Geologic Map of the Aztec 7.5-Minute Quadrangle, San Juan County, New Mexico

By

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EXECUTIVE SUMMARY

Located in northeast San Juan County, New Mexico, partially within and immediately east of the city of Aztec, the Aztec 7.5-minute Quadrangle occupies key locations for understanding the geologic history of the northern San Juan Basin. We build upon previous mapping which produced a 1:50,000-scale geologic map of portions of the surficial geology of the area (Gillam, 1998) 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 Paleogene units. The Aztec 7.5-minute Quadrangle exists in the central San Juan basin (Kelley, 1951; Craigg, 2001), a broken-foreland structural basin formed during the Laramide Orogeny. The quadrangle is located near the San Juan basin's synclinal axis, leading to low dip angles in the bedrock units throughout most of the map area. The bedrock in the map area is comprised of Paleogene siliciclastic sedimentary rocks. There are no known igneous or metamorphic outcrops in the map area. Loosely consolidated to unconsolidated Quaternary surficial deposits exist as sand sheets, terrace alluvium, hillslope deposits, and valley-floor alluvium throughout the quadrangle.

The depositional history of the Aztec 7.5-minute Quadrangle included three broadly defined episodes: first, Paleogene deposition of fluvial siliciclastic sediments during the Laramide Orogeny produced the Nacimiento and San Jose Formations, both of which are preserved in outcrop in the map area. Second, Quaternary fluvial deposition and incision episodes of the Animas River produced coarse-grained, poorly sorted terrace deposits in the northern and western map area. Finally, deposition of eolian sands later in the Quaternary period produced broad sand sheets whose remnants persist in isolated outcrops, and sheetwash and alluvial processes led to the gravels and sands that comprise the unconsolidated deposits found throughout the quadrangle's valleys and canyon floors. Arroyo incision and eolian deposition dominate modern geologic processes in the quadrangle.

The map area is drained by dozens of arroyos that flow into the Animas or San Juan Rivers. Landforms in the quadrangle include arroyos, canyons, mesas, low-relief plains, eolian dunes, and the active alluvial valley of the Animas River. Vegetation includes that typical of US EPA Level III ecoregions 22i (Arizona/New Mexico Plateau San Juan/Chaco Tablelands and Mesas) and 20c (Colorado Plateau Semiarid Benchlands and Tablelands) (USEPA, 2013).

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

INTRODUCTION

This report accompanies the Geologic Map of the Aztec 7.5-minute Quadrangle, San Juan County, New Mexico (NMBGMR GM81). Its purpose is to discuss the map area's geologic setting, explain its geologic history, and identify and explain significant stratigraphic and geomorphic relationships discovered during the course of mapping. This report presents several fundamental geologic aspects of the quadrangle, including geographic and physiographic settings, climate, and previous geologic work. Then it describes, by age, the depositional history of the geologic map units and their depositional settings in greater detail than is possible on the map sheet.

MOTIVATION

Exposures of Cenozoic strata along the Animas River valley and Quaternary surficial deposits in terraces, canyons, and arroyos throughout the area provide the opportunity to reconstruct the geologic history of this area of the Colorado Plateau in New Mexico. A previous mapping effort produced a robust small-scale geologic map focusing upon bedrock units within the quadrangle (Manley et al., 1987). Mapping and description of terraces of the Animas River were the focus of a Ph.D. dissertation (Gillam, 1998), and we relied on initial descriptions and interpretations from that work in this mapping effort. We refined this earlier mapping, with particular focus on adding detail and accuracy to surficial units, contacts, and member-level designations of Paleogene 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 2023 meeting.

CLIMATE

The Aztec 7.5-minute Quadrangle—and most of the San Juan basin—has a cold semi-arid climate (Koppen Classification *Bsk*). Mean annual temperatures are 51.4°F (10.8°C) at Aztec Ruins in the western map area at an elevation of 1,721 m (5,645 ft). Mean annual precipitation is 25.1 cm (9.9 in), with an average of 38 cm (15 in) of snowfall annually. All climate statistics listed above are average values of data collected from 1914 to 2005 (≈91 years) by the National Weather Service Cooperative, Aztec Ruins National Monument station (ID# 290692). (Western Regional Climate Center, 2025).

