



Conversion Factors

0.3937

cubic kilometer (km³) 0.2399

Altitude, as used in this report, refers to distance above the

kilometer (km)

foot (ft)

† Indicates sample location outside map area

SURFICIAL DEPOSITS ALLUVIAL ALLUVIAL POND COLLUVIAL COLLUVIAL DEPOSITS OF THE TAOS PLATEAU VOLCANIC FIELD > TERTIARY 5.33 Ma ≺ OLDER REGIONAL VOLCANIC AND VOLCANICLASTIC ROCKS 23.03 Ma ≺ **DESCRIPTION OF MAP UNITS** dominantly tholeitic basalt, but more complete sampling and compositional characterization of flows throughout the volcanic field reveal basaltic andesite to basaltic trachyandesite compositions that have been included in the Servilleta Basalt (Lipman and Mehnert, 1975, 1979; Dungan and others, 1986; Thompson and Lipman, 1994a). Within

the map area the designation of Servilleta Basalt is restricted to lavas with characteristics

described above and are classified as basalt or basaltic andesite on the IUGS total-alkali-

into informal members based on age, known or inferred source vent, composition, and

textural characteristics that, in some cases, are atypical of Servilleta Basalt elsewhere in

the Taos Plateau. The Servilleta Basalt members included here are the Rio San Antonio

(Tsr), Section 35 (Tse), Wissmath Craters (Tsw), and Pinebetal Mesa (Tsm) members.

prolific within the map area. Whole-rock compositions vary from basaltic to basaltic

andesite but also include mildly alkaline compositions ranging from trachybasalt to

basaltic trachyandesite (fig. 3). Xenocrysts are dominantly quartz and plagioclase but rare

xenocrystic pyroxene glomerocrysts are also observed. Grains identified as xenocrysts

generally demonstrate highly rounded or extensively embayed grain morphologies, and

morphologies with sharp grain boundaries and solid interiors, but mildly embayed grain

boundaries, particularly in olivine, are considered phenocrysts. In rocks with a continuous

plagioclase characteristically displays moderate- to well-developed, sieve-textured

range in grain morphologies, rounded grains with similar characteristics to euhedral

grains are taken into account in modal estimates of phenocrysts. This classification

ignores complexities in the magmatic system where phenocrysts formed at higher

temperature and pressure conditions can be resorbed as the magma ascends and cools,

which may explain the continuous range in grain morphologies from euhedral to highly

embayed as observed in some rocks. Nevertheless, without extensive investigations of

mineral chemistry, this approach to classify xenocrysts is reasonable for our descriptive

Glomerocrysts are frequently present in lava flows of the Taos Plateau volcanic

field. Unit descriptions do not categorize glomerocrysts separately relative to their modal

glomerocrysts. Although glomerocrysts may represent remobilization of either crystals

settled in a magma chamber or crystal accumulations along magma chamber walls, in

indistinguishable from isolated grains. In cases where grains within glomerocrysts are

Xenocrystic basalt of Hill 8489 (early Pleistocene)—Black to dark gray,

moderately vesicular and porphyritic basalt (51 weight [wt.] percent

silicon dioxide [SiO₂]; table 1) lava flows and near-vent pyroclastic

deposits (not on map). Phenocrysts include 4–6 percent elongate to

anhedral olivine with minor iddingsite replacement, up to 1.8 mm; and

plagioclase, olivine, and orthopyroxene are common. Up to 2 percent

xenocrysts that include clear quartz grains mostly 1–5 mm, although

voids in glomerocrysts and plagioclase xenocrysts. Groundmass is

some grains are larger, and plagioclase 1–10 mm. Biotite is present but is

aphanitic to glassy and composed of glass, plagioclase, opaque and other

mafic minerals. Flows are preserved in the southeast corner of the map

and near-vent deposits are preserved east of the map boundary near the

northeast flank of No Agua Peaks. Outflow was mostly east-northeast of

trachyandesite (55 wt. percent SiO₂) lava flows and near-vent pyroclastic

orthopyroxene that is weakly pleochroic from light green to light brown,

0.4–1.2 mm, and rare clinopyroxene and opaque mineral pseodomorphs

after olivine. Opaque mineral pseudomorphs of euhedral and embayed

olivine are up to 0.5 mm and associated with orthopyroxene grains in

glomerocrysts. Xenocrysts are about 1 percent and include plagioclase,

trachytic and intersertal textures is composed of plagioclase, pyroxene,

0.4–8 mm, and quartz up to 2.5 mm. Fine-grained groundmass with

glass, olivine, and opaque minerals. Vent area is located on northeast

flank of San Antonio Mountain. Lipman and Mehnart (1979) report a

from lava near the vent is 2.78±0.05 Ma (RGR–009; table 2)

minor interbedded lava flow material

Near-vent pyroclastic deposits—Cinder and spatter agglutinate with

Lava flows—Massive lava flows 5- to 10-m-thick. A distinct flow lobe

extends to northeast nearly 7 km from the vent area and may be a

Basaltic trachyandesite of Red Hill (Pliocene)—Dark gray, vesicular to

percent tabular to highly elongate plagioclase up to 1 mm that is

occasionally intergrown with olivine; 1 percent euhedral to anhedral

olivine, 0.1–0.4 mm, with iddingsitized cores in euhedral grains and

often highly skeletal grains with little or no iddingsite alteration in

boundary composed entirely of iddingsitized grains that may have

anhedral grains; less than 1 percent orthopyroxene, 0.2–0.4 mm, with

slight pleochroism from tan to light pink, and reaction rims at the grain

originally been olivine or clinopyroxene; and less than 1 percent tabular

clinopyroxene, up to 0.6 mm, with only slightly rounded grain boundar-

ies. Fine-grained to aphanitic groundmass with intergranular and weakly

developed trachytic textures composed of plagioclase, opaque minerals,

and pyroxene. Vent is marked by a large cinder cone at Red Hill about 5

Near-vent pyroclastic deposits—Cinder and spatter agglutinate with

Rio San Antonio member of Servilleta Basalt (Pliocene)—Black, moder-

anhedral to euhedral olivine, 0.1–0.8 mm. Plagioclase is likely a

minor interbedded lava flow material. Cinder cone is being quarried

Lava flows—Massive lava flows 3- to 5-m-thick. At least two flows extend

ately vesicular to non-vesicular, sparsely phyric basaltic andesite (51–52

wt. percent SiO₂). Phenocrysts include 5–10 percent microphenocrysts of

phenocryst phase as well but a distinction cannot be made from ground-

mass based on inspection of thin section alone. Groundmass is medium

grained with intersertal, intergranular, and occasionally weakly trachytic

but equant to tabular grains not uncommon; mostly devitrified glass; and

textures and composed of elongate plagioclase up to 2.5 mm in length,

subophitic clinopyroxene, up to 1.5 mm. Tsr lavas may have erupted

from a single vent or multiple vents approximately coeval as all lavas

may be a circular depression northwest of San Antonio Mountain;

mapped as Tsr occupy the same stratigraphic position. One possible vent

however, flows are higher in elevation south of the depression, suggesting

Tsr flows may have erupted from multiple vents or were tilted eastward

after emplacement. Flow thickness 3–8 m. Whole-rock 40Ar/39Ar age for

sample from northwest of San Antonio Mountain indicates an age of

Upper dacite of San Antonio Mountain (Pliocene)—Black to gray, non-ve-

sicular to moderately vesicular, sparsely porphyritic dacite to trachydacite

(63–65 wt. percent SiO₂) lava flows and near-vent pyroclastic deposits.

