woodruff, Miser, and Baker’s mapping efforts were motivated by oil and gas exploration across the broader Colorado Plateau and Four Corners region as well as assessing potential dam sites. The next phase of mapping was motivated by the mid-20th century pursuit of uranium under the direction of the Atomic Energy Commission, which funded numerous mapping efforts at different scales throughout the region. The motivation for the current geologic map lies in the need for understanding the availability and compartmentalization of various water resources.

Study of the geology of the greater Oljeto region started with Woodruff (1912), who identified the thick eolian bedrock unit exposed at the community of Oljato as the “Oljato sandstone” which was a member of the “Moencopie Formation.” Much of Woodruff’s work was done in the greater Mexican Hat region to support oil and gas exploration. Miser (1924) passed the confluence of Oljeto Wash and the San Juan River while surveying the San Juan River canyon for potential dam sites, but made

few references to the area covered by the Oljeto quadrangle. Baker (1936) produced the first geologic map to include the area immediately around Oljato and the first to name some of the larger geologic structures in the quadrangle: the Organ Rock anticline and Oljeto syncline. His work was part of a broader U.S. Geological Survey (USGS) field investigation of the Monument Valley-Navajo Mountain region during the late 1920s. Baker's (1936) geologic map was the first to entirely encompass the Oljeto quadrangle.

Mid-20th-century mapping in this region consisted of detailed, multi-year projects involving many authors. The most notable work of this era is Witkind and Thaden's 1963 USGS Bulletin paper *Geology and Vanadium Deposits of the Monument Valley Area, Apache and Navajo Counties, Arizona*. The field work for this publication took place in the early 1950s, but the final report and maps were not published until the early 1960s. This publication covers the Arizona side of Monument Valley adjacent to the Oljeto quadrangle and includes a geologic map at 1:62,500 scale. Witkind and Thaden (1963) provide a more detailed description of the units in the Monument Valley region, building on the descriptions of Baker (1936). In the late 1960s, a large mapping project was published covering the entire Navajo Nation as part of a hydrogeology survey of the region (Cooley et al., 1969). This regional map included nine plates, mapping the geology of the Navajo Nation at a scale of 1:125,000. Cooley et al. (1969) remains the most recent geologic mapping available for much of the Navajo Nation.

The Atomic Energy Commission supported the USGS to make air-photo geologic maps of much of the Colorado Plateau, including the Oljeto quadrangle for uranium mining during the Cold War. The first and only pre-existing map at 1:24,000 scale of the Oljeto quadrangle was photo mapped by Fischer (1953). The stratigraphy used in his photogeologic map is based on Baker (1936). To the west of the Oljeto quadrangle, the Jacobs Monument quadrangle was mapped by Fischer also in 1952 (Fischer, 1952; see Plate 2). Immediately north of the Oljeto quadrangle is the Oljeto NE quadrangle mapped in 1955 by Marshall (1955), who also mapped the Goulding NW quadrangle adjoining the northeast corner of the Oljeto quadrangle (Marshall, 1954). The Goulding quadrangle immediately to the east of Oljeto was mapped in 1952 by Eckstein (1952). Preliminary maps to the south of Oljeto were ultimately published as part of Witkind and Thaden (1963).

MINING AND OIL AND GAS EXPLORATION

The Monument Valley region and the broader southern Utah area have been explored for resource extraction for over a century, dating back to an oil boom in the Mexican Hat area in the 1900s and 1910s (Woodruff, 1912). The first documented oil seep was discovered by E. L. Goodrich, who filed a claim in 1882 along the San Juan River near Mexican Hat. In 1907, the first oil well was drilled in the region that would later be called the San Juan oil field (Woodruff, 1912; Wengerd, 1955). At a shallow depth of 225 ft (68 m), wells in the region reached a positively pressured reservoir, requiring little pumping for oil extraction. What followed was a short-lived oil boom with 27 wells drilled by the end of 1911, 9 of which produced oil. Shortly after this oil boom, several wells were drilled in the broader Navajo Nation portion of Utah, including one well (API# 43-037-20599, drilled by Wilson-Cranmer & Co.) within the Oljeto quadrangle that was drilled in 1923 to a depth of 2323 ft (708 m; see Table S1 on Plate 2). A second oil and gas well (API#43-037-11293) was drilled in 1965. The first well on the southern end of the Organ Rock anticline within the Oljeto quadrangle had minor showings of both oil and gas at 950 ft. The second well, just to the west of the quadrangle, was a dry well.

Mineral deposits ultimately surpassed oil and gas as the primary extractive resource in the Monument Valley region. The first people to mine in the region were Native Americans seeking copper. During recorded history, initial explorations for both gold and copper occurred in the 19th and early 20th century (Gregory, 1917). Copper co-occurs with uranium and the minerals that bear it like carnotite (Bullock, 1981). During his initial survey, Gregory (1917) provided a single sentence to describe what half a century later would become a driving economic source for the region: "in the valley, a uranium-vanadium mineral, probably carnotite, was found among the pebbles of the Shinorump [sic] conglomerate and an association with petrified wood of the Chinle formation."

Prior to 1950, only minor amounts of mining and mineral extraction took place on Navajo Nation land for uranium, vanadium, and radium (Witkind, 1961; Chenoweth, 1985). The priority of these initial mining efforts was vanadium. The Vanadium Corporation of America (VCA) claimed many different deposits bearing carnotite and other uranium-bearing minerals throughout the Navajo Nation, including Monument Valley (Witkind, 1961). The Monument Number One mine just south of the border in Arizona was claimed by the VCA in 1942. Vanadium was exclusively supplied to the U.S. steel industry, and uranium-bearing minerals prior to the 1950s were considered gangue minerals and discarded in waste piles (Witkind, 1961). With the onset of the Cold War nuclear arms race, the Atomic Energy Commission increased the demand for uranium by artificially inflating prices.

This policy incentivized extensive geologic research and exploration throughout the Four Corners region. As part of this “uranium rush,” there was extensive mining and prospecting throughout the Oljeto and Monument Valley area. The former waste mineral became a high-priced commodity. Over the next several decades the total production of U_3O_8 (triuranium octoxide, “yellowcake”) from the north-central region which encompassed the Monument Valley mining district, was nearly 9,000,000 pounds (4,082,331 kg; U.S. Environmental Protection Agency, 2007).

The primary host minerals in the uranium ore were carnotite, tyuyamunite, uranophane, autunite, and torbernite, and trace amounts of uraninite. Uranium- and vanadium-bearing minerals often co-occurred with copper-bearing minerals like malachite, azurite, and chalcantite (Lewis and Trimble, 1959). Secondary mineralization of hyalite and, to a lesser extent, chalcedony is identified throughout the Monument Valley mining region with strong fluorescence in those minerals found close to uranium ore (Lewis and Trimble, 1959; Bullock, 1981).

Mining in the Navajo Nation for uranium spanned about 25 years, from the 1940s until 1970 when the Atomic Energy Commission stopped purchasing uranium ore (U.S. Environmental Protection Agency et al., 2020). After 1970, the nuclear power industry became the sole purchaser of milled uranium, and mining essentially ceased on Navajo Nation lands. The early 1970s represented a watershed moment for the broader environmental movement and shortly after the AEC stopped purchasing uranium, the U.S. Environmental Protection Agency and the National Environmental Policy Act were created in 1970. In 1972, the Navajo Environmental Protection Commission was created and in 1974 the Atomic Energy Commission was disbanded and reformed into the Energy Research and Development Administration (U.S. Environmental Protection Agency et al., 2020). The legacy of uranium mining on the Navajo Nation continues to today and has been summarized much more thoroughly in Chenoweth (1985, 1991), Zoellner (2009), and U.S. Environmental Protection Agency et al. (2020).

Mining Legacy

The uranium mines represent a significant anthropogenic hazard within the Oljeto quadrangle. Exposure to uranium mine waste increases the risk of certain types of cancers, such as lung cancer, and reduced kidney function (U.S. Environmental Protection Agency et al., 2020). The Navajo Nation is home to 523 known abandoned uranium mines (AUMs) and approximately 18 of those are within the Oljeto quadrangle (Chenoweth, 1991; Lin et al., 2020). Mines that have detailed information are numbered on Plate 1, and Table A1 in the appendix includes details of mine features. An additional 1000 mine-related features are mapped in the Navajo Nation (e.g., waste dumps, prospects, rim strips, portals, and shafts) (U.S. Environmental Protection Agency, 2023). More than 600 additional abandoned mines or mine features are within one mile of the Navajo Nation border (U.S. Environmental Protection Agency, 2007). The mines in the Oljeto quadrangle are part of the broader Monument Valley mining district. The U.S. Environmental Protection Agency (USEPA) classifies this region as the North Central AUM region and has worked with the Navajo Nation Environmental Protection Agency (NNEPA) to prioritize 16 AUMs for assessment and mitigation (U.S. Environmental Protection Agency, 2023).

