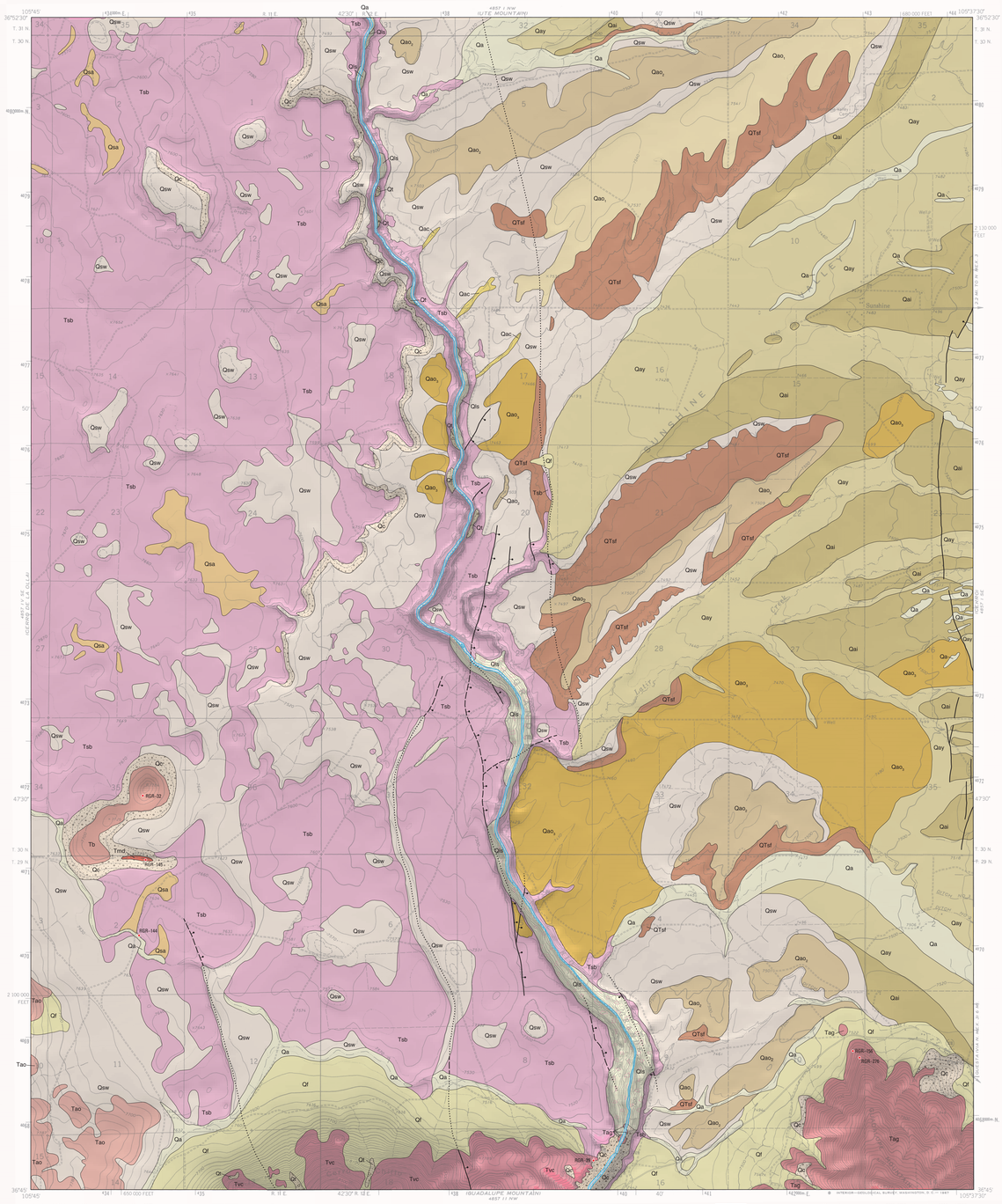
U.S. Department of the Interior
U.S. Geological Survey

Scientific Investigations Map 3283



Base from U.S. Geological Survey, Sunshine, New Mex., 1963

Shaded-relief base generated from U.S. Geological Survey 10-m Digital Elevation Model (DEM) data from the National Elevation Dataset, accessed April 2013 at http://ned.usgs.gov/

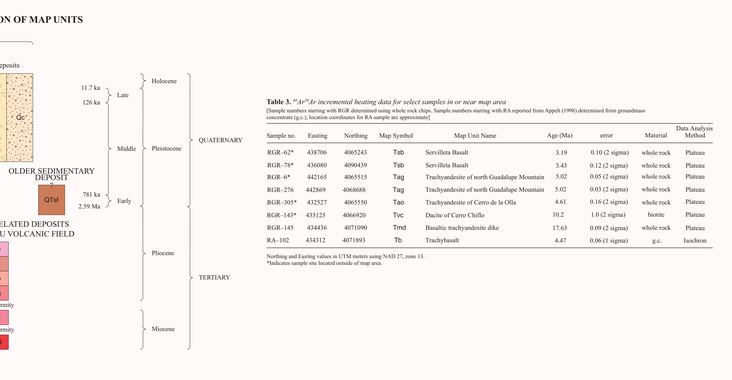
Polyconic projection. 1927 North American Datum (NAD 27)
10,000-foot grid based on New Mexico coordinate system, central zone
1,000-meter Universal Transverse Mercator grid ticks, zone 13

