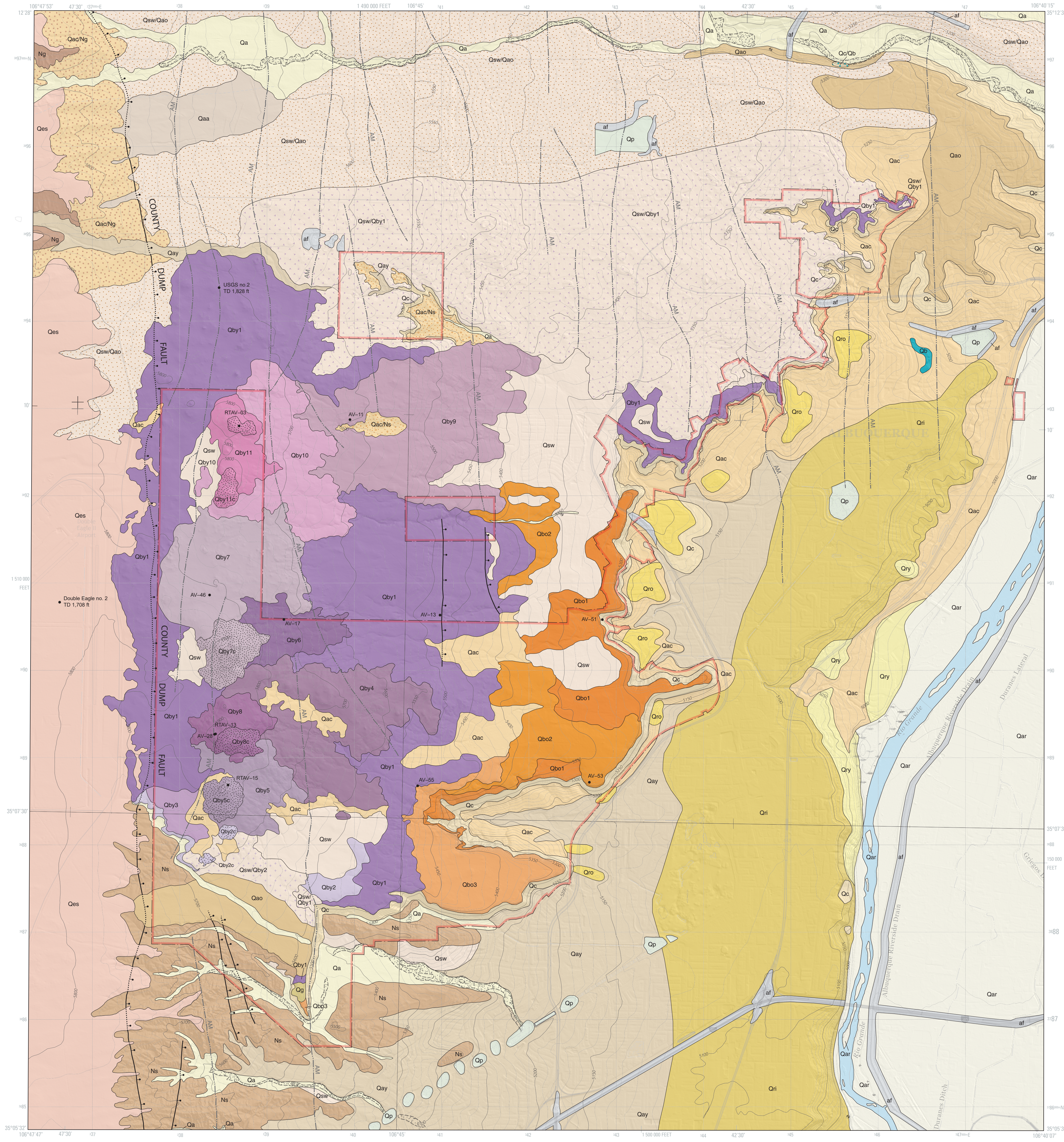
U.S. Department of the Interior
U.S. Geological Survey

Prepared in cooperation with the
National Park Service

Scientific Investigations Map 3447



Topographic base from U.S. Geological Survey 1:24,000-scale The Volcanoes, 2017; Los Griegos, 2017, Albuquerque West, 2017; and Albuquerque East, 2017

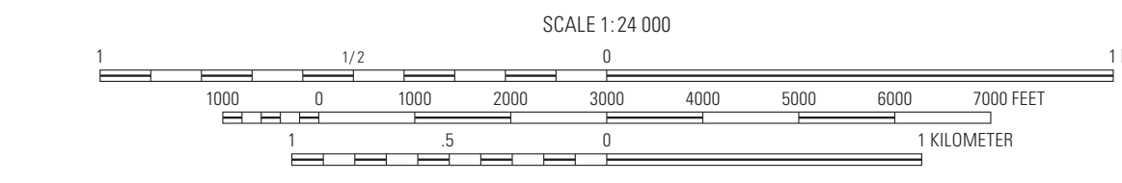
Shaded relief base from U.S. Geological Survey National Elevation Dataset (NED), accessed on March 15, 2016, at https://lta.cr.usgs.gov/NED

North American Datum of 1983 (NAD 83)

World Geodetic System of 1984 (WGS 84), Universal Transverse Mercator, zone 13

Boundary of Petroglyph National Monument from the U.S. National Park Service, April 26, 2017

This map is not a legal document. Boundaries may be generalized at this map scale. Private lands within government reservations may not be shown. Obtain permission before entering private lands.



Many of the geologic units and geologic features shown on the map and much of the text in the map-unit descriptions were modified from published geologic maps (Connell and others, 1998; Shroba and others, 2003; Connell, 2006; Thompson and others, 2009). New mapping, particularly along the eastern Monument boundary by R.A. Thompson in 2017–2018, was compiled and integrated into this compilation.

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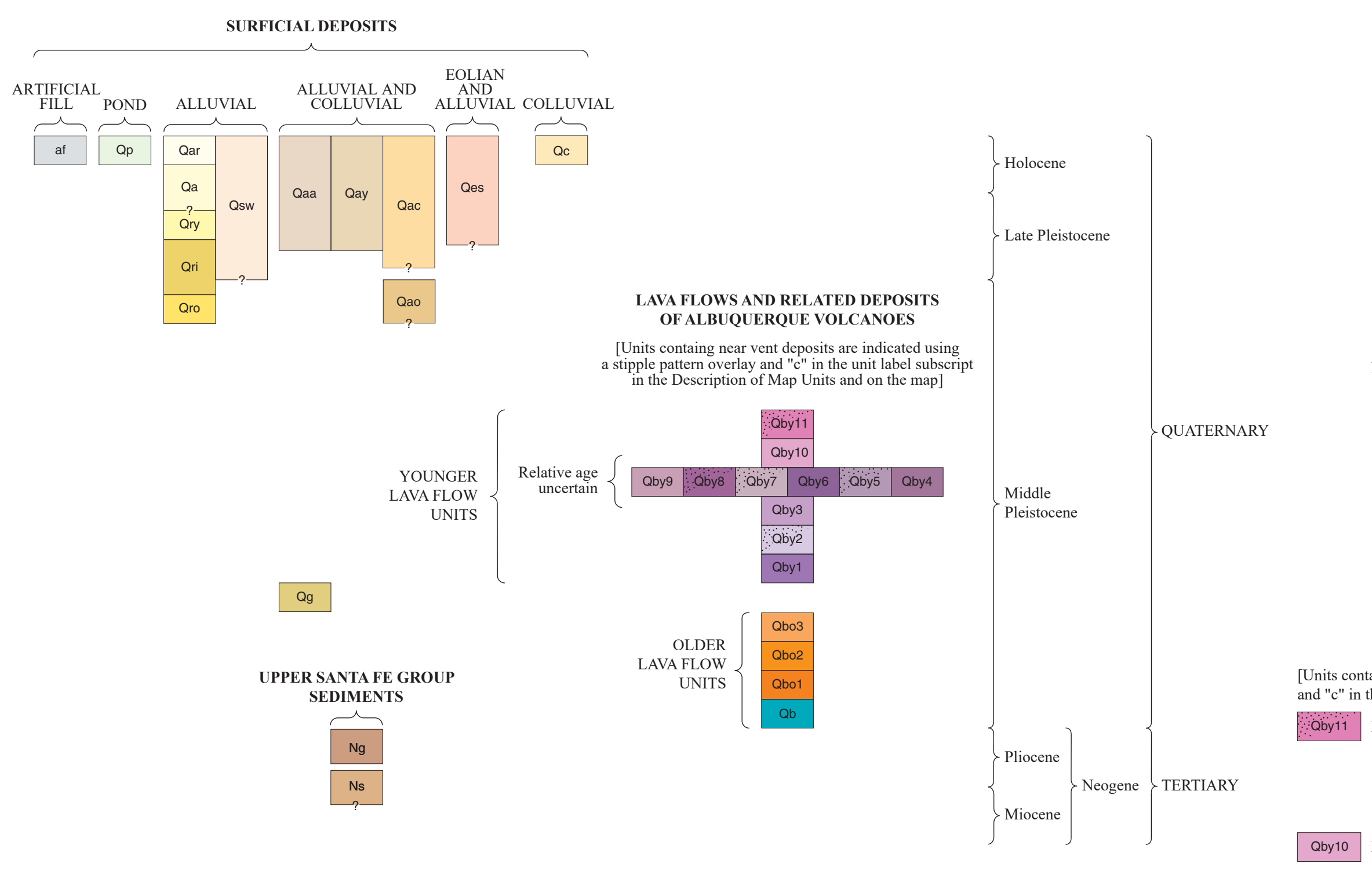
CORRELATION OF MAP UNITS