The USEPA created a hazards ranking system (HRS) for the Navajo Nation with the most important criteria usually related to proximity to water or water sources for any local Diné populace (U.S. Environmental Protection Agency, 2007). Mechanisms of uranium dispersal include contaminated dust, sediments, groundwater, and surface water (U.S. Environmental Protection Agency, 2007). One challenge the USEPA and NNEPA have encountered is that uranium is naturally occurring in the region, so separating the background natural dose rate across the region from anthropogenically elevated dose rates from contamination is challenging. The responsibilities of the remaining uranium infrastructure (mines and mills) are also spread across multiple federal agencies. The USEPA is responsible for AUMs and waste piles through the Comprehensive Environmental Response, Compensation, and Liability Act. Whereas, reclamation of mill sites falls to the Department of Energy and Nuclear Regulatory Commission (U.S. Environmental Protection Agency, 2007). These agencies execute this responsibility under the 1978 Uranium Mill Tailings Radiation Control Act (UMTRCA). UMTRCA is the same policy responsible for reclamation of the Moab uranium mill site adjacent to the Colorado River.

Under the USEPA’s HRS, three of the four highest scoring AUMs across the agency’s north-central U.S. region are in the Monument Valley mining district. All three of these AUMs are located on Oljeto Mesa just east of the Oljeto quadrangle and were reclaimed by the Navajo Abandoned Mine Lands Reclamation Program. The fourth highest scoring site is a uranium dump and staging area 1.5 miles south of the Mexican Hat bridge (U.S. Environmental Protection Agency, 2007). Voluminous reports from the USEPA are available for reference. For more details on the impacts of uranium mining, please see U.S. Environmental Protection Agency (2007, 2020, 2023) for more details.

HYDROGEOLOGY

The Oljeto quadrangle lies in one of the most arid areas of the United States, receiving a little over six inches (15 cm) of annual precipitation (PRISM Climate Group, 2025). Surface water is highly ephemeral, so water supply is limited to groundwater from wells and springs. Maintaining an adequate local water supply for residents of the greater Monument Valley area continues to be a major concern for the Navajo Nation Department of Water Resources (DWR), to reduce the reliance on hauling or piping water into the area. Increased tourism and the effects of long-term drought have exacerbated the issue in recent decades.

Previous work on water supply issues in the Monument Valley area began in the 1950s. This work included an inventory of wells and springs, investigation of area hydrostratigraphy, and feasibility of additional groundwater development (Cooley et al., 1969). More recently, Spangler and Johnson (1999) focused on the alluvial aquifer in the Oljeto quadrangle and to the south, describing in detail the composition, hydraulic properties, and water chemistry of the aquifer.

We compiled existing data from Navajo Nation DWR databases, the Utah Division of Water Rights, and Spangler and Johnson (1999) to inventory current knowledge of the hydrogeology in the Oljeto quadrangle. Available records and logs of 19 wells and 8 springs in the quadrangle are summarized in [Table S2](#) and Figure S1 on Plate 2. More wells likely exist but lack log and completion information.

The primary aquifer is unconsolidated Quaternary alluvium consisting of interbedded clay, silt, sand, and gravel. Nine wells and five springs in the quadrangle produce from this aquifer ([Table S2](#) on Plate 2). Groundwater is also produced from seven wells and three springs from the De Chelly Sandstone and three wells from the Cedar Mesa Sandstone formations of the Permian Cutler Group ([Table S2](#) on Plate 2).

Spangler and Johnson (1999) showed that the upper alluvium is finer grained than the lower part, which consists of sand and gravel and hosts the producing zones of the aquifer. Alluvial thickness from well logs within the quadrangle ranges from 15 ft (4.6 m) in an abandoned borehole (Map ID 24) near the valley margin at the southern end of the quadrangle to 164 ft (50 m) in a recently drilled Bureau of Reclamation drought resiliency well (Map ID 28; drilled 2024) nearby the valley center (Figure S1 on Plate 2). The valley is relatively narrow here and the alluvial thickness supports Spangler and Johnson's (1999) assertion that the thickest alluvium is associated with paleochannels. Alluvial thickness decreases gradually down valley toward the Oljato community, where thickness is around 30 ft (9.1 m). Alluvial thickness also decreases quickly approaching valley margins, as seen in well 21 and borehole 24 (Figure S1 on Plate 2), where thickness is 17 ft (5.2 m) or less. The alluvium is unsaturated to partly saturated, except where the water table intersects the land surface in the vicinity of Oljato Spring and other springs near the community of Oljato, and presumably where several springs are documented in the northern area of the quadrangle (Plate 1; Figure S1 on Plate 2). Saturated thickness ranged from 19 ft (5.8 m; Map ID 9) near the Oljato community to 115 ft (35.1 m) in the 2024 drought resiliency well (Map ID 28). As with alluvial thickness, saturated thickness decreases down valley from this area of maximum thickness. Water levels in observation wells installed during the Spangler and Johnson (1999) study fluctuated 0.2 ft (6 cm) or less on average in monthly measurements from August 1996 to September 1997.

Spangler and Johnson (1999) reported transmissivities for the alluvial aquifer in the Monument Valley area of less than 100 to 2800 ft² day⁻¹ (9.3 to 269 m² day⁻¹); transmissivities for wells within the quadrangle were reported as 290 to 1300 ft² day⁻¹ (26.9 to 121 m² day⁻¹). Spangler and Johnson (1999) noted that several wells are also screened or open to the underlying De Chelly Sandstone, but that despite their hydraulic connection, the hydraulic conductivity of the sandstone is much lower than the overlying alluvium. Although these wells are likely to have low conductivity, the small well yields are sufficient for stock watering and domestic use. At least three springs issue from De Chelly Sandstone on the north side of mesas in the quadrangle (e.g., Holiday Mesa Spring; Plate 1; Figure S1 on Plate 2).

The Cedar Mesa Sandstone is the least utilized aquifer in the Oljeto quadrangle, likely due to its greater depth below the ground surface, with only three wells known to draw from it. Two of these wells have scant records, and the source aquifer is estimated from location and well depth ([Table S2](#) on Plate 2).

MAPPING METHODS

We compiled and mapped the geology in the Oljeto quadrangle using a GPS-enabled tablet (Apple iPad) with ESRI Field Maps app as well as one-meter resolution light detection and ranging (lidar) data (U.S. Geological Survey, 2021). The previous geologic maps in the region (Baker, 1936; Fischer, 1953; Witkind and Thaden, 1963) were referenced for unit descriptions

and some line work, but we largely developed our own geologic line work for the quadrangle. We applied some strike and dip information from Fischer's (1953) map. Mapping was further aided by the help of relative elevation models, a derivative from a Digital Elevation Model (DEM) to ascertain the elevation of different terrace trends relative to the modern drainages (Slaughter and Hubert, 2014; Larrieu, 2022). We also used Google satellite-based imagery and National Agriculture Imagery Program (NAIP) aerial imagery from 2014. The final map was compiled in ESRI ArcGIS Pro, and Adobe Illustrator was used to create and compile Plate 2 materials. Well location and formation depth information for oil and gas wells are from the Utah Division of Oil, Gas and Mining database (Utah Division of Oil, Gas and Mining, 2025).

GEOLOGY

Bedrock Stratigraphy

The exposed bedrock stratigraphy in the quadrangle includes the Paleozoic Cedar Mesa Sandstone, Organ Rock Formation, and De Chelly Sandstone, and the Mesozoic Moenkopi and Chinle Formations. The oldest exposed unit in the map area is the Early Permian (Wolfcampian) Cedar Mesa Sandstone first described by Baker and Reeside (1929) (Huttenlocker et al., 2021). Atop this eolian unit is the Early Permian (Leonardian?) Organ Rock Formation, which represents fluvial sandstones and mudstones. These beds record floodplain and channel deposits that coarsen to the east (Cain and Mountney, 2009). The deposits were shed off the Uncompahgre Uplift of the Ancestral Rocky Mountains—a common source area for many of the units of this age in Utah. The quadrangle also contains the type locality for the Organ Rock Formation, first named by Baker and Reeside (1929) as the Organ Rock tongue and then elevated to formation status by Baars (1962).