slightly pleochroic from light green to light brown and often with darker

brown cores, 0.2–0.4 mm; and 1–2 percent elongate to tabular plagioclase

up to 0.5 mm in long dimension. Orthopyroxene often occurs in glom-

erocrysts. Fine-grained to glassy groundmass with weakly trachytic to

felty texture and composed of glass, plagioclase, pyroxene, and opaque

minerals. Lipman and Mehnart (1979) report a whole-rock K-Ar age of

3.12±0.17 Ma. The preferred whole-rock ⁴⁰Ar/³⁹Ar age sampled from a

black glass to highly oxidized red flow material. Marks late-stage vent

central vent area. Typical flow structure is black and glassy at base of

flow; light gray and fine grained in the middle; and coarse breccia top

fine-grained, and highly to moderately vesicular, sparsely porphyritic

1–3 percent subhedral orthopyroxene often with slightly rounded grain

rachyandesite (63–64 wt. percent SiO.) lava flows. Phenocrysts include

Miocene and Oligocene

flow on the north flank of San Antonio Mountain is 2.9±0.3 Ma

Near-vent pyroclastic deposits—Cinders and spatter with interlayered

Lava flows—Lava flows up to 30-m-thick that radiate outward from a

with red, highly oxidized and black, glassy blocks. Eppler (1976)

provides a more detailed discussion of the internal flow structure

Lower trachyandesite of north San Antonio Mountain (Pliocene)—Black,

area along the southern peak of San Antonio Mountain

Phenocrysts include 2 percent euhedral to subhedral orthopyroxene,

over 4 km from the vent area to south-southeast. At least three more

along U.S. 285 is 2.81±0.04 Ma (RGR–017; table 2)

proximal flows extend to the west and north

2.94±0.12 Ma (RGR–012; table 2)

(RGR-010 [no. 1]; table 2)

km south of San Antonio Mountain. Whole-rock 40 Ar/39 Ar age for sample

compound single flow. A second flow is more proximal to the vent area

non-vesicular, porphyritic basaltic trachyandesite (51 wt. percent SiO₂)

lava flows and near-vent pyroclastic deposits. Phenocrysts include 5–6

potassium-argon (K-Ar) age of 2.24±0.15 Ma. Whole-rock ⁴⁰Ar/³⁹Ar age

deposits. Up to 1 percent phenocrysts that include a combination of

vent area where it flowed over 13 kilometers (km) from the vent.

Whole-rock ⁴⁰Ar/³⁹Ar age is 2.12±0.02 Ma (RGR–421; table 2).

Xenocrystic trachyandesite (Pliocene)—Dark gray, sparsely porphyritic

likely a secondary mineral as grains are only in some small vesicles and

tabular plagioclase, 0.3–2 mm in length; 4–6 percent euhedral to

less than 1 percent anhedral orthopyroxene. Glomerocrysts of

percentage. Rather, modal phenocryst percentages include contributions from

general, phenocrysts that compose the glomerocrysts are petrographically

distinct from isolated grains, the glomerocrysts are identified as xenocrystic.

interiors. Grains interpreted as primary phenocrysts generally display euhedral

Xenocrystic lavas, less common in other parts of the Taos Plateau volcanic field, are

silica classification diagram (LeBas and others, 1986). The Servilleta Basalt is subdivided

CORRELATION OF MAP UNITS

[Due to the addition of a shaded relief base, colors in the Correlation of Map Units and the Description of Map Units may not exactly match unit colors on the map SURFICIAL DEPOSITS

The surficial units on this map are informal allostratigraphic units of the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2005). Mapped surficial deposits are known or estimated to be at least 1 meter (m) thick. Ages of time boundaries are those of the U.S. Geological Survey Geologic Names Committee (2018) except those for the middle-early Pleistocene and late-middle Pleistocene boundaries, which are those of Gibbard and others (2010). 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. Stages of secondary calcium carbonate morphology (referred to as stages I and II that are formed 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

between stream-flow and debris-flow deposits. Eolian deposits are present in the map area but are isolated deposits that are too small to show at the scale of the map. Much of the silty sheetwash alluvium (Qsw) frequently observed on Pliocene lava flows and much of silty fine sand in the matrix of colluvium (Qc) probably is derived chiefly from silty eolian sand. The latter may have been derived in part from silty fine sand eroded from the Los Pinos Formation and was deposited on sparsely vegetated, actively aggrading floodplains of the Rio de los Piños and other major streams within and near the map area. The sparsely vegetated, silty fine sand on these floodplains probably was later deflated and transported by strong winds and deposited as

hyperconcentrated flow deposits. These latter deposits are intermediate in character

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 "clasts" refers to particles larger than 2 millimeters (mm) in diameter, whereas all finer material is called "matrix." Most of the clasts in fan deposits (Qf) within the map area are very angular, whereas most of those in alluvial deposits are very angular to subrounded ALLUVIAL DEPOSITS

Stream alluvium (Holocene and late Pleistocene)—Mostly sand and gravel in stream channels as well as sand, silty sand, and gravel underlying adjacent floodplains and minor low stream terraces. Stream-channel deposits along the Rio de los Piños are composed of slightly bouldery, cobbly pebble gravel. Top of unit Qa is about 1–2 m above modern stream level. Unit Qa locally includes small fan deposits (Qf) and narrow aprons of sheetwash alluvium (Qsw) along valley margins. Low-lying deposits are prone to periodic stream flooding. Estimated thickness 1–5 m along the Rio de los Piños, 1–3 m along other streams Sheetwash alluvium (Holocene and late Pleistocene)—Chiefly slightly pebbly to pebbly, slightly silty to silty sand in aprons that overlie gentle

slopes on Pliocene lava flows near northeastern corner of the map area.