[Units containing near vent deposits are indicated using a stipple pattern overlay and "c" in the unit label subscript in the Description of Map Units and on the map]

DESCRIPTION OF MAP UNITS

[Due to the addition of a shaded-relief base, colors in the Description of Map Units and the Correlation of Map Units many not exactly match unit colors on the map when that layer is active]

SURFICIAL DEPOSITS

ARTIFICIAL FILL DEPOSITS

af **Artificial fill deposits (latest Holocene)**—Compacted fill material composed mainly of silt, sand, and rock fragments. Mapped chiefly beneath and near segments of Interstate 40 and in levees on the east side of the Rio Grande but also present locally in the north part of the map area. Unit af locally includes small areas of disturbed ground where the land was modified by earth-moving equipment so that the original geologic material could not be recognized, but little or no fill was emplaced. The eastern and northeast parts of the map area along and near the Rio Grande locally include extensive areas overlain by thin and discontinuous area of artificial fill that are not shown on the geologic map. Estimated thickness is 1 meter (m) to 10 m

POND DEPOSITS

Qp **Pond deposits (latest Holocene)**—Mostly lenses of sand and pebble gravel that accumulated in man-made basins along and near drainage ways that were designed to detain flood runoff and retain associated flood-borne sediments. Thickness unknown; probably greater than 1 m thick

ALLUVIAL DEPOSITS

Qar **Valley-floor alluvium of the Rio Grande (Holocene)**—Active and inactive channel and flood plain deposits composed chiefly of pebbly sand, sand, and lenses of silt and clayey silt. Luminescence dating of fine sand collected in a construction site, about 1 kilometer (km) east of the map area, suggests that deposition of the upper part of unit Qar occurred about 3 or 4 thousand years ago (ka) (Cole and others, 2007b), during the late Holocene. Thickness is locally greater than 15 m (Connell, 2006)

Qsw **Sheetwash deposits (Holocene and late? Pleistocene)**—Chiefly slightly pebbly to pebbly sand, sand, and silty sand. Small, unmapped deposits locally overlie young alluvial-slope deposits (Qay). Unit Qsw locally includes small unmapped deposits of valley-floor alluvium of intermittent streams (Qa). Estimated thickness is 1–5 m

Qsw/Qao **Sheetwash deposits over old alluvial-slope deposits**—Ongoing slope processes have reworked old alluvial-slope deposits (Qao) into thin sheetwash deposits (Qsw)

Qsw/Qby1 **Sheetwash deposits over younger lava flow unit 1**—Ongoing slope processes have reworked younger volcanic deposit lava flow unit 1 (Qby1) into thin sheetwash deposits (Qsw)

Qsw/Qby2 **Sheetwash deposits over younger lava flow unit 2**—Ongoing slope processes have reworked younger volcanic deposit lava flow unit 2 deposits (Qby2) into thin sheetwash deposits (Qsw)

Qa **Valley-floor alluvium of intermittent streams (Holocene and late? Pleistocene)**—Chiefly poorly sorted sand and sandy pebble gravel in stream channels and beneath treads of discontinuous terraces as much as about 5 m above channels of intermittent streams mainly in the western part of the map area. Unit locally contains thin lenses of cobbly pebble gravel and locally includes minor sheetwash deposits (Qsw).

Luminescence dating near the mouth of Arroyo de las Calabacillas in the northeastern part of the map area suggests that deposition of the upper part of unit Qa in this arroyo occurred about 4.5 ka (Cole and others, 2007b), during the late part of the middle Holocene. Estimated thickness is 1–10 m

Qry **Young terrace alluvium of the Rio Grande (late Pleistocene)**—Chiefly slightly pebbly to pebbly sand, and clast-supported pebble gravel and lenses of cobbly pebble gravel on the west side of the Rio Grande. Unit is locally overlain by thin, discontinuous deposits of eolian sand too small to show at map scale. Unit Qry underlies the Primero Alto surface of Bryan and McCann (1938), which is about 15–20 m above the Rio Grande. Luminescence dating suggests that deposition of the upper part of unit Qry occurred about 47–40 ka (Cole and others, 2007b). Thickness is about 3–6 m (Connell, 2006)

Qri **Intermediate-age terrace alluvium of the Rio Grande (late or middle Pleistocene)**—Chiefly sand, silty sand, and clayey silt as well as thin minor lenses of pebbly sand and pebble gravel on the west side of the Rio Grande. At the Adobe Cliffs section of Lambert (1968) unit Qri consist of beds and lenses of very fine to coarse sand 20–420 centimeters (cm) thick; silty, very fine sand 10–290 cm thick; clayey silt 2–105 cm thick; and minor lenses of pebble gravel as much as about 20 cm thick. Unit Qri underlies the Segundo Alto surface of Bryan and McCann (1938), which is about 44 m above the Rio Grande. Unit Qri is locally overlain by thin, discontinuous deposits of eolian sand too small to show at map scale. Luminescence dating suggests that deposition of the upper part of unit Qri may have occurred as early as 160 ka or as late as 60 ka (Cole and others, 2007b). The older luminescence ages suggest that unit Qri was deposited during the latter part of the Bull Lake glaciation (about 120–190 ka; Sharp and others, 2003; Pierce, 2004; Licciardi and Pierce, 2008; Schweinsberg and others, 2016) during the late or middle Pleistocene. Thickness is about 50 m (Connell, 2006)

Qro **Old terrace alluvium of the Rio Grande (middle Pleistocene)**—Chiefly pebble gravel and cobbly pebble gravel that forms discontinuous terrace deposits on the west side of the Rio Grande. Unit Qro underlies the eroded Tercero Alto terrace surface of Machette (1985), which is about 65 m above the Rio Grande. The upper part of unit Qri locally contains the Lava Creek B tephra (Smith and Kuhle, 1998; Connell and Love, 2001), which is 631.3±4.3 ka (Matthews and others, 2015). Unit Qro is locally overlain by thin, discontinuous sheetwash deposits (Qsw) too small to show at map scale. Thickness is commonly about 3–5 m (Connell, 2006)

ALLUVIAL AND COLLUVIAL DEPOSITS

Qaa **Valley-floor alluvium of intermittent streams and young alluvial-slope deposits, undivided (Holocene and late Pleistocene)**—Alluvium in channels of intermittent streams and beneath low terraces (Qa, described above), and young alluvial-slope deposits (Qay, described below) are mapped as an undivided unit in the northwestern part of the map area. Estimated thickness is 1–15 m

Qay **Young alluvial-slope deposits (Holocene and late Pleistocene)**—Chiefly pebbly sand, pebble gravel, and locally, thin lenses of cobbly pebble gravel on gently sloping surfaces. These sediments are derived in part from the gravel unit of upper Santa Fe Group sediments (Ng). Unit Qay consists chiefly of stream alluvium and minor fan deposits that locally are overlain by thin unmapped sheetwash deposits (Qsw). Unit Qay locally mantles valley sides and hill slopes. It is topographically lower and younger than unit Qao, and grades into and locally includes unmapped deposits of valley-floor alluvium of intermittent streams (Qa). Estimated thickness is 1–15 m