Overlying this unit is the De Chelly Sandstone, initially identified as the “Oljato sandstone” by Woodruff (1912) and formalized as the De Chelly Sandstone by Gregory (1917). The De Chelly is also Early Permian (Leonardian?) in age (Blakey, 1990; Lawton et al., 2015). This unit records a transition from the fluvial and proximal-fluvial facies of the Organ Rock Formation to a sand-dominated erg. The De Chelly in the Oljeto quadrangle contains numerous interdune facies, indicating shallow groundwater was present at the time of deposition. The De Chelly is well displayed in the numerous towers, monuments, buttes, and mesas of the region as the prominent cliff forming unit (Plate 1; Figure S2 on Plate 2). The top of the De Chelly is a sharp unconformity, capped by the first Triassic unit of the quadrangle: the Hoskinnini Member of the Moenkopi Formation. The origin and correlation of the Hoskinnini has been the source of debate (Baker and Reeside, 1929; Stewart, 1957; Blakey, 1974).

The unconformable contact is marked by a sharp color contrast between the tan brown of the De Chelly to darker red brown of the Hoskinnini Member. The Hoskinnini Member was originally described as the “Hoskinnini Tongue of the Cutler Formation” by Baker and Reeside (1929), with its type locality on the northern flank of Hoskinnini Mesa southwest of the Oljeto quadrangle. This initial mapping considered the Hoskinnini to be Permian but subsequent work by Stewart et al. (1959) moved the unit to member status within the Moenkopi and correlated it with the Tenderfoot Member of the Moenkopi in Salt Valley, about 120 miles (~190 km) to the north. To further complicate this unit, Blakey (1974) suggested that the Hoskinnini should be elevated to formation status due to lack of robust Triassic geochronology. However, this proposal was never formalized and recent work by Dubiel et al. (2014) still includes Hoskinnini strata as a member of the Moenkopi Formation. The Hoskinnini in the Oljeto quadrangle is composed of reddish-orange to brown, medium- and finely bedded, planar-bedded sandstones and siltstones and represents a coastal to continental sabkha environment (Dubiel et al., 2014). Similar to the Permian units in the map area, at the time of deposition of the Hoskinnini, sediment was sourced from the east as there was an open marine margin to the west (Dubiel et al., 2014).

A subtle color change atop the Hoskinnini marks the contact with the red Torrey Member of the Moenkopi Formation (Blakey, 1974). The Torrey Member was first formalized by Blakey (1974) and has a type locality in Torrey, Utah, about 100 miles (~160 km) to the northwest. The Torrey Member is characterized by ledge-forming, fluvial sandstone grading up into siltstone and mudstone. The unit is exposed across central and southern Utah and represents deltaic deposition with a source area to the east in the Uncompahgre uplift (Blakey, 1974). The unit is poorly described in the geologic literature for the broader Monument Valley/Oljeto region. However, the Torrey Member here may be characterized by what Blakey (1974) called the Hideout Canyon facies, observed just to the northwest in White Canyon. These facies are fluvial in nature and commonly show lenticular sandstones with erosional bases, fining upward sequences, and occasional intraformational conglomerates (Blakey, 1974). Little formal work has been done on the Torrey Member in the Monument Valley area, and this mapping effort represents the first such work in decades.

The next bedrock unit exposed in the Oljeto quadrangle is the Triassic Chinle Formation. Only two members of the Chinle Formation are mappable: the Shinarump Conglomerate and the Monitor Butte Member. The Shinarump Conglomerate was first

described by Powell (1874) and formalized by Gilbert (1877). The unit was later included as part of the Chinle Formation by Stewart (1957). The Shinarump Conglomerate represents shifting braided streams and is often interpreted as deposited during a humid climate interval, as determined from floral assemblages preserved as petrified wood (Evensen, 1953; Witkind and Thaden, 1963). The thickness of the Shinarump and its grain size vary widely across the map area. In the Monument Valley region, the Shinarump has long been a priority for miners looking for vanadium and then uranium (Witkind and Thaden, 1963; Chenoweth, 1991). See the Mining and Oil and Gas Exploration section for more details.

Overlying the Shinarump Conglomerate is the youngest sedimentary bedrock unit in the Oljeto quadrangle: the Monitor Butte Member. This unit was described initially as “Division D” of the Chinle by Gregory (1917) and later formalized by Witkind and Thaden (1963). The Monitor Butte Member contains fine-grained clays, muds, and sands representing a low-energy flood-plain, with generally north-flowing streams (Witkind and Thaden, 1963). The contact between the Monitor Butte Member and Shinarump is gradational vertically and possibly laterally, adding to its complexity in mapping.

The youngest bedrock mapped in the Oljeto quadrangle is a Cenozoic volcanic dike located along the northeast side of Horse Trail Canyon in the southeast quadrant of the map. This dike was mapped by Baker (1936) and subsequently included in Cooley et al. (1969). The dike likely correlates with similar rocks in the Navajo volcanic field to the south. The primary mapped volcanic feature close to the Oljeto quadrangle is Agathla Peak just north of Kayenta, Arizona, that rises 1400 ft (426 m) above the surrounding landscape (Witkind and Thaden, 1963). Numerous volcanic dikes are exposed across Arizona, Utah, and northwestern New Mexico. Geochemically, these features are ultrapotassic shoshonites and lamprophyres (texturally termed minettes and vogesites) (Witkind and Thaden, 1963; Roden, 1981; Laughlin et al., 1986; Semken, 2001). Texturally, the volcanic features are a mix of breccia and more coherent dikes that cut across the earlier breccias. Agathla Peak just south of the quadrangle has several dikes that cut across breccia visible on its flanks (Witkind and Thaden, 1963).

The dike exposed near Oljato appears to be made up of at least one intrusion, and potentially two, based on exposures in the field. In hand-sample, the dike appears to be a black, slightly vesicular, sub-volcanic rock, potentially hypabyssally intruded with clots of biotite. This hand sample description is consistent with the minette textural description. At the dike margins, country rock was entrained and mobilized in magma flow. A single geochemical sample (Plate 1; Tables 1 and 2 below) reveals a low silica, low sodium potassium classification as a tephrite (Figure 1). A plot of K_2O versus total SiO_2 confirms the ultrapotassic nature of this unit (Figure 2). This plot shows that the dike is in the shoshonitic series, placing it in a rare, ultra-potassic volcanic classification (Figure 2).

Table 1. Major oxides and volatiles in weight percent from the Oljato sample OLJTO25-2 (see Plate 1 for sample location).

Oxide	Value
MAJOR OXIDES (wt %)	
SiO ₂	44.85
TiO ₂	2.3
Al ₂ O ₃	9.04
Fe ₂ O ₃	9.67
MnO	0.15
MgO	12.25
CaO	11.15
Na ₂ O	1.41
K ₂ O	4.08
P ₂ O ₅	1.18
BaO	0.26
Cr ₂ O ₃	0.08
SrO	0.19
VOLATILES & TOTAL (wt%)	
LOI 1000	2.9
Total	99.71
C	0.3
S	0.01

Table 2. Trace elements in parts per million (ppm) for Oljato dike sample OLJTO25-2 (see Plate 1 for sample location).

Parameter	Value	Parameter	Value
TRACE ELEMENTS (ppm)			
Ag	0.8	Pr	38.1
As	6.4	Rb	94.5
Ba	2430	Re	0.001
Bi	0.47	Sb	0.16
Cd	0.5	Sc	18
Ce	311	Se	0.2
Co	49	Sm	25.4
Cr	535	Sn	2.6
Cs	3.39	Sr	1760
Cu	57	Ta	5.6
Dy	7.38	Tb	1.68
Er	3.09	Te	0.01
Eu	5.96	Th	43.1
Ga	15.8	Tl	0.64
Gd	16	Tm	0.35
Ge	1.4	U	11.6
Hf	10.25	V	209
Hg	0.005	W	1.4
Ho	1.14	Y	31.9
In	0.012	Yb	1.99
La	168	Zn	112
Li	130	Zr	394
Lu	0.24		
Mo	2		
Nb	108		
Nd	152		
Ni	349		
Pb	33		

This geochemistry is indicative of enriched magma from a mantle rather than crustal melt as shown through the enrichment of lanthanum and cerium series rare earth elements (Gonzales and Lake, 2017) (Figure 3). Specifically, the enrichment of light rare earth minerals, lanthanum and cerium, shows that there is potentially some degree of partial melt of metasomatized mantle within the source magma. The enrichment is characteristic for the Navajo volcanic field, and speaks to the deeper dynamics and hydration of the upper mantle throughout the mid-to-late Cenozoic (e.g., Schulze et al., 2015).