periodic stream flooding; adjacent slopes may be subject to periodic

Unit Qsw locally includes deposits of stream alluvium (Qa) that are too small to show at map scale. Much of the silt- to fine-sand-size fraction in these deposits is likely to be of eolian origin. Low-lying areas of unit Qsw are susceptible to sheet flooding due to unconfined overland flow. Estimated thickness is 1–5 m neetwash alluvium and stream alluvium, undivided (Holocene and late **Pleistocene**)—Chiefly silty and sandy sheetwash deposits (Qsw) on gentle slopes and undifferentiated sandy and pebbly stream alluvium (Qa) along and near ephemeral streams mainly on Pliocene lava flows and Los Pinos Formation in the eastern part of the map area. Low-lying areas of unit Qsa in and adjacent to stream channels may be subject to

ALLUVIAL AND POND DEPOSITS Sheetwash alluvium and pond deposits, undivided (Holocene and late **Pleistocene**)—Composed chiefly of silty fine sand that accumulated in circular depressions commonly on Pliocene lava flows in the central part of the map area. Much of the unit consists of eolian sediment that was redeposited by unconfined overland flow as sheetwash alluvium (Qsw) or as lacustrine sediment in small ephemeral water bodies. Unit locally may contain marsh deposits. Low-lying areas of unit may be subject to periodic inundation by sheet flooding and ponded water. Estimated thickness is 1–5 m, possibly locally as much as 10 m

sheet flooding. Estimated thickness is 1–5 m

ALLUVIAL AND COLLUVIAL DEPOSIT Fan deposits (Holocene to middle? Pleistocene)—Unit forms an extensive sedimentary apron that was deposited by debris flows and sedimentcharged, ephemeral streams along the lower flanks of San Antonio Mountain. Unit commonly consists of clast- and matrix-supported, locally bouldery, pebbly and cobbly gravel with a silty sand matrix. Near the lower part of the fan apron, deposits locally consist of pebbly and cobbly, slightly silty sand that contains gravel lenses. Rock fragments in deposits of unit Qf are composed of dacite (Tau) eroded from San Antonio Mountain. Eolian sediment may have played an important role in the genesis of debris-flow deposits (Shroba and others, 2007). Stage I and weak stage II carbonate morphology on the bottom of clasts in deposits of unit Qf suggests that these deposits accumulated during the Pinedale glaciation (see table 2 in Machette, 1985), about 12–30 ka (Nelson and others, 1979; Benson and others, 2004, 2005, and references cited therein). Some of the deposits could be as old as 40–47 ka (Cole and others, 2007), and may have been deposited during an early advance of Pinedale ice (Sturchio and others, 1994). Unit locally may include small fan deposits of middle Pleistocene age. Near the lower part of the fan apron, unmapped deposits of sheetwash alluvium (Qsw) and stream alluvium (Qa), too small to show at map scale, locally overlie or are inset into deposits of unit Qf. Low-lying areas adjacent to stream channels are prone to periodic stream flooding and debris-flow deposition. Estimated thickness is 1–10 m

COLLUVIAL DEPOSIT Colluvium, undivided (Holocene to middle? Pleistocene)—Deposits of 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 cobbly and bouldery rubble with a sandy matrix. Unit Qc consists chiefly of debris-flow, rock-fall, and creep deposits, as defined by Cruden and Varnes (1996). Unit locally includes small talus deposits on the upper flanks of San Antonio Mountain, and mass-movement (periglacial?) deposits above an altitude of 9,957 feet (ft) near the head of a small valley on the southeast side of San Antonio Mountain near the summit. Maximum thickness possibly about 15 m

DEPOSITS OF THE TAOS PLATEAU VOLCANIC FIELD The Taos Plateau volcanic field (Lipman and Mehnert, 1979) is a basaltic to rhyolitic, Pliocene to Pleistocene volcanic field underlying the Taos Plateau. The volcanic field is predominantly basaltic with lesser intermediate and rhyolitic compositions that erupted from no fewer than 55 distinct vents. The Taos plateau occupies the southern San Luis Basin in northern New Mexico and southern Colorado and is bordered on the east by the Sangre de Cristo Mountains and on the west by the Tusas Mountains and southeastern San Juan Mountains (fig. 1).

Within the map area, rock compositions include basalt to rhyolite (fig. 3; table 1) and range in age from 4.55–2.12 Ma (table 2). At least 15 exposed vent areas are known, or inferred, that vary from low-relief shields to the steep-sided volcano at San Antonio Mountain, which is composed of glassy dacite lava flows and a summit cinder cone (fig. 2; Eppler, 1976; Thompson and Lipman, 1994a, b). Volcanic edifices composed of basaltic trachyandesite with vent areas concealed by overlying upper dacite of San Antonio Mountain (Tau) may represent cogenetic precursors to the dacite lavas; however, a more thorough investigation is needed to confirm this relationship. Olivine tholeiitic basalt of the Servilleta Basalt is the most voluminous volcanic rock in the Taos Plateau volcanic field. Ages throughout the Taos Plateau range from 5.3 Ma to about 1 Ma (Lipman and Mehnert, 1979; Appelt, 1998; Thompson and others, 2015). The low viscosity olivine tholeiitic basalts were emplaced as floods from low-relief shield

volcanoes throughout the Taos Plateau and share general characteristics: flow thickness

generally less than 10–12 m; olivine phyric; rarely xenocrystic; vesicular segregrations in

the form of vertical pipes and (or) horizontal planes; and groundmass that is usual

medium grained with moderate to well-developed diktitaxitic texture. Composition is

intersertal textures common and composed of, in decreasing order of abundance, glass, plagioclase, pyroxene, and opaque minerals. Exposures limited to the north flank of San Antonio Mountain. Lavas may represent an earlier eruptive episode preceding the main dacitic volcano building event based on similar composition and nearly identical phenocryst content and character. The preferred whole-rock ⁴⁰Ar/³⁹Ar age is 2.91±0.07 Ma (RGR–231; table 2) ower trachyandesite of south San Antonio Mountain (Pliocene)—Black, parsely porphyritic trachyandesite (55–56 wt. percent SiO₂) lava flows Phenocrysts include 1–2 percent elongate to tabular and rarely equant plagioclase, 0.4–1.5 mm; 1 percent anhedral and embayed olivine, 0.1–0.7 mm; and rare tabular to irregular grains of clinopyroxene (much less than 1 percent), up to 0.5 mm. Occasionally, plagioclase phenocrysts are intergrown with olivine and clinopyroxene. Olivine preserved within plagioclase also exhibits embayed grain boundaries. Fine-grained to

glassy groundmass where intersertal texture is dominant but weekly

trachytic to felty textures present and composed of plagioclase, glass,

boundaries, slightly pleochroic from light green to light brown and often

with a darker brown core, 0.4–0.8 mm; and less than 1 percent tabular

plagioclase, mostly 0.5 mm. Orthopyroxene often occurs in glomero-

Fine-grained to glassy groundmass with weakly trachytic to felty and

crysts. Xenocrysts of quartz are rare but can be greater than 1 mm.