Qac **Alluvium and colluvium, undivided (Holocene and late Pleistocene)**—Unit Qac commonly ranges from pebbly, very fine to medium sand to poorly sorted, clast- and matrix-supported, slightly cobbly, pebble gravel that has a sand matrix. Undifferentiated sheetwash deposits, stream-channel deposits of intermittent streams, minor fan deposits, and colluvial deposits that locally overlie upper Santa Fe Group sediments (Ng and Ns). Estimated thickness is 1–5 m

Qac/Ng **Alluvium and colluvium, undivided, over gravel unit of upper Santa Fe Group sediments**—Ongoing slope processes have reworked gravel unit of upper Santa Fe Group sediments (Ng) into thin undivided alluvium and colluvium deposits (Qac)

Qac/Ns **Alluvium and colluvium, undivided, over upper Santa Fe Group sediments, undivided**—Ongoing slope processes have reworked undivided upper Santa Fe Group sediments (Ns) into thin undivided alluvium and colluvium deposits (Qac)

Qao **Old alluvial-slope deposits (middle? Pleistocene)**—Gently sloping deposits composed chiefly of pebbly sand, pebble gravel, and, locally, thin lenses of cobbly pebble gravel near the northern part of the map area. Unit Qao is derived in part from upper Santa Fe Group sediments (Ng and Ns). Unit Qao consists chiefly of stream alluvium and minor fan deposits that are commonly mantled by sheetwash deposits (Qsw). Commonly mapped as fractional unit Qsw/Qao. Unit Qao commonly forms a broad alluvial surface and is topographically higher and older than unit Qay. Estimated thickness is 1–15 m

Qg **Gravelly alluvium (middle Pleistocene)**—Poorly sorted, pebbly silty sand to moderately well sorted, clast-supported, slightly cobbly, pebble gravel that overlies and underlies basaltic lava flows (Qbo3 and Qby1, respectively) at the southern limit of the volcanic field. A thin (about 30 cm), sandy, pumice-bearing layer is present near the middle of the unit. The pumice fragments in this layer probably were reworked from older deposits. Much of the sand and gravel is likely reworked from the upper Santa Fe Group sediments (units Ng and Ns). Thickness is approximately 3 m

EOLIAN AND ALLUVIAL DEPOSITS

Qes **Inactive eolian sand and sheetwash deposits, undivided (Holocene and late Pleistocene)**—Quartz-rich, non-calcareous to calcareous, mostly very fine to medium sand that supports a sparse cover of grasses, shrubs, and annual plants. Scattered pebbles, cobbles, and carbonate-cemented soil fragments in unit Qes probably were derived from the underlying calcic soils and sediments and probably were moved upward by burrowing animals. Some or much of the sand probably was deflated from upper Santa Fe Group sediments that are exposed along the western escarpment of the Llano de Albuquerque west of the map area and was deposited by southwesterly or westerly winds (Shroba and others, 2003). Unit Qes locally includes small, unmapped deposits of valley-floor alluvium of intermittent streams (Qa) and locally may include small, unmapped deposits of active eolian sand. Estimated thickness is 1–10 m

COLLUVIAL DEPOSITS

Qc **Colluvial deposits, undivided (Holocene to middle? Pleistocene)**—Nonsorted and non-stratified, mostly matrix-supported, sandy sediment and basaltic rock debris locally characterized by hummocky topography. Deposits range from pebbly silty sand to bouldery rubble that has a sandy matrix. Unit Qc overlies upper Santa Fe Group sediments (Ns) downslope of basaltic lava flows near the base of the escarpment in the northeastern, central, and southwestern parts of the map area. Unit Qc includes debris-slide, soil-creep, and block-stream deposits, and probably also debris-flow deposits, as defined by Cruden and Varnes (1996). These deposits may be susceptible to continued movement or reactivation due to natural processes and human-induced processes. Some of the sand in unit Qc probably was deposited by overland flow, sheetwash, and other surface runoff processes. Maximum thickness possibly 40 m

Qc/Qb **Colluvial deposits, undivided, over lava flow, undifferentiated**—Ongoing slope processes have reworked an undifferentiated lava flow (Qb) into thin, undivided colluvium deposits (Qc)

LAVA FLOWS AND RELATED DEPOSITS OF THE ALBUQUERQUE VOLCANOES

The Albuquerque Volcanoes is a 10-km-long chain of basalt cones and associated lava flows that erupted from multiple fissure vents, resulting from magma intrusion along conduits following the prominent north-south trending faults in the Albuquerque Basin (fig. 1). The volcanic field forms the Llano de Albuquerque in most of the map area. Kelley and Kudo (1978) identified five prominent cinder cones and a number of vent-related features. However, satellite vents formed along the entire length of the inferred fissure. Lava flows erupted from vents and flowed predominantly eastward for distances as great as 5 km. These flows formed a prominent basalt plateau that covers 60 square kilometers (km^2) of the Llano de Albuquerque geomorphic surface. Basalt flows are exposed prominently along the escarpment on the eastern eroded margin of the Llano de Albuquerque, where their base is about 70–100 m above the modern Rio Grande flood plain.

Volcanic map units are delineated on the basis of lithology, morphology, and stratigraphic position. Units composed primarily of lava flows typically represent individual eruptive events; they are characterized by one or more flows that consist of multiple flow lobes. Locally, the volcanic map units include interbedded pyroclastic deposits. Temporally equivalent near-vent pyroclastic deposits associated with lava flow eruptions are denoted by a black stipple pattern overlay. Detailed descriptions of facies textures of pyroclastic deposits and lava flows are given in Kelley and Kudo (1978), Smith and others (1999), and Crumpler (1999).

A middle Pleistocene age assignment for the volcanic rocks is based on three independent dating techniques. Analytical uncertainty for analyses reported by each technique exceed the total range of reported ages and none of the ages reflect relative stratigraphic position based on mapping within the map area. The preserved morphology of lava flows and the absence of significant erosional unconformities between eruptive units suggest all mapped volcanic units were emplaced within a relatively short time interval. Geissman and others (1990) also reported directions of remanent magnetization of near-vent deposits and proximal lava flows that are statistically indistinguishable from those determined for distal flows at the base of the volcanic section. The consistent but atypical directions reported suggest a short duration of magmatic activity during one of the Brunhes Chron polarity excursions.

A whole-rock potassium/argon (K/Ar) determination of 0.19±0.04 million years (Ma) was reported by Bachman and Mehnert (1978) from Albuquerque Volcanoes; however, an erroneous reported sample location precludes identification of the original sample location or map unit dated. Geissman and others (1990) reported a weighted mean whole-rock K/Ar age of 0.155±0.047 Ma, based on determinations for three samples with reported ages ranging from <0 to 0.17±0.05 Ma but report no sample locations. Singer and others (2008) report an average whole-rock $^{40}Ar/^{39}Ar$ isochron age of 0.218±0.014 Ma based on multiple samples from each of six lava flows and correlate associated paleomagnetic data with the Pringle Falls geomagnetic excursion. No sample locations are reported for this study. A uranium/thorium ($^{238}U/^{230}Th$) isochron determination for three whole- rock samples from units Qby2, Qby9, and Qby11 yielded a mean age of 0.156±0.029 Ma (Peate and others, 1996).

Lava flows and associated near-vent pyroclastic deposits were delineated in the map area. At the southern edge of the volcanic field, intercalated gravel of inferred middle Pleistocene age, lacking obvious soils, separates older cliff-forming basalt flows from younger flows (Shroba and others, 2003). Younger flows (units Qby1–11) above the middle Pleistocene gravels are designated as young (for example, Qby1, young lava flow unit 1). Where mapped eruptive units (Qby1–Qby11) are non-contiguous or stratigraphic position is obscured by poor exposure, even relative age between some units is uncertain. Consequently, the numbering scheme used to designate deposits of any given eruptive event does not necessarily imply relative age. Lava flows underlying the unconformity marked by the local gravel deposit are mapped as four lava flow units of the older lava flow sequence (Qb, Qbo1, Qbo2, and Qbo3).