GEOGRAPHIC AND TECTONIC SETTING

The Aztec 7.5-minute Quadrangle covers approximately 155 km^2 (60 mi^2) in San Juan County, New Mexico. The largest community on the quadrangle is Aztec. There are widely dispersed neighborhoods, suburbs, ranches, and farms throughout the less-populated portions of the quadrangle, especially along the Animas River. Elevations in the map area range from 2,072 m (6,798 ft) at Knickerbocker Peak to 1,709 m (5,606 ft) at the Animas River where it exits the western map boundary. Major drainages in the quadrangle include the Animas River, Hart Canyon, Knowlton Canyon, Hampton Arroyo, Bohanan Canyon, Bloomfield Canyon, Hare Canyon, Potter Canyon, Little Slane Canyon, and Cerritos Canyon, all of which are intermittent or ephemeral except for the Animas River.

The quadrangle lies entirely within the Colorado Plateau physiographic province, a region of relatively minor faulting and folding compared to surrounding provinces. The Colorado Plateau's characteristic lack of abundant major tectonic deformation features is manifest in the Aztec 7.5-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.

MAPPING METHODS

The procedures used to produce this geologic map are divided into four phases, all of which employ digital methods and the authors' direct input of geologic data into a Geographic Information System (GIS) database. The first phase involved the authors identifying geologic units and likely contacts on LiDAR-derived digital elevation models (DEM) 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 stereo photogrammetry image 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 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 a 1:24,000-scale final layout.

The geologic cross section was created after the geologic map was completed. The surface profile and geology were created from topographic and geologic information on the geologic map. Subsurface data were gathered from well logs 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. Well locations are shown on the geologic map and cross section and labeled with their API index number; however, labels exclude the API prefix to save space.

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). The presence or absence of carbonate in sediments was determined by applying 10% HCl (hydrochloric acid) on dry samples. Bed thicknesses and outcrop heights were determined with a 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.

APPENDIX A
DESCRIPTIONS OF MAP UNITS

QUATERNARY UNITS
ANTHROPOGENIC UNITS

af—Artificial fill (recent)—Clay, silt, sand, and pebbles used to construct flood-control dams, berms, and highway grades near the City of Aztec.

afd—Artificial disturbed ground (recent)—Used as an overlay in the map area to indicate areas where urban development has so obscured the landscape that the natural geologic materials beneath the ground must be assumed. On the map, the overlay is used most often in the city of Aztecs' urban areas and industrial areas along U.S. Route 550 in the southern map area.

EOLIAN DEPOSITS

Qer—Remnants of eolian sand sheets (Holocene to Pleistocene)—Weakly consolidated reddened silty sands on high-landscape positions interpreted to be remnants of previous extensive sand sheets. Colors range from 7.5 YR 6/4–10 YR 6/6 (light brown to brownish yellow). Very weak effervescence with HCl at a depth of 30 cm below ground surface. Maximum observed thickness is 4 m (13.1 ft), but it may be thicker.

ARROYO ALLUVIUM

Qaa—Active arroyo alluvium (Recent)—Stream-deposited clay, silt, sand, and gravel within active-ephemeral and intermittent-stream channels. Occupies the lowest geomorphic position in any alluvially-active valley. Mineral composition and grain rounding are 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. Contains anthropogenic detritus at the surface and in cross section outcrop at a depth of up to 2 m (6.6 ft), including common litter, asphalt macadam, wire fencing, fenceposts, rubber tires, household appliances, and the bones of domesticated animals. Bedforms include trough cross-bedding, ripple cross-bedding, 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 deposit but are rarely preserved; muds at the surface presumably are removed during early stages of subsequent streamflow events. Includes minor eolian deposits that are too small to map at the 1:24,000-scale; these dunes are up to 1 m (3.3 ft) high and are rare but present in cross-section outcrops. Does not effervesce in 10% HCl. Primarily unvegetated; primary successional grasses, forbs, cocklebur, tamarisk, and annual flowers are present. Observed thickness is 3.1 m (10.2 ft); total thickness unknown.

Qao—Inactive arroyo alluvium (Holocene)—Loose to weakly consolidated silty sand, sand, and pebbly sand with trace pebbles and cobbles. The lack of outcrop exposures precludes a detailed description of internal structure and total thickness. The deposit has very weak effervescence in 10% HCl at 10–30 cm (4–12 in) depth. No active avulsion or deposition observed in aerial photographs, and the deposit thickness is likely <10 m. The plant community observed at the surface is dominated by saltbrush (*Atriplex canescens*), big sagebrush (*Artemisia tridentata*), nopal (*Opuntia sp.*), and chamisa (*Ericameria nauseosa*).