Geologic Structure

The bedrock units exposed across the Oljeto quadrangle lack any major map-scale faults. One potential fault is queried on Plate 1 on the northwestern margin of the map. Various sets of joints of multiple orientations occur in bedrock across the quadrangle (Plate 1). Two broad, low-amplitude, long-wavelength folds are in the quadrangle: the Organ Rock anticline and Oljeto syncline, both named by Baker (1936). Within the quadrangle, fold limbs dip no more than 12 degrees. However, the Organ Rock anticline's east limb steepens southward to become the dramatic monocline that defines the east margin of Hoskinnini Mesa south of the Oljeto quadrangle (Witkind and Thaden, 1963). The Oljeto syncline also continues at least 20 miles (32 km) to the south into Arizona. Both structures appear to gradually fade to the north across the San Juan River (Baker, 1936). Minor outcrop-scale folds and thrust faults, likely related to regional structures, were observed but not mapped due to scale limitations. Both the Organ Rock anticline and Oljeto syncline are likely tied to the kinematics of the Laramide-age Monument Upwarp and other similar reverse faults across the Colorado Plateau (Blakey and Baars, 1987; Jepson et al., 2025).

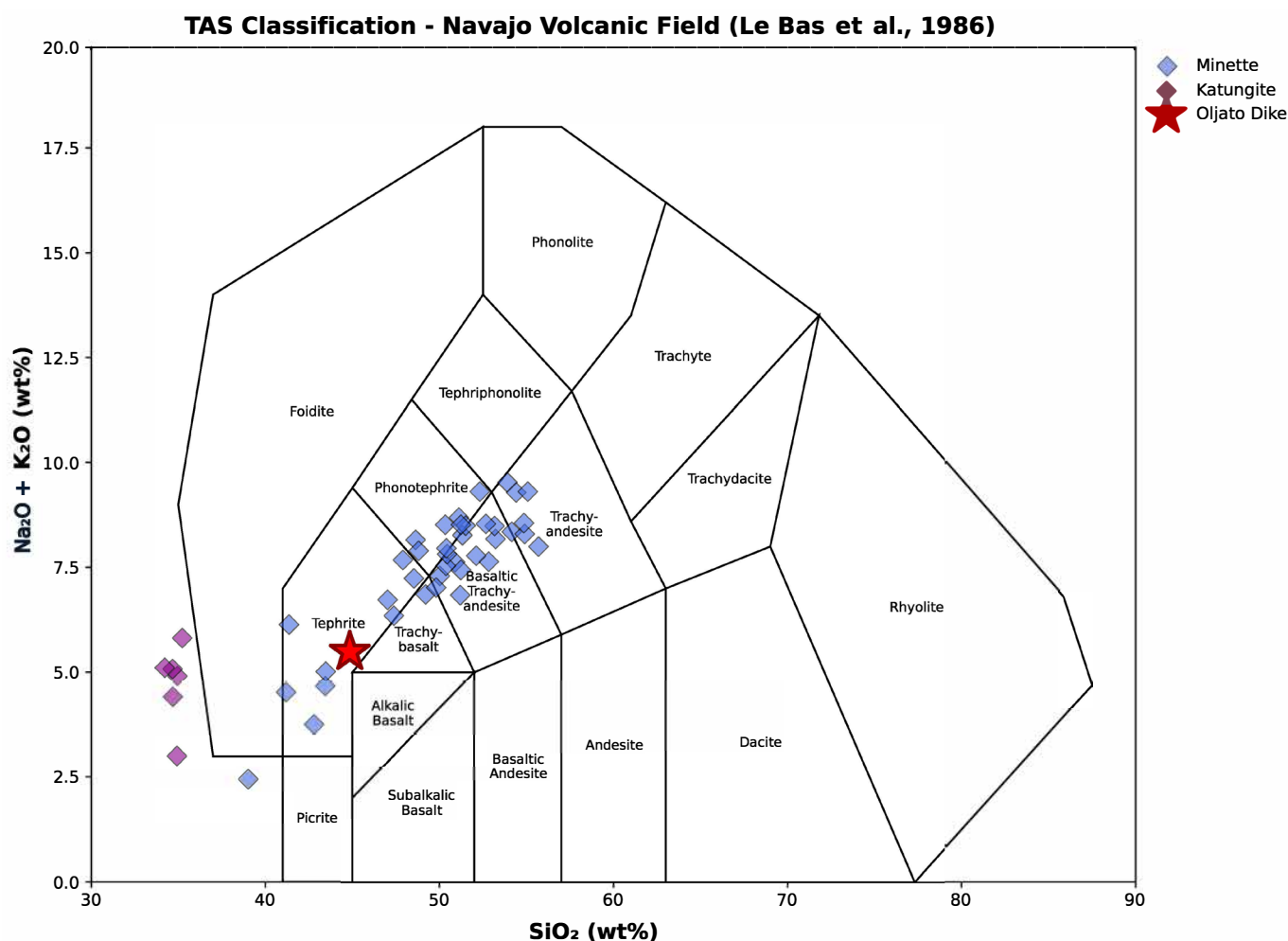
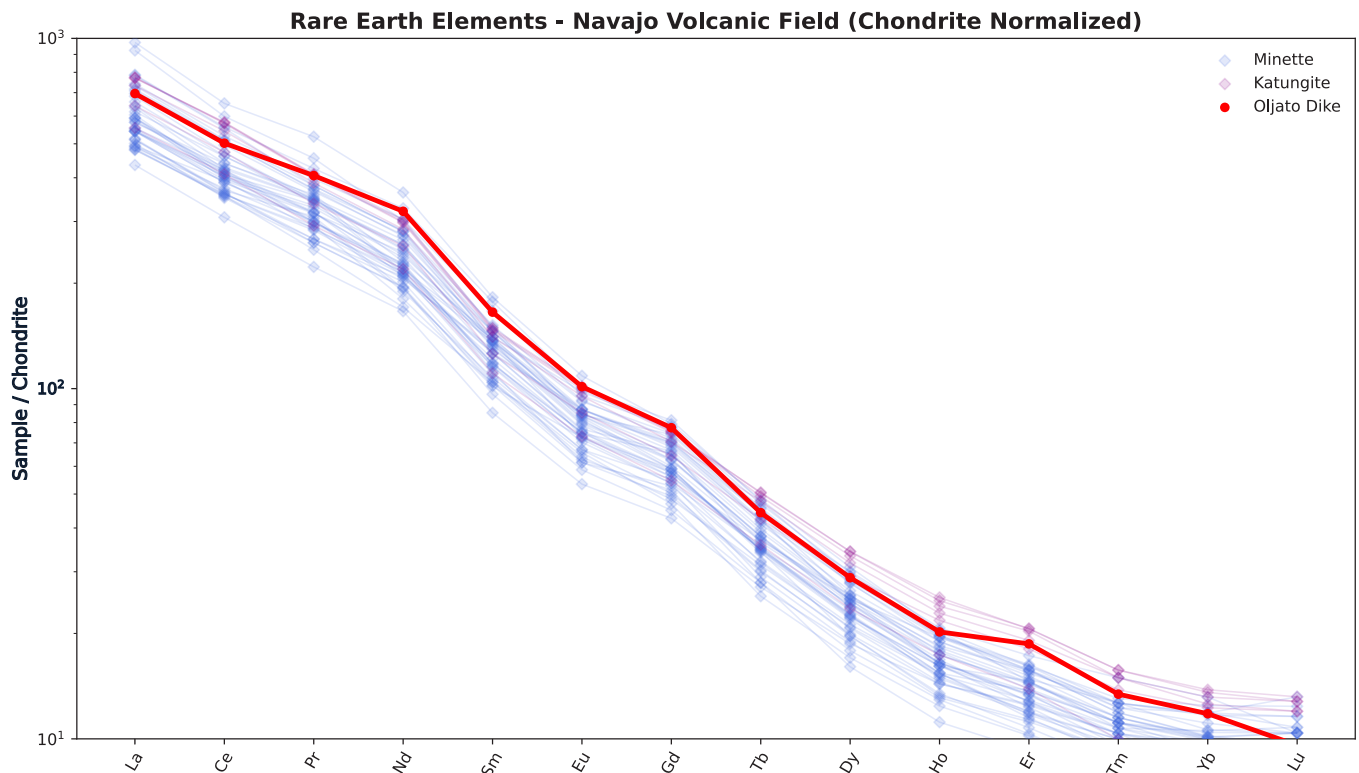
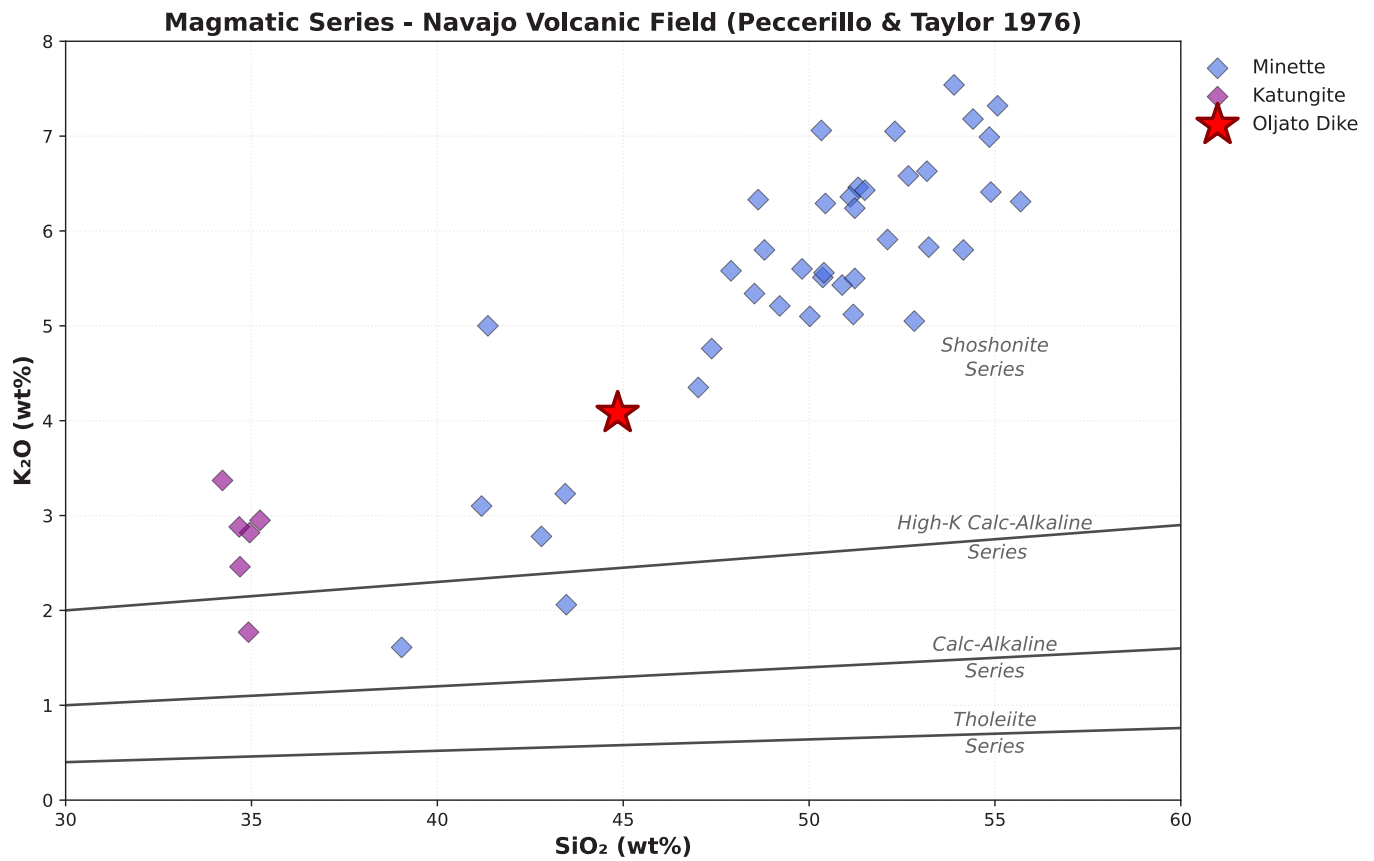