SCALE 1:24 000

CONTOUR INTERVAL 20 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

The geology was mapped from 2006–2009 and modified in 2011 and 2012.
R.A. Thompson and K.J. Turner mapped the volcanic deposits and faults and prepared the digital compilation of the geologic map.
R.R. Shroba and C.A. Ruleman mapped the surficial deposits, M.A. Cosca and J.P. Lee carried out the $^{40}Ar/^{39}Ar$ sampling, analysis and interpretation, and assisted with stratigraphic interpretations.
T.R. Brandt produced the digital topographic base map.
Edit and cartographic layout by L.J. Binder
Denver Publishing Service Center

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

[The surficial units on this map are informal allostratigraphic units of the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983), whereas the other map units are informal lithostratigraphic units. For this reason, subdivisions of stratigraphic units use time terms "late" and "early" where applied to surficial units, but use position terms "upper" and "lower" where applied to lithostratigraphic units. The mapped surficial deposits (Qaoₙ and younger) are known or estimated to be at least 1 m thick. Most of these deposits are poorly exposed.

Surficial map units locally include sheetwash alluvium (Qsw), and alluvium and colluvium, undivided (Qac), that are too small to show as separate map units. Many of the deposits of valley-floor alluvium (Qa), colluvium, undivided (Qc), and talus (Qt) in the Rio Grande gorge are too narrow to show at map scale. Thin (<50 cm), discontinuous sheetwash deposits (Qsw) locally mantle gently sloping map units.

Age assignments for surficial deposits are based chiefly on: (1) the relative heights above modern streams or channels of ephemeral streams, (2) topographic relationships with other surficial deposits, and, to a lesser extent, (3) relative degree of erosional modification of original (depositional) surface morphology.

The heights of units Qao_0, Qao_1, and Qao_4 above the Rio Grande and the gradient of the southward-flowing Rio Grande increase from north to south within the map area. In the northernmost four-fifths of the map area (upstream of the 7,220-ft contour) the average gradient of the Rio Grande is about 2 m/km. However, in the southern one-fifth of map area (south of the 7,220-ft contour), the average gradient of the Rio Grande steepens to about 9 m/km. The southward increase in heights of units Qao_0, Qao_1, and Qao_4 is due chiefly to the average gradients of the Rio Grande (2 and 9 m/km) being greater than the southward decrease in altitude of the tops of these units (about 0.5 m/km). The average depth of the Rio Grande gorge is about 52 m in the northern four-fifths of the map area and increases to about 67 m in the southern one-fifth.

Stages of secondary calcium carbonate morphology (referred to as stages I and II observed on the bottom of clasts) are from Gile and others (1966) and Machette (1985).

In this report, the terms "alluvium" and "alluvial" refer to sediment transported by running water confined to channels (stream alluvium), whereas those deposited by running water not confined to channels are referred to as sheetwash. The terms "colluvium" and "colluvial" refer to sediment transported downslope chiefly by mass-movement (gravity-driven) processes—such as debris flow, rock fall, and near-surface creep—aided by running water not confined to channels (Hilgard, 1892; Merrill, 1897). Surficial map units that include debris-flow deposits probably also include hyperconcentrated flow deposits. These latter deposits are intermediate in character between stream-flow and debris-flow deposits. Eolian deposits were not identified in the map area; however, some of the silty sheetwash alluvium (Qsw) noted on fan deposits (Qf) may be derived from loess. The terms "sticky" and "plastic" in the description of the Santa Fe Group, upper part (QTsf) are defined as follows: The former term refers to moist sediment, which after pressure is applied, adheres to both thumb and finger and tends to stretch somewhat rather than pulling free from either digit. The latter term refers to the extent to which moist sediment changes shape continuously under the influence of an applied stress and then retains the impressed shape on the removal of the stress (Soil Survey Staff, 1951).

Grain or particle sizes of surficial deposits are based on field estimates, using the modified Wentworth scale (American Geological Institute, 1982). In the descriptions of surficial map units, the term "clast" refers to particles larger than 2 mm in diameter, whereas the term "matrix" refers to particles smaller than 2 mm in diameter. Most of the clasts in fan deposits within the map area are angular and subangular, whereas most of those in alluvial deposits are angular to subrounded.

