Geologic Map of the Coyote Canyon 15-Minute Quadrangle, Navajo Nation and McKinley County, New Mexico

By

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View looking northwest across grass- and shrub-dominated Quaternary eolian and alluvial deposits on Tohatchi Flats towards the Chuska Mountains (Níłtsą́ Dził), approximately 30 km distant. Eolian units like those in the foreground, alluvial units like those in the middle distance in Tohatchi Flats, and mass-wasting units like those on the slopes of the Chuska Mountains comprise much of the geological material at the surface within the quadrangle.

Photograph taken 14 September 2023 near the southeastern boundary of the Coyote Canyon 15′ quadrangle at approximately 35.786°N, 108.508°W (Section 14, Township 18N, Range 16W). Chuska Mountains approximately mark the western boundary of the quadrangle.

EXECUTIVE SUMMARY

Located 25 to 56 km north of Gallup, New Mexico, (Na'nízhoozhí, Yootó Hahoodzo) and 0 to 23 km east of Tohatchi (Tó Haach'i'), New Mexico, the Coyote Canyon 15-minute Quadrangle occupies key locations for understanding the geologic history of the southeastern San Juan basin. We refine previous mapping which produced a 1:100,000-scale geologic map of the bedrock geology of the area (Dillinger, 1990) and focus efforts on (1) accurately mapping surficial units that occupy hillslopes, valley bottoms, and plains within the map area; (2) accurately mapping low-angle folds and small-offset faults; and (3) refining member-level designations of the quadrangle's Cretaceous units. The Coyote Canyon 15-minute Quadrangle exists at the intersection of the Chaco Slope, Defiance Monocline, Gallup Sag, Nutria Monocline, and Zuni Uplift portions of the San Juan basin (Kelley, 1951; Craigg, 2001), a broken-foreland structural basin formed during the Laramide orogeny. The quadrangle is located on the southwest limb of the San Juan basin's synclinal axis, leading to generally north-dipping bedrock units throughout most of the map area. Late Cretaceous siliciclastic sedimentary rocks comprise the bedrock in the map area. There are no known igneous or metamorphic outcrops in the map area. Loosely consolidated to unconsolidated Quaternary surficial deposits exist as sand sheets, eolian dunes, pediment-capping alluvium, debris flow deposits, landslide deposits, and valley-floor alluvium throughout the quadrangle.

The depositional history of the Coyote Canyon 15-minute Quadrangle contains three broadly defined episodes: first, Late Cretaceous deposition of marine, shoreface, estuarine, and fluvial siliciclastic sediments during the penultimate and ultimate transgression-regression cycles of the Western Interior Seaway produced the Crevasse Canyon Formation, Point Lookout Sandstone, Mancos Shale, Menefee Formation, and Tohatchi Formation, all of which are preserved in outcrop in the map area. Second, Quaternary mass movements in the Chuska Mountains on the western margin of the map area led to coarse, poorly sorted hillslope and pediment deposits in the western and central map area. Finally, later Quaternary deposition of eolian sands produced the broad sand sheets which predominate in the central and eastern map area, while sheetwash and alluvial processes led to the gravels and sands that comprise the unconsolidated deposits found throughout the quadrangle's valleys and canyon floors. Modern geologic processes in the quadrangle are dominated by arroyo incision and eolian deposition, though creep-dominated mass movements in steeper terrain west of Highway 491 possibly occur.

Deformation structures in the Coyote Canyon 15-minute Quadrangle that are mappable at the 1:62,500 scale include numerous faults in the southeastern map area and low-angle folding throughout the map area. Each fault where offset can be clearly ascertained is a normal fault. These faults' traces trend east-northeast.

The map area is drained by dozens of roughly parallel northeast-flowing ephemeral streams indicative of a youthful landscape. Some of these, such as Red Willow Wash, Red Water Canyon, and Peach Spring Canyon, terminate in dune-dammed playas or blowout depressions lacking external drainage. Most, however, are tributaries to Coyote Wash, itself a tributary to the Chaco River. Landforms in the quadrangle include mountain fronts, arroyos, canyons, mesas, nabkha fields, low-relief plains, eolian dunes, and blowouts. Vegetation includes that typical of US EPA Level III ecoregions 22i (Arizona/New Mexico Plateau San Juan/Chaco Tablelands and Mesas), 22j (Arizona/New Mexico Plateau Semiarid Tablelands), 23 c (Arizona/New Mexico Mountains Montane Conifer Forests), and 23e (Arizona/New Mexico Mountains Conifer Woodlands and Savannas) (Griffith et al., 2006; USEPA, 2006).

LAND ACCESS

Field work on the Navajo Nation was conducted under a permit from the Minerals Department. Any persons wishing to conduct geologic investigations on the Navajo Nation must first apply for and receive a permit from the Minerals Department, P.O. Box 1910, Window Rock, Arizona 86515 and Telephone No. (928) 871-6588.

ABBREVIATIONS and CONVERSIONS

mm	millimeter = 0.03937 inches
cm	centimeter = 0.3937 inches
m	meter = 3.28 feet = 39.37 inches
km	kilometer = 0.6214 miles = 3,281 feet
in	inch = 2.54 centimeters
ft	foot = 0.3048 meters
mi	mile = 5,280 feet = 1,609 meters
ha	hectare = 2.47 acres = 0.01 km^2
F	Fahrenheit
C	Celsius
ka	kiloanni (thousands of years before present)
Ma	megaanni (millions of years before present)
USGS	United States Geological Survey
NMBGMR	New Mexico Bureau of Geology and Mineral Resources
API	American Petroleum Institute

NOTE ON VEGETATION NAMES

In the natural environment, vegetation expresses the interrelationship between all facets of the landscape, including climate, soil, and geochemistry. As such, we believe that any description of geology in the landscape is incomplete without including major plant communities. This report lists plants at first usage by a common name followed by parenthetically offset Navajo (Diné) name and italicized binomial name (for example: wolfberry (Haasch'ééhdą́ą́', *Lycium torreyi*)). After the first usage in this report, only common names are used.

INTRODUCTION

This report accompanies the Geologic Map of the Coyote Canyon 15-minute Quadrangle, Navajo Nation (also within McKinley County, New Mexico) (NMBGMR OF-GM 314). Its purpose is to discuss the geologic setting of the map area, to explain the geologic history of the map area, and to identify and explain significant stratigraphic and geomorphic relationships discovered during the course of mapping. This report presents several fundamental geological aspects of the quadrangle, including the geographic and physiographic settings, climate, and previous geological work. Then it describes the depositional history of the geologic map units and their depositional settings by age in greater detail than is possible on the map sheet. The structural geology and geomorphology of the area are discussed. Figures, figure captions, and appendices are presented at the end of this document.

MOTIVATION

Exposures of Mesozoic strata along the Chuska Mountain front and of Quaternary surficial deposits in terraces, canyons, arroyos, and stabilized dunefields throughout the area allow for the opportunity to reconstruct the geologic history for this area of the Colorado Plateau in New Mexico. A previous mapping effort produced a robust small-scale geologic map focusing upon Cretaceous units within the quadrangle (Dillinger, 1990). We refine this earlier mapping, with particular focus on adding detail and accuracy to surficial units, accuracy of contacts, and member-level designations of Cretaceous units.

This map was initiated, completed, and published by the New Mexico Bureau of Geology and Mineral Resources as part of its mission of creating accurate, up-to-date maps of the state's geology and resource potential. The map area was selected at the suggestion of the New Mexico STATEMAP Advisory Committee in its 2022 meeting.

CLIMATE

The Coyote Canyon 15-Minute Quadrangle – and most of the San Juan basin – has a cold semi-arid climate (Koppen Classification *Bsk*). Mean annual temperatures are 52.3°F (11.3°C) at Tohatchi in the western map area (elevation 6,420 ft (1,957 m)). Mean annual precipitation is 9.62 in (24.4 cm), with an average of 13.4 in (34 cm) of snowfall annually. There is pronounced seasonality of precipitation, with 46% of annual precipitation occurring in July, August, and September. All climate data listed above are from the Tohatchi 1 ESE station (ID# 298919) in the National Weather Service Cooperative Network and averaged over the years 1914 to 1979. (Western Regional Climate Center, 2023).

GEOGRAPHIC AND TECTONIC SETTING

The Coyote Canyon 15-Minute Quadrangle covers approximately 240 mi^2 (622 km^2) in the southeastern Navajo Nation, also in northwestern New Mexico. The quadrangle is entirely within McKinley County, New Mexico. The largest community on the quadrangle is Brimhall Nizhoni (Mą'ii Tééh Yítłizhí), also known as Brimhall or Coyote Canyon. The eastern portions of the community of Tohatchi (Tó Haach'i') also lie on the quadrangle. The quadrangle encompasses large portions of the Tohatchi (Tó Haach'i') Chapter and Coyote Canyon (Mą'ii Tééh Yítłizhí) Chapter of the Navajo Nation and a small (<5 mi^2 [<13 km^2]) portion of the Mexican Springs (Naakaii Bito') Chapter. Human populations in the quadrangle are concentrated near the communities of Tohatchi and Brimhall Nizhoni, with less-dense concentrations near U.S. Highway 491 (formerly U.S. Highway 666) and Navajo Service Route 9 (also colloquially known as "the Crownpoint road"). There are widely dispersed homesteads, ranches, and camps throughout the less-populated portions of the quadrangle. Nonetheless, as of this writing, there exist contiguous tracts of many tens of square miles on the quadrangle with no human population or infrastructure. There are an estimated 1,575 people living within the quadrangle as of 2020 (CIESIN, 2020). Elevations in the map area range from 7,935 ft at an unnamed hill above White Water Spring in the Tocito Wash drainage on the western map margin to 5,720 ft at Coyote Wash where it exits the northern quadrangle boundary. Major drainages in the quadrangle include Coyote Wash, Tocito Wash, Red Willow Wash, Figueredo Wash, Dye Brush Wash, Big Spring Canyon, Wild Berry Canyon, Peach Spring Canyon, and Red Water Canyon, all of which are intermittent or ephemeral. Chuska Lake, a 42 hectare (105 acre) anthropogenic impoundment on Red Willow Wash near Tohatchi, is the only large permanent water body within the quadrangle, though several small (<2 hectare) livestock ponds and blowout depressions were observed holding water during field mapping efforts in spring through autumn 2023.

The quadrangle lies entirely within the Colorado Plateau physiographic province, a region of relatively little faulting and folding compared to surrounding provinces. The Colorado Plateau's characteristic lack of abundant major tectonic deformation features is manifest in the Coyote Canyon 15-Minute Quadrangle by low dip angles and the presence of only small, low-offset faults and gentle folds throughout the quadrangle. Across the Colorado Plateau, broad tectonic uplift occurred during the Cenozoic Era, leading to the high elevations that persist across the map area.

For simplification of regions within the map area, there are three broad geographic categories: (1) in the northwest map area, the Chuska Mountain landslide dominates the steeper and higher terrain west of U.S. Highway 491; (2) in the southeast map area, north-northeast-dipping sandstones of the Point Lookout Sandstone form deep canyons and expansive pavement outcrops; and (3) throughout the central map area, especially along Red Willow, Figueredo, and Coyote Washes, low-relief alluvial plains are punctuated by widely-dispersed low mesas in Tohatchi Flats (Figure 1).

PREVIOUS WORK

Early geologic investigations in the vicinity of the Coyote Canyon 15-Minute Quadrangle was done by Shaler (1906), Reeside (1924), Sears et al. (1936; 1941), Pike (1947), Baltz (1953), Allen and Balk (1954), and Beaumont et al. (1956). Late 20th-Century refinement of structure, stratigraphy, and geomorphology was aided by Sabins (1964), O'Sullivan et al. (1972), Zech (1982), Molenaar (1983), and Wells et al. (1990). O'Sullivan and Beaumont (1957) produced a 1:125,000-scale geologic map of the area that included seven geological units within the Coyote Canyon 15-minute Quadrangle. Hackman and Olson (1977) produced a less-detailed 1:250,000-scale geologic map that also covered the Coyote Canyon 15-Minute Quadrangle. Dillinger (1990) produced the largest-scale geologic map of the area; at the 1:100,000 scale, this map includes little detail on the extensive surficial units of the region. Prior to this work, there exist no known geologic maps of the Coyote Canyon 15-Minute Quadrangle at any scale larger than 1:100,000, but three published 1:24,000-scale geologic maps border it (Kirk and Zech, 1987a and 1987b; O'Sullivan et al., 1989).

Previous mapping of the Chuska Mountain landslide is limited in detail—mainly being mapped as a single polygon. The exceptions are a non-spatially referenced figure (Watson and Wright, 1963), and two plates at the 1:500,000 scale from a publication covering the surficial geology of the state of New Mexico (Cardinali et al., 1990). Watson and Wright (1963) mapped a scarp at the top of the Chuska Mountains and three levels of landsliding. Those authors interpreted the highest elevation landsliding as the youngest; it occurs as a jumble of non-rotated block glide slump blocks. The middle level was interpreted to be intermediate in age while the lowest level was interpreted to be the oldest portion of the landslide. Watson and Wright (1963) also recognized a mud flow to the north of the Coyote Canyon quadrangle. Plate 1 from Cardinali et al. (1990) features a head scarp around the escarpment of the Chuska Mountains as well as one large internal scarp mapped in the middle of the landslide complex approximately at the same location as a scarp from this publication that separates older, undivided, landslides (Qlso) from intermediate rotational landslides (Qrsi). Plate 3 of Cardinali et al. (1990) features the landslide as a single polygon using map unit T (Toreva block complex landslides). Guzzetti et al. (2012) called this slide complex the Naschitii slide.

Byers (1979) published a 1:24,000-scale geologic map of the Crystal 7.5' quadrangle that included the map unit 'Qls' (landslide) in the very northeast corner of the map. This area covers the block glide dominated landslide material most proximal to the main scarp at the top of the Chuska Mountains; this material is found to the west of, but not within, the Coyote Canyon quadrangle. Just to the west of the Coyote Canyon quadrangle is a 1:48,000-scale map of the Fort Defiance and Tohatchi quadrangles by Allen and Balk (1954). These workers mapped the upper portions of the Chuska Mountain landslide as map unit 'Ql' (landslide) over the respective underlying, concealed, bedrock units (e.g. 'Ql/Tc' for landslide over Chuska Sandstone). This map also included slopewash and alluvial map units between Toreva Blocks and other slump blocks that had undergone further dissection. Ziegler (1955) mapped the Toadlena quadrangle to the northwest at a scale of 1:63,360 and mapped the landslide from the main scarp to the landslide toe as map unit 'Qls' (landslide) along with a few polygons of in-situ bedrock. The Naschitti quadrangle at a scale of 1:63,360 was mapped by O'Sullivan (1955) and covers the full extent of the landslide in the Coyote Canyon quadrangle. That publication used map unit 'Qls' (landslide) and captured good detail of embayment where in-situ Cretaceous bedrock is found within the limits of the landslide complex as well as where isolated landslide klippes are found beyond the limits of the main landslide polygon.

A number of maps at smaller scales have also covered the Chuska Mountain landslide. Dillinger (1990) mapped the Gallup 30'x60' quadrangle at the 1:100,000 scale. This map covered the basic extent of the landslide complex using map unit 'Qls' (landslide), included a few in-situ Cretaceous bedrock polygons, and had a syncline extending north-northwest into the southern erosional escarpment of the landslide just north of highway 491. O'Sullivan and Beaumont (1957) mapped the 'Preliminary geologic map of western San Juan basin' at the 1:125,000 scale using map unit 'Qls' (landslide) while capturing moderate detail of Cretaceous bedrock embayment and islands of landslide material. Cooley et al. (1969) mapped at the 1:125,000 scale for a paper addressing the 'Regional hydrogeology of the Navajo and Hopi Indian Reservations' and featured two sheets that include mapping of the Chuska Mountain landslide (Sheet 8 covers the Coyote Canyon 15-minute quadrangle while sheet 7 is north of quadrangle). They mapped the general outline of the landslide complex using map unit 'Qls' (landslide) and captured some detail of the embayment of Cretaceous bedrock and islands of landslide material. Hackman and Olson (1977) mapped the 'Geology, structure, and uranium deposits of the Gallup 1°x2° quadrangle' at the 1:250,000 scale and used map unit 'Qcl' (landslide debris) capturing the landslide complex as one polygon with some embayment of Cretaceous bedrock and polygons of in-situ bedrock outcropping within the landslide. Two statewide 1:500,000-scale maps (Dane and Bachman, 1965; NMBGMR, 2003) map the landslide as map unit 'Ql' (landslide) with a few polygons of Cretaceous bedrock outcropping within. A statewide surficial map at the 1:500,000 scale by Hawley et al. (2021) has the landslide as map unit 'JC' (Colluvium-landslide complexes) while Hunt (1978) mapped the 'Surficial geology of northwest New Mexico' at the 1:500,000 scale and used map unit 'lds' (complex of landslide and avalanche).