HILLSLOPE DEPOSITS

Qct—Colluvium derived from Animas River terrace gravels (Holocene)—Pebbles through boulders on steep slopes immediately beneath gravel-capped terraces. Material is loose to very poorly consolidated, with no noticeable soil development, and ranges in thickness from 0.2–4 m (0.6–13 ft).

Qttc—Colluvium derived from tributary terrace gravels (Holocene)—Pebbles through boulders on steep to moderate slopes beneath gravel-capped terraces. Material is loose to very poorly consolidated, and often includes appreciable silt and fine-grained sand, presumably through eolian input. This deposit has no noticeable soil development and is 0.1–2 m (0.3–6.6 ft) thick.

Qsl—Slopewash deposits (recent to Pleistocene)—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 terrace deposits or Paleogene sedimentary rocks immediately upslope. Forms alluvial-colluvial aprons around steep outcrops of mesas. Bedding not observed, and erosional rills and gullies through this deposit often expose underlying Paleogene siliciclastic units. Differentiated from fan and alluvial deposits 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). The deposit thickness is unknown but assumed to be <5 m (<16.4 ft).

<u>FAN DEPOSITS</u>

Qtf7—Fan deposits covering the Qt7 terrace deposit (recent to Pleistocene)—Deposit of unknown thickness, similar in composition and setting to Qft deposit, but split out as a separate deposit and illustrated as a Map Unit Overlay so as not to obscure details and interpretations of what underlies it. The deposit is easily visible in LiDAR-derived hillshade images and topographic maps.

Qfcm—Canyon-mouth fan deposits (recent to Pleistocene)—Canyon-mouth fan deposits overlying alluvium with unknown thickness.

Qft—Alluvial fan deposits capping terraces of the Animas River (recent to Pleistocene)—Sand-dominated fan alluvium covering terrace deposits, up to 18 m (59 ft) thick and generally sloping toward the Animas River.

<u>TRIBUTARY TERRACE DEPOSITS</u>

Qthc—Terrace of Hart Canyon—(Holocene?/Pleistocene)—Terrace of Hart Canyon. Contains a mixture of rounded cobbles of crystalline rock and quartzite (presumably reworked from higher Animas River terrace deposits upstream in the Hart Canyon drainage) and subangular to rounded cobbles and pebbles of sandstone. Deposit is found at heights of approximately 14 m (46 ft) above the modern bed of Hart Canyon and are 1.5–2.8 m (5–9.2 ft) thick.

Qtrgu—Reworked terrace gravels, undivided—(Pleistocene?)—Clast-supported pebbles through cobbles with trace boulders that are subrounded to rounded and moderately to poorly sorted. Gravels have the same composition as the terraces of the Animas River. The deposit is unconsolidated to loosely consolidated and likely represents the deposits of ancient tributaries of the San Juan or Animas Rivers that had their sediment source among the higher terrace deposits of the Animas River, such as Qt1. Soil development is variable, from none to Stage II Bk horizon. This deposit is widespread on higher isolated ridges and can be found from 19–81 m (62.3–265.7 ft) above modern adjacent stream grades in the easternmost part of the map area. Deposit thickness ranges from 0.5–3 m (1.6–9.8 ft), and its age is unknown.

Qtrg48—Younger terrace of Hare Canyon—(Pleistocene?)—Clast-supported pebbles through cobbles with trace boulders that are subrounded to rounded and moderately to poorly sorted. The deposit is unconsolidated to loosely consolidated and likely represents the deposits of an ancient tributary to the San Juan River that had its sediment source among the higher terrace deposits of the Animas River, such as Qt1. This deposit is 1.5–2.5 m (4.9–8.2 ft) thick and capped by a soil that contains a Stage II Bk horizon. This deposit is 48 m (157.5 ft) higher than the modern grade of Hare Canyon immediately adjacent, and its age is unknown but inferred to be middle Pleistocene based on relative relationships to terraces capped by Qt5 and Qt4.