Lava flows and related deposits (Pleistocene)—Medium- to dark-gray tholeiitic lava flows (47–52 weight [wt] percent silicon dioxide [SiO_2], and up to 3.75 wt percent sodium oxide+ potassium oxide [Na_2O+K_2O], <1.5 wt percent titanium dioxide [TiO_2]) and near-vent pyroclastic deposits associated with Hawaiian-type fissure eruptions (fig. 3; table 2). Deposits proximal to vents include cinder deposits, spatter deposits, spatter agglutinate, breccia and clastogenic lava flows, and locally, thin pahoehoe lava flows that typically are radially distributed around small cones and cone remnants. The lava flows vary in thickness from <1 m to several meters. Both near-vent deposits and lava flows contain ubiquitous phenocrysts (<1–2 millimeters [mm]) of olivine and plagioclase in a fine-grained intergranular matrix of plagioclase, iron-titanium (Fe-Ti) oxides, augite, and interstitial glass (fig. 4)

YOUNGER LAVA FLOW UNITS
(MIDDLE PLEISTOCENE)

[Units containing near vent deposits are indicated using a black stipple pattern overlay and "c" in the unit label here and on the map]

Qby11 **Lava flow unit 11**—Near-vent pyroclastic deposits and intercalated lava flows of Bond Volcano (fig. 2). Lava flows are predominantly shelly pahoehoe with locally developed aa flow texture. Lava tubes are common as are push-up structures and rafted pyroclastic deposits. Near-vent deposits (Qby11c) are heterogeneous and include cinder, spatter, agglutinate, and clastogenic lava flows. Thickness is 40 m

Qby10 **Lava flow unit 10**—Medium- to dark-gray discontinuous shelly pahoehoe to aa lava flows (<1- to 2-m-thick) erupted from vents at or near the current location of Bond Volcano based on lava flow distribution. Forms broad plateau east of Bond and Butte Volcanoes (fig. 2). Lava tubes and ramp structures are common. Thickness is 1–2 m

Qby9 **Lava flow unit 9**—Discontinuous, rubbly, dark-gray, thin (1–2 m), vesicular lava flows in the south-central part of the map area. Lava flows are early eruptive products from vents near Bond and Butte Volcanoes (fig. 2). Thickness is 2–3 m

Qby8 **Lava flow unit 8**—Medium- to dark-gray proximal lava flows and near-vent (Qby8c) pyroclastic deposits of Black Volcano (fig. 2). Lower flows are dark-gray, hummocky, and scoriaceous. Two overlying cones consist of cinders, scoria, spatter, agglutinate and intercalated lava flows (Kelley and Kudo, 1978). The northernmost flanks of Black Volcano consist predominantly of cinders and have been removed by mining. Thickness is 2–3 m

Qby7 **Lava flow unit 7**—Proximal lava flows and associated near-vent pyroclastic deposits of Vulcan Volcano (fig. 2). Medium- to dark-gray lava flows compose a broad highland north of prominent central cone. Lava flows are predominantly shelly pahoehoe with locally developed aa flow textures. Lava tubes are common as are push-up structures and rafted pyroclastic deposits. Near-vent deposits (Qby7c) are heterogeneous and locally include cinder, spatter, agglutinate, clastogenic lava flows and minor columnar jointed flows exposed in breached lava ponds (Smith and others, 1999). Locally these deposits are cut by small dikes typically less than a meter in width. Near-vent deposits on quarried north side of Vulcan Volcano contain abundant partially melted, vesiculated xenoliths of sandstone. Thickness is 50 m

Qby6 **Lava flow unit 6**—Discontinuous, rubbly, dark-gray, thin (1–2 m), vesicular lava flows; early eruptive products from vents of Volcan Volcano (fig. 2). Thickness is 1–3 m

Qby5 **Lava flow unit 5**—Medium- to dark-gray vesicular lava flows exposed along the northern and eastern flanks of cone J A (Kelley and Kudo, 1978) and southern flanks of vent areas of Black Volcano (fig. 2) (Kelley and Kudo, 1978). Lava flows typically are thin (1–2 m), and locally are interbedded with near-vent deposits (Qby5c, scoria, cinders, and spatter associated with fire fountain eruptions from J A Volcano and Black Volcano). Locally, ramp structures, push-up features, and small lava tubes are common. Exposed thickness is 4–5 m in map area; base is generally covered or not well exposed

Qby4 **Lava flow unit 4**—Discontinuous, rubbly, dark-gray, thin (1–2m), vesicular lava flows; early eruptive products from vents of Black Volcano (fig. 2). Thickness is 2–3 m

Qby3 **Lava flow unit 3**—Discontinuous, rubbly, thin (1–3 m) dark-gray vesicular lava flows immediately west of J A Volcano (fig. 2). The unit forms an indistinct low- relief apron around fissure vents and above cliff-forming flows of Push-up structures and rafted pyroclastic deposits are common. Exposed thickness in map area is 2 m; base is generally covered or not well exposed

Qby2 **Lava flow unit 2**—Medium- to dark-gray lava flows exposed along an unnamed wash on the southwest margin of the volcanic field, east of the County Dump fault. The typically, thin (1–2 m) lava flows exhibit transitional pahoehoe to aa surface forms. (The Qby2c units are the cinder deposits on the lava flow). Thickness is 2–6 m

Qby1 **Lava flow unit 1**—Medium- to dark-gray lava flows. Typically, thin (1–2 m) lava flows characterized by surface forms transitional from pahoehoe to aa, parallel to low-relief flow lobes along flow direction. Largest volume eruptive unit in the map area, likely erupted from vent areas obscured by younger eruptions (Qby2–Qby11). Overlying gravel near southern limit of volcanic field (Shroba and others, 2003). Wilkins (1987) reports a thickness of 34 feet (ft) (10 m) in U.S. Geological Survey well 2 (table 1). Thickness is 3–10 m

OLDER LAVA FLOW UNITS
(MIDDLE PLEISTOCENE)

Qbo3 **Lava flow unit 3**—Medium- to dark-gray lava flows underlying gravel near southern limit of basalt in the southeast map area. Typically, thin (1–2 m) lava flows characterized by flow textures transitional from pahoehoe to aa. Best exposed on the south side of Rinconada Canyon (fig. 2). Inferred to have been derived from vent areas to the west now buried by younger lava flow units. Thickness is 3–10 m

Qbo2 **Lava flow unit 2**—Medium- to dark-gray, thin (1–3m), discontinuous lava flows in central part of map area. Best exposed along the northern canyon ledge of Rinconada Canyon (fig. 2) forming thin sequence of flows between basal and uppermost lavas. Poorly exposed in canyons and locally covered, or partially covered by colluvium. Thickness is 3–12 m

Qbo1 **Lava flow unit 1**—Medium- to dark-gray lava flows. Typically, thin (1–3 m) lava flows characterized by flow textures transitional from pahoehoe to aa. Well exposed as the basal lava flow sequence on the north side of Rinconada Canyon and the Llano de Albuquerque escarpment to the north (fig. 2). Inferred to have been derived from vent areas to the west now buried by younger lava flow units (Qby). Base is often not exposed or is poorly exposed, often covered by colluvium (Qc). Thickness is 3–8 m

Qb **Old lava flows, undivided**—Medium- to dark-gray, thin (1–3 m), discontinuous lava flows in central part of map area. Isolated outcrop does not allow discrimination between assignment to younger or older lava flow unit deposits. Locally covered, or partially covered by colluvium. Exposed thickness is 5–7 m

UPPER SANTA FE GROUP SEDIMENTS

Ng **Gravel unit of upper Santa Fe Group sediments (Pliocene)**—Sandy, pebble- and cobble-gravel interbedded with pebbly, medium to coarse sand and sparse coarse gravel that locally contains abundant cobbles and rare boulders as long as 1–1.5 m. Gravel is mostly clast supported. Gravel and sand beds and lenses are moderately well sorted. Most of the deposits are poorly indurated; locally, they contain carbonate cement. Pebbles and cobbles are composed chiefly of sandstone, porphyritic volcanic rock, red granite, gneiss, foliated granite, chert (including Pedernal chert of Maldonado and Kelley, 2009), and sparse quartzite, petrified wood, and basalt. Estimated thickness is 40 m

Ns **Upper Santa Fe Group sediments, undivided, (Pliocene and upper? Miocene)**—Poorly exposed deposits composed chiefly of slightly cobbly, pebble gravel, pebbly sand, and sand. Much of the sand is very fine to very coarse. Sand contains thin (5–50 cm) lenses of pebbly sand and gravel and, locally, thin (5 cm) lenses of silty clay. Clasts are chiefly subangular to rounded granite, chert (including chert fragments from the Pedernal Chert Member of the Abiquiu Formation), sandstone, petrified wood, and basalt. Unit Ns locally includes the gravel unit (Ng); locally includes deposits composed chiefly of pebbly sand; and locally includes beds rich in silt and clay (Lambert, 1968). Estimated thickness is 120 m