Colors of the Santa Fe Group, upper part (QTsf) were determined by comparison of dry matrix with Munsell Soil Color Charts (Munsell Color, 1973). Due to the addition of a shaded relief base, colors on the List of Map Units and the Correlation of Map Units may not exactly match unit colors on the map]

SURFICIAL DEPOSITS

Alluvial deposits

Qa — **Valley-floor alluvium (Holocene)**—Deposits along the Rio Grande are locally boulder, cobbly pebble gravel. Deposits along other streams consist of sand and gravel in stream channels as well as sand, silty sand, and gravel underlying flood plains and adjacent low terraces. The top of unit Qa is about 1 m above channels of ephemeral streams in Sunshine Valley and about 2 m below the top of unit Qay (table 1). Unit Qa locally includes a minor amount of the fan deposits (Qf) and narrow sheetwash aprons (Qsw) along valley margins. Low-lying deposits are prone to periodic stream flooding. Estimated thickness 1–5 m along the Rio Grande, 1–3 m along other streams

Qsw — **Sheetwash alluvium (Holocene and late Pleistocene)**—Alluvial aprons composed chiefly of slightly pebbly to pebbly, slightly silty to silty sand that accumulates on gentle slopes, such as those on Servilleta Basalt (Tsb). Some of the silt- to fine sand-size fraction in these deposits may be of eolian origin (Shroba and Thompson, 1998). Deposits of unit Qsw along the shores of intermittent ponds or small lakes on Servilleta Basalt (Tsb) locally may include or overlie playa deposits. Low-lying areas of unit Qsw are susceptible to sheet flooding due to unconfined overland flow, and locally to stream flooding and gullying. Recently disturbed surface of unit Qsw may be susceptible to minor wind erosion. Estimated thickness 1–5 m, possibly as much as 10 m

Qsa — **Sheetwash and valley-floor alluvium, undivided (Holocene and late Pleistocene)**—Chiefly silty and sandy sheetwash deposits (Qsw) on gentle slopes and a minor amount of undifferentiated sandy and pebbly valley-floor alluvium (Qa) along and near ephemeral streams on Servilleta Basalt (Tsb) near the western boundary of the map area. Low-lying areas of unit Qsa in and adjacent to stream channels may be subject to periodic stream flooding, gullying, and possibly debris-flow deposition; adjacent slopes may be subject to periodic sheet flooding. Estimated thickness is 1–5 m, possibly as much as 10 m

Piedmont-slope alluvium

Five map units of alluvial deposits of three age groups form an extensive alluvial apron (or bajada) between the east flank of the Sangre de Cristo Mountains and the Rio Grande. The alluvial apron is about 13–18 km wide; has average slopes of about 10–50 m/km near the mountain front and about 1–6 m/km within the map area; and was deposited by westward and southwestward flowing streams sourced in the Sangre de Cristo Mountains and in the piedmont west of the mountain front. The westward-sloping landform that developed on the alluvial apron is known as the Costilla Plain (Upson, 1939). Piedmont-slope alluvium commonly consists of pebbly sand and matrix-supported, pebble gravel with a sandy matrix. Some deposits of pebble gravel contain a minor amount of small cobbles. Pebble- and cobble-sized clasts in piedmont-slope alluvium are composed chiefly of volcanic rock fragments from the mid-Tertiary Latir volcanic field (Lipman and Reed, 1989), including Amalia Tuff, as well as granite, quartz, feldspar, pegmatite, felsic gneiss, and a minor amount of pale-green quartzite from Proterozoic sources. These clasts were eroded from bedrock in the Sangre de Cristo Mountains. Small, unmapped deposits of sheetwash alluvium (Qsw), alluvium and colluvium, undivided (Qac) locally overlie deposits of piedmont-slope alluvium. The heights of piedmont-slope deposits above Costilla Creek are higher than those of equivalent deposits along and near channels of unnamed intermittent or ephemeral streams near the northeast and southeast corners of the map area. Deposition of units Qao_0, Qao_2, and Qao_4 predate major downcutting of the Rio Grande gorge (Thompson and Shroba, 2007), which began after about 440 ka (Machette and others, 2007, 2013). The deposits of units Qao_0, Qao_2, and Qao_4 may have accumulated under pluvial climatic conditions associated with pre-Bull Lake glaciations in the Sangre de Cristo Mountains prior to about 440 ka (Ruleman and others, 2013). Deposits of map units Qao_0, Qao_2, and Qao_4 accumulated prior to canyon cutting by the Rio Grande (Shroba and Ruleman, 2007), which began after about 440 ka (Machette and others, 2007, 2013). Low-lying areas adjacent to stream channels are prone to periodic stream flooding.