pyroxene, and opaque minerals. Unit is exposed only on south and southeast flanks of San Antonio Mountain. Whole-rock 40 Ar/39 Ar geochronology indicates age of 3.00±0.04 Ma (RGR-133; table 2) Section 35 member of Servilleta Basalt (Pliocene)—Black, sparsely phyric basalt (50–51 wt. percent SiO₂) lava flows. Basalt is equigranular and medium grained and as a result phenocryst determination other than olivine is unclear. Olivine phenocrysts 5–7 percent as euhedral to anhedral grains, 0.2–1 mm. Groundmass exhibits well-developed diktytaxitic, intergranular, and intersertal textures and is composed of elongate plagioclase, 0.2–2.5 mm; equant clinopyroxene, 0.1–0.5 mm; opaque minerals; and brown to completely devitrified glass. Source of lava flows is undetermined but is inferred to be buried beneath the eastern flank of San Antonio Mountain or the alluvial fans that extend east from San Antonio Mountain based on lava distribution. The lava flows overlie flows of the Wissmath Craters member of the Servilleta Basalt (Tsw) east of the map boundary. Lava flow thickness about 10 m Wissmath Craters member of Servilleta Basalt (Pliocene)—Black,

sparsely vesicular, porphyritic basalt to basaltic andesite lava flows (48–52 wt. percent SiO₂). Phenocrysts include 1–5 percent euhedral to irregular olivine, less than 2.8 mm, irregular grains with sometimes highly embayed boundaries suggesting some grains may be xenocrystic; 2–7 percent plagioclase with sharp grain boundaries and solid interiors. Glomerocrysts of plagioclase and olivine present in some samples. Less than 1 percent xenocrysts that include plagioclase, up to 6 mm, mostly with highly developed sieve-textured interiors and a thin mantle, but also present as large solid-cored grains with highly embayed grain boundaries; and orthopyroxene with irregular grain boundaries rimmed by clinopyroxene (Dungan, 1987). Aphanitic to medium-grained groundmass with intergranular texture and patchy subophitic pyroxene that forms a mottled appearance in thin section. Groundmass composed of plagioclase, pyroxene, olivine, opaque minerals, and minor glass. Lavas are compositionally similar despite the range in SiO, and are interpreted to have erupted from a central vent marked by the depression at Wissmath Craters located immediately east of the eastern map boundary (fig. 2). However multiple source vents could explain the petrographic variability and range in SiO content Additionally e U.S. 285 northwest of No Agua Peaks (fig. 1), a thin sedimentary interbed separates compositionally similar lavas indicating a hiatus in eruption, which could indicate multiple sources. Lava flows are observed stratigraphically above xenocrystic basaltic andesite of La Segita Peaks (Tls) in the southern part of Wissmath Craters. Flows associated with Wissmath Craters shield within the map area are over 6 km southwest of the crater, but east of the map area, flows extend 10 km east of Wissmath Craters. Whole-rock 40 Ar/39 Ar age from sample in the southwest area of

the map near U.S. 285 is 3.20±0.05 Ma (RGR–235; table 2) Xenocrystic basaltic andesite of La Segita Peaks (Pliocene)—Black, moderately vesicular, sparsely porphyritic basaltic andesite (53–55 wt. percent SiO₂) lava flows and red, scoriaceous near-vent pyroclastic deposits (east of map area). Phenocrysts include 1–2 percent euhedral to subhedral olivine, 0.2–1.3 mm. Up to 2 percent xenocrysts that include plagioclase with solid cores surrounded by fine sieve texture and thin mantle at outer grain boundary; and quartz grains up to 6 mm. Groundmass exhibits intersertal to intergranular textures and is composed of plagioclase, pyroxene, olivine, glass, and opaque minerals. Vent area is inferred from thick accumulation of near-vent scoriaceous deposits and agglutinated spatter that underlie most of the high points at La Segita Peaks located immediately east of the eastern map boundary. Unit extends to the southwest but is mostly concealed below Wissmath Craters member of the Servilleta Basalt (Tsw). 40Ar/39Ar geochronologic analysis on a whole-rock sample resulted in discordant data and therefore is not reported in table 2. However, analytical results are reported in the data release that supports this report (sample RGR–135, Turner and

Pinebetal Mesa member of Servilleta Basalt (Pliocene)—Gray, moderately vesicular, sparsely phyric to porphyritic basalt lava flows (49 wt. percent SiO₂). Rock is generally coarse grained and equigranular rendering phenocryst determination in most samples difficult with the exception of a sample from the depression rim at the main shield, which is porphyritic with a fine-grained to aphanitic groundmass. Phenocryst percentages based on porphyritic sample include 10–15 percent elongate plagioclase, 0.2–5 mm, that are occasionally intergrown with olivine and other plagioclase; and 7–10 percent subhedral to anhedral olivine, 0.1–2 mm, occasionally with moderately embayed grain boundaries. Samples with coarse-grained groundmass exhibit diktytaxitic, intergranular, and intersertal textures and are composed of platy plagioclase, up to 8 mm; subophitic pyroxene; glass, usually devitrified; and opaque minerals. Vent area for some lava flows is a shield with a central depression located northwest of San Antonio Mountain on Pinabetal Mesa. Flows may also have erupted from north-aligned depressions west of the main shield. Some lavas flowed south from the main vent where they ponded in paleotopographic lows and formed flows 20–30 m thick where exposed along the Rio San Antonio. Most lavas flowed north and northeast of the vent area for at least 10 km, at which point they are concealed by overlying Rio San Antonio member of Servilleta Basalt (Tsr). One lava tube is known to exist on Pinabetal Mesa, accessed through a collapsed ceiling at Cisneros Mine (Rogers and others, 2000). Flows in the northeastern corner of the map are also distinctly coarse grained and occupy the same stratigraphic position so are included in the Pinabetal Mesa member of the Servilleta Basalt; although, it is unknown if these lavas erupted from the same vent. With exception of ponded lava flows, flow thickness generally 5–10 m. Whole-rock 40 Ar/ 39 Ar age is 3.33±0.14 Ma (RGR–013;

others, 2018)