Qtrg61—Older terrace of Hare Canyon—(Pleistocene?)—Clast-supported pebbles through cobbles with trace boulders that are subrounded to rounded and moderately to poorly sorted. The deposit is unconsolidated to loosely consolidated and likely represents the deposits of an ancient tributary to the San Juan River that had its sediment source among the higher terrace deposits of the Animas River, such as Qt1. The deposit is capped by a soil that contains a Stage II Bk horizon, has a thickness of 1.5–4 m (5–13 ft), and is 61 m (200 ft) higher than the modern grade of Hare Canyon immediately adjacent. Its age is unknown but inferred to be middle Pleistocene based on relative relationships to terraces capped by Qt5 and Qt4.

Qtta—Terrace of tributaries, unknown origin (Pleistocene?)—Clast-supported pebbles through boulders (predominantly cobbles) that are subrounded to rounded and poorly sorted. The deposit contains lenses of moderately sorted, subangular to subrounded medium- through coarse-grained sand. The deposit is unconsolidated to loosely consolidated, except where cemented by pedogenic carbonate. Gravels (those materials coarser than granules) contain approximately 50% quartzite, 35% volcanic and metavolcanic rocks, 8% intrusive igneous rocks, 5% foliated metamorphic rocks, and traces of limestone, sandstone, and locally derived sedimentary rocks. It is unknown whether this deposit is a previously unreported high terrace of the San Juan River or a tributary terrace of reworked older, higher gravels of Animas Terraces, such as those exposed on Knickerbocker Peak. This deposit has an observed thickness of 9 m (29.5 ft) and is capped by a soil that contains up to a Stage III Bk horizon. The deposit is approximately 125 m (410 ft) higher than the modern Animas River, which is 12 km (7.5

mi) northwest of the deposit's outcrops. The deposit is approximately 165 m (550 ft) higher than the San Juan River, which is 5 km (3 mi) south of the deposit outcrops. Age unknown, but inferred to be greater than 631 ka, given relative relationship to the height of Qt4, and only exists on a few mesas in the far southeastern map area.

ANIMAS RIVER DEPOSITS

W—Water—Surface water in the channel of the Animas River is visible in aerial imagery. This deposit includes water in a few small reservoirs and sewage treatment facilities east of the Animas River.

Qaf—Floodplain alluvium of the Animas River (Holocene)—Clay, silt, sand, pebbles, and cobbles (predominantly silt through pebbles) deposited by the Animas River after the abandonment of the lowest terrace (Qt7) in the map area. It was developed mainly for irrigated agriculture and suburban residential purposes, and hosts riparian and shrubland vegetation. Outcrops of this deposit are rare, and the thickness is unknown.

Qabc—Bar and channel deposits of the Animas River (Holocene)—Clast-supported pebbles through boulders (predominantly cobbles) that are subrounded to rounded and poorly sorted. The deposit contains alluvial clay, silt, and sand at the surface. After alluvial deposition, the deposit was partly covered with minor eolian silt and sand at the surface. Exhibits clearly expressed bar-and-swale topography, supports riparian vegetation, and was likely reworked during modern floods on the Animas River.

Qob—Oxbow lake-deposits (Holocene)—Alluvial deposits in former oxbow lakes on the lowest terraces and modern floodplain of the Animas River. Deposits were identified in aerial imagery and not sampled due to land access limitations.

Terrace Deposits

Qt7—Terrace Deposit 7 (Pleistocene)—Clast-supported pebbles through boulders (predominantly cobbles) that are subangular to rounded and poorly sorted. The deposit contains lenses of moderately sorted, subangular, medium- through very coarse-grained sands. The deposit is unconsolidated to loosely consolidated, and contains approximately 40% quartzite, 39% volcanic and metavolcanic rocks, 15% intrusive igneous rocks, 5% foliated metamorphic rocks, 1% limestone, and traces of locally derived sedimentary rocks. Lower contact not observed, and the thickness is unknown. The deposit is found at heights of approximately 3–10 m (10–33 ft) above the modern Animas River. In the map area this deposit is largely covered with deposits of younger alluvial fans and is utilized for extensive irrigated agriculture. This deposit's age is inferred to be Late Pleistocene (ca. 10–20 ka) by Gillam (1998) and might merge with the modern floodplain, but further work would be needed to test that hypothesis.