Qay — **Younger piedmont-slope alluvium (late Pleistocene)**—Top of unit Qay is about 3 m above channels of ephemeral streams in the western part of Sunshine Valley and about 3 m below the top of unit Qai (table 1). In the adjacent Ute Mountain quadrangle, deposits of unit Qay appear to be graded to deposits of unit Qf. Stage I and weak stage II carbonate morphology on clasts in unit Qf suggests that unit Qf, as well as unit Qay, accumulated during the Pinedale glaciation (table 2 in Machette, 1985), about 12–30 ka (Nelson and others, 1979; Benson and others, 2004, 2005). Deposits of unit Qay could be as old as 40–47 ka (Cole and others, 2007). Estimated thickness is 1–3 m

Qai — **Intermediate piedmont-slope alluvium (late? and middle Pleistocene)**—Top of unit Qai is about 6 m above channels of ephemeral streams in the western part of Sunshine Valley and about 6 m below the top of unit Qao_1 (table 1). Unit Qai may have accumulated during the Bull Lake glaciation, about 120–170 ka (Sharp and others, 2003; Pierce, 2004). Estimated thickness is 1–3 m

Qao_1 — **Lower older piedmont-slope alluvium (middle Pleistocene)**—Top of unit Qao_1 is about 18 m above channels of ephemeral streams in the western part of Sunshine Valley, and about 12 m below the top of unit Qao_0 (table 1). In the northern part of the map area the top of unit Qao_1 is about 56 m above the Rio Grande, and about 7 m below the top of unit Qao_2. In the southern part of the map area the top of unit Qao_1 is about 73 m above the Rio Grande, and about 9 m below the top of unit Qao_2 (table 1). Deposits of unit Qao_1 are preserved on both the east and west sides of the Rio Grande gorge (Cañon del Rio Grande). Estimated thickness is 1–3 m

Qao_2 — **Higher older piedmont-slope alluvium (middle Pleistocene)**—Top of unit Qao_2 is about 30 m above channels of ephemeral streams in the western part of Sunshine Valley, and about 3 m below the top of unit Qao_1 (table 1). In the northern part of the map area the top of unit Qao_2 is about 63 m above the Rio Grande, and about 13 m below the top of unit Qao_1. In the southern part of the map area the top of unit Qao_2 is about 82 m above the Rio Grande. Estimated thickness is 2–3 m

Qao_4 — **Highest older piedmont-slope alluvium (middle Pleistocene)**—Top of unit Qao_4 near the northeast corner of the map area, is about 35 m above channels of ephemeral streams in the western part of Sunshine Valley, about 13 m above the top of unit Qao_2, and about 76 m above the Rio Grande (table 1). Estimated thickness 2–3 m

Alluvial and colluvial deposits

Qac — **Alluvium and colluvium, undivided (Holocene and late? Pleistocene)**—Consists chiefly of valley-floor alluvium (Qa), sheetwash alluvium (Qsw), and fan deposits (Qf) primarily along minor tributary drainages of the Rio Grande. Unit Qac ranges from slightly pebbly, silty sand to poorly sorted, clast- and matrix-supported, locally bouldery, cobbly and pebbly gravel with a sandy matrix. Low-lying areas of the map unit are prone to periodic stream and sheet flooding and locally to debris-flow deposition. Deposits composed of silty sand are prone to gullying. Estimated thickness is 1–10 m

Qf — **Fan deposits (Holocene and late? Pleistocene)**—Chiefly clast-and-matrix supported, locally bouldery, pebbly and cobbly gravel with a silty sand matrix. Deposits locally consist of pebbly and cobbly, slightly silty sand that contains gravel lenses. Rock fragments in unit Qf, near the southern boundary of the map area (from east to west) are composed chiefly of rhyolite tephra in Jemez Mountains, Nacimiento Mountain (Tag), dacite of Cerro Chiflo (Tvc), and trachyandesite of Cerro de la Olla (Tao). One small deposit of unit Qf, that overlies alluvium of unit Qay near the west end of Sunshine Valley, is composed of sediment eroded from the upper part of the Santa Fe Group (QTsf). Deposits of unit Qf commonly form fan-shaped and lobate masses of sediment deposited by debris flows and by sediment-charged, ephemeral streams. Eolian sediment may have played an important role in the genesis of these debris flows (Shroba and others, 2007). Levees that contain abundant cobbles and boulders formed at the margins of some debris flows. Erosional modification of original surface morphology of fan deposits in areas between washes ranges from little, if any, to minor. Washes commonly have steep sides that are only slightly modified by erosional processes. Small, unmapped deposits of sheetwash alluvium (Qsw) and alluvium and colluvium, undivided (Qac) locally overlie deposits of unit Qf, such as on the large fan along the base of Cerro Chiflo. Deposits of unit Qf may have accumulated under pluvial climatic conditions associated with the Pinedale glaciation, as well as during major precipitation events, such as intense summer thunderstorms during the Holocene. Low-lying areas adjacent to stream channels are prone to periodic stream flooding and debris-flow deposition. Maximum thickness possibly about 50 m

Colluvial deposits

Qls — **Landslide deposits (Holocene and late Pleistocene)**—Deposits of unsorted to partly unstratified debris that commonly display hummocky topography. All of the landslides and landslide deposits are within the Rio Grande gorge. They are formed from the Servilleta Basalt (Tsb) and sediment between or below some of the lava flows. Sliding of the Servilleta Basalt is probably due in part to reduction of lateral support provoked by incision of the floor of the gorge by the Rio Grande. The largest landslide deposits are in the southern half of the map area where displacement along faults near the Rio Grande gorge may have significantly weakened the Servilleta Basalt, and may have made it susceptible to sliding. Much of unit Qls probably includes material displaced chiefly by translational sliding and locally by rock creep as defined by Cruden and Varnes (1996). Deposits of unit Qls are susceptible to reactivation due chiefly to stream incision by the Rio Grande. Unit Qls locally include minor deposits of talus (Qt) and colluvium, undivided (Qc). Maximum thickness possibly about 85 m

