Geologic Map of the Cedar Hill 7.5-Minute Quadrangle, San Juan County, New Mexico; and Southern Ute Reservation and La Plata County, Colorado

By

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EXECUTIVE SUMMARY

Located along the Animas River approximately 13 km north-northeast of Aztec, New Mexico, in northeast San Juan County, the Cedar Hill 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 Cedar Hill 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 gently-dipping bedrock units throughout most of the map area. Paleogene 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, terrace alluvium, hillslope deposits, and valley-floor alluvium throughout the quadrangle.

The depositional history of the Cedar Hill 7.5-minute Quadrangle contains 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 led to coarse, poorly sorted terrace deposits in the northern and western map area. Finally, later Quaternary deposition of eolian sands produced the broad sand sheets whose remnants persist in isolated outcrops, 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.

The map area is drained by dozens of arroyos that flow into the Animas River. 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 Cedar Hill 7.5-minute Quadrangle, San Juan County, New Mexico (NMBGMR GM83). Its purpose is to discuss the geologic setting of the map area, explain the geologic history of the map area, and identify and explain significant stratigraphic and geomorphic relationships discovered during 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, 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 of 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, accuracy of contacts, and member-level designations and descriptions 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 just south of the map area at an elevation of 5,645 ft (1,721 m). Mean annual precipitation is 9.9 in (25.1 cm), with an average of 15 in (38 cm) of snowfall annually. All climate data listed above are from the Aztec Ruins National Monument station (ID# 290692) in the National Weather Service Cooperative Network and averaged over the years 1914 to 2005. (Western Regional Climate Center, 2025).

GEOGRAPHIC AND TECTONIC SETTING

The Cedar Hill 7.5-Minute Quadrangle covers approximately 60 mi^2 (155 km^2) in San Juan County, New Mexico. The largest community on the quadrangle is Cedar Hill. 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 6,902 ft (2,104 m) at an unnamed peak near the northern map boundary, just west of Cox Canyon, to 5,690 ft (1,734 m) at the Animas River, where it crosses the southern map boundary. Named drainages in the quadrangle include the Animas River, Cox Canyon, Ditch Canyon, Miller Canyon, Arch Rock Canyon, Kiffen Canyon, Deer Canyon, Flume Canyon, Tucker Canyon, and Bohanan 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 little faulting and folding compared to surrounding provinces. The Colorado Plateau's characteristic lack of abundant major tectonic deformation features is manifest in the Cedar Hill 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 input of geological data directly into a Geographic Information System 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 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 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 1:24,000-scale final layout.

The geologic cross-section was created after completion of the geologic map. 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 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.

CROSS SECTION CONSTRUCTION

The two cross sections included in this map were constructed by selecting a line with good coverage of oil and gas wells along the line's length and then creating a topographic profile along that line in ArcGIS. Geological contacts and well locations along the topographic profile were denoted in ArcGIS. Only vertical wells were used in cross-section construction; therefore, wells were projected straight downward from the topographic profile. Formation tops (also known as "picks") were collected from drillers' logs from the New Mexico Oil Conservation Division databases or, in some cases, from electronic logs from each well. Most wells were completed in the Cretaceous Pictured Cliffs Sandstone. Four wells at the western end of Cross Section A-A′ penetrated the Huerfanito Bentonite Bed of the Lewis Shale. To increase visibility of small-scale structures and topography, both cross sections are illustrated at 10x vertical exaggeration. Most surficial units were not illustrated in cross sections due to their thinness; only select Animas River terraces along cross section lines are thick enough to appear.

GEOCHRONOLOGY

To constrain the deposition-age of sedimentary units in the map area, five samples of sedimentary units in the quadrangle were analyzed for detrital-sanidine Ar^{40}/Ar^{39} geochronology at the New Mexico Geochronology Research Laboratory (NMGRL) at the New Mexico Bureau of Geology and Mineral Resources. The methodology for these analyses can be obtained from the NMGRL. Of the five samples analyzed, four were Paleogene bedrock units and one was a Quaternary alluvial terrace deposit. Unfortunately, none of the five samples yielded a maximum depositional age consistent with the assumed ages of deposition; for instance, the terrace unit's maximum depositional age is ca. 9 Ma, much older than the assumed Pleistocene age of the unit. All four Paleogene units produced maximum depositional ages from the

Cretaceous, again making them unreliable. Ultimately, detrital-sanidine geochronology efforts for this map project did not improve understanding of the area's geochronology. Results and data tables from the analyses are included in Appendix B of this report.