EXPLANATION

———	**Contact**
—•—······	**Normal fault**—Dashed where inferred from aerial photographs, dotted where concealed; bar and ball on apparent downthrown side
-- · AM · --	**Aeromagnetic survey**—Inferred normal fault located using aeromagnetic survey. Sense of displacement uncertain
———	**Petroglyph National Monument (PNM) boundary**
▨	**Cinder deposits**—Indicated by a "c" at the end of the unit label
AV–46 ●	**Sample location**—With sample number
Double Eagle no. 2 TD 1,708 ft ○	**Well location**—With name and total depth (TD) in feet (ft)

Divisions of Quaternary and Neogene time used in this report[1]

Period or subperiod	Epoch		Age
Quaternary	Holocene	late	0–4.2 ka
		middle	4.2–8.2 ka
		early	8.2 ka–11.7 Ma
	Pleistocene	late	11.7–132 ka
		middle	132–788 ka
		early	788 ka–2.588 Ma
Neogene	Pliocene		2.588–5.332 Ma
	Miocene		5.332–23.03 Ma

[1] Ages of time boundaries are those of the U.S. Geological Survey Geologic Names Committee (2010) except for those within the Holocene, which are those proposed by Walker and others (2012) and the late-middle Pleistocene boundary and middle-early Pleistocene boundary, which [illegible] expressed in ka for kilo-annum [illegible]

INTRODUCTION

This geologic map depicts and briefly describes geologic units underlying Petroglyph National Monument and immediately adjacent areas in Bernalillo County, New Mexico. The Monument is underlain dominantly by Quaternary basalts of the Albuquerque Volcanoes volcanic field, and is composed of a series of basin-filling volcanic flows and associated vents from a monogenetic volcanic highland along the eastern margin of the Llano de Albuquerque (figs. 1 and 2), (Kelley and Kudo, 1978; Geissman and others, 1990; Crumpler, 1999; Smith and others, 1999; Singer and others, 2008; Thompson and others, 2009). Outcrops of these basaltic lava flows host hundreds of petroglyphs from which the monument derives its name (National Park Service [NPS], 2019). Underlying deposits of the upper Santa Fe Group are exposed in the western part of the map area. Informal nomenclature for Santa Fe Group stratigraphy is used for these units. Drill hole data for well sites indicated on the map are summarized in table 1.

Many of the geologic units and geologic features shown on the map and much of the text in the map-unit descriptions were compiled from published geologic maps (Connell and others, 1998; Shroba and others, 2003; Connell, 2006; Thompson and others, 2009). New mapping, particularly along the eastern Monument boundary (fig. 2), was compiled and integrated into this compilation to provide a seamless, uniform geologic map and geographic information system (GIS) database of the area. This U.S. Geological Survey (USGS) ScienceBase data release accompanies this report and can be accessed at https://doi.org/10.5066/P9LW817K (Thompson and others, 2019).

This geologic map emphasizes the distribution of Quaternary volcanic vent areas and lava flow deposits which were incompletely mapped in previous publications. Surficial deposits are simplified, but uniformly mapped and described in contrast to varying map unit distributions, names and descriptions presented previously.

The mapped distribution of some of the map units is based in part on the interpretation of lidar (light detection and ranging) data acquired during September, 2010 (OpenTopography, http://opentopo.sdsc.edu/usiei?id=ID_10281). Fractional map symbols (for example, Qsw/Qao) are used where ongoing slope processes have reworked old alluvial-slope deposits (Qao) into thin sheetwash deposits (Qsw). This fractional unit is not described here; instead refer to the individual units in the Descriptions of Map Units section of this report. Fractional units are not shown on the Correlation of Map Units diagram either but are equivalent in age to the unit shown in the numerator of the unit. Extensive building, landscaping, and paving, as well as the placement of thin discontinuous deposits of artificial fill at and near constructions sites, have modified the upper part of surficial deposits throughout the map area. Areas of human-modified land are not shown on the geologic map with the exception of artificial fill (af) and pond deposits (Qp). Terrace deposits of the Rio Grande (Qry, Qri, and Qro) are rich in stream-transported clasts composed of quartz-rich Proterozoic metamorphic rocks and porphyritic volcanic rocks of felsic and intermediate composition suitable for aggregate. The reader is referred to Cole and others (2007a) for more detailed descriptions of gravels. All colors used in map descriptions are informal field designations of these lithologies.

STRATIGRAPHY OF DEEP DRILL HOLES IN THE MAP AREA

Six deep drill holes in and near the map area provide significant information concerning subsurface Santa Fe Group sediments (table 1). The deepest hole (West Mesa Federal 1) was drilled for hydrocarbon exploration in Cretaceous units beneath Santa Fe Group sediments. The other five drill holes are water wells.

Shell Oil Company drilled West Mesa Federal 1 in 1983 to a total depth of 19,375 ft (5,905 m). Lithologic descriptions and a generalized cross section indicate that the drill hole penetrated at least 16,830 ft (5,133 m) of Tertiary sediments and bottomed in Mesozoic rocks (table 1). The Tertiary sediments consist of about 8,550 ft (2,608 m) of Santa Fe Group sediments, 7,170 ft (2,187 m) of a unit of Isleta no. 2 of Lozinsky (1988, 1994), and 1,110 ft (338 m) of Galisteo Formation (Lozinsky, 1994). In the Albuquerque basin, Lozinsky's unit of Isleta no. 2 commonly consists of purplish-red to gray, well-indurated, poorly to moderately sorted, fine- to coarse-grained, volcaniclastic sandstone that contains interbeds of claystone and silicic- to intermediate-volcanic flows and tuffs (Lozinsky, 1994). The drill hole also penetrated about 1,655 ft (504 m) of Cretaceous rocks and about 900 ft (274 m) of Jurassic rocks. Inferred thicknesses of lithologic units in the Santa Fe Group are based on interpretation of cuttings from a nearby water well.

The U.S. Geological Survey drilled well 2 in 1981 to a total depth of 1,828 ft (557 m). Lithologic logs and grain-size analyses of the cuttings suggest that the drill hole penetrated (from top to bottom) 8 ft (2 m) of surficial deposits, 34 ft (10 m) of basalt, and >1,786 ft (544 m) of Santa Fe Group sediments. The upper 746 ft (228 m) of the Santa Fe Group sediments commonly contains 10–30 percent granules plus gravel (>2 mm), whereas the lower 1,040 ft (317 m) consists of sand and finer material. The greatest amount of sand and coarser material (about 90 percent >0.062 mm) is in the upper 291 ft (89 m) of the Santa Fe Group sediments. These coarse-grained sediments may be equivalent to gravel unit (Tg) and the pebbly sand unit (Tps) of the Santa Fe Group sediments mapped near the western boundary of the map area (fig. 5). The content of silt plus clay (<0.062 mm) varies with depth, and is about 10 percent at 42–333 ft (13–101 m), 20–30 percent at 333–788 ft (101–240 m), 40–60 percent at 788–1,289 ft (240–393 m), and about 35 percent at 1,289–1,828 ft (393–557 m) (Wilkins, 1987).

The other three water wells (Black Ranch Test Well, City of Albuquerque Soil Amendment Facility 1, and Double Eagle 2) penetrated Santa Fe Group sediments to total depths of 1,708–3,030 ft (521–924 m). See table 1 for additional information concerning Santa Fe Group lithologic units penetrated.

The 98th Street core hole is located just north of Interstate 40 in the adjacent Albuquerque West 7.5-minute quadrangle. It is about 190 m east and about 3,660 m south of the southeast corner of the The Volcanoes 7.5-minute quadrangle. The core hole was drilled by the USGS in 1996 to a total depth of 1,560 ft (476 m) to determine the lithostratigraphy and hydrogeologic characteristics of the aquifer system. Sampling recovered 760.6 ft (231.8 m) of core. The core hole penetrated about 19 ft (6 m) of Quaternary eolian sand and alluvium; 78 ft (24 m) of the upper gravelly unit of the Santa Fe Group; and at least 1,463 ft (446 m) of the middle unit of the Santa Fe Group (Stone and others, 1998). The upper gravelly unit of the Santa Fe Group consists chiefly of sand, gravel, and lenses of pebbly sand, silt, and clay. The middle unit of the Santa Fe Group is mostly interbedded sand, silty sand, silty clay, and clay (Stone and others, 1998). The upper gravelly unit of the Santa Fe Group probably is laterally equivalent to the gravel unit of the upper Santa Fe Group sediments (Tg) and the pebbly sand unit of the upper Santa Fe Group sediments (Tps) in The Volcanoes quadrangle, the Ceja Member of the Santa Fe Formation of Kelley (1977), and the Sierra Ladrones Formation (Stone and others, l998).