Qt — **Talus deposits (Holocene to middle? Pleistocene)**—Composed mostly of angular, tabular blocks of dacite of Cerro Chiflo (Tvc) deposited chiefly by rock fall on the flanks of Cerro Chiflo along the southern boundary of the map area. Also includes small deposits exposed along Rio Grande gorge composed mostly of angular blocks of Servilleta basalt (Tsb). Maximum thickness possibly about 15 m

Qc — **Colluvium, undivided (Holocene to middle Pleistocene)**—Chiefly non-sorted and non-stratified, mostly matrix-supported, sandy sediment and rock debris on and near steep slopes. Deposits range in size from pebbly silty sand to bouldery rubble with a sandy matrix. Unit Qc consists mostly of debris-flow, rock-fall and creep deposits, as defined by Varnes (1978) and Cruden and Varnes (1996). Unit locally includes small deposits of sheetwash alluvium (Qsw), and alluvium and colluvium, undivided (Qac). Two large deposits in the Rio Grande gorge include talus (Qt) and landslide (Qls) deposits. Unit Qc may be susceptible to continued movement or reactivation due to natural and human-induced processes. Maximum thickness possibly about 20 m

OLDER SEDIMENTARY DEPOSIT

QTsf — **Santa Fe Group, upper part (middle? Pleistocene to Pliocene)**—Exposed deposits at scattered outcrops consist of silty to very silty, mostly very fine to medium sand that overlies Servilleta Basalt (Tsb). Deposits are weakly consolidated, slightly sticky, plastic to very plastic, and are commonly brown, strong brown, and reddish yellow (7.5YR 5/4, 5/6, 6/6, and 6/7) in color (Munsell Color, 1973). The abundance of medium sand and finer sediment suggests deposition in a low energy, closed basin environment, such as ephemeral playa lakes (Summers and Hargis, 1984). Sediments in the lower part of the Santa Fe Group are not exposed, but drill-hole data indicate that they are preserved in the subsurface beneath the Servilleta Basalt (Winograd, 1959). Unit QTsf overlies, and is younger than, the about 3.5 Ma Servilleta Basalt. The minimum age of unit QTsf is not well constrained in the map area. However, tephra in nearby areas help to constrain its minimum age. About 25 km south of the map area near Questa, New Mexico, the upper part of the Santa Fe Group contains the Tsankawi Pumice Bed of the Tshirege Member of the Bandelier Tuff (Pazzaglia and Wells, 1990) that has a K-Ar age of 1.12 ± 0.03 Ma (Izett and others, 1981). About 33 km northeast of the map area near San Luis, Colorado, the upper part of the Santa Fe Group contains Lava Creek B ash less than 2 m below the eroded(?) top of the unit (Machette and others, 2008). The ash has a $^{40}Ar/^{39}Ar$ age of 639 ± 2 ka (Lanphere and others, 2002). Exposed thickness is 1–2 m, possibly as much as 50 m (Winograd, 1959)

LAVA FLOWS AND RELATED DEPOSITS OF THE TAOS PLATEAU VOLCANIC FIELD

The Taos Plateau volcanic field is a basaltic to rhyolitic volcanic plateau of the southern San Luis Basin (Lipman and Mehnert, 1979) of northern New Mexico and southern Colorado (fig. 1). The volcanic plateau is bordered by the high mountains of the Sangre de Cristo Range, up to 4,000 m to the east, and the east-dipping ramp of the Tusas Mountains to the west (fig. 1). Predominantly basaltic to andesitic lava flows underlie the approximately 2,300-m elevation tablelands; punctuated by eroded volcanic edifices of more evolved compositions reaching elevations greater than 3,000 m. Lavas and related pyroclastic deposits of this field are locally exposed over 500 km^2 and reflect eruption of predominantly mafic and intermediate composition magma, mainly between 5 and 1 Ma. No fewer than 55 distinct eruptive centers of the Taos Plateau volcanic field have been identified ranging from small volume (<1 cubic kilometer) cinder cones, to the largest centers such as Ute Mountain that record original eruptive volumes likely in excess of 12 km^3. Most of the eruptive centers in the Taos Plateau volcanic field are central-vent volcanoes ranging from low-relief shield centers and steep-sided breeched cinder cones to remnants of large composite volcanoes and lava domes. These lavas have from 48 to 68 weight percent SiO_2 and exhibit a strong correlation between landform and whole-rock chemistry. The low-silica, subalkaline basaltic lavas erupted from broad shield volcanoes and formed variably thin (<3–5 m) to thick (>15 m) low-viscosity flows that traveled far following paleotopography; conversely, transitional to mildly alkaline basalts and basaltic andesites formed thick (as much as 20 m) discontinuous lavas flows that erupted from high relief, dissected vents. Dacitic lavas form lava domes and large composite centers, often with poorly preserved stratigraphy, and rhyolite is restricted to steep-sided lava domes with associated small volume proximal pyroclastic deposits. $^{40}Ar/^{39}Ar$ ages are dominantly Pliocene (M.A. Cosca and J.P. Lee, unpub. data, 2013; Appelt, 1998).