Figure 1. Total Alkali Silica plot for the OLJTO25-2 (Plate 1) sample collected from the dike exposed just north of Oljeto Wash (Le Bas et al., 1986). The dike plots in the tephrite field. The other samples from dikes and diatremes across the Navajo volcanic field are added for reference (Gonzales and Lake, 2017).



Geologic Hazards

The most prominent geologic hazard in the Oljeto quadrangle is flooding along Oljeto Wash. Reviewing multiple years of National Agriculture Imagery Program (NAIP) imagery shows evidence of significant channel migration (up to 200 ft [60 m]) due to flash flooding during the summer monsoon season. Although ungaged, Oljeto Wash likely experienced flooding contemporaneously with other damaging regional events recorded recently in nearby drainages. The Gouldings and Monument Valley quadrangles to the east, recorded flooding August 29, 2002 (National Centers for Environmental Information [NCEI], 2002). During this flood event, three paved county roads were partially destroyed. The Monument Valley High School football field was flooded with a foot of mud, and the rain gauge at the high school recorded 1.28 inches (3.3 cm) of rain in 40 minutes.

The largest historical floods in the region took place in 1911 and 1927. During the October 1911 flood, every bridge over the San Juan River in San Juan County was washed out or destroyed. It is likely that the San Juan River crested at approximately 150,000 cubic-feet per second (cfs) (Webb et al., 2001). During the 1927 event, the San Juan River reached about 70,000 cfs. Historical records appear to contain fewer references to significant damage associated with the 1927 flood in Utah (Webb et al., 2001). However, the flood appears to have been more destructive in the upper Animas River catchment in the Durango, Colorado, area (Durango Herald, 2019). There are no records of how these floods impacted the area within the Oljeto quadrangle, however, a photo of the Oljeto trading post from 1924 shows a very incised Oljeto Wash (Utah State Historical Society, 1924). This incision was possibly due to the flooding in the 1911 event. By using a relative elevation model derived from 2021 lidar data (see Methods section), most areas within 5 ft (1.5 m) vertically of the Oljeto Wash channel were included in the map unit “Qa” to address the flood hazard.

Rockfalls sourced from local cliffs present a significant hazard to the many homes situated near their bases. Numerous large talus blocks are found hundreds of feet from the base of the cliffs of De Chelly Sandstone. The Shinarump Conglomerate that caps many of the mesas in the Oljeto quadrangle is also a prolific rockfall producer. These cliffs will continue to generate rock-fall events with intermittent frequency.

Several earthquakes have been recorded within the Oljeto quadrangle, up to magnitude 3.4 (Bowman and Arabasz, 2017). However, there are no mapped Quaternary faults in the quadrangle. The Bright Angel fault, a class B Quaternary fault, is located ~2 miles from the quadrangle near the north end of Hoskinnini Mesa (Machette et al., 2003). The earthquake risk for this quadrangle is low, as it is for much of the Colorado Plateau (Petersen et al., 2024). Low risk is defined as a less than 5 % chance of shaking from a damaging earthquake in the next 100 years (Petersen et al., 2024).

DESCRIPTION OF MAP UNITS

QUATERNARY-TERTIARY SURFICIAL DEPOSITS

Human-Derived Deposits

- Qh **Fill and disturbed land** (historical) – Undifferentiated artificial fill and disturbed land related to construction, road embankments, and dam embankments; the extent of fill and disturbed land are based on 2021 1-meter lidar (U.S. Geological Survey, 2021); this unit is only mapped in larger areas of disturbed land; thickness up to 20 ft (0–6 m).
- Qhd **Dam impoundment sediments** (historical) – Slackwater sediments from damming of ephemeral channels for water storage; largely silt dominated with some sand and minor gravel; also found upstream of some road embankments; thickness up to 20 ft (0–6 m).
- Qhm **Human modified mining deposits** (historical) – Undifferentiated artificial fill and disturbed land related to various mining activities in the region; the extent of fill and disturbed land are based on 2021 1-meter lidar (U.S. Geological Survey, 2021); unit is commonly related to legacy uranium mining within the quadrangle; this unit is only mapped in larger areas of disturbed land; thickness up to 20 ft (0–6 m).

Alluvial Deposits

- Qa **Younger stream alluvium** (Holocene) – Light-tan-brown to brownish-red, moderately sorted, unconsolidated sand and silt with minor clay and cobble- to occasional boulder-size clasts; clasts are sub-rounded to well-rounded; deposited by

flood overbank, channel migration, and other active channel processes; forms modern channels and floodplains of Oljeto Wash and other drainages in the quadrangle; locally grades into mixed alluvial and colluvial deposits (**Qac**) and is incised into older alluvial deposits (**Qao**); extent of **Qa** mapped largely using 5 ft (1.5 m) relative elevation datum above modern channel; many springs in the map area issue from this unit, including Oljeto Spring; estimated thickness 3 to 30 ft (1–9 m).