In addition to the above-mentioned detrital-sanidine geochronology attempts, there exists one referenced geochronology point within the map area. An outcrop of felsic volcanic ash is located in the southeastern map area within sediments of the Terrace Deposit 4b (map unit Qt4b). This ash was geochemically identified as Lava Creek B by Gillam (1998) with an inferred age of 631 ka (Matthews et al., 2015).

APPENDIX A
DESCRIPTIONS OF MAP UNITS

QUATERNARY UNITS
ANTHROPOGENIC UNITS

af—Artificial fill (recent)—Clay, silt, sand, and pebbles used for the construction of highway grades along U.S. Route 550.

GEOMORPHIC SURFACE DEPOSITS

Qp—Pediment deposits (Pleistocene to Holocene?)—Sand and lag gravels that discontinuously cover a graded bedrock surface above the Qt5 terrace tread approximately 1 km (0.6 mi) north of the mouth of Kiffen Canyon on the west side of the Animas River valley. The surface grades to the upper edge of the terrace tread and likely represents the surface on which a prior fan deposit rested. That presumed past fan deposit has been removed due to headward erosion of a tributary to Kiffen Canyon, just west of the pediment, which effectively decapitated the fan from its sediment source farther west. The unit is thin and discontinuous. The lack of public access in this area prevented deeper investigation.

Qlg—Lag gravels (Holocene)—Unconsolidated pebbles- through boulders (primarily cobbles and boulders) derived from terrace deposit Qt2 in the northeast map area. These sediments have been moved downslope from their original positions and form contiguous areas of loose clasts up to 1 m (3.28 ft) thick.

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. Armored mud balls are present but rare. Contains anthropogenic detritus at the surface and in cross-section outcrop at a depth of up to 2 m (6.6 ft), including common household refuse, pieces of 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 cm (4 in) depth. No active avulsion or deposition observed in aerial photographs, and the deposit thickness is likely <10 m (32.8 ft). 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 0.1 to 4 m (0.33–13.12 ft).

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).

FAN DEPOSITS

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.

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 near 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 and is likely inundated by Animas River waters during major floods. 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 clay, silt, minor eolian silt, and sand at the surface. After alluvial deposition, the deposit was partly covered with minor eolian silt and sand at the surface. Deposit clearly expressed bar-and-swale topography, supports riparian vegetation, and were likely reworked during modern floods on the Animas River. The deposit thickness is unknown but is likely less than 5 m (16.4 ft).

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 is 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).

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. Massive beds were the only observed bedform. Clast imbrication not observed. 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 Cuba Mesa Member of the San Jose Formation. Observed thickness is 3–7 m (9.8–23 ft). Found at heights of approximately 107–135 m (350–450 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).

Qt2—Terrace Deposit 2 (Pleistocene?)—Pebbles through boulders (predominantly cobbles) that are subangular to rounded and poorly sorted. Relative proportions of gravel to finer grain sizes were not observed in outcrop and are not reported here. Unit is unconsolidated to loosely consolidated. Gravels in this unit contain approximately 50% quartzite, 25% volcanic and metavolcanic rocks, 15% intrusive igneous rocks, 10% foliated metamorphic rocks, and traces of limestone and locally derived sandstones presumed to be from the San Jose Formation. Bedforms or clast imbrication were not observed. Soils developed atop this unit vary in development stage; the most-developed soils host Stage III Bk horizon. Appears to rest upon a bedrock strath developed on the Ditch Canyon Member of the San Jose Formation. Observed thickness is 2–6 m (6.6–20 ft); Gillam (1998) reports a thickness of up to 8 m (26 ft) nearby. Found at heights of approximately 270–300 m (880–980 ft) above the modern Animas River. In the map area, this unit is found only on the mesa west of the Animas River at the New Mexico-Colorado state line in the northeasternmost corner of the quadrangle. Age inferred to be Pliocene or Early Pleistocene by Gillam (1998).