Lithologic units were delineated on the basis of map distribution, stratigraphic position, petrography, geochemistry, $^{40}Ar/^{39}Ar$ geochronology and, in places, rock magnetic properties derived from field magnetic flux density measurements and aeromagnetic signature (Bankey and others, 2005). Volcanic rock names are based on the standard International Union of Geological Sciences (IUGS) classification scheme (Le Bas and others, 1986) modified by ferric/ferrous iron ratios as proposed by Middlemost (1989). Geochemical analyses of select samples are presented in table 2. Some volcanic units contain rocks of variable composition, spanning classification boundaries. In these cases, the dominant rock type was used for the unit name. Results of new $^{40}Ar/^{39}Ar$ age determinations are presented in unit descriptions. Select $^{40}Ar/^{39}Ar$ results are presented in table 3. Some map units consist of multiple deposits of limited extent that have been consolidated based on similar lithologic character, stratigraphic position, inferred age, and aeromagnetic signature. Colors of the lava flows and related deposits used in unit descriptions were determined by comparison with a Geological Society of America Rock-Color Chart (Munsell Color, 2009).

Tsb — **Servilleta Basalt (Pliocene)**—Black to dark-gray tholeiitic basalt to basaltic andesite (49–53 weight percent SiO_2) lava flows in western map area. Highly vesicular, having characteristic vesicle pipes and segregation trains; intergranular, seriate, weakly defined trachytic and diktytaxitic groundmass textures common with plagioclase, clinopyroxene, olivine, and oxides. Plagioclase (An_{70-50}) composes 60–80 percent of rock; grains are elongate ranging in size from 0.4 to 2.4 mm in length and less than 0.04–0.4 mm in width. Clinopyroxene ($En_{39-30}Fs_{16-22}Wo_{45-48}$) composes 15–20 percent of rock as phenocrysts, groundmass and as late stage ophitic to subophitic grains, grain size ranges 0.01–1.0 mm, generally light green to colorless, often with iddingsitized rims. Olivine (Fo_{66-58}) composes 5–15 percent of rocks as euhedral to anhedral phenocrysts, commonly skeletal, that average 0.3–0.4 mm, but as large as 1.5 mm and smaller than 0.2 mm. $^{40}Ar/^{39}Ar$ geochronology on samples (samples RGR–78 and RGR–62; table 3) from the Rio Grande gorge rim, west of Ute Mountain and south of Cerro Chiflo, yield interpreted ages of 3.43 ± 0.12 Ma and 3.19 ± 0.10 Ma respectively. Ages throughout the Taos Plateau volcanic field range from 2.4 to 5.3 Ma (M.A. Cosca and J.P. Lee, unpub. data, 2013; Appelt, 1998). Lava flow thickness commonly 3–5 m in the map area but is consistently thicker (>10 m) to the south, where exposed in the Rio Grande gorge near Taos, New Mexico

Ttb — **Trachybasalt (Pliocene)**—Gray, fine-grained trachybasalt (59 weight percent SiO_2) lava flows and associated near vent pyroclastic deposits including cinder, spatter and spatter agglutinate. Likely a small, eroded vent complex near the western edge of map area. Intergranular and weakly trachytic groundmass textures with 0.1–0.15 mm plagioclase and 0.01–0.02 mm pyroxene. Only phenocrysts of olivine present, about 5 percent of rock, as skeletal, euhedral and anhedral grains and fragments of euhedral grains ranging in size from 0.15 to 0.9 mm, with no alteration or minor iddingsitized rims and fractures. Appelt (1998) reports a $^{40}Ar/^{39}Ar$ date of 4.47 ± 0.06 Ma from this center (sample RA–102; table 3). Lava flows are thin (<3 m), but poorly exposed

Ttao — **Trachyandesite of Cerro de la Olla (Pliocene)**—Gray to black basaltic trachyandesite to trachyandesite (55–59 weight percent SiO_2; McMillan and Dungan, 1988). Distal lava flows erupted from prominent Cerro del Olla edifice southwest of map area. Groundmass with intersertal texture composed of glass, feldspar microlites, and opaque minerals. Phenocrysts include olivine, pyroxene, and plagioclase. Light-green olivine composes about 7–10 percent of rock as 0.2–1 mm euhedral to anhedral phenocrysts. Some grains show olivine cores with pyroxene overgrowths. Pyroxene grains are dark brown to black in hand sample and compose 3–5 percent of rock as 0.3–1 mm euhedral to anhedral grains. Plagioclase phenocrysts are more equant than highly elongate grains in groundmass and range in size from 0.1 to 0.5 mm. Glomerocrysts composed of olivine, pyroxene, and plagioclase are abundant and range in size from 0.5 to 4 mm. Sparse quartz xenocrysts observed as large as 2 mm. A $^{40}Ar/^{39}Ar$ date of 4.61 ± 0.16 Ma (sample RGR–305; table 3) obtained from Cerro de la Olla southwest of map area.Thin lava flows in map area (<2–3 m); flows thicken closer to edifice