Tohatchi Formation Controversy

A controversial subject in this area has been the designation of the sedimentary rocks that overlie the Allison Member of the Menefee Formation as either the Tohatchi Formation or the Fruitland Formation and Kirtland Formation, undivided. Gregory (1917) worked in this area where he called the rocks the Tohatchi Shale. He placed them in the Tertiary because the sedimentary sequence looked similar to the Nacimiento Formation elsewhere in the San Juan Basin. Gregory (1917) described the upper contact to be conformable while the basal contact was unconformable where a conglomerate of the Tohatchi Shale made contact with the Menefee Formation. Wright (1954) recognized that Gregory (1917) had based these observations on what had appeared to be in-situ Cretaceous bedrock, but was actually material that had been downdropped as part of a landslide. So, rather than a basal conglomerate of the Tohatchi Shale, Gregory (1917) was observing the mass wasted basal conglomerate of the Chuska Sandstone that overlies the top of the Tohatchi Shale. The nature of these contacts were corrected by Allen (1953) who went on to rename the sequence the Tohatchi Formation, designate three different members, and assign it to the Mesaverde Group. At the base of the formation he described a conformable contact between the Menefee Formation and his newly designated Lower Carbonaceous Member. At the top of the formation he described an unconformable contact between the new Upper Bentonitic Member and the overlying Chuska Sandstone. Wright (1954) followed the lead of Allen (1953): correcting the basal contact, calling the sedimentary rocks the Tohatchi Formation, and including them in the Mesaverde Group. Allen and Balk (1954) expanded their interpretations by designating the sandstones near the base of the Lower Carbonaceous Member to be a pinchout of the Cliff House Sandstone and Pictured Cliffs Formation while they interpreted the Upper Bentonitic Member as an equivalent of the Fruitland Formation and parts of the Kirtland Formation.

Since then, workers have made a variety of interpretations of the Cretaceous stratigraphy of the southern Chuska Mountains. Some maps have lumped all the rocks into the Menefee Formation leaving both the Tohatchi Formation and Kirtland/Fruitland Formations absent in this area (O'Sullivan, 1955; Dane and Bachman, 1957; Dane and Bachman, 1965; Cooley et al., 1969; Hackman and Olson, 1977). The 1:500,000-scale Geologic Map of New Mexico (NMBGMR, 2003) included polygons of the Kirtland and Fruitland Formations along the mountain front but has the Menefee Formation in contact with the Chuska Sandstone at the southern escarpment of the Chuska Mountains; presumably this is a scale issue that prevented the limited aerial extent of Kirtland and Fruitland Formation outcrop from being displayed on the map. Other workers have simply assigned all sedimentary rocks underlying the Chuska Sandstone in the southern Chuska Mountains to the Kirtland and Fruitland Formations (Ziegler, 1955; O'Sullivan and Beikman, 1963; O'Sullivan et al., 1972; Young, 1973; Hackman and Olson, 1977).

Lucas et al. (2003) revisited the Tohatchi Formation and published observations and biostratigraphic data that set the formation apart from the Kirtland and Fruitland Formations. They moved the basal contact of Allen and Balk (1954) a few hundred feet upsection and renamed the Lower Carbonaceous Member to the Separate Hill Member and the Upper Bentonitic Member to the Red Willow Wash Member based on measured type sections. They made note of bedform and lithologic changes at the base of the formation where bench, shoulder, and slope forming very friable, thick bedded, very fine-grained subarkoses of the Menefee Formation graded into ledge, cliff, and bench-forming well indurated and thin bedded sands of the basal Separate Hill Member of the Tohatchi Formation (Fig. 2). The upper Red Willow Wash Member is marked by the change to predominant mudstone from predominant sandstone of the lower member. Palynomorph analysis from samples collected in the Tohatchi Formation and Menefee Formation point towards an early (but not earliest) Campanian age for the base of the formation. Some hesitancy is expressed in that report as the authors note that "defining species of the zone boundaries" were not seen; however, the rocks were included in the early

Campanian biozone because the assemblage was overall similar to a regional biostratigraphic correlation for the intermountain west by Nichols et al. (1982) and Nichols (1994). That designation places the Tohatchi Formation with the R-4 regression of the upper Mesaverde Group which predates the late Campanian R-5 regression and turnaround of the Cliff House Sandstone and Pictured Cliffs Formation, above which the Kirtland and Fruitland Formations are found (Molenaar, 1983; Lucas et al., 2003).

Chuska Sandstone

While not within the Coyote Canyon 15′ quadrangle, the Chuska Sandstone accounts for a large portion of the landslide material within the northwestern quadrangle area. While early workers (Gregory, 1917; Reiche, 1941) described the Chuska Sandstone to have lithologic equivalents elsewhere in the Four Corners area, Wright (1954) argued that it was a standalone formation. Wright (1954) measured sections and designating the basal fluviatile conglomerate as the Deza Formation of the Chuska Sandstone. He described the contact of the Deza Formation to be gradational with the overlying eolianite of the Chuska Sandstone and provided locations of several quality outcrops of the basal conglomerate. Watson and Wright (1963) assumed the sediments to be Miocene in age but stated some hesitancy about that age designation. Lucas and Cather (2003) revisited the Chuska Sandstone where they measured section, investigated vertebrate fossils, described the stratigraphy, collected samples for geochronology, and renamed the Deza Formation to the Deza Member and assigned the overlying sandstones to the Narbona Pass Member of the Chuska Sandstone. $^{40}Ar/^{39}Ar$ geochronology dates provided an age of 34.75±0.20 Ma for the basal Deza Member, 33.31±0.25 Ma for the lower portion of the Narbona Pass Member, and 25±0.16 Ma for an overlying trachybasalt (Lucas and Cather, 2003).

MAPPING METHODS

The procedures used to produce this geologic map are divided into four phases, all of which employ digital methods and the input of geological data directly into a Geographic Information System (GIS) database by the authors. The first phase involved the authors identifying geologic units and likely contacts on LiDAR-derived digital elevation models and aerial digital photographs with the aid of previously published maps and reports. Aerial photographs include imagery from Google Earth and the National Aerial Imagery Program (NAIP), though digital stereogrammetric photograph pairs were most heavily utilized. Stereo Analyst for ArcGIS 10.8 software was used to draw contacts and faults. The second phase involved field-checking specific areas for contact accuracy, lithologic character, and stratigraphic relationships; this phase used traditional field methods as outlined by Compton (1985) as a foundation. This phase also included measurement and description of units' structural, stratigraphic, and sedimentologic properties. This phase includes recording pertinent points and lines in a handheld GPS unit. The third phase involved updating the locations of contacts and faults and revising lithologic identification based on field checks in the second phase. Finally, the map was simplified for the purpose of 1:62,500-scale final layout. Geographic division of the authors' mapping efforts is represented in Figure 3, with Krupnick focusing on the Chuska Mountain landslide, and Hobbs focusing on Tohatchi Flats and the sandstone canyons of the southeast map area.

The geologic cross-section was created after completion of the geologic map. The surface profile and geology was created from topographic and geologic information on the geologic map. Subsurface data were gathered and interpreted from a well log and drillers' reports on file with the New Mexico Oil Conservation Division of the Energy, Minerals, and Natural Resources Department and the NMBGMR's Subsurface Library. The location and API number of the well are included on the geologic map and cross-section.

Bed thickness descriptions use the terminology of Ingram (1954). Sedimentary clast and grain descriptions follow Wentworth (1922). Sandstone and sand classification terminologies follow Folk (1974). Sediment and rock colors are based on visual comparison of dry (unless otherwise noted) samples to Munsell soil color charts (Munsell Color, 2009). Clast counts of pediment-terrace gravel composition were conducted by randomly placing a rigid 2-m ruler on an appropriate outcrop; every clast greater than 1 cm B-axis diameter within 10 cm of that ruler was counted until a minimum population (usually 100 clasts) was counted. The presence or absence of carbonate in specimens was determined by the application of 10% HCl (hydrochloric acid) on dry samples. Bed thicknesses and outcrop heights were determined with measuring tape, ruler, or a Nikon® Forestry Pro II laser rangefinder/hypsometer. Slope angles of geomorphic surfaces or pavement outcrops were determined with the aforementioned laser rangefinder/hypsometer, Abney level on Jacobs staff, or by calculating surface slopes in ArcGIS using elevation data derived from SPADTM rasters.

Mapping of the Chuska Mountain landslide was completed with LiDAR data sets, NAIP satellite imagery, and fieldwork to ground truth observations made from remote sensing data. In the field, roads and drainages were the primary access to the extremely hummocky topography. Individual polygons were mapped based on observation of morphological features (lateral margins, toes, internal scarps, transverse ridges, etc.) and relative ages were based on the degree of back rotation, mixing & deformation, landscape position, and surface texture in imagery. Categorization of landslide type was inspired by Burns and Madin (2009) but based on the schema of Varnes (1978).

Mapping of the contact between the Menefee Formation and Tohatchi Formation was based on gradational sedimentological changes described by Lucas et al. (2003). The contact was primarily mapped from imagery but was field checked in two locations, the contact is mapped as approximate throughout the map area due to low-moderate confidence in the identification of the contact.

STRATIGRAPHY

Geological materials in the Coyote Canyon 15-Minute Quadrangle include sedimentary rocks and unconsolidated sediments. We discuss the bedrock units in ascending chronologic order, followed by surficial sediments. Many surficial units likely have long-term simultaneous depositional histories that make narrative chronologic relation difficult. Because of that, surficial sediments in this section are grouped by depositional style more so than chronologic order of deposition. Full unit descriptions are included as Appendix A.

Cretaceous Sedimentary Strata

Most of the map area contains a conformable succession of intertonguing Cretaceous strata that characterizes much of the southern and western margin of the San Juan basin. The stratigraphically lowest and oldest unit at the surface in the map area is the Gibson Coal Member of the Crevasse Canyon Formation (Fig. 4), a suite of sandstones, mudstones, and coals deposited on coastal floodplains near the peak of the Santonian (penultimate) transgression of the Western Interior Seaway. Cavaroc and Flores (1984) interpret the Gibson Coal Member of the Crevasse Canyon Formation in the southwestern San Juan Basin as having been deposited in north-flowing low-energy distributary rivers, floodplains, and deltas, an interpretation with which we agree and apply to outcrops within this quadrangle.

The Crevasse Canyon Formation is conformably overlain by the Point Lookout Sandstone, which is predominately sandstone with subordinate shales. Fossils of shark teeth and *Inoceramid* shell fragments and impressions are found throughout this unit (Figs. 5 and 6). Those, along with sedimentary structures and facies geometry, lead to its interpretation as a record of the passage of the Western Interior Seaway shoreface during the penultimate Cretaceous highstand. In the map area, the Point Lookout Sandstone is split into two tongues: the lower Hosta Tongue, which records a small-scale transgression after deposition of the Crevasse Canyon Formation, and the "main body" of the Point Lookout Sandstone, which mostly records the beginning of the penultimate regression of the Western Interior Seaway that began in the Santonian and persisted into the early Campanian. Zech (1982), Wright (1986), and Devine (1991), among other workers, interpret the Point Lookout Sandstone as a beach and/or strandplain sandstone correlative to the Virgelle Sandstone in Montana and the Star Point Sandstone in Utah, an interpretation with which we agree based upon our observations in the canyons in the southern portions of this map area.

In the map area, the two tongues of the Point Lookout Sandstone are split by the Satan Tongue of the Mancos Shale in the eastern portions of their outcrop belt (Fig. 7). Among the units exposed at the surface, the Satan Tongue of the Mancos Shale represents the highest sealevel and westernmost transgression of the Western Interior Seaway in the map area (there is another tongue of the Mancos Shale in the subsurface of this map area that likely represents an even higher sealevel and farther-west transgression; that tongue is not exposed at the surface within the Coyote Canyon 15-Minute Quadrangle. See Kirk and Zech (1977) for discussion of that subject.) The Satan Tongue of the Mancos Shale in the map area contains interbedded mudstones and sandstones (Fig. 8) with abundant fossil remains of marine invertebrates (Fig. 9). Compared to its type locality at Satan Pass, approximately 40 km southeast of the map area, the Satan Tongue of the Mancos Shale here is much sandier, thinner, and less shaly. The unit pinches out to the west completely between Wild Berry Canyon and Coyote Canyon; this pinchout represents the farthest-west transgression of a Santonian marine depositional environment in the map area. The Satan Tongue of the Mancos Shale interfingers with the Point Lookout Sandstone.

The Point Lookout Sandstone is conformably overlain by the Menefee Formation, which in this map area contains two members: the lower Cleary Coal Member and the conformably overlying Allison Member. These two members represent the progradation of fluvial systems across the landscape as the Western Interior Seaway receded during the Santonian/Campanian (penultimate) regression. Lithologic composition of these two members is similar, except for the presence of more thick coals in the lower Cleary Coal Member. Thinner and more discontinuous coals also are present within the thicker and more geographically widespread Allison Member, which is found throughout much of the map area. Fossils of trees, turtles, and dinosaurs, along with fluvial bedforms and the presence of coals, lead to the interpretation of these members of the Menefee Formation as terrestrial-dominated deposits of northeast-flowing paleorivers. Mudstones and sandstones dominate, with traces of conglomerate and coal.

Overlying the Allison Member of the Menefee Formation is the Tohatchi Formation, which has also been mapped and described as the Fruitland and Kirtland Formations in some publications (see discussion above). This publication uses Tohatchi Formation, as the regression of the Western Interior Seaway that resulted in the terrestrial deposition of the Tohatchi Formation was the R-4 regression of Molenaar (1983) which precedes the regression that deposited the Kirtland Formation. The Tohatchi Formation was deposited in coastal plain, swamp, lacustrine, fluvial, and floodplain environments (Young, 1973; Cather, 2004). It appears to include estuarine or intertidal brackish environments as there is a presence of marine dinoflagellates (Lucas et al., 2003). However, it is possible that these dinoflagellates were reworked from marine deposits in sediment source areas. These rocks also yielded terrestrial vertebrate bone fragments and fossils of non-marine mollusks (Lucas et al., 2003).

Paleogene Sedimentary and Volcanic Strata

To the west of the quadrangle, the Deza Member of the Chuska Sandstone overlies the Tohatchi Formation at an angular unconformity on a low-relief beveled surface (Wright, 1956). The sedimentary rocks of the Deza Member are dominated by conglomerate (Fig. 10) derived from the San Juan Uplift and record distal piedmont alluvial and fluvial facies (Cather et al., 2003; Cather, 2004). The gradationally overlying Narbona Pass Member of the Chuska Sandstone represents an ergdepositional system with as much as a kilometer of deposition from the middle Eocene to early Oligocene (Cather et al., 2008; Fasset, 1985). To the northwest of the quadrangle the Chuska Sandstone is intruded and overlain by volcanic rocks of the Navajo volcanic field (Appledorn and Wright, 1957). A date of 25±0.16 Ma was acquired for a trachybasalt from $^{40}Ar/^{39}Ar$ dating by Lucas and Cather (2003).

Quaternary sediments

Quaternary sediments in the Coyote Canyon 15-Minute Quadrangle can be placed into six categories: mass wasting units, alluvial units, fan units, lacustrine units, eolian units, and slope deposit units. Each of these categories contains multiple map units which are defined and explained in the Description of Map Units. We do not propose formal names for these units and instead here use informal descriptive names and map symbol abbreviations. Here, we give broad introductions to the processes and products of each category.