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 rare but present where elongated clasts exist. Soils developed atop this unit vary in development stage; the most-developed soils host Stage III Bk horizon. Appears to rest upon a bedrock strath developed on the Ditch Canyon Member of 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 370 m (1,220 ft) above the modern Animas River. In the Cedar Hill 7.5′ Quadrangle, this unit is only found on Lone Tree Mountain and an unnamed peak (Peak 7079) 900 m (2952.8 ft) south-southwest of Lone Tree Mountain in the northwestern area of the map. Age inferred to be Pliocene by Gillam (1998).

PALEOGENE UNITS

BEDROCK 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 purplish to reddish-gray 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 east of the map area at the member's type section. The maximum observed thickness is 189 m (620 ft) in the map area.

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 purplish to reddish-gray 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 that sometimes hosts secondary quartz with well-developed prismatic crystals along fracture faces. 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 12–50 m (39.4–164 ft).

PEnk—Kutz Member of the Nacimiento Formation (Paleocene)—Terrestrial mudstones, sandstones, and rare conglomerates. Sandstones contain fine- to very coarse-grained sand with trace- to 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 sometimes have erosional bases that exhibit up to 11 m (36 ft) of erosion into underlying beds. 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. The unit contains logs of silicified petrified wood that typically range in color from very pale brown to pale brown. 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 by Cather et al. (2019) to be up to 300 m (984 ft); however, the maximum observed thickness in the map area is 160 m (525 ft).

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 424 m (1,391 ft) thick in the map area based on logs of the Aztec #201A well (30-045-32179) in the southeastern map area.

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 13–46 m (43–151 ft).