Qt6—Terrace Deposit 6 (Pleistocene)—Clast-supported pebbles through boulders (predominantly cobbles) that are subangular to rounded and poorly sorted. The deposit contains lenses of moderately sorted, subangular, medium- through very coarse-grained sands. Gravels (those materials coarser than granules) make up 50–70% of the deposit. Sands have an average composition of 45% quartz, 30% feldspar, and 25% lithic fragments. Sand color is 7.5 YR 5/3–6/3 (brown to light brown) when dry. The deposit is unconsolidated to loosely consolidated. Gravels contain approximately 40% quartzite, 39% volcanic and metavolcanic rocks, 15% intrusive igneous rocks, 5% foliated metamorphic rocks, 1% limestone, and traces of locally derived sedimentary rocks. Bedforms are rarely observed but include massive beds and low-angle plane beds, and clast imbrication is common. Deposit hosts a variably developed soil at its surface that contains up to a Stage I+ Bk horizon and appears to rest upon a bedrock strath developed on the Nacimiento Formation. Observed thickness of the deposit is 3–6 m (1.8–3.7 ft) and is found at heights of approximately 25 m (82 ft) above the modern Animas River. Deposit age is inferred to be Late Pleistocene (ca. 100–130 ka, potentially coeval with the termination of Bull Lake glaciation) by Gillam (1998).

Qt5t6—Terrace Deposit 5 and 6, combined (Pleistocene)—An intermediate deposit representing the junction of deposits Qt5 and Qt6. Gillam (1998) documented these two deposits merging. Due to limited access, the precise thickness and composition of this deposit in the map area is not known but is assumed to be similar to that of deposits Qt5 and Qt6, described above and below.

Qt5—Terrace Deposit 5 (Pleistocene)—Clast-supported pebbles through boulders (predominantly cobbles) that are subangular to rounded and poorly sorted. The deposit contains lenses of moderately sorted, subangular, medium- through very coarse-grained sands. The deposit is unconsolidated to loosely consolidated. Gravels (those materials coarser than granules) make up 50–70% of the deposit. Sands have an average composition of 45% quartz, 30% feldspar, and 25% lithic fragments. Sand color is 7.5 YR 5/3–6/3 (brown to light brown) when dry. Gravels contain approximately 40% quartzite, 39% volcanic and metavolcanic rocks, 15% intrusive igneous rocks, 5% foliated metamorphic rocks, 1% limestone, and traces of locally derived sedimentary rocks. Bedforms are rarely observed but include massive beds and low-angle plane beds, and clast imbrication is common. Deposit hosts a variably developed soil at its surface that contains up to a Stage II Bk horizon. The deposit appears to rest upon a bedrock strath developed on the Nacimiento Formation. Observed thickness of the deposit is 3–8 m

(1.8–5 ft) and is found at heights of approximately 50 m (165 ft) above the modern Animas River. Age inferred to be middle Pleistocene (ca. 240 ±20 ka, Chibanian) by Gillam (1998).

Qt4—Terrace Deposit 4 (Pleistocene)—Clast-supported pebbles through boulders (predominantly cobbles) that are subangular to rounded and poorly sorted. Contains lenses of moderately sorted subangular medium- through very coarse-grained sands. Gravels (those materials coarser than granules) make up 50–70% of the deposit. Sands have an average composition of 45% quartz, 30% feldspar, and 25% lithic fragments. Sand color is 7.5 YR 5/3–6/3 (brown to light brown) when dry. The deposit is unconsolidated to loosely consolidated. Gravels contain approximately 40% quartzite, 39% volcanic and metavolcanic rocks, 15% intrusive igneous rocks, 5% foliated metamorphic rocks, 1% limestone, and traces of locally derived sedimentary rocks. Bedforms are rarely observed but include massive beds and low-angle plane beds, and clast imbrication is common. Deposit hosts a variably developed soil at its surface that contains up to a Stage II Bk horizon. Appears to rest upon a bedrock strath developed on the Nacimiento Formation. Observed thickness of the deposit is 4–11 m (13–36 ft), though Gillam (1998) reports a gravel thickness of 45 m (147.6 ft) in this deposit near the map area, which is interpreted as the axis of the paleo-Animas River at the time of deposition. Found at heights of approximately 76–94 m (250–310 ft) above the modern Animas River. Age constrained to be slightly older than 631 ka due to the presence of well-preserved ash-fall geochemically correlated to the Lava Creek B eruption by Gillam (1998). The ash-fall deposit is near the top of the deposit, implying that most deposition of Qt4 materials occurred prior to the Lava Creek B eruption.