- Qao Older stream alluvium** (Holocene) – Light-tan-brown to reddish-brown, poorly to moderately sorted, unconsolidated silt, sand, and gravel; clasts subrounded to well rounded; deposited by flood overbank, channel migration, and other active channel processes; forms terraces approximately 3 to 7 ft (1–2 m) above modern floodplains along Oljeto Wash and its tributaries; locally may grade into alluvial-colluvial deposits (**Qac**); thickness poorly constrained, estimated at 3 to 30 ft (1–9 m).
- Qaf Alluvial-fan deposits** (Holocene? to late Pleistocene) – Light-brown to reddish-brown, poorly to moderately sorted, angular to subangular, pebble to boulder clasts in a matrix of sand, silt, and minor clay; crudely stratified to massive; clast composition reflects local source areas; deposited by debris flows, debris floods, and channel processes at the mouths of active drainages; locally grades into younger stream deposits (**Qa**), older stream deposits (**Qao**), and alluvial-colluvial deposits (**Qac**); thickness 0 to 30 ft (0–9 m).
- Qap₁ Pediment alluvium, level 1** (Holocene) – Brown to red-brown, moderately to moderately well sorted sand to small cobble clasts; clasts subrounded to well-rounded and include silicified sandstone from the Shinarump Conglomerate and mixed recycled clasts from other bedrock units; matrix of quartz-rich sand; locally mantled by poorly developed eolian dunes; minor dune anchoring vegetation present; mapped largely using hillshade derived from lidar showing slope and aspect where fine distributary channels aid identification; distinguished from alluvial-fan deposits by shallow bedrock beneath surface; thickness approximately 10 to 40 ft (3–12 m).
- Qap₂ Pediment alluvium, level 2** (Holocene to late Pleistocene?) – Brown to reddish-tan-brown, moderately to moderately well sorted sand to small cobble clasts; clasts subrounded to well-rounded and include silicified sandstone from the Shinarump Conglomerate and mixed recycled clasts from other bedrock units; matrix of quartz-rich sand; locally mantled by poorly developed eolian dunes stabilized by sparse vegetation; mapped using slope-direction shader derived from lidar; alluvial texture more subdued than **Qap₁**; surface approximately 3–6 ft (1–2 m) above surrounding **Qap₁** where present; thickness approximately 10 to 40 ft (3–12 m).

Mass-Movement Deposits

- Qmt Talus deposits** (Holocene to Late Pleistocene) – Tan-brown to khaki and blackish-brown, color variable depending on source; poorly sorted, angular, cobble- to boulder- to house-size clasts; clasts derived from De Chelly Sandstone or Tertiary intrusive dike (**Ti**); accumulates below and on cliffs and slickrock of De Chelly Sandstone and on periphery of the igneous dike exposed on north side of Oljeto Wash; represents a coarse end member of the continuum of deposits within **Qmtc**; may overlap or overlie pediment alluvium level 2 (**Qap₂**), alluvial-colluvial deposits (**Qac**), or eolian deposits (**Qae**); thickness uncertain, up to 10 to 13 ft (3–4 m).
- Qmtc Talus and colluvium deposits** (Holocene to Late Pleistocene) – Ochre, red-brown, and yellowish-brown, color variable depending on source; unsorted to poorly sorted, subangular to angular, silt with rare clay to cobble and boulder clasts; primarily matrix-supported with sand and silt, locally clast-supported; likely includes some debris-flow deposits; clasts derived from Moenkopi Formation or Shinarump Conglomerate; commonly drapes over De Chelly Sandstone below cliffs of Moenkopi Formation or Shinarump Conglomerate; present across quadrangle, more common than talus deposits (**Qmt**); locally grades into talus deposits (**Qmt**); near the summit of Train Rock may contain more colluvium than talus thickness typically 6 to 10 ft (2–3 m), but up to 16 ft (5 m) thick locally.

Eolian Deposits

- Qed Eolian sand dunes** (Holocene) – Light-tan-brown to pale tan color; well-sorted, unconsolidated, fine to medium sand; rounded to well-rounded quartz sand; forms linear and uncommonly barchan dunes; also includes coppice dunes; distinguished from eolian sand deposits (**Qes**) by presence of linear and barchan dune forms; sand likely sourced from Oljeto Wash alluvium (**Qa**); dunes decrease in size with distance from Oljeto Wash, indicating limited sediment supply; mapped based on texture on lidar slopeshade and slope-direction shader; locally grades into eolian sand deposits (**Qes**) and mixed eolian and alluvial deposits (**Qea**); thickness approximately 2 to 13 ft (0.5–4 m).

- Qes Eolian sand deposits** (Holocene) – Light-tan-brown to khaki, well-sorted, unconsolidated, fine to medium sand; grains subrounded to well rounded, nearly pure quartz; forms sand sheets with minor coppice dunes anchored by sparse vegetation; distinguished from eolian dune deposits (**Qed**) by absence of linear and barchan dune forms; sand likely sourced from Cedar Mesa Sandstone, De Chelly Sandstone, and reworked alluvium from **Qa** and **Qao** proximal to Oljeto Wash and other drainages; mapped throughout area atop Organ Rock anticline and low lands across the quadrangle; locally grades into mixed eolian and alluvial deposits (**Qea**) and eolian dune deposits (**Qed**); overlies or interfingers with pediment alluvium (**Qap₁**, **Qap₂**) and stream alluvium (**Qa**, **Qao**); occasional pieces of bedrock crop out through this unit; thickness approximately 2 to 13 ft (0.5–4 m).

Mixed-Environment Deposits

- Qac Mixed alluvial and colluvial deposits** (Holocene to late Pleistocene) – Brown to reddish-brown, poorly to moderately sorted, generally poorly stratified sediment ranging from clay- to boulder-size; clasts angular to rounded; intermixed alluvial and colluvial deposits that grade into one another and cannot be differentiated at map scale; mapped at the base of steep slopes and in incised canyons where stream alluvium, fan alluvium, and colluvium are intermixed; small, unmapped deposits likely present in most minor drainages; thickness less than 15 ft (<5 m).
- Qae Mixed alluvial and eolian deposits** (Holocene) – Brown to light-brown with minor red, moderately to well-sorted, unconsolidated mud, silt, and sand deposited by both alluvial and eolian processes; consists of alluvial deposits reworked by wind and intermixed with windblown sand and silt; mapped on margins of **Qap₂**, **Qes**, and **Qea** where alluvial channels have been inundated by windblown sand and silt; thickness 3 to 40 ft (1–12 m).
- Qea Mixed eolian and alluvial deposits** (Holocene) – Light-brown to brown with minor red, moderately to well-sorted, unconsolidated sand and silt with minor gravel; predominantly deposited by eolian processes with subordinate alluvial and debris-flow deposits; commonly mapped on the east and north sides of buttes and mesas, that is the lee side of the predominant south and southwest wind directions; differentiated from **Qae** by the preponderance of aeolian bed forms relative to alluvial channels, rills and gullies; thickness 3 to 40 ft (1–12 m).

Stacked Units

Qes/Qap₁

Eolian sand deposits over level-1 Pediment alluvium (Holocene) – Light-tan-brown to pale tan, well-sorted, unconsolidated, fine to medium sand; grains subrounded to well rounded, nearly pure quartz; forms sand sheets with minor coppice dunes anchored by sparse vegetation; locally grades into mixed eolian and alluvial deposits (**Qea**) and eolian dune deposits (**Qed**); overlies or interfingers with pediment alluvium (**Qap₁**, **Qap₂**) and stream alluvium (**Qa**, **Qao**); thickness approximately 2 to 13 ft (0.5–4 m).

- Qac/Po Mixed alluvial and colluvial deposits over Organ Rock Formation** (Holocene) – Brown to reddish-brown, poorly to moderately sorted, generally poorly stratified sediment ranging from clay- to boulder-size; clasts angular to rounded; intermixed alluvial and colluvial deposits that grade into one another and cannot be differentiated at map scale; mapped at the base of steep slopes and in incised canyons where stream alluvium, fan alluvium, and colluvium are intermixed; small, unmapped deposits likely present in most minor drainages; mapped where a discontinuous veneer of **Qac** covers the Organ Rock Formation; thickness less than 15 ft (<5 m).

Qea/Pcm

Mixed eolian and alluvial deposits over Cedar Mesa Sandstone (Holocene) – Light-brown to brown with minor red, moderately to well-sorted, unconsolidated sand and silt with minor gravel over the Cedar Mesa Sandstone; predominantly deposited by eolian processes with subordinate and undifferentiated alluvial and debris-flow deposits; mapped where a discontinuous veneer of **Qea** covers the Cedar Mesa Sandstone in the northeast part of the quadrangle; thickness 3 to 40 ft (1–12 m).