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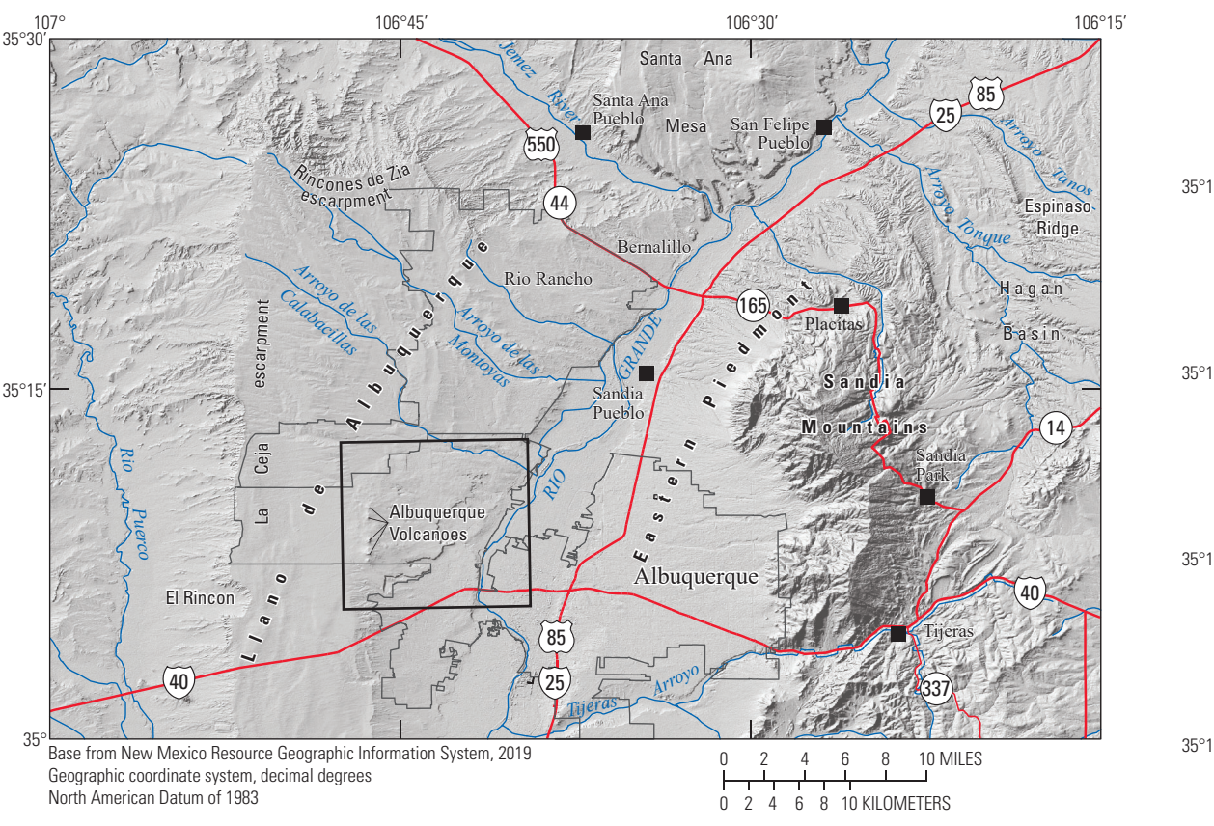


Figure 1. Geographic setting of the Petroglyph Monument geologic map area. Map area boundary show by black rectangle.

Eroded flow fronts of tholeiitic lava flows within older lava flow units (Qbo deposits). Photograph by Ren A. Thompson, 1996. Rock hammer, visible in left center of photo, for scale.

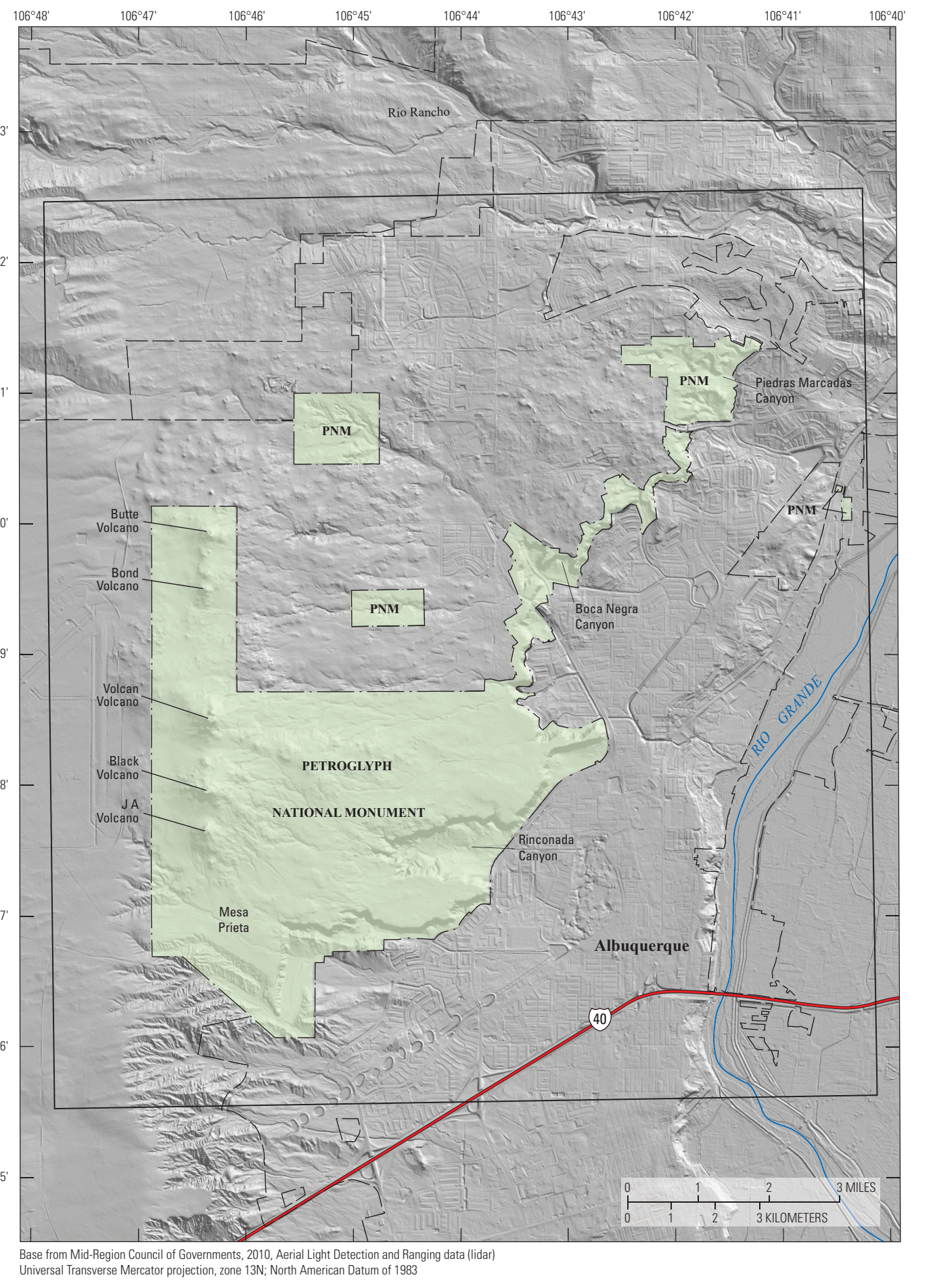


Figure 2. Shaded relief index map of the map area. Petroglyph National Monument (PNM) shown in green. Major canyons and volcanic vent areas of the monument are labeled.