Antonio Mountain Basaltic trachyandesite of Los Cerritos de la Cruz (Pliocene)—Gray to black, vesicular to nonvesicular, porphyritic basalt to trachyandesite (51–57 wt. percent SiO₂) lava flows and near-vent pyroclastic deposits. Phenocrysts are difficult to distinguish because of high xenocryst content, but grains interpreted to be phenocrysts are cumulatively 2–3 percent and include tabular to elongate plagioclase, 0.5–1.5 mm, with either sharp or only slightly rounded grain boundaries; euhedral to anhedral grains and grain fragments of olivine, 0.2–1.5 mm, with moderately to highly embayed grain boundaries and resorbed interiors suggesting some olivine may be xenocrystic; and rare euhedral clinopyroxene, up to 1.5 mm. Xenocrysts are up to 7 percent of rock and include plagioclase and alkali feldspar 5 mm and larger; rounded quartz, 3 mm and larger (Thompson and Lipman, 1994b); orthopyroxene, 0.5–1 mm, with grain boundaries rimmed by clinopyroxene; and glomerocrysts usually consisting of 20 or more grains of 0.5 mm clinopyroxene. Very fine grained groundmass with intersertal to intergranular textures composed of plagioclase, pyroxene, olivine, and sparse glass. North and south cinder cones mark vent areas. Mapped as a single unit because stratigraphic order between outflow from north and south vents could not be established in the field and eruptive activity is inferred to be similar in age; however, aeromagnetic data indicate normal polarity for the south cone but reversed polarity for the north cone indicating some amount of elapsed time between eruptions of the north and south cones (Drenth and others, 2011). Whole-rock ⁴⁰Ar/³⁹Ar age on lava flow located between north and south cones is 3.36±0.05 Ma (RGR–015; table 2)

table 2) on a sample from the rim of Rio San Antonio west of San

lava flow material preserved at two cones **Lava flows**—Multiple lava flows 3–8 m thick originating from both vent areas Basaltic andesite of Rio de los Piños (Pliocene)—Gray, sparsely vesicular, porphyritic basalt to basaltic andesite (50–53 wt. percent SiO₂) lava flows and near-vent pyroclastic deposits. Phenocrysts include 2–4 percent tabular to elongate plagioclase up to 2 mm with occasionally rounded grain boundaries; and 1–3 percent anhedral to subhedral olivine 0.1–1.2 mm, some grains exhibit skeletal morphologies or are slightly embayed, and iddingsite replacement varies from moderate to none. Glomerocrysts of plagioclase and olivine are ubiquitous. Less than 1 percent xenocrysts of plagioclase (2.5 mm) and quartz (3 mm). Fine-grained groundmass with intergranular, moderate- to well-developed trachytic texture, and patchy subophitic pyroxene results in a mottled appearance. Groundmass composed of plagioclase, subophitic pyroxene, olivine, opaque minerals, and sparse glass. Flows originated from a single vent area at an unnamed hill north of the Rio de los Piños. Lavas that flowed to the northeast extend over 10 km from the main vent, drape older Valdez Tank lava flows (Tb), and appear to have filled a paleochannel. Lavas that flowed east rest on basaltic andesite of Cañada los Ranchos (Tca) south of the Rio de los Piños. Lavas are difficult to differentiate from Valdez Tank lavas in hand sample but basalt of Rio de los Piños has fewer plagioclase xenocrysts, occasionally has quartz xenocrysts, and lacks pyroxene phenocrysts. Preferred whole-rock 40 Ar/ 39 Ar age is 3.39 \pm 0.04 Ma (RGR–374; table 2) Near-vent pyroclastic deposits—Cinder and spatter agglutinate with

minor lava flow material

Table 2. Summary of ⁴⁰Ar/³⁹Ar geochronologic ages.

Sample ID Easting Northing Map Unit

RGR-009

RGR-035

RGR-014

Near-vent pyroclastic deposits—Cinder and spatter agglutinate and minor

Lava flows—Multiple lava flows from 5- to 10-m-thick Basaltic andesite of Cañada los Ranchos (Pliocene)—Black to dark gray, moderately vesicular to highly vesicular, porphyritic basaltic andesite (52–53 wt. percent SiO₂) lava flows. Phenocrysts include 2–3 percent euhedral to anhedral olivine, 0.2–1 mm, skeletal grains are common and some grains exhibit embayed grain boundaries; 1–2 percent elongate plagioclase, 0.5-1 mm. Xenocrysts (less than 1 percent) include plagioclase up to 3 mm, quartz up to 0.6 mm and rare (only observed in one thin section) elongate orthopyroxene, 0.2–0.6 mm, with rounded grain boundaries and rimmed by clinopyroxene. Fine-grained to glassy groundmass with trachytic, intersertal and intergranular textures common and patchy subophitic pyroxenes result in a mottled appearance in thin section. Groundmass composed of plagioclase, pyroxene, glass, olivine, and opaque minerals. Main vent is located near western map boundary, north of Rio San Antonio, where a circular depression is at the summit of

a low-angle shield. At least seven moderately oxidized, highly vesicular, 1- to 2-m-thick flows are exposed in the wall of the depression. Northeast of the main vent area along the Rio San Antonio gorge is a dike associated with minor cinder deposits interlayered with lava flows indicating a possible fissure eruption linked with the main vent. Flows extend at least 16 km to the northeast. Preferred whole-rock ⁴⁰Ar/³⁹Ar age is 3.32±0.06 Ma (RGR-221; table 2). Although the mean age is younger than overlying basaltic andesite of Rio de los Piños (Trl), the ages are indistinguishable within analytical error suggesting the units were erupted at about the same time

415631 4069545 Tbx Xenocrystic basalt of Hill 8489

411835 4084940 Tlx Xenocrystic trachyandesite

RGR-012 406854 4084244 Tsr Rio San Antonio member of Servilleta Basalt

407415 4077090 Tau Upper dacite of San Antonio Mountain

399646 4090465 Trl Basaltic andesite of Rio de los Piños

405826 4086085 Tca Basaltic andesite of Cañada los Ranchos

410159 4082952 Tan Lower trachyandesite of north San Antonio Mountain

410590 4073355 Tas Lower trachyandesite of south San Antonio Mountain

Tna Rhyolite of No Agua Peaks*

403003 4093022 Tb Basalt and basaltic andesite of Valdez Tank (basaltic andesite)

398025 4091882 Tb Basalt and basaltic andesite of Valdez Tank (basalt)

392235 4108018 Thl Hinsdale Formation, alkaline basalt to basaltic trachyandesite

398841 4091038 Tbc Basalt and basaltic andesite of Valdez Tank (basaltic andesite)

Tna Rhyolite of No Agua Peaks

412885 4073069 Tsw Wissmath Craters member of Servilleta Basalt

404240 4079557 Tsm Pinabetal Mesa member of Servilleta Basalt

404862 4075955 Tcx Basaltic trachyandesite of Los Cerritos de la Cruz

RGR-010 (no. 1) 408888 4083000 Tau Upper dacite of San Antonio Mountain

RGR-010 (no. 2) 408888 4083000 Tau Upper dacite of San Antonio Mountain

RGR-149 (no. 1) 399235 4091508 Trlc Basaltic andesite of Rio de los Piños

RGR-149 (no. 2) 399235 4091508 Trlc Basaltic andesite of Rio de los Piños

RGR-131[†] 399410 4080612 Tca Basaltic andesite of Cañada los Rancho

400749 4089240 Tcb Basalt of Chino Peak

400691 4087852 Tcbc Basalt of Chino Peak

403603 4072691 Tlb Basalt of Lucero Lake

RGR-466 396803 4091475 Ttc Chiquito Peak Tuff

† indicates sample location outside map area.