CRETACEOUS UNITS

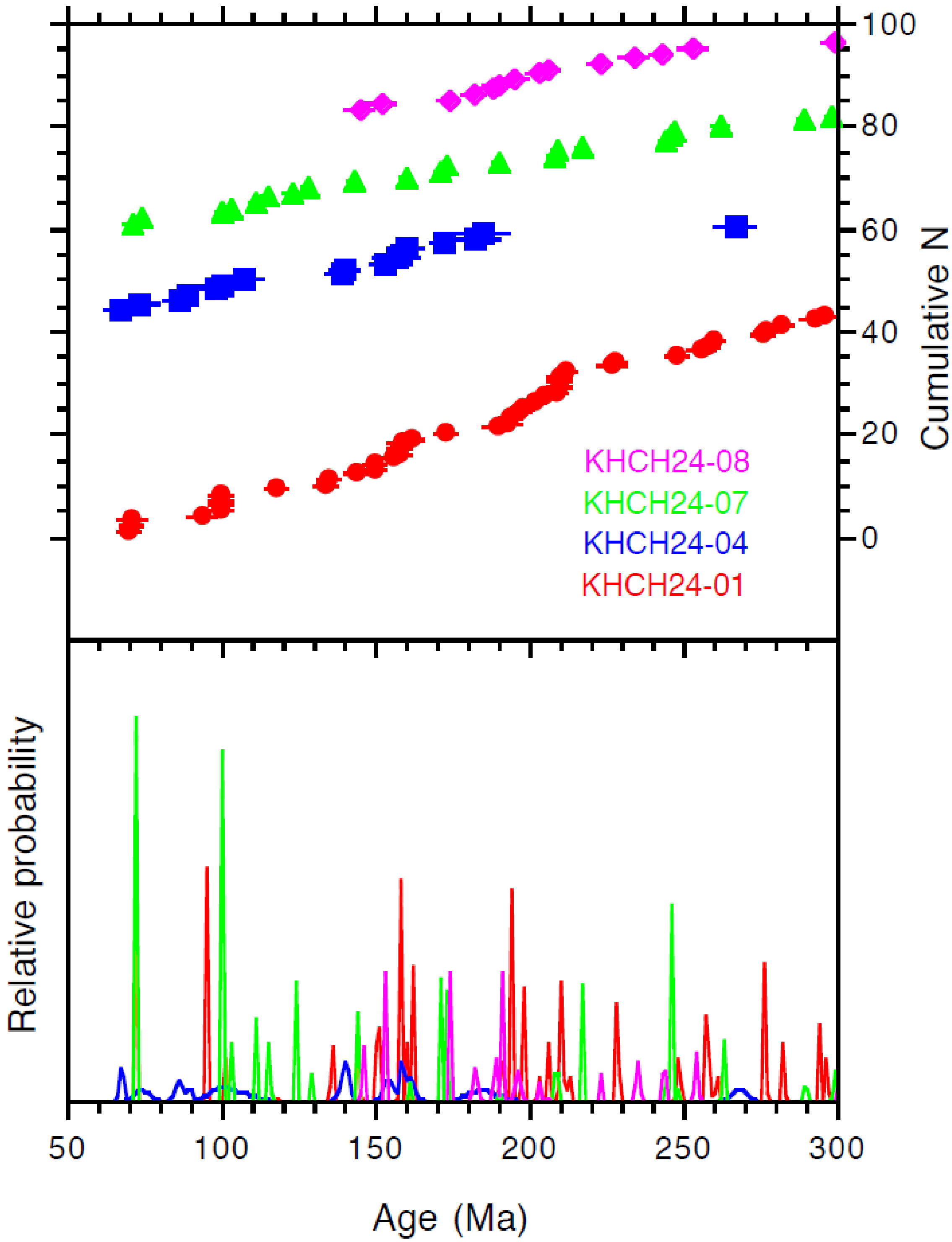
Kk—Kirtland Formation (cross section only) (Late Cretaceous)—Terrestrial mudstones and sandstones. The unit is not exposed on the map and is approximately 190–450 m (623.4–1,476.4 ft) thick according to well logs in the map area.

Kf—Fruitland Formation (cross section only) (Late Cretaceous)—Terrestrial mudstones and sandstones. Not exposed on the Cedar Hill 7.5′ Quadrangle. Approximately 120 to 240 m (394–787.4 ft) thick according to well logs in the map area.