Mass wasting units

Much of the map area west of Highway 491 contains surficial deposits of landslides and earthflows. We interpret four broadly-defined episodes of mass movement activity defined by cross-cutting relations, landscape position, and soil development. In general, older mass movement deposits occupy higher landscape positions than do younger deposits. Determination of numeric ages of mass movements was not an objective of this mapping effort. The authors recognized an 'older' generation of land sliding preserved at the far west margin of the map in an area of denudated and infilled landslide debris as well as near the base of the Chuska Mountain landslide where remnants of the older landslide deposits are preserved in high topographic positions. Incision and embayment created accommodation space for later intermediate and younger landslide deposits. During the Holocene, the hummocky landslide terrain has been infilled by alluvial, eolian, and slopewash processes as well as recent landslides occurring in ephemeral drainages and along erosional escarpments. Anthropogenic activity has further altered the landslide landscape through the construction of roads, structures, and artificial ponds.

Alluvial units

Quaternary alluvium in the quadrangle is subdivided into three units separated based on relative age or genetic origin. All were deposited in intermittent to ephemeral streams contained within valleys, and are lithologically similar. Map unit Qao is geomorphically higher than map unit Qa and represents alluvial deposition before more recent incision of the alluvial system (Fig. 11). Map unit Qas contains significant slopewash alluvium. Map unit Qao is presumed to be late Pleistocene to Holocene, though numeric ages are not known; map units Qa and Qas are Holocene.

Fan units

Alluvial fans in the map area range in size from a few meters across to over a kilometer in width and commonly occur at the debouchment of streams from the Chuska Mountain front onto the low-relief Tohatchi Flats, and on Tohatchi Flats as parts of discontinuous arroyos or where arroyos enter dune-dammed playas. Alluvial fans in the map area contain silt through gravel derived from higher elevations to the west and south. Given their sand-dominated composition and the high eolian deposition rates across the map area, fan units in the coyote Canyon 15-Minute Quadrangle typically lack desert pavements of pebbles as are common in other alluvial fans in the region. Deposition on active alluvial fans was observed during the summer 2023 mapping effort, and frequent but episodic deposition can be observed throughout the 21st Century on historic aerial imagery. Alluvial fan deposits frequently interfinger with adjacent lacustrine, alluvial, and/or eolian units.

Lacustrine units

In sag ponds on and near the Chuska Mountain landslide, in dune-dammed playas, blowout depressions, and behind anthropogenic dams, clay- through gravel-sized sediment accumulated in standing water. Clay and silt predominate in these deposits. Mudcracks and vertebrate footprints (of livestock, canids, and birds) indicate that these environments of deposition episodically dry out completely. These units constitute a small portion of the map area.

Eolian units

Much of the central map area contains expansive deposits of eolian sands. These take the form of mixed eolian/alluvial units in valley bottoms (Fig. 12), large linear and parabolic dunes up to several km long and elongated to the northeast in alignment with prevailing southwesterly winds, and as large semi-stabilized sand sheets (Fig. 13) that likely represent Pleistocene deposition across much of the landscape. In all settings, the majority of the sand in these eolian deposits is derived from sand-bed arroyos within and upstream of the map area.

Slope deposit units

Slopewash and colluvium are found across much of the map area where terrain steepness prevents channelized flow and soil development is minimal. Given the steep landscape positions where they occur, neither slopewash nor colluvium is likely to be preserved as a geological material long-term. Because of this, we interpret these units be Holocene in age, at the oldest. Minor alluvial and eolian deposits can be found among these slope deposit units.

Pediment-terrace deposits

Wide terrace-like features below the Chuska Mountain front are interpreted as pediment-terraces *sensu* Howard (1942) (Fig. 14). Each of these landform features, most of which are found near Highway 491 in the western map area, also contains an associated deposit of moderately- to poorly-sorted alluvial sand through boulders (Fig. 15) derived from highlands to the west and the Chuska Mountains. The composition of these deposits is included in Appendix B. Each of these units represents a two-stage process of erosion and deposition: first, the landscape downslope of the Chuska Mountain front or Tohatchi Flats where the deposits are found was beveled by erosion. After landscape planation, high-energy streams and/or alluvial fans deposited sand through boulders in broad sheets across the beveled landscape. The slope of the top surface of these deposits is parallel to the surface of planation; these slopes are considerably steeper than the slopes of modern arroyos in the study area. The topographic relief between modern streams and the pediment-terrace deposits ranges from 8 to 54 m; we interpret the highest surfaces/deposits as the oldest, and the lowest as the youngest (Fig. 16). Some of these pediment-terrace deposits appear to grade into landslide deposits at the Chuska Mountain front, leading to the interpretation that episodes of mass movement likely coincide with production of transportable material and subsequent episodes of pediment deposition.

Anthropogenic units

Throughout the map area, small berms and dams have been constructed as impoundments across arroyos and streams. The materials for these features were gathered from the immediate vicinity of the impoundment. Aggregate for the construction of Highway 491 is partially local, but also contains materials transported from well outside the map area. These anthropogenic units comprise a minute portion of the map area, but their impoundment of drainages leads to significant alteration of geological processes, hence their inclusion as a separate map unit.

DEFORMATION STRUCTURES

Bedding orientation throughout the map area generally exhibits shallow dip angles of less than 10°. In the southeast map area, beds strike northwest-southeast, broadly parallel to the northeast limb of the Zuni uplift as it dips northeast into the Chaco slope. A faintly-expressed but mappable syncline, anticline, and monocline trend parallel to this structure, as well; all three of these folds shallowly plunge northwest. In the southwestern quarter of the map area, in Tohatchi Flats, bedding strikes southwest-northeast and generally dips northwest. We interpret this as an expression of transition from the Zuni uplift/Chaco slope to the east into the Gallup sag to the west, based on the structural orientations of Kelley (1951), Woodward (1973), Hackman and Olson (1977), Craigg (2001), and Thacker (2021). In the northern half of the map area, limited bed orientation measurements display variable strikes and shallow dips. In the northeastern map area, the lack of bedrock outcrops on which bedding orientation can be measured prevents meaningful structural interpretation. In the northwestern map area on the Chuska Mountain landslide, it is difficult to know with certainty if beds of Cretaceous bedrock have been transported or rotated in mass movements, again preventing meaningful structural interpretation from this mapping effort.

In the southeastern map area, six roughly parallel northeast-trending normal faults are well-expressed where they crosscut Cretaceous sandstones and mudstones (Fig. 17). These faults' traces are approximately 2.5 to 4.5 km long. Fault planes dip southeast at 75 to 85°. Observed fault offset is greatest near the center of a fault's trace, and approaches zero near the faults' tips where the faults appear to become fractures with no noticeable offset. Maximum observed offset is 8 m. Kinematic indicators (slickensides) were only observed at one fault; they indicate pure dip-slip motion. Timing of motion on these faults is unknown. Further investigation is needed to determine causes of stress, relative timing, and relationships to other local and regional structures for these faults.

SCHEMATIC MODEL OF CHUSKA MOUNTAIN LANDSLIDE

The following description is primarily based on field observations and supported by interpretive observations from NAIP and LiDAR imagery. Field checking included observations of landslide consistency, morphology, defining features (transverse ridges, toes, lateral margins, scarps), existence of subsequent Quaternary deposits (lacustrine, alluvial, eolian, slopeswash, recent landslide), and mapping of Cretaceous contacts. While landslides are split into rotational, earthflow, and undivided types, there is likely a mix of other mass movement influences throughout each deposit including creep, solifluction (Blagbrough, 1965), rock falls, and debris flow transport. Past workers have interpreted landsliding to have occurred during the Pleistocene with colder temperatures and higher precipitation (Watson and Wright, 1963). Figure 18 aims to tell the same story as the following paragraphs while giving the reader a visual to aid to understand the text. These descriptions are based on the most representative locations (west to east movement) unless explicitly mentioned to be about slides off the southern escarpment.

The original landslide material on the landscape extending east off the Chuska Mountains was likely the product of a sequence of mass wasting rather than a single event. This deposit represents the oldest landslide material found in the map area and is mapped as 'Qlso' (Older Landslide Deposits) due to its raised landscape position, cross cutting relationships with more recent slides, and subdued textural expression at the surface. During the initiation of these mass wasting events the Deza Bluffs (east facing escarpment of the Chuska Mountains) is inferred to have been considerably east of its present location. The slides likely occurred as rotational slump blocks that graded into more flow-dominated slides helping to prograde the toe of the landslide to the east of its present day termination (approximately at map unit 'Qlso/Qper). The landslide would have come to rest on the valley floor where fluvial and alluvial processes would have incised the valley floor and landslide leaving behind a pediment-terrace deposit ('Qper' and 'Qpc'). Watson and Wright (1963) interpreted the lowest level (farthest east and lowest elevation) of landslides to be the oldest which matches up with interpretations from this publication; however, subsequent mass wasting causes a majority of this lowest level to be younger in age, leaving behind limited remnants of the older landslide deposits. Deposits are predominantly boulders of Chuska Sandstone within a matrix containing a higher percentage of sand when compared to subsequent sliding that features more mixing with Cretaceous mudstones.

Vertical denudation of the landscape, incision of minor east-west streams cutting the landslide material, and horizontal embayment of the landslide mass would have produced sufficient accommodation space for subsequent mass wasting of unstable slopes. The next generation of landslides, here named 'Qrsi' (Intermediate Rotational Landslide Deposits) occurred first along moderately deep (estimated 50-150m) concave-up rotational failure surfaces. These failures would have moved expansive swaths of material downslope while backrotating both the previously subhorizontal Cretaceous strata as well as the overlying mantle of landslide debris from the older landslide deposits. Back rotation along the failure planes of these rotational slides was observed to be mostly limited to the Tohatchi Formation except along the southern escarpment where some back rotation within the Menefee Formation was observed in an intermediate rotational landslide. While not observed, some Menefee Formation may also have been moved by intermediate rotational landslides along the eastern slope. At one location along the southern escarpment (approximately 35.89734°, -108.74493°), the failure plane seems to have terminated before rupturing all the way to the surface distal from the scarp. To the north of this location, one can observe the intermediate-aged scarp along with north-dipping back rotation of the Tohatchi Formation, overlying sediments, and the upper 5-10 meters of the Menefee Formation. However, instead of a failure plane cutting through the lower deformed strata, they have an east-northeast trending anticlinal buckle before returning to more sub-horizontal dips to the south. To avoid confusion, it is important to note that a thin (5m) and shallowly concave-up younger rotational slide can be observed overlying the lightly folded Cretaceous strata in approximately the same location (Fig. 19). Material resulting from these slides are backrotated but largely intact (Fig. 20) with moderate deformation and folding (Fig. 21), and minor mixing with debris from the older landslide material. Cardinali (1990) mapped a landslide scarp at approximately the same location as the scarp for intermediate-aged rotational slides from this publication.

Concurrent with, and following, the rotational slides, 'Qefi' (Intermediate Earth Flow Landslide Deposits) would have moved down the over steepened slopes near the terminus of the rotational failure surface where they would cut into the older landslide surfaces and prograde over top the valley floor (surface mapped as 'Qptm'). The valley floor would now be considerably lower than the pediment surface which older landslide deposits were deposited onto and it is inferred that the toe of intermediate aged slides did not extend as far east as older landslide deposits. No intermediate aged earthflow landslide deposits are interpreted to remain at its terminal location due to erosion and re-working by 'younger' slides. However, multiple 'Qlsi' (Intermediate Landslide Deposits, undivided) polygons were mapped in raised topographic positions near the end of the slide at an elevation and slope that would grade into the 'Qptm' surface. These undivided deposits are differentiated from Qefi because the mappers were unable to identify defining morphological characteristics and gradational relationships with other intermediate aged slides. Watson and Wright (1963) interpreted slides of intermediate age to be found on the far western map area where this publication has older landslide deposits mapped. The material mapped here as intermediate in age was inferred to be the oldest by Watson and Wright (1963) who thought all the material that prograded eastward to lower elevations was the oldest. However, this material includes abundant slides from intermediate, younger, and recent mass wasting in addition to subordinate remnants of the oldest landslide material. Intermediate earthflow deposits typically are dominated by poorly sorted boulders of sandstone in a homogenous grayish matrix of mudstone (Fig. 22) with large blocks of partially deformed Cretaceous strata mixed in. Continued vertical denudation, incision, and embayment again made space available for the next generation of 'younger' mass wasting events. Map unit 'Qrsy' (Younger Rotation Landslide Deposits) occurred along concave-upward failure surfaces that were less concaveand penetrated to shallower depths than the intermediate rotational slides. These younger rotational slides served to rework previous slides as they caused backrotation of intermediate aged earth flows and rotational slides as well as the underlying Allison Member of the Menefee Formation and the lower portions of the Tohatchi Formation. While younger rotational landslides further backrotated Cretaceous strata, no location was found to measure bedding orientation in one of these polygons. In addition to a greater degree of backrotation, these deposits exhibited more deformation and mixing of sediments: patches of what had previously been older landslide mantle are commonly found between swaths of rotated and deformed Cretaceous strata. Like the intermediate aged slides, the distal end of the younger rotational slides grades into 'Qefy' (Younger Earth Flow Deposits) which exhibited flow like conditions during their movement. These deposits cut into the surrounding older and intermediate aged deposits (Fig. 23) as they move downslope and eastward to prograde onto the valley floor grading into the next lower pediment-terrace surface (the Salt Springs Wash surface, marked with deposits of map unit 'Qpss'). The material in these slides tends to be smaller clasts of sandstone in a poorly sorted gray matrix of sands and clays with occasional boulders of Cretaceous sandstone in the well-mixed material. In one location (35.92272°, -108.740893°), a landslide interpreted to be a younger rotational slide occurs higher on the hillslope out of sequence from the other younger rotational slide polygons. This slide terminates with a 400 m-long jumble that is similar to younger earthflows but mapped as 'Qlsy' (Younger Landslide Deposits, undivided).

Since the deposition of the younger generation of landslides, further incision and embayment created accommodation space for 'Qlsr' (Recent Landslides, undivided). These slides tend to be small in aerial extent and are usually found in actively incising ephemeral drainages (Fig. 24) or along erosional escarpments. A small complex of these slides is found filling the accommodation space created by the slump bench of intermediate aged rotational slides where intact and in-situ Tohatchi Formation is mantled by older landslide deposits.

Watson and Wright (1963) interpreted the jumble of huge blocks accumulating at the base of the Deza Bluffs (west of the Coyote Canyon 15′ map area) to be the youngest generation of slides; however, they also interpreted them to be deposited on top of the next youngest landslide which we interpret to be the oldest generation. They interpreted these huge blocks (up to 1 km in length) to be the product of block glide and lateral spread made possible by sand piping, resulting from higher water tables, exacerbating weakness at the base of blocks (Watson and

Wright, 19563). They differentiate these blocks from Toreva blocks due to the lack of back rotation, as they are largely sub-horizontal with minor components of forward rotation (Watson and Wright, 19563). They interpret these processes to have ceased since the Pleistocene.