Qt4e—Terrace Deposit 4e (Pleistocene)—A 4–8 m (13–26 ft) thick terrace that formed late in the episode of the fluvial system—interpreted by Gillam (1998) as a strath terrace based on exposures outside of the map area—and produced all Terrace Group 4 deposits (only one other Terrace Group 4 deposit is present on the map (Gillam 1998)).

Qt4b—Terrace Deposit 4b (Pleistocene)—A 4–11 m (13–36 ft) thick cut terrace that formed after maximum aggradation of the fluvial system that produced Terrace Group 4 deposits (the oldest Terrace Group 4 deposit, Qt4a, is not present in this map area but was mapped and defined by Gillam (1998)). The surface of this deposit is typically ≈20 m (≈65 ft) higher than that of the immediately adjacent deposit Qt4e.

Qt3—Terrace Deposit 3 (Pleistocene)—Clast-supported pebbles through boulders (predominantly cobbles) that are subangular to rounded and poorly sorted. Contains lenses of moderately sorted subangular medium- through very coarse-grained sands.

Gravels (those materials coarser than granules) make up 50–70% of the deposit. Sands have an average composition of 45% quartz, 30% feldspar, and 25% lithic fragments. Sand shows color gradation from 7.5 YR 5/3–6/3 (brown to light brown) when dry. The deposit is unconsolidated to loosely consolidated. Gravels contain approximately 40% quartzite, 39% volcanic and metavolcanic rocks, 15% intrusive igneous rocks, 5% foliated metamorphic rocks, 1% limestone, and traces of locally derived sedimentary rocks. Bedforms are rarely observed, but when present, include massive beds and low-angle plane beds, and clast imbrication is common. Deposit hosts a variably developed soil at its surface that contains up to a Stage II Bk horizon. Appears to rest upon a bedrock strath developed on the Nacimiento and/or San Jose Formation. Observed thickness is 3–7 m (9.8–23 ft). Found at heights of approximately 107–113 m (350–370 ft) above the modern Animas River. Age inferred to be middle Pleistocene (ca. 700–920 ka, Chibanian to Calabrian) by Gillam (1998). This deposit is older than deposit Qt4b, whose age is constrained by the presence of the Lava Creek B ash at approximately 631 ka (Matthews et al., 2015).

Qt1—Terrace Deposit 1 (Pleistocene?)—Clast-supported pebbles through boulders (predominantly cobbles) that are subangular to rounded and poorly sorted. Contains lenses of moderately sorted subangular medium- through very coarse-grained sands. Gravels (those materials coarser than granules) make up 50–70% of the deposit. Sands have an average composition of 45% quartz, 30% feldspar, and 25% lithic fragments. Sand color is 7.5 YR 5/3–6/3 (brown to light-brown) when dry. The deposit is unconsolidated to loosely consolidated. Gravels contain approximately 40% quartzite, 39% volcanic and metavolcanic rocks, 15% intrusive igneous rocks, 5% foliated metamorphic rocks, 1% limestone, and traces of locally derived sedimentary rocks. Bedforms are rarely observed but include massive beds and low-angle plane beds, and clast imbrication is common. Deposit Qt1 hosts a variably developed soil at its surface that contains up to a Stage III Bk horizon and appears to rest upon a bedrock strath developed on the San Jose Formation. It has an observed thickness of 2–6 m (6.5–19.6 ft) and is found at heights of approximately 340 m (1,114 ft) above the modern Animas River. This deposit is only found on Knickerbocker Peak in the east-central map area. The deposit's age is inferred to be early Pleistocene by Gillam (1998).

BEDROCK UNITS
PALEOGENE UNITS

PEsjd—Ditch Canyon Member of the San Jose Formation (Eocene or Paleocene)— Interbedded terrestrial sandstones and mudstones with minor conglomerate.