402621 4092353 Tht Hinsdale Formation, tholeitic basalt

388663 4076306 Tht Hinsdale Formation, tholeiitic basalt

395099 4073140 Thb Hinsdale Formation, basaltic andesite

399855 4077961 Thp Hinsdale Formation, porphyritic basalt

RGR-017† 412362 4066591 Trx Basaltic trachyandesite of Red Hill

Map Unit Name

Rhyolite of No Agua Peaks (Pliocene)—Gray to pale brown perlitized rhyolite (73 wt. percent SiO₂) flows, tuffs, and breccias. Lava flows are commonly flow banded, include obsidian to microcrystalline groundmass, and have onionskin and perlitic fracture textures. Degree of vesiculation varies from 2–20 percent of rock, where less vesicular varieties are generally less perlitized (Neart and others, 1980). Phenocrysts (xenocrysts?) include alkali feldspar as euhedral grains and irregular fragments. Previous investigations suggest No Agua rhyolites erupted from 1–4 vents (Neart and others, 1980; Lipman and Mehnert, 1979; Whitson, 1982; Breese, 1984; Chamberlin and Barker, 1996). No Agua rhyolite is present in the southeastern corner of the map area with all

inferred vents located southeast of the map boundary. Dickens (2007) determined ⁴⁰Ar/³⁹Ar ages based on laser fusion of glass and feldspar separates indicating temporally distinct eruptive episodes at 3.88±0.06 and 4.1±0.03 Ma. Some single-grain laser-fusion ages determined on alkali feldspar yielded ages of 25.35±0.13 Ma, which Dickens (2007) suggests indicates incorporation of feldspar xenocrysts from an Amalia Tuff-related source Basalt of Chino Peak (Pliocene)—Gray to black, moderately vesicular and

porphyritic basalt (49–50 wt. percent SiO₂) lava flows and near-vent pyroclastic deposits. Although range in SiO₂ content is narrow, lavas included in map unit have substantial variability in wt. percent magnesium oxide (MgO), potassium oxide (K₂O), and numerous trace elements including rubidium (Rb), niobium (Nb), and lanthanum (La). Petrographically, rocks are broadly similar. Phenocrysts include 1–4 percent euhedral to anhedral, and commonly skeletal, olivine, 0.1 to 2.5 mm; 1 percent tabular to elongate plagioclase, 0.1 to 1 mm. Sparse xenocrysts include plagioclase and orthopyroxene where grain boundary is irregular and mantled by completely iddingsitized olivine(?) grains. Mediumgrained to aphanitic groundmass with intergranular to rarely intersertal texture composed of plagioclase, pyroxene, olivine, and opaque minerals. Micro enclaves of quenched melt inclusions that consist dominantly of brown glass, opaque minerals, elongate plagioclase and pyroxene are present in samples with greater than 8.0 wt. percent MgO (8.04–9.55) and wt. percent K₂O less than 0.5 (0.43–0.49). Samples with wt. percent MgO less than 7.0 (5.95–6.77) and wt. percent K₂O greater than 0.9 (0.9–1.02) do not contain enclaves of melt inclusions. Two compositionally transitional samples with 7.40–7.95 wt. percent MgO and 0.75–0.77 wt. percent K₂O also contain enclaves of melt inclusions. These compositional and petrographic characteristics may indicate a magma mixing relationship. A single vent area is identified by a cinder cone at Chino Peak; however, highly oxidized cinders and agglutinate are located northwest of the cinder cone just east of a small fault. The preferred whole-rock ⁴⁰Ar/³⁹Ar age is 4.31±0.07 Ma (RGR–014; table 2) from a sample of lava with MgO less than 7.0 wt. percent that is interbedded

within the cinder cone Near-vent pyroclastic deposits—Cinder and spatter agglutinate and minor lava flow material Lava flows—Multiple flows originating from vent area up to 18-m-thick

where exposed along the Rio de los Piños

Basalt and basaltic andesite of Valdez Tank (Pliocene)—Black to gray, weakly to moderately vesicular, porphyritic basalt to basaltic andesite lavas and near-vent pyroclastic deposits. Unit includes three compositional groups that form a broadly continuous progression in composition and possess similar petrographic characteristics; lava types include basalt (48–51 wt. percent SiO₂), silicic basalt (50–51 wt. percent SiO₂), and pasaltic andesite-basaltic trachyandesite (51–55 wt_percent SiO) Finegrained to aphanitic groundmass composed of plagioclase, clinopyroxene, opaque minerals, olivine, and sparse minor glass. Seriate texture common in low-silica basalt and shows continuous grain size from less than 0.05 mm up to 1.5 mm. Porphyritic, intergranular, and trachytic texture common in all types with groundmass up to 0.5 mm and phenocrysts up to 1.5 mm. Low-silica basalt phenocrysts include 1–2 percent plagioclase and 1–2 percent olivine; silicic basalt and basaltic andesite-basaltic trachyandesite groups include phenocrysts of 1–2 percent plagioclase, 1 percent clinopyroxene, 1 percent orthopyroxene, and up to 1 percent olivine. Glomerocrysts are common and consist of plagioclase only, plagioclase and both pyroxenes, and plagioclase and olivine with and without pyroxenes. All three compositional groups contain up to 1 percent xenocrysts of plagioclase (up to 3.5 mm). Multiple vent areas are identified: low-silica basalt correlates to a 1.5-m-wide dike approximately 2.5 km north of Bighorn Peak, north of the map boundary; basaltic andesite-basaltic trachyandesite correlates to a low-profile cinder cone along the north rim of Rio de los Piños and cinder deposits and lavas approximately 2 km to the north-northwest; and silicic basalt correlates to cinder deposits and lavas about 2 km north of Bighorn Peak just north of the map boundary. Lava types are grouped as a single map unit because differentiation in the field was not possible and the continuous compositional progression and similar eruption ages suggest they may be cogenetic. Preferred whole-rock 40Ar/39Ar ages for the distinct compositional types include ages of 4.36±0.05 Ma (RGR-364; table 2) for basalt; 4.36±0.04 Ma (RGR-362; table 2) for