FIGURES

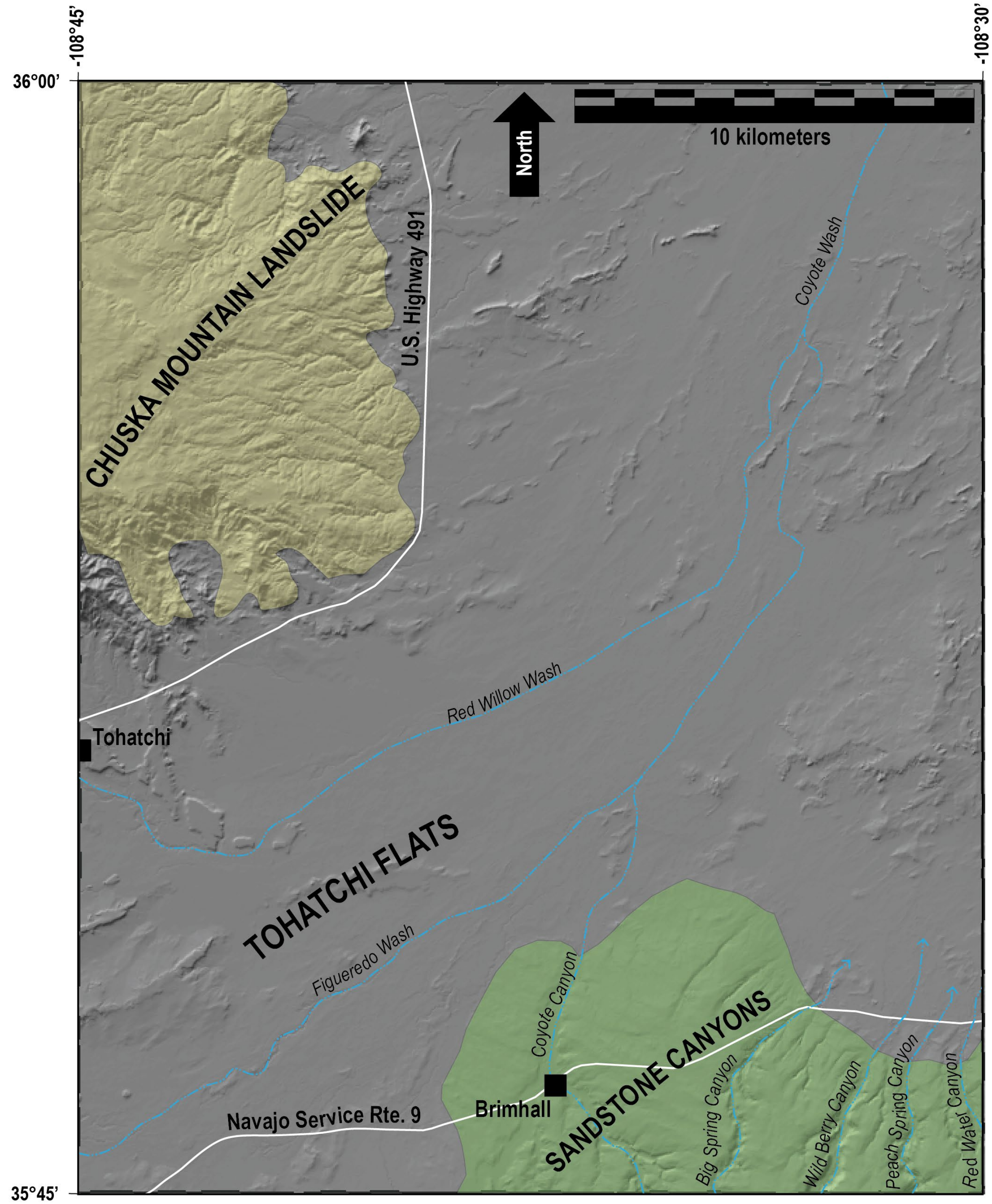

Figure 1. Digital shaded relief image of the area of the Coyote Canyon 15-Minute Quadrangle showing the basic physical geographic regions, the two major highways, major drainages, and the locations of the communities of Tohatchi and Brimhall. Note that only the easternmost portions of the community of Tohatchi are within the map area.

Figure 2: Exposure of in-situ Cretaceous bedrock featuring approximate contact between underlying Menefee Formation and Tohatchi Formation. A vegetated younger earth flow deposit can be seen on the far side of the exposures in the foreground. Photo taken at approximately 35.96888°, -108.72056°.

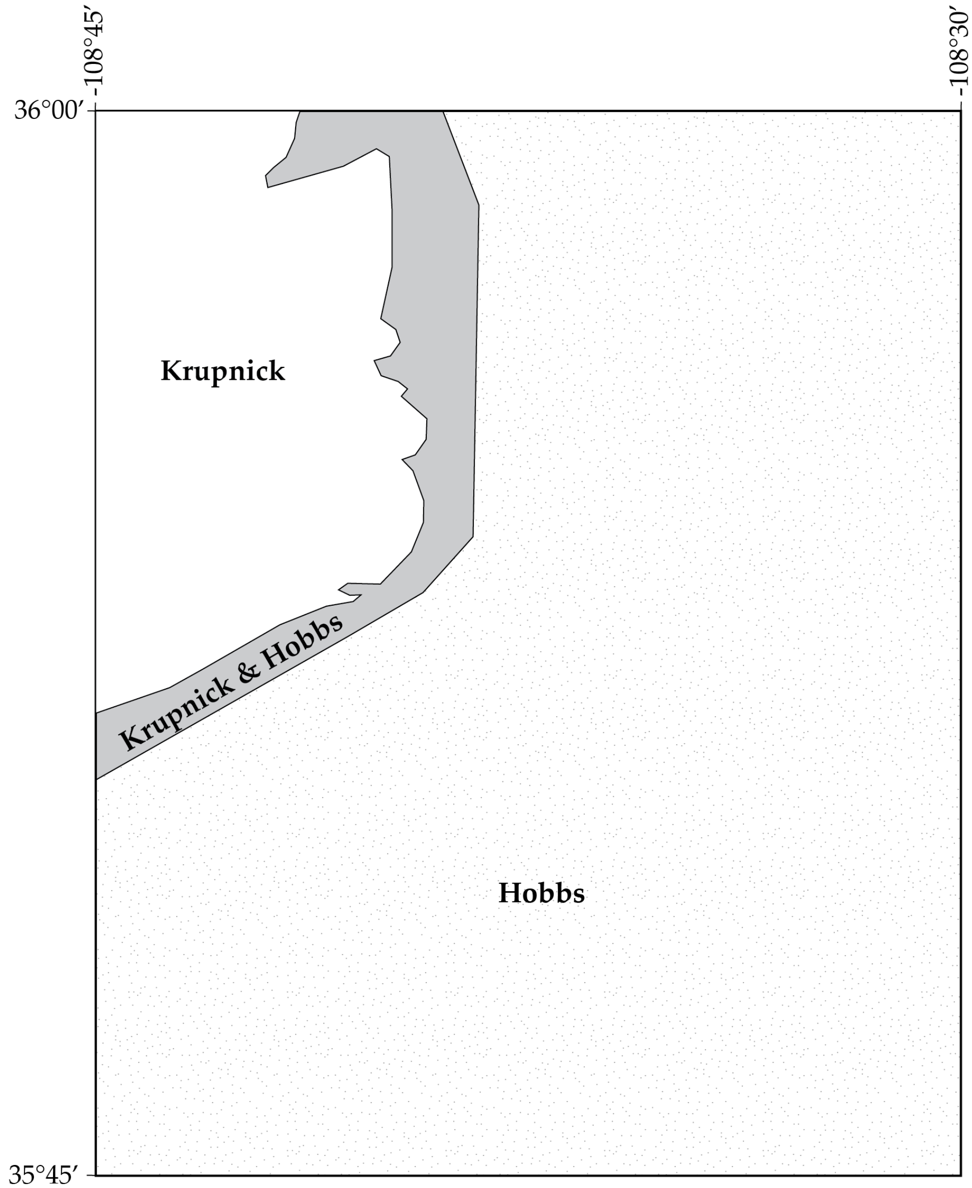

Figure 3. Map showing geographic division of mapping efforts by authors Hobbs and Krupnick.

Figure 4. Typical outcrop of coal within the Gibson Coal Member of the Crevasse Canyon Formation (map unit Kcg) in the map area. The coal is the dark, recessed horizon at the base of the vertical outcrop. Approximately 1 m of mudstones within Kcg are preserved above the coal at this outcrop in Peach Spring Canyon; the majority of the vertical outcrop is Quaternary alluvium of map unit Qa. Yellow staff is 2m long.

Figure 5. *Inoceramidae* shell impression in sandstone of the Hosta Tongue of the Point Lookout Sandstone in Big Spring Canyon. For scale, marker is 14 cm long. Shell impression is 37 cm x 15 cm.

Figure 6. Field photograph of *Inoceramidae* shell fragment in cross-section in a quartz arenite of the Hosta Tongue of the Point Lookout Sandstone. Shell fragment dimensions are approximately 4 mm x 5 mm.

Figure 7. Field photograph (top) and annotated photograph (bottom) of the Point Lookout Sandstone-Satan Tongue of the Mancos Shale interval in Peach Spring Canyon. Photograph taken at approximately 35.7660°, -108.5181°, looking southwest. The Satan Tongue interval is approximately 5 m thick at this location. A down-to-the-left normal fault offsets these units approximately 6 m. The total thickness of the Point Lookout Sandstone is not observed here. Qa = Quaternary alluvium; Kplh = Hosta Tongue of the Point Lookout Sandstone; Kms = Satan Tongue of the Mancos Shale; Kpl = Point Lookout Sandstone (main body).

Figure 8. Interbedded mudstones and sandstones of the Satan Tongue of the Mancos Shale in Big Spring Canyon. Outcrop height is approximately 3 m.

Figure 9. Shell impressions and fossil hash in a sandstone of the Satan Tongue of the Mancos Shale in Peach Spring Canyon. For scale, marker is 12 mm in diameter.

Figure 10: Probable Deza Member of the Chuska Sandstone conglomerate. Found in back rotated material of map unit Qrsi at approximately 35.97822°, -108.74225°.

Figure 11. Remnant of older alluvium (map unit Qao) in a sandstone cliff alcove above Peach Spring Canyon. The top of this Qao remnant is approximately 13 m above the modern streambed of Peach Spring Canyon, indicating at least that much incision since deposition of Qao.

Figure 12. Mixed eolian/alluvial unit (map unit Qea) in Red Willow Wash, near 35.9425°, -108.5604°. The taller nabkha left of the truck is approximately 3.3 m in height; nearby nabkhas are up to 4.5 m tall. Note the mudcracks in foreground, indicating recent standing water at this location. These nabkhas, like most in the map area, are anchored by greasewood (Díwózhiishjiin; *Sarcobatus vermiculatus*) and four-winged saltbrush (Díwózhiiłbéíí; *Atriplex canescens*).

Figure 13. Semi-stabilized sand sheet (map unit Qess) in the southeastern map area near 35.756°, -108.515°. As is typical of this unit in the map area, most of this surface is vegetated, but a non-negligible portion is barren, aiding the process of eolian deflation. Annual grasses, herbs, and flowers, snakeweed (ch'il diilyésii dzaa; *Gutierrezia sarothrae*), juniper (gad; *Juniperus monosperma*), and piñon (chá'oł; *Pinus edulis*) dominate the plant communities on this unit throughout the map area.

Figure 14. An isolated pediment-terrace on a small erosional-remnant mesa on Tohatchi Flats at approximately 35.772°, -108.737°. The 4 m-thick deposit atop this mesa belongs to the pediment-terrace deposit of the Salt Springs Wash surface (map unit Qpss). The Chuska Mountains, seen on the horizon in the background, are the presumed source for the sediment capping this mesa.

Figure 15. Compositional features of pediment-terrace deposits in the map area. A: very poorly sorted deposits of map unit Qptw in Figueredo Wash. Yellow ruler is 2m long; largest sandstone boulder is approximately 1 m x 2.5 m. B: Bedded sands through cobbles in map unit Qptw in Figueredo Wash. Yellow ruler is 2 m long. C: Contact of the Menefee Formation (map unit Kmfa; below white dashed line) and pediment-terrace deposits of the Sitting Coyote Mesa surface (map unit Qpsc; above white dashed line) at Sitting Coyote Mesa. Hammer is 32 cm long. D: Well-sorted laminated sand horizon within pediment-terrace deposit (map unit Qpsc) at Sitting Coyote Mesa. Hammer handle is 4 cm diameter at thickest point.

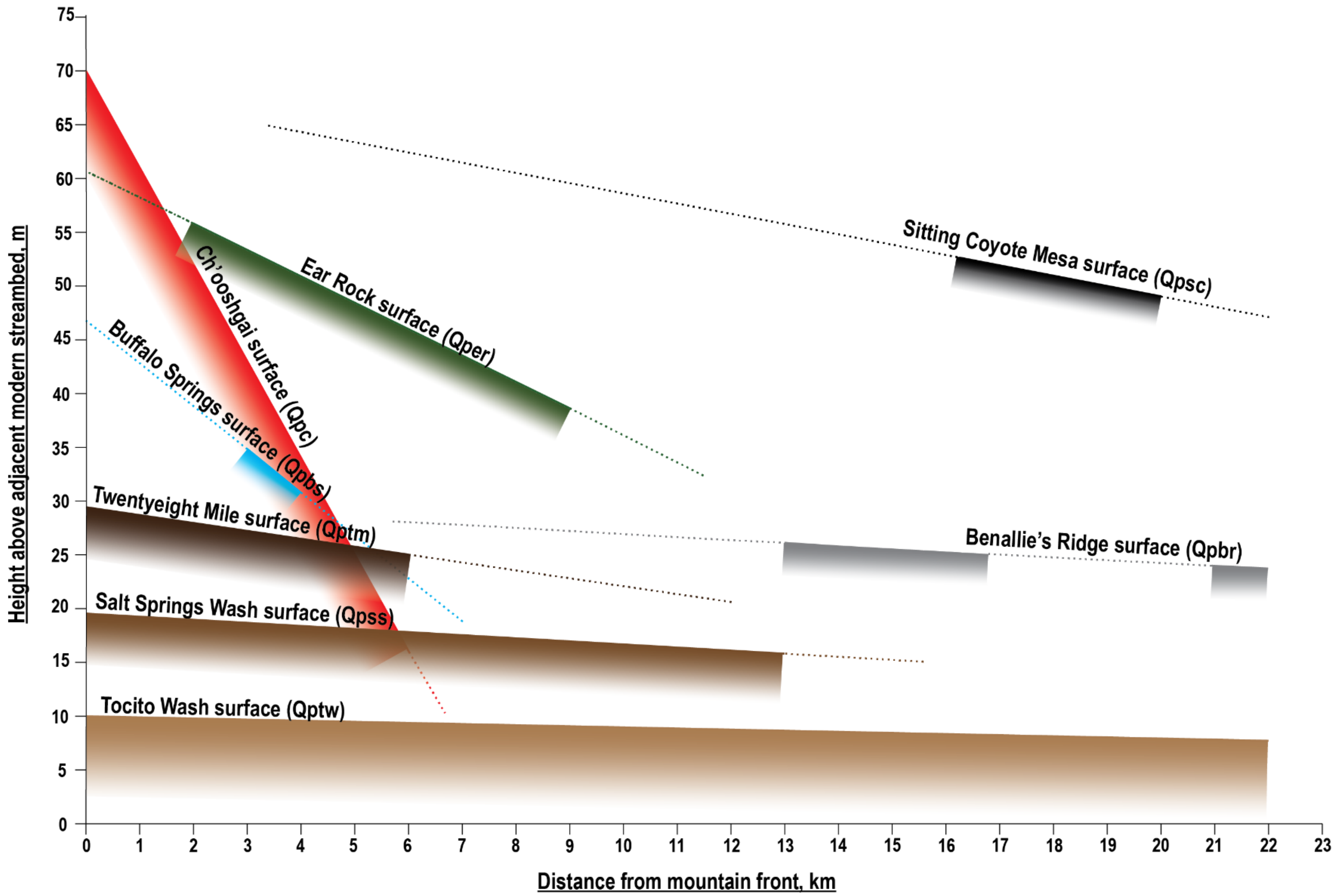

Figure 16. Schematic topographic profiles of pediment-terraces and their associated deposits on the Coyote Canyon 15-Minute Quadrangle. Solid boxes show where pediment-terrace surfaces exist in the Coyote Canyon 15-minute quadrangle; dashed lines show their projections. Note that we do not show curvature of pediment-terrace surfaces, even though the surfaces likely are curved to become less steep farther from the mountain front. Further surveying and GIS analysis is needed to quantify and accurately portray this presumed curvature.