Sandstones contain medium- through very coarse-grained, moderately to well-sorted, angular to subangular sand with stringers of subrounded granules and pebbles, and rare beds of granule-dominated arenites. Sandstone composition varies between 40–80% quartz, 15–65% feldspar, and trace- 8% lithic grains. Most feldspars are white or gray; approximately 5% are pinkish or reddish. Pebbles are dominated by quartzite, with far smaller proportions of arenite, milky quartz, granite, felsic volcanic rocks, chert, mudstones, and black petrified wood clasts. Sandstone outcrop colors when dry include 2.5 Y 5/4, 10 YR 5/3, and 10 YR 6/3 (light olive brown, yellowish brown, and pale brown). Sandstones form cliffs and steep slopes. Sandstone bedding includes very thin to thin cross-beds, low-angle plane beds, horizontal plane beds, graded beds, and massive beds. Contorted beds are rare. Individual sandstone packages in the Ditch Canyon Member are up to 27 m thick. Mudstones in the Ditch Canyon Member contain silty claystones, silty sandy claystones, and clayey siltstones ranging in color from 7.5 YR 4/3–10 YR 3/2–2.5 Y 4/2 and 2.5 Y 7/1 (brown to very dark grayish brown to dark grayish brown and light gray). Individual mudstone packages in the Ditch Canyon Member are up to 12 m (39 ft) thick. Sandstones are approximately 67% of the Ditch Canyon Member, with mudstone making up 33% (Smith, 1992). The upper contact is not observed in the map area. Smith (1992) interprets the Ditch Canyon Member to interfinger with the coeval Regina Member of the San Jose Formation to the east and south. The thickness reported by Smith (1992) is 220 m (722 ft) just north of the map area at the member's type section.

PEsjc—Cuba Mesa Member of the San Jose Formation (Eocene or Paleocene)— Terrestrial sandstones with minor conglomerate and mudstones. Sandstones contain medium- through very coarse-grained, well-sorted, angular to subangular sand with stringers of subrounded granules and pebbles. Sandstone composition averages 45% quartz, 55% feldspar, and trace lithic grains. Most feldspars are white or gray; approximately 5% are pinkish or reddish. Pebbles are dominated by quartzite, with far smaller proportions of arenite, milky quartz, granite, felsic volcanic rocks, chert, mudstones, and black petrified wood clasts. Sandstone outcrop colors when dry include 7.5 YR 8/4, 10 YR 8/2, 10 YR 7/6, and 10 YR 8/6 (pink, very pale brown, and yellow). The member forms cliffs and steep slopes. Bedding includes laminated to thin low-angle plane beds (by far the most common bedform), horizontal plane beds, trough cross-beds, and massive beds, and contorted beds are rare. Contains white to pink, poorly preserved, and often iron-stained petrified wood. The upper contact is placed at the base of the lowest overlying, laterally continuous, recessive siltstone or mudstone and is rarely well-expressed in outcrop. The unit appears to be paraconformable, and its thickness in the map area is 38–55 m (124.6–180.4 ft).

PEnk—Kutz Member of the Nacimiento Formation (Paleocene)—Terrestrial mudstones, sandstones, and rare conglomerates. Sandstones contain fine- to very coarse-grained sand with 1–4% pebbles. Sandstone composition averages 65% quartz, 30% feldspars, and 5% lithic grains. Sandstones are well-sorted with angular to subangular grains. Pebbles are subrounded and contain reddish and orangish chert, milky quartz, crystalline felsic rocks, and petrified wood. Sandstone colors range from 10 YR 8/2–10 YR 6/6 (very pale brown to brownish yellow) on weathered faces when dry. Sandstones mostly form steep slopes or cliffs. Sandstones contain laminated to thin (predominantly very thin) horizontal plane beds, trough cross-beds up to 160 cm (63 in) in height, cut-and-fill structures, low-angle plane beds, and rare contorted beds. Sandstones have erosional bases with up to 11 m (36 ft) of topography into underlying units. Individual sandstone packages are 1–17 m (3.3–55.7 ft) thick and discontinuous over hundreds of meters. Mudstones contain clay through fine-grained sand (predominantly silt) and range in color from 5 YR 3/3–7.5 YR 6/1 (dark reddish brown to pinkish grey), with rare 10 YR 4/1 (dark gray) on dry weathered surfaces. Mudstones typically form slopes with a crumbly popcorn-like texture at the surface when dry. Contains logs of silicified petrified wood that are typically very pale-brown to pale-brown in color. Upper contact is placed at the base of the lowest laterally-continuous sandstone that can be traced for over 1 km (0.6 mi). The unit's upper contact is uneven but conformable and exhibits about the same amount of relief as the bases of individual sandstone units within the Kutz Member; its lower contact was not observed here. The unit's thickness was reported to be up to 300 m (984 ft) by Cather et al. (2019).