silicic basalt; and 4.37±0.03 Ma (RGR-371; table 2) for basaltic andesite-

trachyandesite lavas overlie both basalt types but no relative order was

basaltic trachyandesite. Stratigraphically, basaltic andesite-basaltic

determined between basalt and silicic basalt types. If eruptions were coeval stratigraphic order may not be consistent **Near-vent pyroclastic deposits**—Cinder and spatter agglutinate and minor lava flow material Lava flows—Lava flows originating from multiple vent areas north of Rio de los Piños. Individual lava flows are 3–12 m thick, but, where tops are eroded erosional remnants can be less than 1 m **Basalt of Lucero Lakes (Pliocene)**—Light gray to gray, fine-grained, sparsely phyric basalt (49.5–50.1 wt. percent SiO₂) lava flows. Microphenocrysts are difficult to differentiate from groundmass because of seriate texture but include 1–2 percent olivine, 0.1–0.25 mm with little or no iddingsite replacement, and 1–2 percent tabular to elongate pyroxene, 0.1–0.6 mm, dark green with moderate to extensive iddingsite replacement and some

with well-developed skeletal texture. Sparse xenocrysts of quartz, plagioclase and pyroxene only observed in one sample. Fine-grained to aphanitic groundmass with intergranular and seriate textures and patchy subophitic pyroxene forms a mottled appearance in thin section. Groundmass composed of plagioclase, pyroxene, olivine, opaque minerals, and minor glass. Flows originated from Lucero Lakes area (fig. 1) and were channelized by paleovalleys with east- to southeast-directed flow. Lava flow thickness from 5–10 m. A northwest-trending, approximately 0.5-m-wide, dike that is sparsely phyric with rare green olivine phenocrysts protrudes above the surface in the southeast flank of Lamy Peak. Compositional data for the dike are not available; however, the physical characteristics of the dike are consistent with the basalt of Lucero Lakes rather than the Hinsdale Formation basaltic andesite (Thb) that caps Lamy Peak, and, therefore, the dike is considered part of the basalt of Lucero Lakes. Whole-rock 40 Ar/ 39 Ar age is 4.55 \pm 0.07 Ma (RGR–036; table 2) OLDER REGIONAL VOLCANIC AND VOLCANICLASTIC ROCKS

Volcanic and volcaniclastic deposits that predate deposits of the Taos Plateau volcanic field record volcanism of the Southern Rocky Mountains volcanic field (SRMVF) and filling of early extensional basins. The SRMVF is a composite mid-Tertiary (38–23 Ma) volcanic field in northern New Mexico and Colorado (Steven, 1975; Lipman, 2007). Loci of volcanism of the SRMVF surrounding the map area include the San Juan Mountains, San Luis Hills, and the Latir volcanic locus near the town of Questa, New Mexico. Volcanic deposits associated with the southeastern San Juan Mountains are present in the northwestern part of the map area. Conejos Formation (Tcf) deposits represent the early magmatic system in the San Juan Mountains and are composed of mostly andesite to dacite lavas flows and breccias and derivative volcaniclastic rocks associated with central volcanoes. Eruption of intermediate-composition lavas was superseded by multi-cyclic caldera formation at the Platoro caldera complex associated with eruption of at least seven major ignimbrites (individual ignimbrite volumes range between 75–1,000 km³) between ~29–30 Ma that collectively form the Treasure Mountain Group (Lipman and others, 1996). The Chiquito Peak Tuff (Ttc) is the only distinct ignimbrite present in the map area, exposed along the Rio de los Piños in the northwest part of the map. Along the western margin of the San Luis Valley, the Chiquito Peak Tuff has previously been mapped as Masonic Park Tuff (Lipman, 1975a, b; Manley, 1982a) and was inferred to have erupted from a buried source in the central San Juan Mountains (Lipman, 1975a). However, based on compositional, mineralogical, geochronologic, and stratigraphic evidence, Lipman and others (1996) determined previous usage of the Masonic Park Tuff combined two distinct ignimbrites and they renamed the ignimbrite that erupted from the Platoro caldera as the Chiquito Peak Tuff. The Chiquito Peak Tuff is the youngest widely distributed ignimbrite originating from the Platoro caldera complex and erupted at 28.94 Ma (RGR-466; table 2). Undivided Treasure Mountain Group deposits (Tt) below the Chiquito Peak Tuff are largely covered by rock-fall and colluvial

The Los Pinos Formation is composed of redeposited volcanic material sourced from surrounding volcanic highlands (Manley, 1981). In the northern part of the map area, clasts within Los Pinos deposits are dominantly intermediate-composition volcanic rocks from the southeast San Juan Mountains and the San Luis Hills, which is diagnostic of the Esquibel Member (Tle). The base of the Esquibel Member is placed at the top of the Chiquito Peak Tuff (28.94 Ma). In the southern part of the map area, intermediatecomposition clasts become smaller and volumetrically minor compared to abundant rhyolitic clasts of the Amalia Tuff that characterize the Cordito Member (Tlc). Manley (1981) placed the base of the Cordito Member at the top of the Amalia Tuff (25.4 Ma; Zimmerer and McIntosh, 2012) where the units are in stratigraphic position south of the map area. The contact between the two members is time-transgressive as deposition of the Esquibel Member continued in the northern part of the map area coeval with deposition of Cordito Member. Interbedded within the Los Pinos Formation is the Hinsdale Formation, which

includes basalt to rhyolite lava flows throughout its regional extent including the San Juan Mountains, San Luis Hills, and Sangre de Cristo Mountains adjacent to the southern San Luis Valley. Lipman and Mehnert (1975) suggested all basaltic lava flows interbedded within the Los Pinos Formation should be included in the Hinsdale Formation including some Pliocene lava flows correlative with flows within the map area. However, the Hinsdale Formation is here restricted to Oligocene and Miocene volcanic rocks due to the substantial age gap between the Miocene and Pliocene rocks and because the Pliocene volcanic rocks are compositionally and temporally related to the Taos Plateau volcanic field. Within the map area, deposits of the Hinsdale Formation consist of basalt to trachyandesite lava flows and are predominantly Oligocene in age. A single remnant of Miocene lava flow (Thl) is preserved capping Bighorn Peak in the northwest part of the map area. This lava flow is compositionally distinct from Pliocene and Oligocene lavas in the map area but is similar (fig. 3) to Miocene lavas more widely distributed to the north of the map area in southern Colorado (Lipman, 1975b).