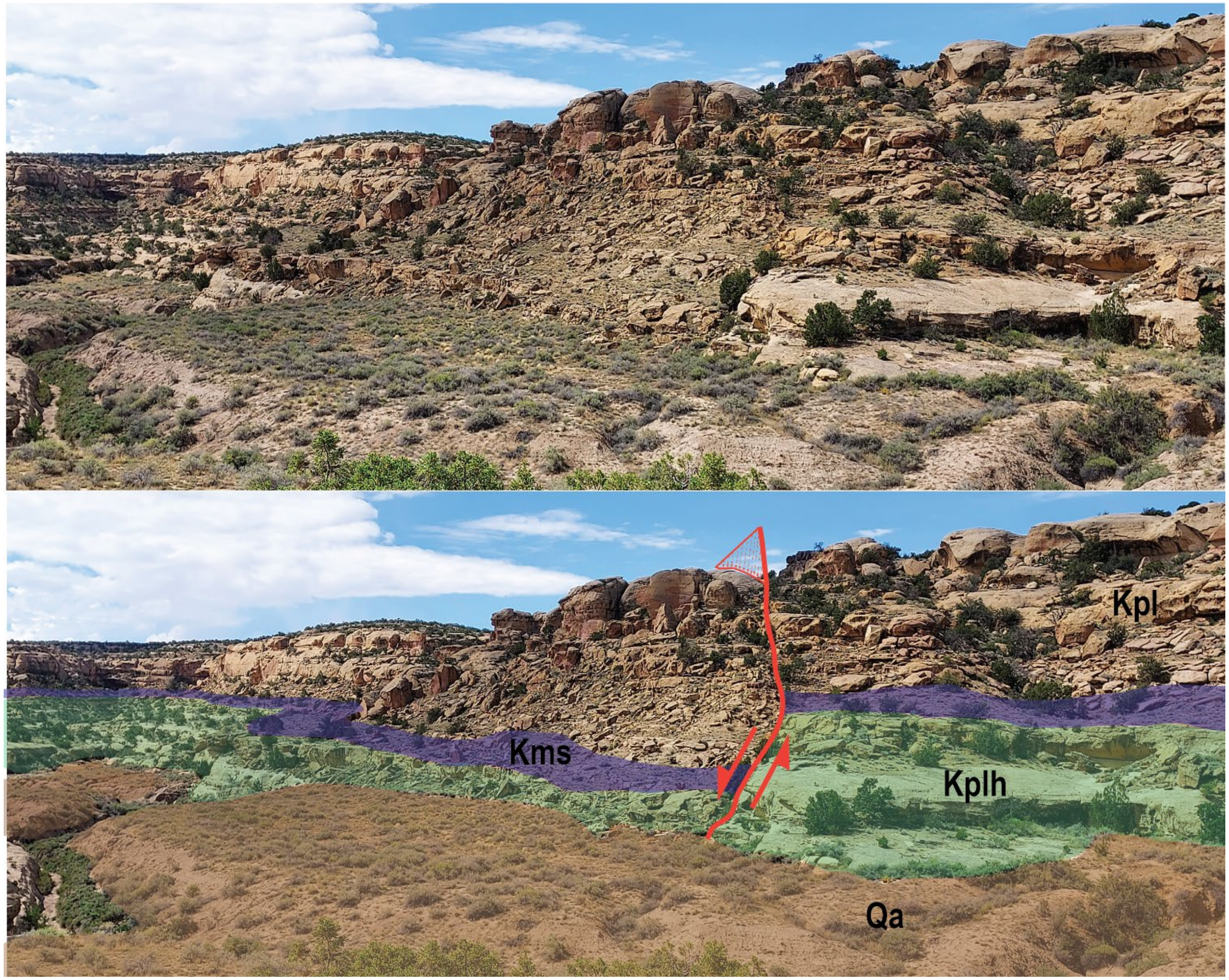

Figure 17. Steeply dipping normal fault offsetting Cretaceous sedimentary rocks in Peach Springs Canyon. View is slightly oblique to the fault trace, which passes to the right of the viewer. Quaternary unit postdates fault motion. Total fault offset here is approximately 6 m.

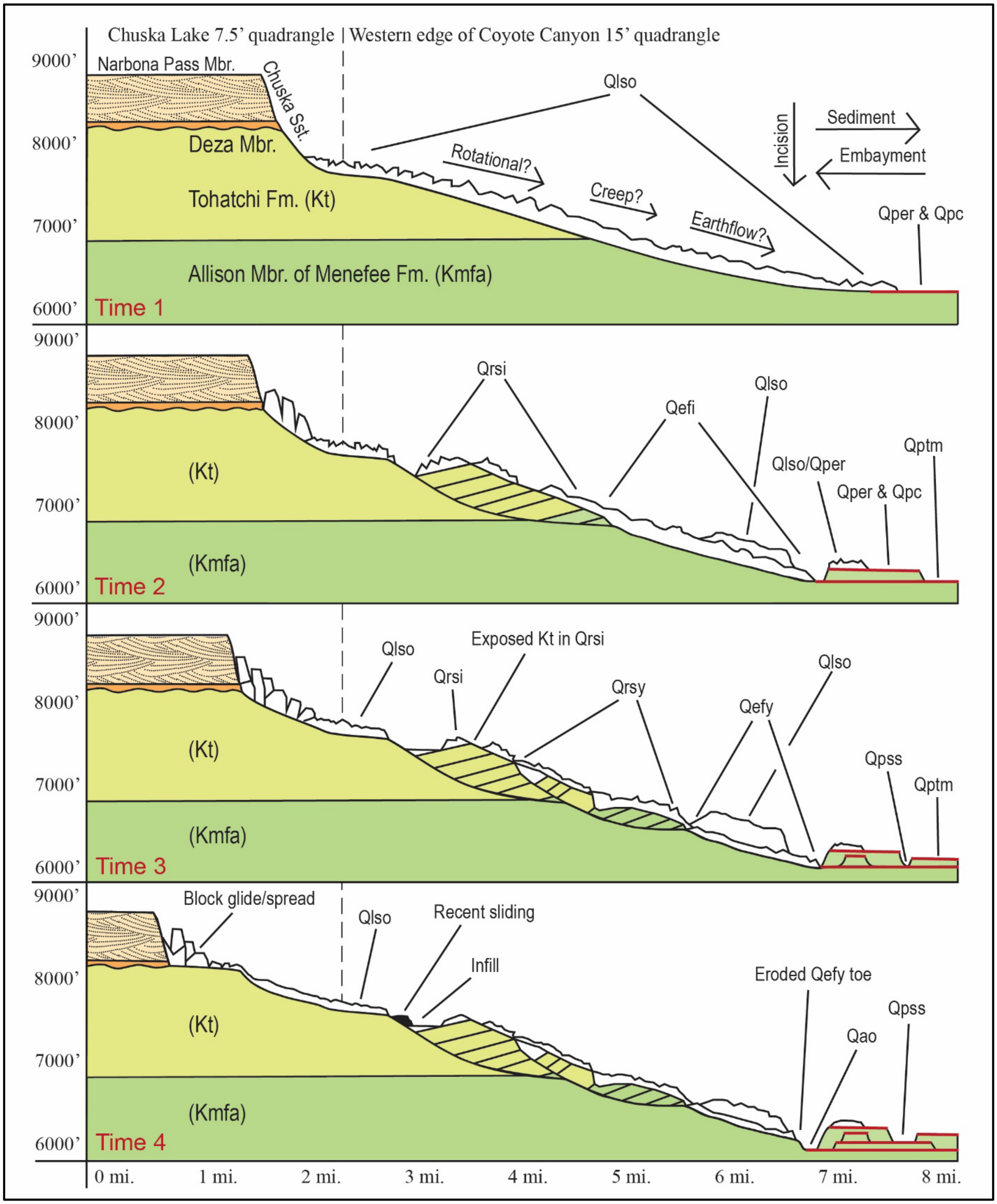

Figure 18: Schematic cross section diagram of development of the Chuska Mountain landslide. Red lines are gravels mantling pediment surface. Time 4 shows approximate present-day landscape.

Figure 19: Thin younger rotational slide cross cutting lightly back rotated Cretaceous strata at the top of the slope in the center of the picture.

Figure 20: Largely intact Tohatchi Formation (Kt) bedrock backrotated and exposed. A mantle of older landslide debris can be seen to the top right.

Figure 21: Folding and deformation within Cretacous bedrock in an intermediate aged rotational landslide deposit.

Figure 22: Poorly sorted matrix of an intermediate aged earthflow deposit.

Figure 23: Lateral margin of younger earthflow deposit (Qefy) inset into Cretaceous bedrock.

Figure 24: A recent landslide filling in a modern stream channel. Deposit is found at 35.97339°, -108.71824°.

Figure 25: Pebbles found strewn across backrotated Tohatchi Formation (Kt) in an intermediate rotational landslide deposit (Qrsi).

Figure 26: Undifferentiated intermediate aged landslide deposits (Qlsi) over the Allison Member of the Menefee Formation (Kmfa) incised by a west to east flowing drainage shortly after a flash flood.

Figure 27: Back rotated Tohatchi Formation (Kt) found under overlying Alluvium and Slopewash deposits (Qas). Dominantly alluvial in this outcrop but significant slopewash to margins of polygon.

Figure 28: Sandy siltstones (gray) and cross bedded sandstones (brown) of the Tohatchi Formation (Kt) in an intermediate aged rotational landslide deposit.

Figure 29: Silicified wood in the Tohatchi Formation.

Figure 30: Carbonized wood from the Allison Member of the Menefee Formation.

APPENDICES

APPENDIX A
DESCRIPTIONS OF MAP UNITS

QUATERNARY

Anthropogenic deposits

Artificial fill (af): (ca. 0.1 ka to present-day) — Accumulations of clay, silt, sand, and gravel for the construction of dams, berms, and roads. Includes deposits of clay, silt, sand, and pebbles on upstream sides of dams with alluvial and minor eolian and slopewash input. Color and composition is variable throughout the map area and dictated by the properties of the source of the unit at each location. Throughout most of the map area, this unit is locally derived, especially for the construction of dams. Along U.S. Highway 491, this unit contains recycled asphalt and cobble-sized clasts of rounded quartzite derived from outside the map area and presumably trucked in for road-construction aggregate. Deposits upstream of dams are terminally drained; non-dissected planar surface; high organic content; sparsely to non-vegetated. Where exposed in outcrop by erosion, this unit lacks bedding. Does not effervesce in 10% HCl. Unit is 1 to 5 m thick.

Mass Wasting Deposits (Qlsr, Qefy, Qrsy, Qlsy, Qefi, Qrsi, Qlsi, Qlso): (Pleistocene to present) — Variable consistency of intact, deformed, and mixed bedrock and unconsolidated sediments. Includes mudstone, siltstone, sandstone, conglomerate, carbonaceous shales, and coal. Mudstones are white to light gray, tan brown, and orange red, with variable silt and sand content. Occasionally variegated, weathering to popcorn texture, and containing selenite. Sandstones are white, pale brown, reddish yellow to red, yellowish brown, and dark gray to dark brown. Dominantly silica-cemented Chuska Formation sandstone. Block diameters are commonly up to 15 m and occasionally up to 100 m, poorly indurated to well indurated. Scattered, variably colored pebbles of chert, quartz, and petrified wood (Fig. 25) are occasionally found as intact float within moderately indurated pebble conglomerate sandstone. Abundant, highly deformed, white to gray weathering light-gray, bentonitic and carbonaceous sandy siltstone are present. Within any given landslide polygon there may be multiple generations of mass movement (e.g. multiple scarps within a rotational slide or multiple flows within an earth flow).

Recent Landslide Deposits, undivided (Qlsr): (Holocene to present) — Undivided slides, spreads, and flows are observable as fresh features on the landscape. Unconsolidated with variable consistency of jumbled mudstones, sandstone, and conglomerate with occasional in-tact but rotated and deformed Cretaceous strata. Blocks are up to 10 m. Generally consists of existing landslide material from young to intermediate earth flows and rotational slides. Exception in the west-central area of the landslide complex where large, intermediate aged, rotational slide slump benches create abundant accommodation space and recent landslides consist of Kirtland and Fruitland Formation mantled by remnant older landslide material (Qlso). Individual slides occupy small areas where accommodation space has been generated by incision of drainages, escarpment retreat, or rotational slides. Commonly creates choke points that serve to raise local base level in east to west oriented drainages. Minimally dissected, moderately smooth to very rough surface texture, distinct lateral margins, transverse ridges, negligible soil formation. Unit is approximately 3 to 12 m thick.

Young Landslide Deposits, undivided (Qlsy): (Pleistocene to Holocene) — Variable consistency of intact and deformed bedrock with unconsolidated sediments. Exhibits crosscutting relationships with pre-existing intermediate to older landslides and Cretaceous bedrock. Moderate to very rough surface texture with low to moderate incision. Distinct from younger rotational and earthflow landslide deposits due to lack of discernable morphological features and small areal extent. The unit is approximately 3 to 40 m thick.

Young Earth Flow Landslide Deposits (Qefy): (Pleistocene to Holocene) — Flow and creep of matrix supported sandstone and mudstone blocks creating distinct down slope flow patterns; hummocky; topographically inset and exhibiting cross-cutting relationships with existing intermediate to older aged earth flow, rotational, and undivided slides. Consists of liquefied fines to jumbled, blocky, and rotated mudstones, sandstones, and conglomerates. Proximal to initiation area flow exhibits a degree of coherence: muds disturbed but bedding recognizable, gradational change from back rotation to earthflow occurs over approximately 500 m. Distal from initiation, the flow exhibits a high degree of mixing. Deposits are un-graded, un-sorted, and consist of 60 to 70% sandstone in fine matrix of poorly sorted muds, silts, and sands. Commonly jumbled to an incoherent mass that supports blocks and boulders of intact strata. Distinct lateral margins parallel to flow direction observable in LIDAR imagery and field observation where flow scours into either pre-existing slides or bedrock. Young earth flow landslide deposits have gradational relationship with young rotational landslide deposits as rotated blocks of Cretaceous strata give way to liquefaction and flow derived deposits of earth flow landslides. Commonly has defined lobate toe deposited over existing topography, moderately dissected (5 to 20 m deep channels), smooth to moderately rough surface texture, common flow parallel ridges. Grades into pediment-terrace deposits (Qptw). Unit is approximately 10 to 20 m thick.

Young Rotational Landslide Deposits (Qrsy): (Pleistocene to Holocene) — Rotational blocks of deformed, mixed, and occasionally intact bedrock with material from pre-existing mantle of older and intermediate aged landslide. Younger rotational slides may initiate within in-situ bedrock or within pre-existing slides causing an increased degree of mixing. Commonly back rotated between 35 to 45°; occasionally up to 90°; back rotation decreases with distance from head scarp. Movement is perpendicular to head scarp and sub-parallel to earth flow direction; head scarp creates accommodation space for deposition of younger surficial units. Features concave up sliding surface with a 1 to 2 m scour horizon. Moderately to heavily eroded transverse ridges are present and integrated into an east to west oriented stream networks draining the Chuska Mountain landslide. Exhibits cross-cutting relationships with existing intermediate to older aged earth flow, rotational, and undivided slides. Mantle material is hummocky, occasionally mixed into rotational blocks. Material is un-graded, un-sorted and consist of bedrock block as well as sandstone, siltstone, mudstone, and conglomerate in a fine matrix of poorly sorted muds, silts, and sands. Unit is approximately 3 to 75 m thick.

Intermediate Landslide Deposits, undivided (Qlsi): (Pleistocene) — Variable consistency of intact and deformed bedrock with unconsolidated sediments. Exhibits crosscutting relationships with pre-existing older landslides and Cretaceous bedrock (Fig. 26). Moderate smooth to moderately rough surface texture with moderate to high incision. Distinct from intermediate rotational and earthflow landslide deposits due to lack of discernable morphological features and small areal extent. The unit is approximately 5 to 50 m thick.