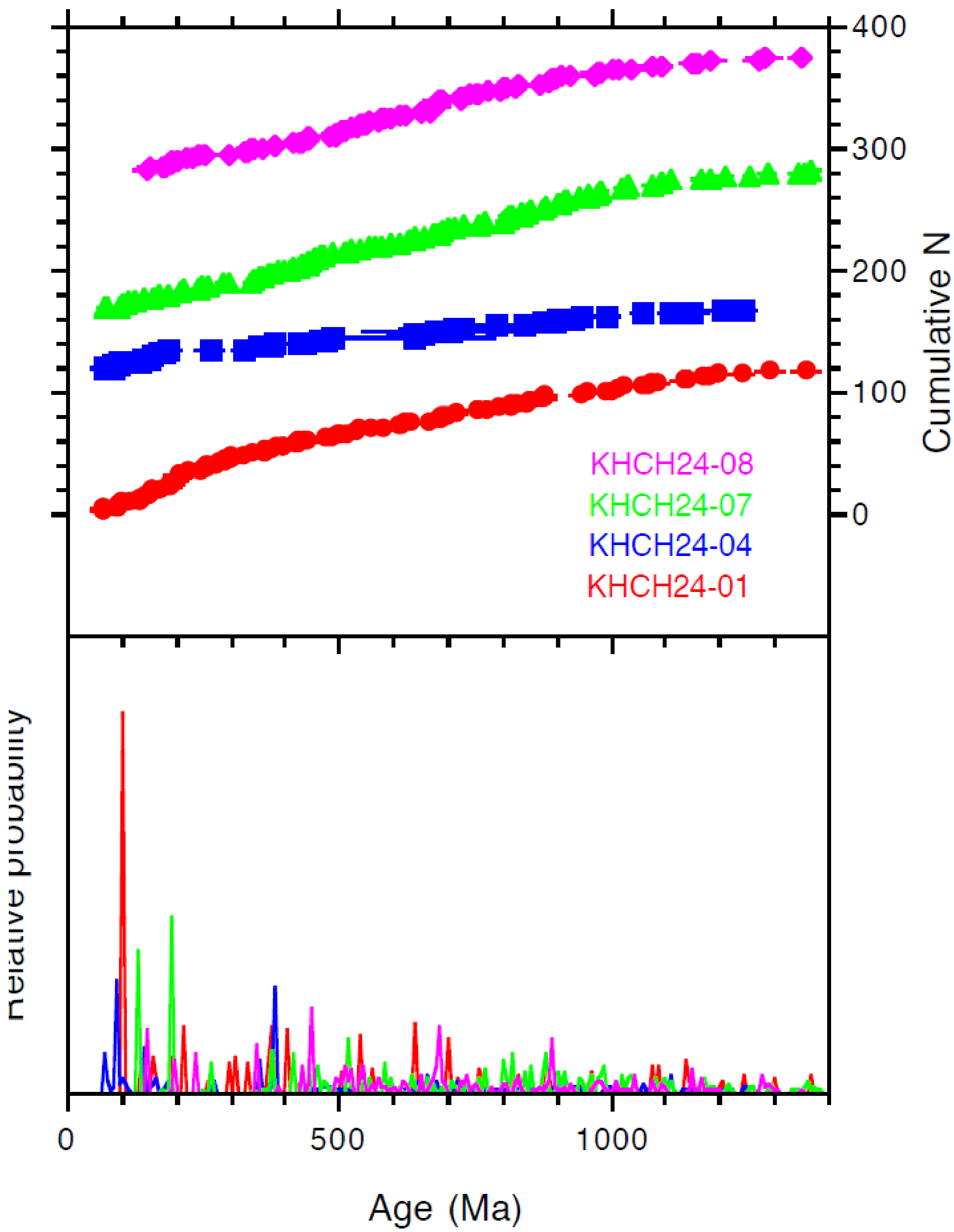
Ku—Cretaceous units, undivided (cross section only) (Late Cretaceous)—Sandstones, siltstones, and mudstones. Capped with the Pictured Cliffs Sandstone, in which most wells in the map area are set. The units are not exposed on the map, and their total thickness is variable; the bottom contact is not illustrated on the cross sections.

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).