Ttag — **Trachyandesite of north Guadalupe Mountain (Pliocene)**—Gray to black trachyandesite to trachyte (59–63 weight percent SiO_2) lava flows in the southeast map area. Groundmass with intersertal texture composed of glass, feldspar microlites, and opaque minerals. Phenocrysts include orthopyroxene, clinopyroxene, and feldspar in all samples; olivine present only in lowest stratigraphic flows sampled along the Rio Grande gorge. Enstatite ($En_{68-62}Fs_{31-37}Wo_{1-2}$) composes 3–7 percent of rock and occurs as isolated euhedral grains and fragments or within glomerocrysts where it is the sole constituent, or is associated with augite grains; occasionally enstatite grains are highly elongate up to 1.3 mm in length with 0.01 mm width; grain size is highly variable from 0.1 to 1 mm and glomerocrysts solely composed of enstatite are up to 3 mm. Augite ($En_{41-40}Fs_{17-19}Wo_{39-41}$) composes less than 1–5 percent of rock and occurs as isolated euhedral grains and fragments or within glomerocrysts where it is the sole constituent or is associated with enstatite; augite grains are commonly twinned including sector twins; grain size highly variable from 0.1 to 1 mm and glomerocrysts solely composed of augite up to 1 mm. Feldspar composes 1–7 percent of rock as highly elongate grains up to 1 mm length or as more tabular grains up to 0.2–0.4 mm width and 0.3–0.6 mm length. Olivine (Fo_{68-63}) only present in one sample but where present comprises 3 percent of rock as euhedral to anhedral grains commonly skeletal or with embayed boundaries; grains vary from no alteration to near complete replacement by iddingsite. $^{40}Ar/^{39}Ar$ geochronology on a sample 1.5 km south of quadrangle boundary indicates an age of 5.02 ± 0.05 Ma (sample RGR–6; table 3). An additional $^{40}Ar/^{39}Ar$ date of 5.02 ± 0.03 Ma obtained from lava flow in southwest part of map area (RGR–276, table 3). Distinguished from lava flows of south Guadalupe Mountain, on adjacent quadrangle to the south, by reversed aeromagnetic polarity. Thickness of lava flows typically 5–15 m

Tvc — **Dacite of Cerro Chiflo (Miocene)**—Pink to light-gray lava flow remnants and associated lava dome deposits of predominantly dacite composition (66–67 weight percent SiO_2) along south map border. Glassy groundmass with feldspar microlites and elongate amphibole grains up to 0.15 mm length and 0.01 mm width. Phenocrysts include amphibole, feldspar, biotite, and opaques. Amphibole composes about 15 percent of rock, is pleochroic from light brown to dark brown, euhedral to anhedral grains ranging in size from 0.2 to 1 mm, and some grains are skeletal or have resorbed edges. Feldspar phenocrysts are about 12–15 percent of rock; euhedral to subhedral grains range in size from 0.2 to 1 mm, rounded edges or embayed edges are ubiquitous. Biotite is minor, 1–3 percent of rock, with tabular grains ranging in size from 0.2 to 0.8 mm; strongly pleochroic from light brown to dark brown that produces anomalous interference colors. Rare, conspicuous orthopyroxene grains observed; tabular grains are pleochroic light green to tan. Parts of intrusion contain high proportions of schist and gneiss xenoliths. Lipman and Mehnert (1979) report K-Ar age determination for intrusion from biotite and plagioclase as 10.15 ± 0.53 Ma and 10.28 ±0.37 Ma, respectively. A $^{40}Ar/^{39}Ar$ date of 10.2 ± 1.0 Ma was obtained from the west flank of Cerro Chiflo (RGR–143, table 3). Base not exposed

INTRUSIVE ROCKS

Tmd — **Basaltic trachyandesite dike (Miocene)**—Gray, fine-grained basaltic trachyandesite (51 weight percent SiO_2) vertical, east-west trending dike approximately 30 m wide in southwest part of map area. Mapped until shows dike and local deposits adjacent to dike which likely represent erosional remnants of associated extrusive deposits. Intergranular and weakly trachytic groundmass texture with plagioclase, pyroxene, and opaques with grain size 0.02–0.2 mm. Phenocryst assemblage consists of pyroxene and olivine. Pyroxene, probably clinopyroxene, based on petrographic characteristics, composes up to 7 percent of rock as glomerocrysts and isolated phenocrysts; glomerocrysts 0.3 mm up to 1.5 mm in size with individual euhedral to anhedral grains 0.05–0.2 mm; isolated grains generally similar in size to grains in glomerocrysts but some grains up to 0.8 mm. Olivine composes 2 percent of rock as euhedral to subhedral grains with bimodal size distribution. Grains 0.15–0.3 mm are completely or nearly completely replaced by iddingsite, larger grains 1–2 mm have iddingsitized rims or are unaltered. A $^{40}Ar/^{39}Ar$ date of 17.63 ± 0.09 (sample RGR–145; table 3) was obtained from the dike interior