Intermediate Earth Flow Landslide Deposits (Qefi): (Pleistocene) — Flow and creep of matrix supported sandstone and mudstone blocks creates distinct down slope flow patterns; hummocky; topographically inset and exhibiting cross-cutting relationships with existing older undivided slides. Consists of jumbled, blocky, and rotated bedrock with a moderate proportion of poorly sorted muds to boulders. Jumbles, blocks, and rotated bedrock include sandstones, siltstones, conglomerates, and mudstones, while the poorly sorted matrix is light gray with boulders up to 1 m. Rotated blocks moved by flow processes but found in proximity to gradational contact with intermediate aged rotational slides. Exhibits significant winnowing at surface creating a roughly 5 m thick mantle of dominantly sandstone blocks. Proximal to initiation, area flow exhibits a higher degree of coherence: muds disturbed but bedding recognizable, gradational change from back rotation to earthflow occurs over approximately 500 m. Distal from initiation of the flow exhibits higher degree of mixing: deposits contain some jumbles and blocks but are dominantly un-graded, un-sorted sandstone in fine matrix of poorly sorted muds, silts, and sands. Distinct lateral margins parallel to flow direction observable in LIDAR imagery and field observation where flow scours into either pre-existing slides or bedrock. Intermediate earth flow landslide deposits have gradational relationship with intermediate rotational landslide deposits, as rotated blocks of Cretaceous strata give way to liquefaction and flow derived deposits. Lower reaches of intermediate earthflow deposits have been re-worked by subsequent mass wasting. Well dissected (10 to 15 m deep channels), moderately smooth surface texture, and common flow parallel ridges. Unit is approximately 1 to 30 m thick.

Intermediate Rotational Landslide Deposits (Qrsi): (Pleistocene) — The unit consists of rotational blocks of intact, deformed, and mixed material from pre-existing mantle of an older aged landslide. Intermediate rotational slides initiate within in-situ bedrock covered by up to 15 m of material from pre-existing slides causing mixing of deformed bedrock with unsorted and ungraded older landslide material. Commonly back rotated between 25 to 35°; occasionally up to 45°; back rotation decreases with distance from head scarp. Movement is perpendicular to head scarp and sub-parallel to earth flow direction; head scarp creates accommodation space for deposition of younger surficial units including recent landslides. Features concave up sliding surface, with a 1 to 2 m scour horizon. Lacking transverse ridges, distinct lateral margins, and a defined toe. Exhibits cross-cutting relationships with existing older aged undivided slides. The mantle material is hummocky, occasionally mixed into rotational blocks. Toreva blocks are present as heavily weathered to mounds of sandstone blocks subparallel to the scarp. There is occasional antiformal and synformal folding and buckling of Cretaceous strata as a result of partial rupture or detachment. Material is un-graded, poorly sorted, and consists of bedrock blocks as well as sandstone, siltstone, mudstone, and conglomerate in a fine matrix of poorly sorted muds, silts, and sands. The unit is approximately 50 to 150 m thick.

Older Landslide Deposits, undivided (Qlso): (Pleistocene) — Undivided slides, spreads, and flows found as a 0 to 15 m mantle on the Chuska Mountain landslide surface; re-worked into intermediate, younger, and recent slides. In-situ in far northwest map area between latitude 12S 703085m E, 3975855m N and 12S 702966m E 3981198m N to west of intermediate and younger rotational slide head scarps. Unconsolidated with variable consistency of jumbled mudstones, sandstone, and conglomerate with common in-tact, but dissected and rotated, Toreva blocks of Chuska Formation sandstone. Blocks are up to 15 m in diameter and 100 m in length. Consists of Chuska Formation sandstone and conglomerate as well as undivided Kirtland Fruitland Formation sandstones, siltstones, and shales; does not include any material from the Allison Member of the Menefee Formation. Heavily dissected by subsequent sliding but minimally dissected by integrated streams, smooth to moderately rough surface texture. Lacking distinct lateral margins, transverse ridges, and toe. Head scarp is present to the west of the map area but subsequent rock fall and topples have obscured its surface. Grades into high terrace at eastern end of landslide where raised surface representing landslide-terrace transition zone is preserved. Unit thickness is 10 to 40 m.

Transitional deposits

Transitional deposits between older landslides and pediment-terrace of the Ear Rock surface (Qlso/Qper): (Pleistocene) — Unconsolidated sand through boulders on an isolated, small (approximately 1 ha) mesa near the northern map boundary adjacent to Salt Springs Wash and 6.03 km north-northwest of the NM DOT Buffalo Springs Patrol Station. This surface is approximately 115 m higher than the grade of Salt Springs Wash, and likely graded laterally up into deposits of Qlso and laterally down into pediment-terrace deposits of Qper. Landscape dissection has obscured or removed these inferred gradational boundaries. Unit thickness is 10 to 30 m.

Alluvial deposits

Active alluvium (Qa): (Holocene to present) — Stream-deposited clay, silt, sand, and gravel within channels of active ephemeral and intermittent streams. Occupies the lowest geomorphic position in any alluvially-active valley. Mineral composition and grain rounding is influenced by and largely inherited from the bedrock composition of the drainage basin in which the deposit is found; deposits typically have the composition of feldspathic arenite or feldspathic wacke. A typical deposit consists of light-yellowish-brown, pale-brown, light-brownish-gray, or light-gray unconsolidated sand and silty sand with subordinate pebbly silty sand, sandy silt, pebbles, and silty clay, with trace cobbles. Contains trace pebble- through boulder-sized rounded to spherical clasts of mud. In Tohatchi Flats, the unit sometimes contains pebbles of reddish-brown "clinker", presumably derived from Cretaceous units upstream of the quadrangle. Contains anthropogenic detritus at the surface and in cross-section outcrop at a depth of up to 2 m, including common litter, asphalt macadam, wire fencing, fence posts, rubber tires, household appliances, and the bones of domesticated animals. Bedforms include trough crossbedding, ripple crossbedding, ripple laminations, graded bedding, scour-and-fill structures, and plane bedding. In cross-section, horizontal plane bedding is the predominant bedform. Waning-stage mud films often overlie this unit but are rarely preserved; muds at the surface presumably are removed during early stages of subsequent streamflow events. Includes minor eolian dunes that are too small to map at the 1:62,500 scale; these dunes are up to 2 m high and are rare but present in cross-sectional outcrops. Does not effervesce in 10% HCl. Primarily unvegetated; primary successional grasses, forbs, cocklebur (Tániits'éhii, *Xanthium sp.*), tamarisk (K'eiłichii'its'óóz, *Tamarix ramosissima)*, and annual flowers are present. Observed thickness for the unit is 5.2 m; total thickness is unknown.

Alluvium and Slopewash (Qas): (Holocene to present) — Unconsolidated clays, silts, sands, and gravels in active alluvial channels and floodplains with significant input from sheet flow off hillslopes (i.e. slopewash). Alluvial sediments are mottled grayish brown weathering light brownish gray; includes clays to boulders, are angular to subrounded, and poorly sorted. Occasionally stratified with alternating horizons of clean sands and organic-rich sandy silts; common channels up to 1 m thick containing sandstone blocks up to 30 cm. Sands are tan to yellow, fine lower to medium upper, well-sorted, with orange stained quartz. Sandy silt horizons are dark gray with abundant carbonaceous material, burrows, and carbonate rhizoliths. Forms flat to subdued topography with moderately to deeply incised channels. It is vegetated with sagebrush. Slope wash dominated sediments at margins of deposits tend to be brown to dark reddish brown. Coarsen and slope upwards towards hillslopes. Likely contains some portion of eolian sands and colluvial debris. Occasional re-worked carbonized organic material. Abundant near landslide scarps (Fig. 27). Estimated thickness of the unit is 0.2 to 8 m.

Older alluvium (Qao): (Holocene) — Stream-deposited clay, silt, sand, and gravel underlying terraces 3 to 15 m above the active stream bed. Sediment is in laminated to thick tabular to lenticular beds with crossbeds, ripple crossbeds, graded bedding, scour-and-fill structures, and horizontal plane beds. In cross section, horizontal plane beds comprise approximately 90% of observed bedforms; trough crossbeds comprise approximately 10% of observed bedforms. Mineral composition and grain rounding is influenced by and largely inherited from the bedrock composition of the drainage basin in which the deposit is found; deposits typically have the composition of feldspathic arenite with subordinate feldspathic wacke. A typical deposit consists of brown, light-brown, or yellowish-brown, loosely to moderately consolidated sand with subordinate silty sand, pebbly silty sand, and sandy silt, with trace sandy gravel. In Peach Spring Canyon, this unit hosts a buried reddish-brown to light-reddish-brown paleosol with columnar peds, root traces, and a stage II calcic horizon. Forms vertical faces up to 12 m tall. Where observed, this unit has a distinct contact with underlying units (typically Cretaceous sandstones of the Point Lookout Sandstone or Crevasse Canyon Formation). Gradational contacts with surrounding fans and colluvial deposits. This unit occupies the highest landscape position of any alluvial units in the map area. Moderate effervescence with 10% HCl at depths of 10 to 30 cm. Surface of this unit typically contains plant communities dominated by big sagebrush (Ts'ahtsoh, *Artemisia tridentata*), chamisa (Ch'ildiilyésiits'óóz, *Ericameria nauseosa*), and saltbrush (Díwózhiiłbéíí, *Atriplex canescens*), with rare cottonwood (T'iis, *Populus fremontii*), juniper (Gad, *Juniperus sp.*), piñon (Chá'oł, *Pinus edulis*), cane cholla (Hoshdítsáhii, *Cylindropuntia imbricata*), and nopal (Hoshniteelí, *Opuntia sp.*). Unit includes debris fans, canyon-mouth fans, colluvium, and minor sheetwash alluvium. Surface topography is muted. Since the 19th Century, this unit has been incised by up to 10 m. Observed thickness is 0 to 14 m; total thickness of the unit is unknown.

Fan deposits

Alluvial fan deposits (Qfa): (Holocene to present) — On the Chuska Mountain front, west of Highway 491, the unit consists of unconsolidated sands, gravels, boulders, silts, and clays forming incised lobate landforms. Boulders and gravels are angular to subangular, sorted into channels up to 0.5 m thick and around 2 m wide. Sands are well rounded and mixed with clays, silts, and organics. Alluvial sediments are mottled grayish brown weathering light brownish gray. Found on landslide benches where confined channels open up onto flat topography; lateral contacts are gradational in direction of flow. Estimated thickness of the unit is 0 to 10 m.

On low-relief, lower-elevation surfaces on and near Tohatchi Flats, the unit consists of loose to weakly consolidated silty sand, sand, and pebbly sand with trace pebbles and cobbles. Lithologic composition was inherited from bedrock composition of drainage upstream of deposit. Internal structures include massive horizontal plane beds, lenticular beds, cut-and-fill structures, and pebble imbrication. Sand is typically pale brown, light brown, light yellowish brown, or brownish yellow. No soil development observed. Does not react with 10% HCl. Up to 100 cm of channel and swale topography on the surface of this deposit. In aerial photographs, active avulsions and deposition can be observed within this unit in the interval between 1997 and 2023. Plant community includes grama grass (Tł'ohnást'ąsi, *Bouteloua sp.*), galleta grass (Tł'ohdich'ízhí, *Hilaria jamesii*), cheatgrass (Shíyináldzidí, *Bromus tectorum*), saltbrush, big sagebrush, wolfberry (Haasch'ééhdą́ą́', *Lycium torreyi*), and chamisa, with cocklebur common at areas of recent sand deposition. Flow paths show radial flow directions from fan apex. At places where fans enter dune-dammed playas, this unit grades laterally into and interfingers with lacustrine deposits (Ql). Includes minor eolian deposits of well-sorted coarse silt through medium sand at its surface. Interfingers with adjacent alluvial deposits of the same age. Incised by up to 1.5 m. Unit Thickness is <10 m.

Older alluvial fan deposits (Qfo): (Holocene) — Loose to weakly consolidated silty sand, sand, and pebbly sand with trace pebbles and cobbles. Lithologic composition is inherited from bedrock composition of drainage upstream of the deposit. The lack of outcrop exposures precludes detailed description of internal structure and total thickness. This unit occupies a higher landscape position than adjacent younger fan deposits of Qfa. Surface of this unit is smoother than that of Qfa. Very weak effervescence in 10% HCl at a depth of 10 to 30 cm. No active avulsion or deposition observed in aerial photographs. Plant community at the surface is dominated by saltbrush, big sagebrush, nopal, and chamisa. Interfingers with adjacent alluvial deposits of the same age. Where this unit borders younger fan deposits of Qf, it is 1 to 2 m higher. The unit Thickness is likely <10 m.

Lacustrine deposits

Lacustrine deposits (Ql): (Holocene to present) — Unconsolidated clay, silt, and very fine lower sands in terminally drained ponds on benches formed by slump blocks of rotational landslides, and unconsolidated clay, silt, and sand in shallow depressions in blowouts or where drainages are impounded by eolian dunes. When excavated, fresh sediment is pale brown, light yellowish brown, very pale brown, and light gray. Sediment at land surface after standing water evaporates commonly appears lighter-colored due to alkali crusts on surface; this crust is removed by subsequent precipitation. Abundant dark-brown organic content; minor eolian and slope wash input. Terminally drained; non-dissected planar surface; sparsely vegetated. Bedforms are entirely horizontal laminae. Mudcracks and bioturbation are common. Includes rare isolated laminae to very thin beds of very well-sorted very fine sand, presumably deposited via eolian processes during episodes when standing water is not present. Does not react with 10% HCl. Often entirely unvegetated. Where present, plant communities include cocklebur and annual sunflower (Nidíyílii, *Helianthus annuus*). Gradational and interfingering contact with underlying and adjacent alluvial deposits mostly occurs east of Highway 491 and north of Navajo Service Route 9, or below landslide scarps on the Chuska Mountain front. Not observed in vertical outcrop, so upper limit of thickness is unknown. Presumed thickness of the unit is 0 to 4 m.

Eolian deposits

Eolian deposits derived from sand-bed arroyos and in valley bottoms (Qea): (Holocene to present) — Well-sorted coarse silt to medium-grained sand that is light yellowish brown, pale brown, brownish yellow, and white, unconsolidated. There is a dearth of outcrops in this deposit, but where they exist, there are observed laminated to very thin crossbeds with subordinate laminated horizontal plane beds. Asymmetric ripples and sand avalanches seen on active deposits. Grains are subrounded to subangular and comprised of quartz, feldspars, and lithic fragments. No frosting observed. Deposits have the composition of feldspathic arenite. Includes coppice dunes up to 4.5 m tall. Frequently reworked by lateral migration of active stream channels. Dunes of this deposit sometimes divert or impound drainages. Includes minor amounts of alluvium and sheetwash around active and stabilized dunes. Where dunes block surface drainages and in deflation blowouts, includes subordinate palustrine deposits consisting of horizontal plane laminated clay and silt. Active dunes are 0.5 to 7 m tall. Stabilized dunes typically contain sandhill muhly (Béé'ézhóó', *Muhlenbergia pungens*), grama grass, cocklebur, greasewood (Díwózhiishjiin, *Sarcobatus vermiculatus*), and saltbrush. Does not react with 10% HCl. Sharp contact with underlying deposits; interfingers with adjacent eolian and alluvial deposits. No soil development observed within deposits of this unit. Sometimes buries riparian trees and shrubs. Unit is 1 to 8 m thick.

Linear, parabolic, and rising dunes (Qed): (Holocene to present) — Very well-sorted fine- to medium-grained sand that is light brown, light yellowish brown, pale brown, and very pale brown, unconsolidated. Bedding not observed in outcrop, but depositional processes observed during mapping suggest that laminated to very thin crossbeds predominate, with subordinate ripple cross laminations and horizontal to gently dipping beds. Sand composition is 85 to 94% quartz, 4 to 14% feldspars, and trace to 3% lithics. Includes coppice dunes up to 3 m tall. This unit includes rising dunes that become linear or parabolic dunes when they reach upland areas of low relief. Includes linear dunes up to 3 km in length. Includes parabolic dunes up to 1.1 km in length and associated blowout features in and near Tohatchi Flats. Includes smaller eolian deposits found on the lee sides (generally, the northeast sides) of topographic features like sandstone mesas in broad flats. Repeat aerial imagery of these deposits in the interval between 1997 and 2023 suggests that these features experience years-long episodes of inactivity and minor stabilization interrupted by episodes of denudation, transport, and deposition. Vegetation includes ricegrass (Ndídlídii, *Achnatherum hymenoides*), grama (Tł'ohnást'ąsi and Tł'ohnást'ąsłizhiní; *Bouteloua sp*.), broom snakeweed (Ch'il Diilyésii dzaa, *Gutierrezia sarothrae*), maravilla (*Mirabilis multiflora*), and sandhill muhly. On longer upland linear and parabolic dunes, there is a slight effervescence in 10% HCl at a depth of 30 cm below ground surface but no observed soil development. Active deposits, smaller dunes, and dunes on the lee sides of topographic features do not react with 10% HCl. Sharp contact with underlying deposits; sometimes interfingers with adjacent alluvial deposits. Unit Thickness is 0 to 15 m.