- Qed/Po Eolian sand dunes over Organ Rock Formation** (Holocene) – Light-tan-brown to pale-tan, well-sorted, unconsolidated, fine to medium sand over the Organ Rock Formation; grains subrounded to well rounded, nearly pure quartz; forms linear dunes with minor coppice dunes and occasional barchans; locally grades into eolian sand deposits (**Qes**) and mixed eolian and alluvial deposits (**Qea**); mapped where a thin covering of **Qed** overlies the Organ Rock Formation; thickness approximately 2 to 13 ft (0.5–4 m).

Qes/Pcm

Eolian sand deposits over Cedar Mesa Sandstone (Holocene) – Light-tan-brown to khaki, well-sorted, unconsolidated, fine to medium sand over the Cedar Mesa Sandstone; grains subrounded to well rounded, nearly pure quartz; forms sand sheets with minor coppice dunes anchored by sparse vegetation; locally grades into mixed eolian and alluvial deposits (Qea) and eolian dune deposits (Qed); overlies or interfingers with pediment alluvium (Qap₁, Qap₂) and stream alluvium (Qa, Qao); mapped where a thin covering of Qes overlies the Cedar Mesa Sandstone; thickness approximately 2 to 13 ft (0.5–4 m).

Qes/Po Eolian sand deposits over Organ Rock Formation (Holocene) – Light-tan-brown to khaki, well-sorted, unconsolidated, fine to medium sand over the Organ Rock Formation; grains subrounded to well rounded, nearly pure quartz; forms sand sheets with minor coppice dunes anchored by sparse vegetation; locally grades into mixed eolian and alluvial deposits (Qea) and eolian dune deposits (Qed); overlies or interfingers with pediment alluvium (Qap₁, Qap₂) and stream alluvium (Qa, Qao); thickness approximately 2 to 13 ft (0.5–4 m).

BEDROCK UNITS

OLIGOCENE–MIOCENE

Ti Tertiary intrusive dike (Oligocene–Miocene) – Dark-gray to black, fine-grained to porphyritic, slightly vesicular shoshonitic to tephritic dike rock; phenocrysts include distinct biotite, pyroxene (likely diopside or augite), sparse whitish feldspar (albite?), and a reddish bladed mineral in a dark, microcrystalline matrix; typically lacks quartz; locally exhibits crude columnar jointing; margins commonly contain entrained and mobilized clasts of host rock (xenoliths); the intrusive of the Navajo volcanic field have been dated to between 28 and 18 Ma (Nowell, 1993); the dike is approximately 1760 ft (536 m) long; the widest part of the dike on its southern end is ~160 ft wide (49 m), narrowing to the north to less than 20 ft (6 m wide).

This unit is the youngest bedrock mapped in the quadrangle and is likely part of the Navajo volcanic field to the south (Witkind and Thaden, 1963; Semken, 2001). Geochemical analysis of this dike (sample OLJTO25-2) indicates the rock is a low-silica, ultrapotassic shoshonite or tephrite, texturally and in hand sample it would be classified as a minette (Peccerillo and Taylor, 1976; Le Bas, 1986). It displays enrichment in light rare earth elements (lanthanum and cerium), suggesting a source from partial melting of a metasomatized mantle (Schulze et al., 2015). The dike is included on maps by Baker (1936) and Cooley et al. (1969).

Major Unconformity

TRIASSIC

Tcmb Monitor Butte Member of Chinle Formation (Late Triassic, Norian) – Dark-gray to grayish-orange and grayish-yellow-green claystone, siltstone, fine- to coarse-grained sandstone, conglomeratic sandstone, and limestone; thin to thick bedded with planar to trough cross-bedded in sandstone facies; contains distinctive dark-brown conglomerate composed of angular to subrounded intraformational limestone clasts up to 3 inches (8 cm) long in sparry calcite matrix; forms badlands and gentle slopes, bentonitic mudstone locally weathers to characteristic “popcorn” texture; lower contact gradational with Shinarump Member; upper contact not exposed in map area (R.B. Irmis, Natural History Museum of Utah, personal communication, 2025); mapped only atop Oljeto Butte; about 107 ft (33 m) thick at type locality near Monitor Butte, Arizona (Witkind and Thaden, 1963); age based on fauna correlation from the type section; incomplete thickness up to 33 ft (10 m) in map area.

Tcs Shinarump Conglomerate of the Chinle Formation (Late Triassic, Carnian to Norian) – Light-brown to yellowish-brown, medium- to very coarse grained sandstone and pebble to cobble conglomerate; weathers rusty brown to yellowish brown; unit commonly has well-developed desert varnish and case hardening; subrounded to angular quartz and quartzite grains with lesser chert; planar bedded to trough cross-bedded; thick to very thick bedded; silica cemented, with calcite cement dominant in channel-fill facies; silicified logs common throughout, rusty brown to light brown, locally with carnotite and other uranium-bearing minerals; mudstone rip-up clasts of underlying Torrey Member common in basal beds; both channel-fill and non-channel facies present; channel systems were targets for

historical uranium mining (Lewis and Trimble, 1959); forms cliffs and ledges; lower contact is an erosive unconformity cut into the Moenkopi Formation, with channels visibly incising into the Torrey Member across the map area; locally basal beds contains rip-up clasts of Torrey Member; upper contact gradational with Monitor Butte Member; 20 to 50 ft (6–15 m) thick in interchannel areas, up to 100 ft (30 m) or more in channel fills; age based on Riggs et al. (2016); maximum thickness 210 ft (64 m) reported at Monitor Butte (Baker, 1936).

U3 Unconformity

U₃ T_m Moenkopi Formation, undivided (Early to Middle Triassic) – Red, reddish-brown, reddish-orange, to maroon, slope- and ledge-forming, very fine to fine-grained sandstone and siltstone; comprises the Torrey and Hoskinnini Members (in descending order), separated by an internal unconformity; Torrey Member forms ledges of cross-stratified and ripple-laminated sandstone with interbedded mud-cracked siltstone; Hoskinnini Member weathers to characteristic nodular, knobby slick rock and contains scattered well-rounded, frosted quartz grains reworked from the underlying De Chelly Sandstone (diagnostic of the Hoskinnini; Mullens, 1960); lower contact sharp to irregular on De Chelly Sandstone (Permian); upper contact sharp and erosive beneath the Shinarump Member of the Chinle Formation; shown in cross section only; combined thickness about 155 to 180 feet (47–55 m).

U₃ T_{mt} Torrey Member of the Moenkopi Formation (Early to Middle Triassic, Spathian to early Anisian?) – Red to dark-red and reddish-brown, ledge- and slope-forming, very fine to fine-grained sandstone and siltstone; moderately to well indurated; ledgy sandstone units range from a few feet to about 20 ft (1–6 m) thick and display diverse bed-forms including planar and trough cross-stratification, horizontal lamination, and climbing ripple lamination; interbedded slope-forming siltstone is thin bedded to finely laminated with abundant ripple marks and mud cracks; finer grained beds contain detrital mica on bedding surfaces; flame structures and load casts occur locally; rare simple horizontal burrows present but not identified to ichnotaxa; the Torrey Member is regionally significant for hosting extensive vertebrate and invertebrate trackways elsewhere in Utah (Mickelson, 2004); lower contact placed just above two silicified marker beds (limestone beds of Witkind and Thaden, 1963) at the top of underlying Hoskinnini Member; upper contact sharp and erosive where overlain by Shinarump Member of Chinle Formation; about 90 to 100 ft (28–30 m) thick.

Unconformity

U₃ T_{mh} Hoskinnini Member of the Moenkopi Formation (Early Triassic?) – Reddish-orange to deep red-brown and maroon, slick rock and slope-forming, very fine to fine-grained sandstone and siltstone; arkosic composition with approximately 73 percent quartz, 26 percent feldspar, and 1 percent mica (Stewart et al., 1972); thin to medium bedded with bedding planes; weathers to characteristic nodular or knobby surfaces and slick rock; contains scattered medium to coarse, well-rounded, frosted quartz grains reworked from underlying De Chelly Sandstone eolianites that are a diagnostic feature distinguishing the Hoskinnini from underlying Permian De Chelly (Mullens, 1960); lower contact with De Chelly Sandstone is sharp to irregular with local load structures described as whorls by Witkind and Thaden (1963); upper contact placed at top of two silicified marker beds (limestone beds of Witkind and Thaden, 1963) that may represent a silicified evaporitic horizon; overlain by Torrey Member; deposited in a coastal to continental clastic sabkha setting (Dubiel et al., 2014); age based on correlation to the north (Dubiel et al., 2014); 65–80 ft (20–24 m) thick.