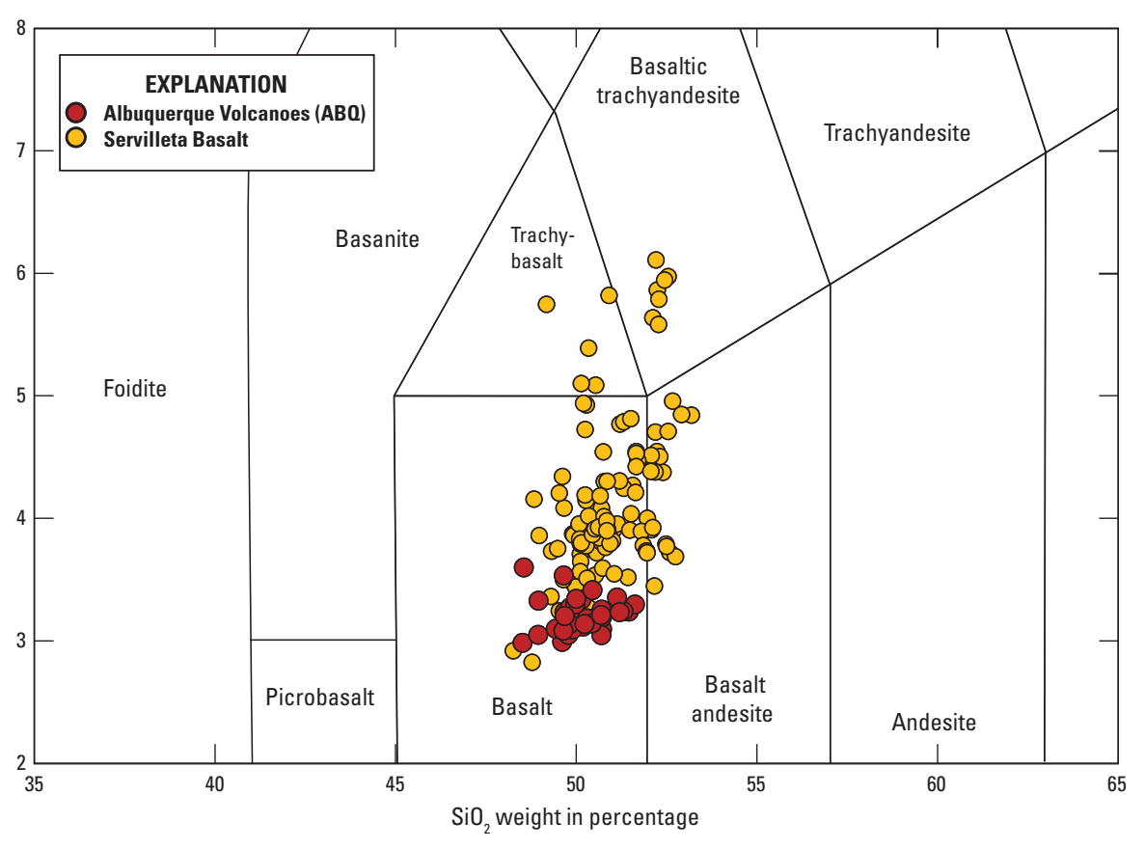
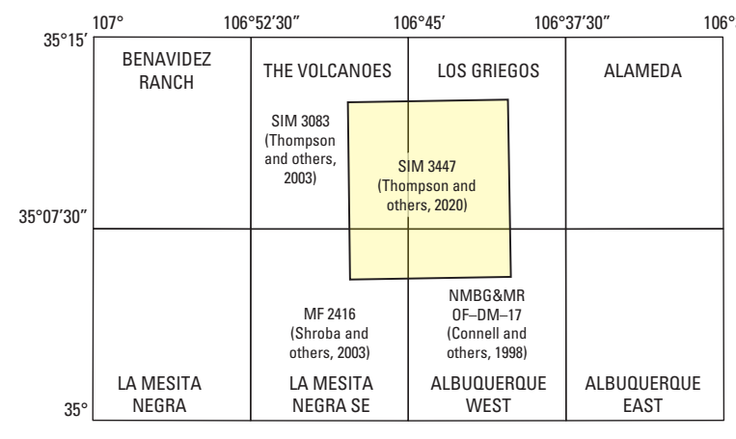


Figure 3. Total alkali (Na_2O+K_2O) vs. silica diagram of Le Bas and others (1986). Data are recalculated volatile free and total iron as FeO. The Albuquerque Volcanoes (ABQ) have low alkalis and are dominated by olivine tholeiite basalts. For comparison, Servilleta Basalt compositions from the Taos Plateau volcanic field to the north are also shown. The Servilleta compositions reflect greater total compositional diversity but compositionally overlap the more primitive basalts within Petroglyph National Monument.

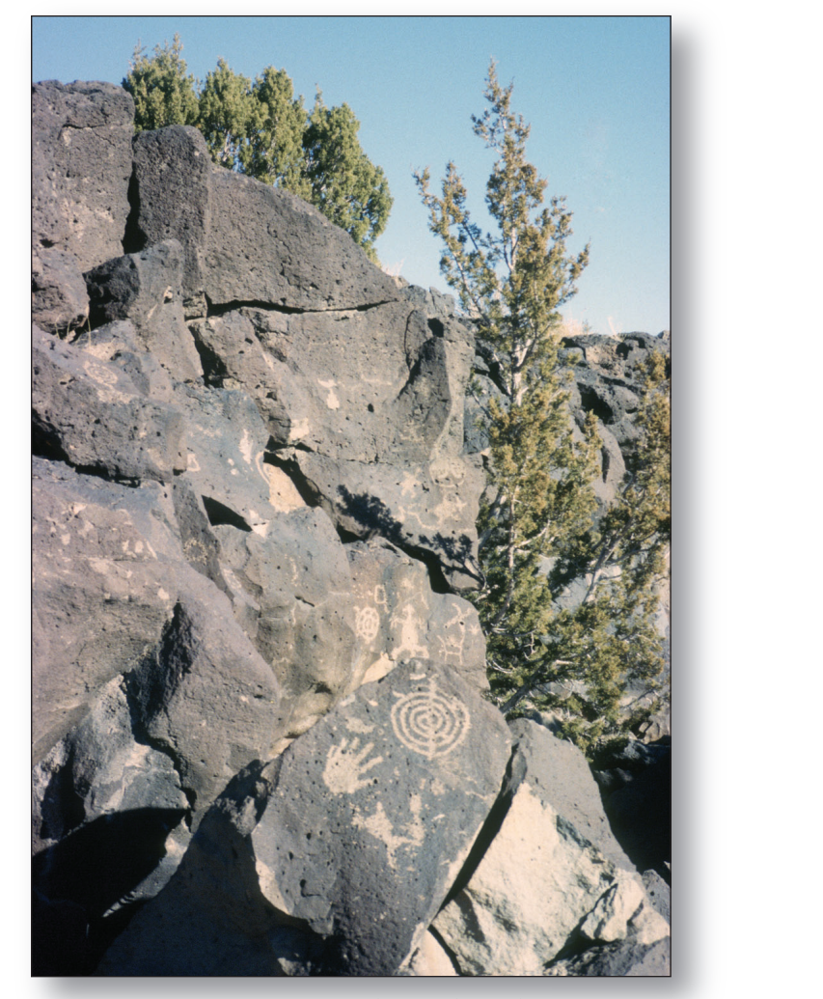


Index map showing map area in yellow, and adjacent 7.5' U.S. Geological Survey (USGS) quadrangles. For USGS publications, the publication number, author(s) and year of publication are shown. For non-USGS publications, the agency, author(s), and year of publication are shown. NMBG&MR; New Mexico Bureau of Geology and Mineral Resources.

CONVERSION FACTORS

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
millimeters	0.03937	inches (in.)
centimeters	0.3937	inches (in.)
meters (m)	3.281	feet (ft)
kilometers (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)



Petroglyphs etched into eroded faces of lava flows along the eastern margin of the Albuquerque Volcanoes volcanic field. Photograph by Ren A. Thompson, 1996.

Figure 4. Photomicrographs of macroscopic textures of Albuquerque Volcanoes, cross-polarized light. *A*, Resorbed olivine grains in a groundmass of plagioclase>>olivine>> augite>> opaques. *B*, In most samples, olivine is the dominant phase although there are a couple of samples where plagioclase and olivine are subequal. Augite is a late-forming mineral that usually appears to form interstitially. *C*, Glomerocrysts of olivine and plagioclase are common as cumulophyric clusters. Pl, plagioclase; Ol, olivine; Aug, augite; mm, millimeters.