Discontinuous eolian deposits (Qe): (Holocene to present) — Loose to weakly consolidated light-brown, pale-brown, light-yellowish-brown, and brownish-yellow coarse-grained silt through medium grained sand in coppice dunes, discontinuous sand sheets, and muted small linear and parabolic dunes overlying Cretaceous bedrock or older Quaternary deposits. Underlying units are exposed by erosion or by discontinuous eolian deposition in 25 to 75% of the area included in this unit.

Bedforms include crossbeds and parallel laminae. Where stabilized by vegetation, there is a weak effervescence in 10% HCl at a depth of 20 to 30 cm; elsewhere, there is no reaction with HCl. No soil development observed. Includes active eolian deposits and blowouts. Vegetation includes ricegrass (Ndídlídii, *Achnatherum hymenoides*), grama, sandhill muhly, cheatgrass, chamisa, and Russian thistle (Ch'ildeeníní, *Salsola australis*). Coppice dunes are up to 3 m tall. Thickness of the unit is <6 m.

Eolian Sediments and Slope wash (Qes): (Holocene to present) — Unconsolidated clays, silts, and sands deposited on raised topographic surfaces or in small shallow basins containing windblown sediments that are reworked, and with input from, sheet flow off hillslopes (i.e. slope wash). Sediments are clay to medium (upper)- grained sands, moderately to poorly sorted, subrounded to rounded, with occasional angular clasts. Forms smooth to bumpy texture in LIDAR imagery. May have minor degree of incision but no source for alluvial input or drainage. Dune forms subdued but present and contain sediments with higher degree of sorting. Unit has an estimated thickness of 0 to 3 m.

Eolian sand sheets (Qess): (Pleistocene to Holocene) — Loose to weakly consolidated sand in broad sheets and stabilized dunes in southern map area. Younger deposits contain light-brown, pink, reddish-yellow, well-sorted, laminated to very thin, cross-bedded or massive, quartz arenitic to feldspathic arenitic (80 to 95% quartz) very-fine- to fine-grained sand in muted linear dunes. Older deposits are more common and consist of light-brown, reddish-yellow, or light-yellowish-brown, loosely consolidated, moderately sorted to well-sorted, subrounded, coarse-grained silt to medium-grained sand in stabilized longitudinal dunes and sand sheets on upland areas. Bedding is disturbed to the point of obscurity in lower portions of the unit. Effervescence in 10% HCl is highly variably at different locations within this unit, likely due to the history of episodic stability and reactivation of eolian processes. The upper 20 cm of this unit is uniformly noneffervescent in 10% HCl; lower paleosols within the unit are effervescent, indicating the presence of calcium carbonate. At least two stratigraphically-distinct paleosols are present in older deposits; these comprise pale-brown to brown, poorly sorted to moderately sorted, clay to medium-grained sand, silty sand, sandy silt, and clayey silt massive horizons with block ped structures and up to Stage II^- pedogenic carbonate horizons with few filamental coatings. Distinct contact with underlying units, though this contact sometimes is overprinted by a paleosol. Stabilized dunes are typified by big sagebrush-dominated plant communities, with subordinate ricegrass, grama grass, cheatgrass, saltbrush, broom snakeweed (Ch'il Diilyésii dzaa, *Gutierrezia sarothrae*), chamisa, maravilla, and sandhill muhly. Piñon pines and juniper are present on these deposits at higher elevations, mostly south of Navajo Service Route 9. Generally poorly exposed; well exposed only in active headcuts and construction trenches for pipelines and roads. Average sediment eolian transport azimuth is 057° as determined by dune morphologies in aerial imagery. Stabilized longitudinal dunes are up to 6 m tall. Thickness 2 to 10 m; potentially thicker in broad sheets in southern map area.

Slope deposits

Slope wash deposits (Qsl): (Holocene) — Unconsolidated to very weakly consolidated, very-pale-brown, pale-brown, light-yellowish-brown, and brownish-yellow silt, sand, and gravel whose composition is dictated by the composition of the pediment-terrace deposits or Cretaceous sandstones immediately upslope. Forms alluvial to colluvial aprons around steep outcrops of pediment-terraces, sandstone mesas, and at the foot of steep toes of the Chuska Mountains landslide complex. Bedding not observed. Erosional rills and gullies through this unit often expose underlying Cretaceous siliciclastic units. Differentiated from fan and alluvial units by its lack of bedding, geomorphic position at the foot of steep landforms, and steeper slopes (typically 2° or greater, as opposed to <1° for alluvial fans in this map area). Unit Thickness is <2 m.

Slope wash and Alluvium (Qsa): (Holocene to present) — Unconsolidated clays, silts, sands, and gravels in small basins dominated by internally drained alluvial channels and sheet flow off hillslope (i.e. slope wash). Tends to have inflow and outflow of alluvial material despite being largely internally drained. Forms flat to subdued topography with nonexistent to shallowly incised channels. Slope wash dominated sediments at margins of deposits tend to be brown to dark reddish brown. Abundant near landslide scarps and between Toreva blocks. Coarsen and slope upwards towards hillslopes. Likely contain significant portion of eolian sands and colluvial debris. Vegetated with big sagebrush. Estimated thickness of unit is 0.2 to 8 m.

Slope wash and Eolian Sediments (Qse): (Holocene to present) — Unconsolidated clays, silts, and sands deposited in small shallow basins, or on semi raised topographic positions, containing sheet flow sediments sourced from hillslopes (i.e. slope wash) with input of windblown sediments. Sediments are light-brown to brown clays, silts, and very fine (lower)- to medium (upper)-grained sands, moderately to poorly sorted, subrounded to rounded; moderate organic content. In closed basins with no source for alluvial input or drainage and in proximity to landslide scarps and between Toreva blocks, as well as in raised positions on top of landslide debris. Margins of deposits coarsen to pebble and cobble sized clasts transported by sheet flow from hillslopes. Dune forms not present but veneer of thin, well-sorted, silt to very fine-grained sand at surface indicate significant presence of wind transported material. Unit Thickness is 0 to 3 m.

Colluvium, undivided (Qcu): (Holocene to present) — Unconsolidated boulders, cobbles, and gravels forming colluvium aprons at the angle of repose. Downslope movement causing aggradation of material by rock fall, creep, and dry ravel. Angular, poorly sorted, non-stratified. Along cliff edges in the southern portion of the Chuska Mountain landslide. Estimated thickness of the unit is 5 m.

Pediment-terrace deposits: (Pleistocene to Holocene?) — Eight different units separated by source area, morphology, height above base level, and inferred age. Relative age of the units is assumed based upon the surfaces' heights above base level: the highest unit is oldest, and the lowest is youngest. All units contain two primary compositions: loosely consolidated clast-supported conglomerate and loosely consolidated to unconsolidated sand. Conglomerates contain weakly bedded, granule- through boulder-sized (predominantly cobble-sized), poorly sorted, very angular to subrounded (predominantly subangular) clasts of sandstone, chert, iron oxide concretions, petrified wood, quartzite, and quartz pebbles, in descending order. Gravel clast imbrication is present in some beds. Conglomerate bed thickness ranges from 2 to 60 cm. Sands contain fine- to very-coarse grained, moderately well-sorted, angular to rounded (predominantly subangular) clasts with an average composition of approximately 60% quartz, 20% feldspar, and 20% lithic fragments. Sand is deposited in laminated to thin (predominately laminated) horizontal plane beds and trough crossbeds and contains trace to 3% granules and pebbles. Good outcrops of these deposits are rare, and therefore the conglomerate-to-sand ratio is difficult to ascertain. However, where outcrops exist, sands comprise <5% of the volume of these deposits. All pediment-terrace deposits in the quadrangle are presumed to have been derived from the Chuska Mountains and Defiance Uplift (not on this map) to the west, as evidenced by their clast composition, clast imbrication, slopes of their surfaces and straths, and regional topography. These deposits rest upon pediplains cut into the Menefee Formation; this planation was unaffected by the lithologic composition of the underlying units, as neither paleovalleys in softer Cretaceous mudstones nor inselbergs of harder Cretaceous concretionary sandstones are observed.

Pediment-terrace deposit of the Tocito Wash surface (Qptw): (Pleistocene?) — Inferred to be the youngest geomorphic surface in the map area given its lowest landscape position. The surface is 8 to 10 m higher than floor of adjacent modern large drainages. Conglomerate clast composition is 58% quartz arenite, 35% subarkosic arenite (presumed to be Cretaceous sandstones), 4% chert, 3% iron concretions, 1% quartzite, and trace petrified wood. Given the widespread outcrop area of this unit, it is likely that its clast composition will vary significantly depending on source area. Surface has Stage I calcic horizon, with thin, discontinuous pebble coatings and visibly imperceptible disseminated carbonate detected by weak effervescence with 10% HCl in finer facies. Type locality is at 35.818371°, -108.666822°. Surface dips 0.70 to 0.87° in a generally east-northeast direction. Deposit is 2.0 to 3.2 m thick.

Pediment-terrace deposit of the Salt Springs Wash surface (Qpss): (Pleistocene?) — Inferred to be the second-youngest geomorphic surface due to the fact that only one pediment-terrace deposit is found lower. The surface is 20 to 16 m higher than the floor of adjacent drainages. Conglomerate clast composition is 76% quartz arenite, 21% subarkosic arenite (presumed to be Cretaceous sandstones), 1% iron concretions, 1% quartzite, and 1% petrified wood. Surface has Stage I calcic horizon, with thin, discontinuous pebble coatings and visibly imperceptible disseminated carbonate detected by strong effervescence with 10% HCl in finer facies. This unit grades upward into the young earthflow deposits (Qefy) and likely represents the downstream alluvial products of the mass movement-alluvial continuum processes at work during the creation and deposition of these units. Type locality is at 35.992327°, -108.688016°. Deposit is 4.5 to 5.5 m thick.

Pediment-terrace deposit of the Twenty-eight Mile surface (Qptm): (Pleistocene) — Inferred to be younger than the pediment-terrace deposit of the Buffalo Spring surface and older than the pediment-terrace deposit of the Salt Springs Wash surface. Potentially coeval with the pediment-terrace deposit of the Benallie's Ridge surface, but from a different source area. The surface is 28 to 25 m higher than floor of adjacent modern large drainages. Conglomerate clast composition is 84% quartz arenite, 14% subarkosic arenite (presumed to be Cretaceous sandstones), 1% iron concretions, 1% quartzite, and trace petrified wood. Surface has a Stage II calcic horizon, with continuous carbonate clast coatings <1 mm thick. This unit grades upward into the intermediate landslide deposits (Qlsi); this gradation is best expressed at 35.88864°, -108.69066° and likely represents the downstream alluvial products of the mass movement-alluvial continuum processes at work during the creation and deposition of these units. Surface dips 2.1° at azimuth of 115°. Type locality is at 35.878105°, -108.677125°. Deposit is 1 to 4.5 m thick.

Pediment-terrace deposit of the Benallie's Ridge surface (Qpbr): (Pleistocene) — Inferred to be younger than the pediment-terrace deposit of the Buffalo Springs surface and older than the pediment-terrace deposit of the Salt Springs Wash surface. Potentially coeval with the pediment-terrace deposit of the Twenty-eight Mile surface, but from a different source area. The surface is 26 to 24 m higher than floor of adjacent modern large drainages. The surface of this deposit is inset lower than the adjacent pediment-terrace deposit of the Sitting Coyote Mesa surface by approximately 12 m. Conglomerate clast composition is 24% quartz arenite, 58% subarkosic arenite (presumed to be Cretaceous sandstones), 8% iron concretions, 2% quartzite, 2% petrified wood, 1.5% quartz pebbles, 1.5% chert, and 1.5% pebbly sandstone. Soil development unknown due to limited land access. Type locality is at 35.813166°, -108.742035°. Deposit is 2.5 to 4.5 m thick.

Pediment-terrace deposit of the Buffalo Spring surface (Qpbs): (Pleistocene) — Inferred to be the second-oldest geomorphic surface in the drainage where it is found due to its occupation of the second-highest landscape position. Found only on three mesas just east of Highway 491, 3.1 to 5.1 km north-northeast of the NM DOT Buffalo Springs Patrol Station. The surface is 31 to 35 m higher than floor of adjacent modern large drainages. Surface dips 0.98°at azimuths of 085 to 005°, suggesting that the depositional environment was a large mountain-front fan draining the area between Tocito Wash in the south and Salt Springs Wash in the north. Clast composition and soil development unknown due to limited land access. Deposit is 4 m thick.

Pediment-terrace deposit of the Sitting Coyote Mesa surface (Qpsc): (Pleistocene) — Inferred to be the oldest geomorphic surface in the drainage where it exists due to its occupation of the highest landscape surface; age relative to the pediment-terrace deposit of the Ch'ooshgai surface and the pediment-terrace deposit of the Ear Rock surface is unknown but potentially coeval or slightly younger. The surface is 52 to 49 m higher than the floor of adjacent modern large drainages. Conglomerate clast composition is 68% quartz arenite, 27% subarkosic arenite (presumed to be Cretaceous sandstones), 3% iron concretions, 1% chert, and 1% petrified wood. Unlike other pediment-terrace deposits in the quadrangle, this unit contains approximately 10% matrix-supported conglomerate. At the surface, this unit contains a Stage II calcic horizon, with sub-mm discontinuous clast coatings and small (1 to 2 mm) carbonate nodules. This unit was heavily exploited, and in places completely removed, for aggregate in mesa-top quarries on and near the western map boundary in the middle 20th Century. Because of the quarry-related removal of this unit in most of its previous position within the map area, the type locality for this unit is slightly off the map at an unquarried exposure at 35.806990°, -108.765468°. Surface slopes approximately 0.9° at an azimuth of 071°. Deposit is 4 to 10.2 m thick.

Pediment-terrace deposit of the Ear Rock surface (Qper): (Pleistocene) — Inferred to be the oldest geomorphic surface in the drainages where it is found due to its occupation of the highest landscape position. It does not exist in the same drainages as the pediment-terrace deposit of the Ch'ooshgai surface; its age, relative to the pediment-terrace deposit of the Ch'ooshgai surface, is unknown but likely coeval. Near Highway 491, the surface is 52 to 58 m higher than floor of adjacent modern large drainages. Near Ear Rock, the surface is 39 to 42 m above the floor of modern drainages. Conglomerate clast composition is 88% quartz arenite, 3% subarkosic arenite (presumed to be Cretaceous sandstones), 4% chert, and 1% each petrified wood, quartzite, iron concretions, and quartz pebbles. Surface has a Stage III calcic horizon with carbonate coatings up to 1.5 mm thick on the bottoms of some clasts and carbonate nodules up to 3 mm diameter in fine-grained strata. This deposit is likely the downstream alluvial equivalent to Qlso and Qlso/Qper. Surface slopes 0.55° at an azimuth of 071°. Type locality is at 35.951336°, -108.623676°. Deposit is 3.5 to 6 m thick.