The Hoskinnini has a complex nomenclatural history. Originally defined as the Hoskinnini Tongue of the Permian Cutler Formation (Baker and Reeside, 1929; Baker, 1936), the unit was reassigned to the Moenkopi Formation based on the presence of reworked eolian quartz grains from the underlying De Chelly and White Rim Sandstones that could only have been incorporated after Permian-Triassic erosion (Stewart et al., 1959; Mullens, 1960; Stewart et al., 1972, p. 197; Dubiel et al., 2014). Despite this reassignment, no age-diagnostic fossils or radiometric dates have been obtained from the Hoskinnini, and its age remains uncertain.

U1 Unconformity

U₁ Pd De Chelly Sandstone (Early Permian, Leonardian?) – Grayish-yellow to tan, cliff-forming, fine-grained, cross-bedded sandstone; bimodal grain-size distribution with coarser mode averaging about 0.30 mm and finer mode about 0.10 mm; grains subround to round, mostly quartz with minor microcline, plagioclase, chalcedony, muscovite, biotite, and zircon (Witkind and Thaden, 1963); grains coated with thin brown iron oxide film that imparts color to unit; weakly

cemented by chalcedony, calcium carbonate, and iron oxide, resulting in friable outcrop and slick rock; characterized by large-scale sweeping cross-bedding typical of eolian deposition; locally contains interdunal facies with trough cross-beds, mud drapes, debris-flow deposits, and extensive bioturbation indicating periodic wet conditions within the dune field (R.B. Irmis, Natural History Museum of Utah, personal communication, 2025); variable grain size with localized coarser grained beds and erosion surfaces; localized concretions and bleaching zones related to groundwater flow; forms prominent vertical cliffs, alcoves, slick rock and the main mass of monuments and buttes in the region; lower contact with Organ Rock Formation sharp to gradational; upper contact is a regional unconformity with overlying Hoskinnini Member marked by abrupt change from massive cross-bedded sandstone to dark-red planar-bedded sandstone, load structures are noted locally at contact; about 260 to 330 ft (80–100 m) thick.

Unconformity

- Po Organ Rock Formation** (Early Permian, Early Leonardian) – Reddish-brown, slope-forming, poorly sorted siltstone and silty very fine grained sandstone; composed mainly of angular to subangular quartz grains with pronounced iron-oxide stain, average grain size about 0.05 mm; abundant interstitial clay and disseminated very fine white mica flakes; cemented by iron oxide with scattered calcite splotches throughout; minor constituents include magnetite, gypsum, zircon, biotite, and muscovite; dominantly parallel bedded; individual sandstone beds are 3 to 10 ft (1–3 m) thick, and laterally discontinuous but can be traced up to a few hundred yards; contains scattered coarse pebbly to cobbly channel deposits up to 1.5 ft (0.5 m) thick preserved at various stratigraphic levels including upper contact with De Chelly Sandstone; limestone-pellet conglomerate beds fill small channels at base of some sandstone beds; paleosols common in finer-grained facies, characterized by nodular calcareous and siliceous concretions and calcareous-cemented rhizoliths ranging from pencil-size to larger; contains irregularly spaced pale-green mottled areas and bleached fractures related to root systems, particularly in lower two-thirds of unit; light-gray highly calcareous fine-grained sandstone beds up to 3 ft (1 m) thick occur locally in upper part; upper 25 to 50 ft (8–15 m) coarsens upward toward De Chelly Sandstone contact; forms badlands where unprotected and gently concave slopes where capped by De Chelly Sandstone; lower contact with Cedar Mesa Sandstone is gradational to sharp; upper contact with De Chelly Sandstone gradational to sharp; deposited by relatively sluggish westerly flowing streams in a continental fluvial setting (Witkind and Thaden, 1963); a potential Wolfcampian (Early Permian) age is suggested by vertebrate fossils from the region (Sumida et al., 1999); about 450 ft (138 m) thick.
- Pcm Cedar Mesa Sandstone** (Early Permian, Wolfcampian) – Grayish-white to very pale orange and moderate orangish-brown, cliff-forming, well-sorted, cross-bedded, fine- to very fine grained sandstone; composed of subrounded to rounded quartz grains averaging about 0.06 mm in diameter with faint iron-oxide stain; weakly cemented by calcium carbonate; minor constituents include calcite and green chlorite-like mineral (Witkind and Thaden, 1963); characterized by long sweeping cross-beds typical of eolian deposition in beds 8 to 40 ft (2.5–12 m) thick; horizontal bedding planes truncate cross-bedded sandstone packages with thin reddish-brown siltstone; locally contains interdune facies with fine-bedded sands, silt and clay partings, and limestone beds with possible microbial structures; trace fossil burrows and bioturbation common, including burrows 5 to 7.5 mm wide with calcite backfilling; paleosols with white reduced zones present locally in fine grain interbeds; contains lenticular beds of dense gray limestone up to 1 foot (0.3 m) thick and limestone-pellet conglomerate filling channels up to 7 ft (2 m) deep; upper part grades into interbedded reddish-brown siltstone and sandstone toward contact with overlying Organ Rock Formation; upper contact gradational to sharp, marked primarily by color change; lower contact with Halgaito Formation not exposed in map area; deposited primarily as coastal and inland sand dunes with periodic flooding by shallow lakes or marine transgressions (Mullens, 1960); Wolfcampian (Early Permian) age based on fusulinids from correlative marine units (Baars, 1962; Loope, 1984); at least 135 ft (41 m) thick, but base not exposed, Witkind and Thaden (1963) measured the Cedar Mesa thickness in Arizona as 315 ft (96 m) and Miser (1924) estimated it at ~600 ft (182 m).

SUBSURFACE BEDROCK UNITS

- IPh Halgaito Formation** (Pennsylvanian to Early Permian?) – Shown only in cross section; moderate reddish-brown to chocolate-brown, thin-bedded shaly siltstone and silty very fine grained sandstone with thin lenses of blue-gray unfossiliferous limestone; fining-upward sequences common; deposited by westward-flowing streams with intermittent playa lakes (Witkind and Thaden, 1963); contains vertebrate fauna indicative of the Pennsylvanian–Permian Coyotean land vertebrate faunachron (Huttenlocker et al., 2018); conodonts from marine marker beds place the Carboniferous–Permian boundary within the upper Halgaito Formation (Huttenlocker et al., 2021); conformably underlies Cedar Mesa Sandstone; about 400 to 425 ft (120–130 m) thick regionally (Baker, 1936; Witkind and Thaden, 1963).

- Ph Honaker Trail Formation** (Pennsylvanian, Desmoinesian to Missourian) – Shown only in cross section; gray to medium-dark-gray, cyclic limestone, sandstone, and shale; limestone fine to very fine crystalline, fossiliferous, locally cherty with white, brown, gray, and black chert nodules; contains bryozoans, brachiopods, fusulinids, rugose corals, foraminifers, conodonts, and crinoid ossicles; includes scattered phylloid algal boundstone mounds composed of *Eugonophyllum* and other algal plates; cycles typically 6 to 20 ft (2–6 m) thick; sandstone increases upsection reflecting progressive filling of Paradox Basin by sediment shed from Uncompahgre uplift (Goldhammer et al., 1991); upper contact placed at top of massive blocky cliff-forming limestone known informally as “The Horn” (Wengerd and Matheny, 1958); conformably overlies Paradox Formation; Desmoinesian-Missourian boundary placed within formation based on conodont biostratigraphy (Ritter et al., 2002); 583 ft (178 m) thick at Honaker Trail (Wengerd, 1963).
- Pp Paradox Formation** (Middle Pennsylvanian, Desmoinesian) – Shown only in cross section; gray limestone, dolomitic limestone, and interbedded gray to greenish-gray shale; limestone fine crystalline, fossiliferous, locally oolitic and cherty; subdivided into six informal sequences in southeast Utah (from base to top): Barker Creek, Akah, Lower Desert Creek, Upper Desert Creek, Lower Ismay, and Upper Ismay (Goldhammer et al., 1991); sequences bounded by dark-gray, organic-rich shale beds that correlate with evaporite cycles in basin center (Hite, 1960); ;lower Ismay sequence contains well-developed phylloid algal mounds that form primary petroleum reservoirs in nearby Aneth field (Pray and Wray, 1963; Chidsey et al., 1996); evaporite facies (gypsum, anhydrite, halite) present in basin center but largely absent in map area; thickness variable, thickens dramatically to northeast toward basin center.

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APPENDIX

Table A1. Mine Locations and attributes.

https://ugspub.nr.utah.gov/publications/open_file_reports/ofr-781/ofr-781a1.xlsx