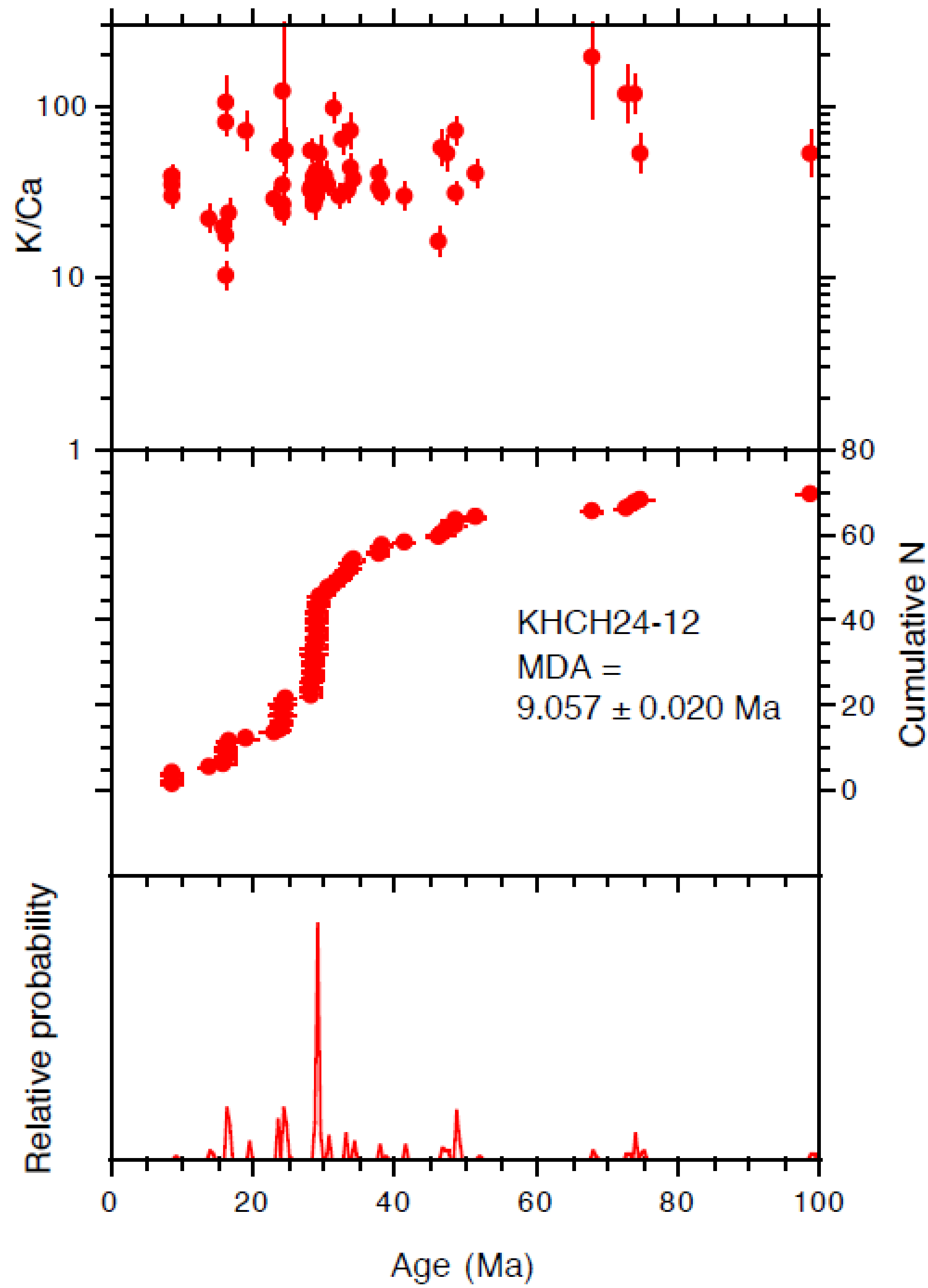
APPENDIX B
GEOCHRONOLOGY DATA



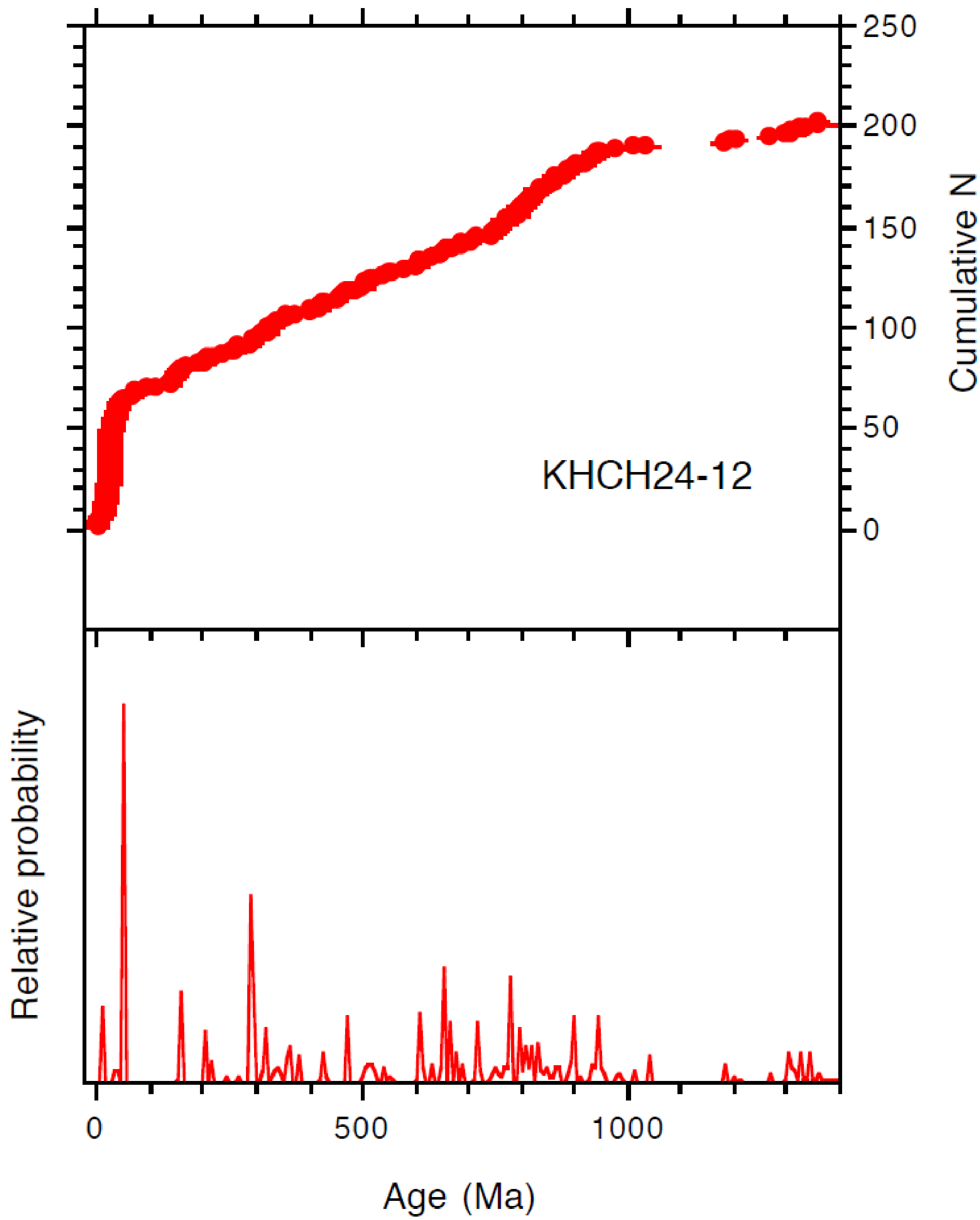
Age probability and cumulative N diagrams for detrital grains less than 300 Ma. No samples yield dates younger than late Cretaceous.



Age probability and cumulative N diagrams for all dated detrital grains. Grains with dates greater than 300 Ma are likely microcline where as less than 300 Ma are likely sanidine.



Age probability, cumulative N and K/Ca diagrams for dated detrital grains less than 100 Ma. Three youngest dates define the maximum depostional age (MDA).



Age probability and cumulative N diagrams for all dated detrital grains. Grains with dates greater than 300 Ma are likely microcline where as less than 300 Ma are likely sanidine.

Summary of $^{40}Ar/^{39}Ar$ results

						Mean Age						
Sample	L#	Irrad	min	analysis	n	MSWD	K/Ca	±	1σ	Age(Ma)	±	1σ
KHCH24-01	72067	NM-345D	DetritalSanidine	MDA	1		144.7			70.547	±	0.038
KHCH24-04	72070	NM-345D	DetritalSanidine	MDA	1					67.38	±	0.67
KHCH24-07	72118	NM-345G	DetritalSanidine	MDA	1		1247			71.96	±	0.04
KHCH24-08	72069	NM-345D	DetritalSanidine	MDA	1		693			145.79	±	0.39
KHCH24-12	72071	NM-345D	DetritalSanidine	MDA	3	5.9	35.2	±	5.4	9.057	±	0.020

Notes

MDA - Maximum depositional age based on either n = 1 dates or the inverse variance weighted mean of selected dates.

K/Ca - For n>1 K/Ca is mean ± standard deviation of crystals defining the MDA. For n = 1, K/Ca is measured value.

L# - Lab identifier

Irrad - Irradiaiton identifier

n - number of dates defining MDA

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.