Pediment-terrace deposit of the Ch'ooshgai surface (Qpc): (Pleistocene) — Inferred to be the oldest geomorphic surface in the map area due to its occupation of the highest landscape position. Near Highway 491, the surface is up to 70 m higher than floor of modern large drainages. Near Red Willow Farms, the surface is 16 to 25 m above the floor of modern drainages. Conglomerate clast composition is 84% quartz arenite, 14% subarkosic arenite (presumed to be Cretaceous sandstones), and trace quartzite and iron concretions. Surface has a Stage II+/III- calcic horizon with carbonate coatings up to 1.5 mm thick on the bottoms of some clasts. This unit was heavily exploited for aggregate in quarries south and east of Highway 491 near Tohatchi. This deposit is likely the downstream alluvial equivalent to older landslide deposits (Qlso). Surface slopes 1.22° at azimuth of 177° near Highway 491; slopes become more northerly farther north, suggesting the deposit was a large mountain-front fan. Type locality is at 35.853075°, -108.726638°. Deposit is up to 9 m thick and thins downgradient.

CRETACEOUS

Tohatchi Formation (Kt): (Campanian, ca. 83.6 to 72.1 Ma) — Intercalated sandstone, mudstone, siltstone, and coal. Dominantly thick sequences of sandy siltstone that is white to gray weathering light gray (Fig. 28), with well-sorted silts and very fine (lower)- to very fine (upper)-grained sand fraction; occasionally $CaCO_3$-cemented. Abundant carbonaceous material, brown-gold bentonite, selenite, and splintery silicified wood (Fig. 29). Occasional clay rip ups and iron staining. Bentonitic, weathering to popcorn texture, and interbedded with dark-gray mudstones. Sandstones are reddish yellow to red and lenticular fining into red (7.5R 4/6) siltstones, flaggy and crossbedded light-gray sandstone weathering very dark gray to dark brown, or planar and yellowish orange and interbedded with mudstones. Reddish-yellow to red sandstones increase up section, are laterally discontinuous (around 10 to 15 m wide and 2 to 3 m thick), grade into siltstone with very fine-grained sand fraction and $CaCO_3$ nodules. Dark brown weathering sandstones are very fine (lower)- to fine (upper)-grained, subangular, moderately well to well-sorted. Contains abundant quartz and dark metallic minerals; $CaCO_3$ cement. Trough crossbedded with flaggy bedding 1 to 5 cm thick; in concretionary channels 1 to 2 m wide. Commonly associated with presence of organic material, found in proximity to orange-red sandstone horizons, and overly sandy siltstone horizons with gray clay rip-ups. Other sandstones include yellowish orange very fine (lower)- to coarse (lower)-grained, poorly to moderately well-sorted, angular to subrounded; contains quartz, magnetite, and lithics; planar and interbedded with dark gray muds containing selenite. Sandstones have occasional flute casts, 1 cm iron concretions, potassium or plagioclase feldspar, clay cement, and botryoidal iron concretions. Red mudstones, sandy siltstones, and coarse, well-sorted sandstones found intercalated within thick sequences of gray weathering siltstone and mudstone. Mudstones white to gray and brown to black weathering gray, silty to sandy, waxy texture, 1 mm laminations, $CaCO_3$ present, abundant carbonaceous fragments. Interbedded with carbonaceous shale and brown-gold bentonitic horizons. Carbonaceous shales are dark gray to dark brown and black, finely laminated, abundant carbonaceous fragments, oxidized, and gypsiferous. Includes low grade coal up to 1 m thick.

Allison Member of the Menefee Formation (Kmfa): (Campanian to Santonian, ca. 72.1 to 86.3 Ma) — Upper portion (generally west of Highway 491 in this quadrangle) is yellowish-brown, gray, and dark-brown beds of thick discontinuous sandstone in mudstone interbedded with thin sandstones, siltstone, and coal. Sandstones white tan and yellow orange and brown, very fine- (upper) to medium (lower)-grained, poorly to moderately sorted, subangular to well-rounded, poorly to well indurated. Quartz dominant and includes colorful grains, lithic fragments abundant, occasional muscovite; $CaCO_3$- and iron-oxide-cemented. Found in massive to trough cross bedded and occasionally laminated beds 3 to 5 m thick; lenticular but laterally persistent over large distances (1 to 3 km). Sandstones occasionally light brown and quarzitic or very fine-grained with carbonaceous material and heavy minerals. Commonly intercalated with white to gray or tan-brown mudstone and siltstone beds. Beds scour into one another and have variable thicknesses. Siltstones are sandy with interbeds of mudstone, bentonite, and sandstone; commonly carbonaceous or nodular. Mudstones are variegated and commonly contain carbonaceous material. Occasional carbonized organic material (Fig. 30), rip-up clast horizons, and bulbous iron concretions. Gradational contact with overlying Kirtland and Fruitland Formation occurs at 30 m thick sequence of tightly interbedded sandstone and mudstone. This can be identified where ledge and bench forming "very friable, thick bedded, yellowish orange, very fine-grained subarkoses" of the Allison Member grades upwards to "indurated, thin bedded, and yellowish brown" ledge and cliff forming sandstones of the Tohatchi Formation (Lucas et al., 2003).

The lower portion of the Allison Member (generally east and south of Highway 491 in this quadrangle) is predominantly yellowish-brown, light-olive-brown, and light-yellowish-brown shale and siltstone with interbedded yellowish-brown, light-yellowish-brown, and brownish-yellow sandstone with dark-grayish-brown to brown concretionary sandstone. Shale and siltstone are poorly exposed and typically observed only as interbeds between more resistant sandstone strata. Where observed, shale and siltstones contain mostly clay through fine silt in laminated to thin horizontal plane beds and low-angle crossbeds. Wood and plant impressions are present but rare on bedding planes. Sandstones are carbonate-, clay-, and iron-oxide-cemented very fine- to fine-grained (with trace medium to coarse grains), angular to subangular, well-sorted to very well-sorted lithic arkose (50% quartz, 25% feldspar, 25% lithics). Lithic fragments include black grains presumed to be oxide minerals and reddish-orange chert. Sandstone beds are laminated to thin horizontal plane beds, tabular crossbeds, and low-angle tangential crossbeds. Sandstones exhibit shallow cut-and-fill structures up to 60 cm deep, rare mud-clast conglomerates with angular to subangular clasts with b-axis diameters of up to 6 cm, and wood impressions up to 50 cm long. Sandstones have sharp but interfingering contacts with encapsulating mudstones. Concretionary strata within the Allison Member are texturally identical to the sandstones described above, but are darker (lower Munsell value) and better-cemented, presumably with an oxide of iron, manganese, or magnesium, though this was not confirmed with chemical analysis. Concretions are globular and spherical to elongated masses up to hundreds of meters long that are the most weathering-resistant geological products in the map area, often holding up hoodoos, ridges, or mesas such as Dził Nda K'ai' Mountain and Little Ear Mountain. Contact with the underlying Cleary Coal Member of the Menefee Formation is difficult to ascertain in the field and is mapped at the approximate level of the highest observed carbonaceous shale in the Cleary Coal Member; the nature of this contact is unknown but likely gradational and interfingering.

Thickness of the Allison Member is at least 195 m at a borehole 8.45 km due east of the Tohatchi Chapter House (API #30-031-05301); total thickness on this quadrangle is estimated to be between 450 and 550 m.

Cleary Coal Member of the Menefee Formation (Kmfc): (Campanian to Santonian, ca. 72.1 to 86.3 Ma) — Interbedded grayish-brown, gray, and light-yellowish-brown shale and siltstone; yellowish-brown to yellow sandstone; dark-gray carbonaceous shale, black lignitic to subbituminous coal, and brown concretionary sandstone. Shale and siltstone contain clay through coarse grained silt in laminated to thin beds, form recessive outcrops, and interfinger with sandstones within the same unit. Sandstones are clay- and silica-cemented coarse-grained silt through medium-grained, subangular to subrounded with trace well-rounded, moderately sorted, arkose (55% quartz, 40 % feldspar, 5% lithics) in weathering-resistant pavement and small cliff outcrops. Sandstone beds include trough crossbeds, planar crossbeds, and horizontal plane beds. Sandstones contain rare wood impressions on bedding planes. Coals are lenticular, discontinuous, and <30 cm thick where observed. Carbonaceous shales form recessive outcrops but support little vegetation, leading to larger outcrop areas approximately 3.2 km north of the Coyote Canyon Chapter House and just north of where Navajo Service Route 9 crosses Big Spring Canyon. Concretionary sandstone horizons are noticeably darker-colored than surrounding sandstone, and form globular spherical to elongated concretions that are the most weathering-resistant geological products in the map area, often holding up small mesas or hoodoos. Sandstones, shales, and siltstones within this unit interfinger with each other. Contact with the underlying Point Lookout Sandstone is sharp but interfingering. Contact with the overlying Allison Member of the Menefee Formation is difficult to ascertain in the field and is mapped at the approximate level of the highest observed carbonaceous shale in the Cleary Coal Member; the nature of this contact is unknown but likely gradational and interfingering. Thickness on this quadrangle is approximately 60 m.

Point Lookout Sandstone, main body (Kpl): (Santonian, ca. 86.3 to 83.6 Ma) — Pale-brown, light-yellowish-brown, yellowish-brown, and brownish-yellow sandstone comprising of calcareous very fine to fine, well-sorted, subangular to rounded (predominantly subrounded) grains. Lithologic composition is subarkose (80 to 85% quartz, 15 to 18% feldspar, trace to 1% lithics; lithics are predominately black oxide minerals). Bedforms include horizontal to gently dipping plane beds, low-angle trough and tabular crossbeds, minor herringbone beds, undulating laminae, and hummocky crossbeds. Sedimentary structures include ripples and contorted bedding. Includes interbeds of siltstone and shale of similar composition to those in the Satan Tongue of the Mancos Shale; these make up a trace amount of the total volume of the unit in the quadrangle. Forms a thick body of sandstone in the southeastern map area where it is best exposed in widespread pavement outcrops and steep canyon walls between Red Water Canyon and Big Spring Canyon. This unit is separated from the Hosta Tongue of the Point Lookout Sandstone by the Satan Tongue east of the pinchout of the Satan Tongue. Where the Satan Tongueis not present (on this quadrangle, only in upper Coyote Canyon near the southern map boundary), this unit includes all of the Point Lookout Sandstone. Upper contact is sharp and placed at the uppermost laterally-extensive sandstone bed beneath the shales and siltstones of the Menefee Formation. Intertongues with the Satan Tongue (where present) and the Gibson Coal Member of the Crevasse Canyon Formation. The portion of the Point Lookout Sandstone above the Satan Tonguethins westward, from 62 m in Red Water Canyon to 42 m in Big Spring Canyon near Navajo Service Route 9. Thickness of the combined Point Lookout Sandstone in Coyote Canyon is 75 m.

Satan Tongue of the Mancos Shale (Kms): (Santonian, ca. 86.3 to 83.6 Ma) — Interbedded gray, dark-gray, and dark-grayish-brown shale and siltstone; pale-brown to light-yellowish-brown sandstone. Shale comprises 15 to 30% of the Satan Tongue interval in the quadrangle and contains fissile, calcareous laminated to thin-bedded (predominantly very thin-bedded) horizontal plane beds with trace ripple marks and abundant burrow and trail trace fossils on bedding planes. Siltstone comprises 45 to 60% of the Satan Tongue of the Mancos Shale interval in the quadrangle and contains well-sorted muddy calcareous silt in laminated to thin (predominantly very thin) horizontal plane beds with rare wavy laminations and ripple crossbeds and abundant fragments of *Inoceramid* shells and rare sharks' teeth, fish scales, and bioturbated bedding planes. Shales and siltstones commonly are stained strong brown, presumably with oxides of iron, on fracture surfaces and bedding planes. Shales and siltstones are recessive, forming slopes and exposed well only in arroyo walls or between more resistant beds of sandstone. Sandstone comprises 25 to 45% of the Satan Tongue interval and contains very fine- to fine-grained subarkose to quartzarenite (85 to 90% quartz, 8 to 10% feldspar, trace to 2% lithics) in laminated to very thin horizontal plane beds and parallel low-angle beds. Sandstone is carbonate-cemented, more weathering-resistant than shales and siltstones within the same unit, with which it interfingers with sharp intramember contacts (but more recessive than subjacent and superjacent sandstones of the Point Lookout Sandstone), and breaks cleanly along shale interbeds leading to flaggy talus below outcrops. Interfingers with the underlying Hosta Tongue of the Point Lookout Sandstone; lower contact is placed at the lowest horizon where mudstone is more abundant than sandstone over a 2 m interval. Interfingers with the overlying Point Lookout Sandstone (main body); upper contact is placed at the horizon where sandstone is more abundant than mudstone over a 2 m interval. The Satan Tongue interval becomes sandier and thins to the west in the quadrangle, from 14 m in Red Water Canyon, to 7 m in Big Spring Canyon, pinching out completely between Wild Berry Canyon and Coyote Canyon.

Hosta Tongue of the Point Lookout Sandstone (Kplh): (Santonian, ca. 86.3 to 83.6 Ma) — Mostly the same mineral and textural composition as the Point Lookout Sandstone, main body (Kpl), along with horizons of brown, very well-cemented, very fine- to fine-grained, well-sorted, subrounded to subangular quartzarenites that are more fossiliferous and weathering-resistant than other sandstones within the unit. Includes fragments of *Inoceramids*, sharks' teeth, and fish scales, and impressions of *Inoceramids* up to 37 cm long. Upper contact is gradational and interfingering with the Satan Tongue of the Mancos Shale. Lower contact with the Gibson Coal Member of the Crevasse Canyon Formation is sharp but can be difficult to recognize when sand-on-sand; the quartz-rich clast composition of the Hosta Tongue is the primary indicator in these situations. Forms steep canyon walls in inner Red Water Canyon, Peach Spring Canyon, and Wild Berry Canyon. This unit is inseparable from the main body of the Point Lookout Sandstone west of the pinchout of the Satan Tongue. Unit thickness is 15 to 42 m.

Gibson Coal Member of the Crevasse Canyon Formation (Kcg): (Santonian, ca. 86.3 to 83.6 Ma) — Interbedded gray to brown shale and siltstone; light-brown, yellow, and brownish-yellow sandstone; dark-gray, gray, and grayish-brown carbonaceous shales; and black subbituminous coals. Shale and siltstone contain clay through coarse-grained silt in laminated to very thin horizontal beds, form recessive outcrops, contain fossil traces of wood and plant debris as impressions on bedding planes, and interfinger with sandstones within the same unit. Sandstones are very fine- to fine-grained with trace coarse grains to granules, moderately sorted, subangular to subrounded arkose (60% quartz, 35% feldspar, 5% lithics) in cliff- and ledge-forming laminae to medium beds (predominantly thin beds) that are broadly lenticular and contain trough and planar crossbeds, horizontal plane beds, and asymmetrical ripple marks. Sandstones also contain petrified wood fragments and impressions of fossil plant material on bedding planes. Coals are 20 to 85 cm thick; persistent outcrops of coal in this member were not observed on this quadrangle, so their lateral extent is not known. Contact with the overlying Hosta Tongue of the Point Lookout Sandstone is generally sharp, though intertonguing over approximately 65 cm is observed in Peach Spring Canyon near the southern map boundary. Lower contact not observed on this quadrangle. Occurs only at Peach Spring and Wild Berry Canyons near the southern map boundary. Maximum observed thickness on this quadrangle is approximately 60 m at Wild Berry Canyon; total thickness not measured for this map.

APPENDIX B

	Pediment-terrace map unit				
	Qpc (n = 260)	**Qper** (n = 122)	**Qpsc** (n = 154)	**Qpbr** (n = 254)	**Qptw** (n = 221)
Clast type					
Cretaceous arenite	9.9	3.3	27.3	57.8	24.3
Quartz arenite	85.7	88.5	68.2	24.2	71.2
Petrified wood	0.7	0.8	0.6	2.3	0.0
Red quartzite	1.1	0.8	0.0	2.3	0.9
Iron concretions	0.0	0.8	3.2	7.8	1.8
Quartz pebbles	0.4	0.8	0.0	0.8	0.0
Red very fine grained arenite	0.0	0.0	0.0	1.6	0.0
Chert	2.2	4.9	0.6	1.6	1.8
Pebbly Sandstone	0.0	0.0	0.0	1.6	0.0
Total	100.0	100.0	100.0	100.0	100.0

Appendix B. Composition of clasts >1 cm B-axis diameter in pediment-terrace deposits in the Coyote Canyon 15-Minute Quadrangle map area.

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