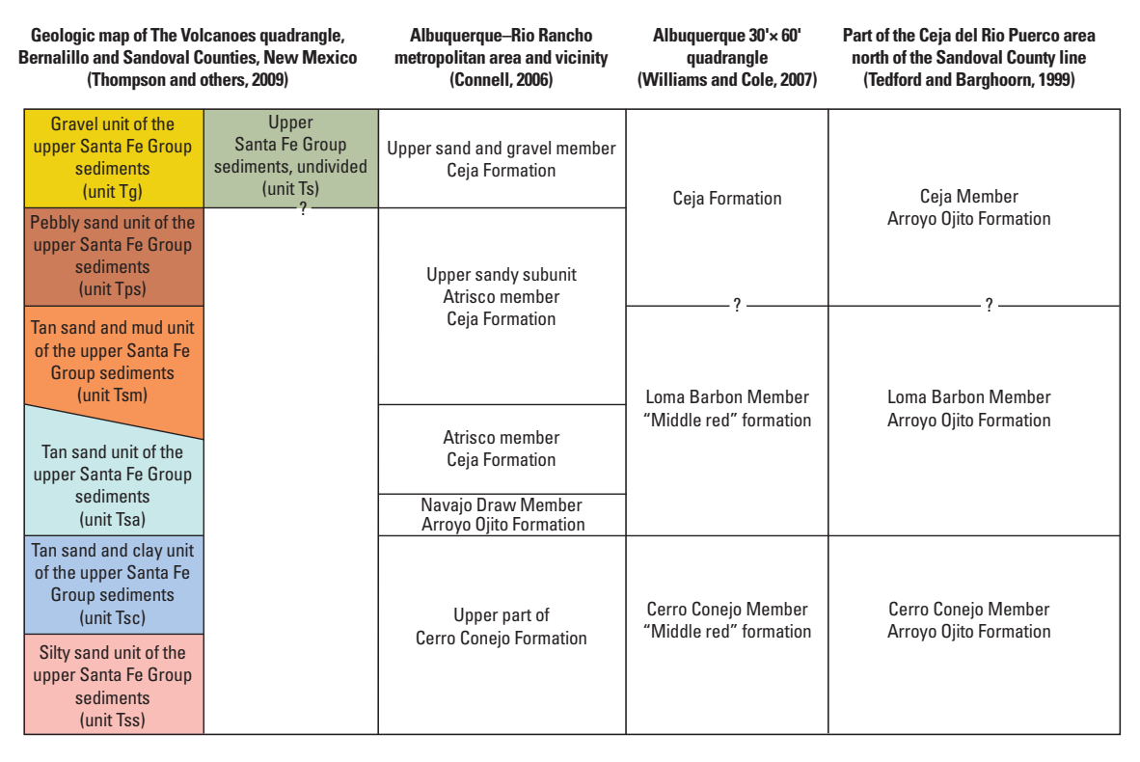


Figure 5. Generalized stratigraphic relations of Santa Fe Group sediments mapped in the map area (from Thompson and others, 2009).

Pahoehoe lava flow textures typical of tholeiitic basalt lava flows. Photograph by Ren A. Thompson, 1996.

Thinly bedded lava flows interpreted as small lava lake deposits of the Volcan eruptive center. Photograph by Ren A. Thompson, 1996.

Table 1. Thickness of geologic materials penetrated in deep drill-holes in and near the map area (modified from Thompson and others, 2009).

[USGS, U.S. Geological Survey, ---, not described; >, greater than; ~, approximately. All elevations and material thicknesses are in feet; well locations are in latitude and longitude coordinates. Sources of information: L, Lozinsky, 1994; T, Thompson and others, 2009; ST, Stone and others, 1998; W, Wilkins, 1987]

Well name	Shell Oil Mesa Federal[1]	USGS Well	Black Ranch Test Well[1]	City of Albuquerque Soil Amendment Facility[1]	Double Eagle	USGS 98th Street core hole[1]
Well number	1	2		1	2	2
Latitude (N)	35°10'06"	35°10'46"	35°12'44"	35°08'53"	35°08'48"	35°05'24"
Longitude (W)	106°46'59"	106°46'27"	106°49'05"	106°49'28"	106°47'36"	106°44'52"
Ground surface elevation (ft)	5,775	5,730	5,920	5,865	5,805	5,320
Total Depth (TD, ft)	19,375	1,828	3,030	2,428	1,708	1,560
	Thickness (ft)					
Surficial deposits	---	8	---	---	---	19
Basalt	---	34	---	---	---	---
Santa Fe Group						
Gravelly sediment	~200	196	220	233	203	78
Medium to coarse sand	~180	592	181	454	300	344
Silty sediment	~400	443	407	675	388	346
Medium sand	~1,600	555	778	1,066	694	
Fine to medium sand	6,170		1,444		123	773
Unit of Isleta no. 2	>1,170					
Galisteo Formation	~1,110					
Cretaceous Rocks, undivided	~1,655					
Jurassic rocks, undivided	~900					
Total thickness of Santa Fe Group	**~8,550**	**>1,786**	**>3,030**	**>2,428**	**>1,708**	**>1,541**
Sources of information	L, T	W, T	T	T	T	ST

[1] Drill hole is outside of map area.

Table 2. Representative bulk-rock chemical analyses for select samples from the map area.

[Units are in weight percent (wt%) for major oxides and parts per million (ppm) for trace elements. LOI, loss on ignition; latitude and longitude in World Geodetic System 1983 (WGS 83); N, north; W, west]

Sample	AV–51	AV–53	AV–55	AV–13	RTAV–15	AV–17	AV–46	RTAV–13	AV–28	AV–11	RTAV–03
Geologic Map Unit	Qbo1[*]	Qbo2	Qbo3	Qby1	Qby5	Qby6	Qby7	Qby8	Qby8	Qby9	Qby11c
Latitude (N)	35°08'45"	35°07'44"	35°07'42"	35°08'45"	35°07'41"	35°08'43"	35°08'52"	35°07'60"	35°07'60"	35°09'59"	35°09'55"
Longitude (W)	106°43'31"	106°43'35"	106°44'53"	106°44'45"	106°46'19"	106°45'55"	106°46'29"	106°46'25"	106°46'25"	106°45'27"	106°46'17"
SiO_2	48.98	49.37	48.61	48.42	50.6	48.51	47.45	49.4	47.84	49.55	49.8
TiO_2	1.44	1.36	1.34	1.35	1.65	1.36	1.93	1.45	1.55	1.35	1.43
Al_2O_3	14.79	14.53	14.28	14.54	14.1	14.25	14.22	15.5	14.96	15.41	14.6
Fe_2O_3	12.33	11.94	11.48	11.73	12.2	11.71	12.72	11.8	12.22	11.84	12.1
MnO	0.17	0.16	0.15	0.16	0.18	0.16	0.17	0.19	0.16	0.16	0.16
MgO	9.15	8.97	8.59	9.00	7.61	8.89	7.14	8.81	8.21	8.80	9.42
CaO	9.41	9.68	10.99	9.94	9.71	10.13	11.34	9.87	10.61	9.56	9.32
Na_2O	2.64	2.61	2.50	2.65	2.64	2.51	2.84	2.65	2.57	2.69	2.77
K_2O	0.51	0.48	0.48	0.50	0.59	0.50	0.68	0.47	0.41	0.49	0.54
P_2O_5	0.21	0.20	0.20	0.20	0.28	0.20	0.31	0.24	0.23	0.20	0.2
LOI	0.20	0.60	1.80	0.7	0.18	1.3	1.6	0.03	1.12	0	0.25
Sums	**99.84**	**99.89**	**100.42**	**99.18**	**99.74**	**99.51**	**100.40**	**100.41**	**99.88**	**100.03**	**100.59**
Trace elements											
Cr	300	300	290	300	230	290	200	225	219	230	300
Ni	243	246	232	247	168	236	123	225	169	232	237
Rb	9.3	9.1	8.4	9.9	8.1	9.2	8.4	6.0	4	6.7	11.5
Sr	295	297	306	317	307	327	387	339	355	287	313
Ba	176	163	200	168	282	326	239	330	378	196	156
Y	18.5	17.7	17.8	17.6	22.8	18.1	24	18.3	24	17.4	18.4
Zr	90.5	84.6	84.7	84.7	115	94.9	129	98.7	123	81.7	88.6

[*] Sample outcrops may be too small to show at map scale and may appear to be in a surrounding mapped unit.

Geologic Map of Petroglyph National Monument and Vicinity, Bernalillo County, New Mexico

By

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