PEn—Nacimiento Formation, undivided (cross section only) (Paleocene)—Terrestrial mudstones, sandstones, and rare conglomerates. Only the upper member, the Kutz Member of Cather et al. (2019), is exposed on the map. Approximately 435 m (1,427 ft) thick in the southeastern map area based on logs of the Schumacher 11M well (30-045-30066).

PEoa—Ojo Alamo Formation (cross section only) (Paleocene)—Used here in the sense of Baltz (1967) to exclude the Maastrichtian-aged Naashoibito Member, the unit is not exposed on the map. However, well logs in the map area provide a thickness of approximately 15–45 m (49–147.6 ft).

CRETACEOUS UNITS

Kkf—Kirtland and Fruitland Formations, combined (cross section only) (Late Cretaceous)—The unit is composed of terrestrial mudstones and sandstones, approximately 385–440 m (1,263–1443.5 ft) thick in well logs in the map area, and not exposed on the map.

Kpc—Pictured Cliffs Sandstone (cross section only) (Late Cretaceous)—Shoreface sandstones, approximately 23–53 m (75.4–173.8 ft) thick in well logs in the map area and not exposed on the map.

Kl—Lewis Shale (cross section only) (Late Cretaceous)—Marine shale, not exposed on the map, but identified in well logs, the portion of the unit above the Huerfanito bentonite bed is approximately 200 m (656 ft) thick in the map area.

Klhb—Huerfanito bentonite bed of the Lewis Shale (cross section only) (Late Cretaceous, 75.76 ±0.34 Ma)—An altered volcanic ash-fall deposit widely used as a stratigraphic marker in the subsurface of the San Juan basin and not exposed on the map. Unit age reported by Fassett et al. (1997).

Ku—Cretaceous units, undivided (cross section only) (Late Cretaceous)—Includes Cretaceous sedimentary units below the Huerfanito Bentonite Bed and is not exposed on the map.

REFERENCES

Baltz, E.H., 1967, Stratigraphy and regional tectonic implications of part of Upper Cretaceous and Tertiary rocks, east-central San Juan Basin, New Mexico: United States Geological Survey Professional Paper 552, 101 p., https://doi.org/10.3133/pp552

Cather, S. M., Heizler, M. T., & Williamson, T. E., 2019, Laramide fluvial evolution of the San Juan Basin, New Mexico and Colorado: —Paleocurrent and detrital-sanidine age constraints from the Paleocene Nacimiento and Animas Formations: Geosphere, v. 15, no. 5, p. 1641–1664, . https://doi.org/10.1130/GES02072.1

Fassett, J.E., Cobban, W.A., and Obradovich, J.D., 1997, Biostratigraphic and isotopic age of the Huerfanito bentonite bed of the upper Cretaceous Lewis Shale at an outcrop near Regina, New Mexico: New Mexico Geological Society Guidebook 48, p 229-232, https://doi.org/10.56577/FFC-48.229

Gillam, M. L., 1998, Late Cenozoic geology and soils of the Lower Animas River Valley, Colorado and New Mexico [Ph.D. thesis]: Boulder, University of Colorado, 477 p.

Manley, K., Scott, G.R., and Wobus, R.A., 1987, Geologic map of the Aztec 1° x 2° quadrangle, northwestern New Mexico and southern Colorado: U.S. Geological Survey, Miscellaneous Investigations Series Map I-1730, scale 1:250,000, https://doi.org/10.3133/i1730

Matthews, N.E., Vazquez, J.A., and Calvert, A.T., 2015, Age of the Lava Creek supereruption and magma chamber assembly at Yellowstone based on 40Ar/39Ar and U-Pb dating of sanidine and zircon crystals: Geochemistry, Geophysics, Geosystems, v. 16, n. 8, p. 2508-2528, https://doi.org/10.1002/2015GC005881

Smith, L.N., 1992, Stratigraphy, sediment dispersal and paleogeography of the lower Eocene San Jose Formation, San Juan Basin, New Mexico: New Mexico Geological Society Guidebook 43, p. 297-309, https://doi.org/10.56577/FFC-43.297

U.S. Environmental Protection Agency, 2013, Level III and IV ecoregions of the continental United States: Corvallis, Oregon, U.S. EPA, National Health and Environmental Effects Research Laboratory, map scale 1:3,000,000, https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states, accessed 1 April 2025.

Western Regional Climate Center, 2025: Available online at http://wrcc.dri.edu/, accessed 1 April 2025.