EXPLANATION

Contact

Normal fault—Dashed where approximately located, dotted where concealed; bar and ball on apparent downthrown side

RGR–22 • **Geochemical analysis sample location**—With sample number. See table 2 for values

CONVERSION FACTORS

Multiply	By	To obtain
millimeters	0.03937	inches (in.)
centimeters (cm)	0.3937	inches (in.)
meters (m)	3.281	feet (ft)
square meters (m^2)	10.76	square foot (ft^2)
kilometers (km)	0.6214	mile (mi)
square kilometer (km^2)	0.3861	square mile (mi^2)
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)

DIVISION OF QUATERNARY AND NEOGENE TIME USED IN THIS REPORT[1]

Period or subperiod	Epoch		Age
Quaternary	Holocene		0–11.7 ka
	Pleistocene	late	11.7–126 ka
		middle	126–781 ka
		early	781–2.59 Ma
Neogene	Pliocene		2.59–5.33 Ma
	Miocene		5.33–23.0 Ma

[1]Ages of time boundaries are those of the U.S. Geological Survey Geologic Names Committee (2010) except those for the late-middle Pleistocene and middle-early Pleistocene boundaries, which are those of Gibbard and others (2010). Ages are expressed in ka for kilo-annum (thousand years) and Ma for mega-annum (million years).

INTRODUCTION

The Sunshine 7.5' quadrangle is located in the south-central part of the San Luis Basin of northern New Mexico, in the Rio Grande del Norte National Monument (fig. 1), and contains deposits that record volcanic, tectonic, and associated alluvial and colluvial processes over the past four million years. Sunshine Valley, named for the small locale of Sunshine, is incised by a series of northeast-trending drainages cut into Tertiary and Quaternary alluvial deposits forming an extensive alluvial apron between the east flank of the Sangre de Cristo Mountains and the Rio Grande. These deposits predominantly overlie gently eastward-dipping lava flows of Pliocene Servilleta Basalt erupted from centers west of the map area. Servilleta Basalt lava flows terminate to the south against the elevated topography of three volcanic centers of the Taos Plateau volcanic field. From west to east these are Cerro de la Olla, Cerro Chiflo, and Guadalupe Mountain that are exposed in the southern part of the map area (fig. 2). Remnants of Miocene volcanic rocks are exposed near the southwestern edge of the map area and record evidence of an eroded volcanic terrain underlying deposits of the Taos Plateau volcanic field. These deposits are likely fault bounded to the east, roughly coincident with north to northwest trending, down-to-east faults in the southwestern quarter of the map area. The down-to-east normal faults reflect the basinward migration of the western margin of the Sunshine Valley sub-basin of the southern San Luis Basin (Ruleman and others, 2013).

Pliocene and younger basin deposition was accommodated along predominantly north-trending fault-bounded grabens and is preserved as poorly exposed fault scarps that cut lava flows of Ute Mountain volcano, north of the map area. The Servilleta Basalt and younger surficial deposits record largely down-to-east basinward displacement. Faults are identified with varying confidence levels in the map area. Recognizing and mapping faults developed near the surface in relatively young, brittle volcanic rocks is difficult because: (1) they tend to form fractured zones tens of meters wide rather than discrete fault planes, (2) the relative youth of the deposits has resulted in only modest displacements on most faults, and (3) some of the faults may have significant strike-slip components that do not result in large vertical offsets that are readily apparent in offset of sub-horizontal contacts. Those faults characterized as "certain" either have distinct offset of map units or had slip planes that were directly observed in the field. Lineaments defined from magnetic anomalies form an additional constraint on potential fault locations.

The mapped distribution of units is based primarily on interpretation of U.S. Geological Survey (USGS) 1:40,000-scale, black-and-white, aerial photographs, U.S. Department of Agriculture (USDA) color orthoimagery, and 2012 GeoEye (*http://www.digitalglobe.com/resources/satellite-information*) satellite imagery. Most of the contacts on the map were transferred from the aerial photographs using a photogrammetric stereoplotter and subsequently field checked for accuracy and revised based on field determination of allostratigraphic and lithostratigraphic units. Determination of lithostratigraphic units in volcanic deposits was aided by geochemical data, $^{40}Ar/^{39}Ar$ geochronology, and aeromagnetic data (Bankey and others, 2005). Supplemental revision of mapped contacts was based on interpretation of USGS 1-meter orthoimagery. The geologic mapping was carried out in support of the USGS Rio Grande Basins Project, funded by the USGS National Cooperative Geologic Mapping Program.

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