Los Pinos Formation (Miocene and Oligocene)—Beds and lenses of poorly sorted to moderately well sorted sandy pebble to slightly bouldery cobble conglomerate and friable, well stratified fine-grained to pebbly, coarse-grained, tuffaceous(?) sandstone. Much of the moderately well sorted conglomerate appears to be of fluvial origin, whereas the poorly sorted, sparsely bouldery cobble conglomerate may reflect debris flow deposits. Unit locally includes thin siltstone lenses and sandy-over-gravelly sheetflood(?) deposits. Unit locally may include lenses and thin beds of claystone derived from the alteration of volcanic ash. Sheetflood deposits consist of rhythmically bedded couplets consisting of alternating thin (5–40 centimeters [cm]), well-stratified layers composed of small-pebble, coarse-grained sandstone that commonly overlie slightly cobbly pebble conglomerate. Conglomerate clasts commonly are subrounded to well rounded and range in size from 1–2 cm up to 1.5 m in diameter. Clasts are dominantly volcanic and intrusive in origin shed from volcanic highs in the southeast San Juan Mountains, San Luis Hills, and the Latir volcanic locus. Locally, deposits include clasts of Proterozoic granitic gneiss and quartzite. Formation consists of the upper Cordito Member and the lower Esquibel Member (Manley, 1981) separated by a time transgressive boundary. Estimated thickness, as much as 400 m

Age (Ma)±error (2σ) MSWD Age (Ma)±error (2σ) MSWD n/(total) 40Ar/36Ar

 2.12 ± 0.02

 2.87 ± 0.09

 3.13 ± 0.09

3.45±0.15

 3.41 ± 0.06

 3.49 ± 0.10

 3.16 ± 0.12

 3.48 ± 0.11

 4.1 ± 0.4

4.33±0.11

 4.60 ± 0.11

3.0 19/(19) 303±3

4.1 12/(13) 291±10

1.7 15/(15) 294±15

2.0 12/(13) 300±30

1.9 11/(13) 299.6±1.7

6.9 14/(16) 298±3

26.0 14/(15) 280±30

4.4 15/(17) 296±3

41.0 18/(18) 295±8

2.9 14/(15) 304±18

2.8 15/(15) 301±7

1.3 15/(17) 278±3

2.3 15/(17) 200±20

4.3 17/(18) 298±5

2.9 15/(15) 295±4

Insufficient dispersion of step-heating analyses to calculate

7.3 13/(18)

34.0 15/(15)

9.7 18/(18)

1.3 10/(13)

6.5 13/(15)

7.9 18/(18)

5.7 9/(16)

11.0 9/(16)

3.5 6/(15)

272±7

290±20

295±4

288±18

280±30

293±3

307±19

303±9

304±4

 2.82 ± 0.06

 3.06 ± 0.11

 3.08 ± 0.07

2.91±0.07

 3.0 ± 0.04

 3.29 ± 0.11

 3.33 ± 0.14

 3.38 ± 0.05

 3.32 ± 0.09

3.39±0.09

 3.52 ± 0.10

 3.28 ± 0.09

 3.39 ± 0.10

 4.0 ± 0.3

 4.27 ± 0.09

 4.36 ± 0.06

 4.23 ± 0.07

 4.54 ± 0.08

25.11±0.35

25.47±0.35

26.17±0.07

[Table shows ages determined using plateau, inverse isochron, and integrated age calculation methods for samples measured by step-heating methods for sample

 2.78 ± 0.05

 2.81 ± 0.04

2.94±0.12

no plateau

no plateau

no plateau

 3.20 ± 0.05

 3.33 ± 0.14

 3.36 ± 0.05

 3.39 ± 0.04

 3.47 ± 0.09

 3.29 ± 0.05

 3.32 ± 0.06

 4.24 ± 0.10

 4.31 ± 0.07

 4.37 ± 0.05

 4.32 ± 0.03

 4.55 ± 0.07

20.61±0.07

25.54±0.24

25.67±0.20

26.05±0.21

 26.17 ± 0.07

ing and Easting values in meters using North American Datum 1983 (NAD83), Universal Transverse Mercator (UTM) zone 13. MSWD, mean square of weight deviates; n, number of heating steps used in calculation of isochron age; Ma, million years; σ, sigma; λ, lamda; Ar, argon; K, potassium. Ages determined using Fish Canyon Tuff as a neutron flux monitor w

Preferred unit age

(Ma)±error (2σ)

 2.78 ± 0.05

 2.81 ± 0.04

 2.91 ± 0.07

 3.0 ± 0.04

 3.20 ± 0.05

 3.33 ± 0.14

 3.36 ± 0.05

 3.39 ± 0.04

 3.32 ± 0.06

 3.88 ± 0.06

4.1±0.03

 4.31 ± 0.07

 4.36 ± 0.05

4.55±0.07

20.61±0.07

25.67±0.20

26.05±0.21

26.17±0.07

28.94±0.31

ages reported by Dickens (2007) and represent weighted mean of multiple ages determined on grains of glass and (or) feldspar. Reported ages calculated relative to Fish Canyon Tuff neutron flux monitor age of 28.02 Ma. Ages shown here are adjusted by a factor of 1.006 (determined by 28.201/28.02 = 1.006) to account for different flux monitor age.

an age of 28.201 ± 0.023 Ma (1σ) (Kuiper and others, 2008), 40K decay constants of $\lambda = (5.463\pm0.214)\times10^{10yr-1}$ and $\lambda(e^-) = (0.580\pm0.007)\times^{10-10yr-1}$ (Min and others, 2006). Analytical data for all samples can be accessed at https://doi.org/10.5066/F72N51M5 (Turner and others, 2018)]

Cordito Member—Commonly contains clasts of Amalia Tuff and other volcanic and intrusive rocks from the Latir volcanic locus of the Southern Rocky Mountains volcanic field. Typically, the matrix of Cordito is lighter colored than that of the underlying Esquibel Member due chiefly to a more tuffaceous matrix and more abundant felsic clasts transported

from the Latir volcanic locus along west- to northwest-directed paleodrainages that flowed into, and through, the Tusas Mountains **Esquibel Member**—Commonly contains abundant clasts of andesite, dacite, and basalt volcanic and intrusive rocks eroded from the southeast San Juan Mountains and the San Luis Hills. Clasts of welded ignimbrite erupted from the Platoro caldera complex in the southeast San Juan Mountains are also observed. North of the map area, in southern Colorado, early Miocene basaltic lava flows are interbedded with deposits of the Esquibel Member (Lipman and Mehnert, 1975). Miocene Hinsdale Formation lava flow that caps Bighorn Peak (Thl) suggests the Esquibel Member is as young as Miocene in the map area. Distinction from the Cordito Member is based chiefly on the absence of Amalia Tuff clasts. Clast provenance from the San Luis Hills and southeast San Juan Mountains indicates transport along paleodrainages that flowed south to southwest into and through the northern Tusas Mountains

Hinsdale Formation (Miocene and Oligocene)—Includes Oligocene-aged, porphyritic basalt (Thp), trachyandesite (Tha), basaltic andesite (Thb), and tholeiitic basalt (Tht), as well as a single isolated outcrop of Miocene basaltic lava flow (Thl) that caps Bighorn Peak. Tholeitic basalt (Tht) and basaltic andesite (Thb) are most abundant Hinsdale Formation types within the map area whereas trachyandesite and porphyritic basalt types are more aerially restricted. Miocene basaltic lava is compositionally distinct from all other Hinsdale in the map area but is correlated to similar rocks to the north, which are about 20 Ma (table 2) Alkaline basalt to trachybasalt (Miocene)—Black to gray, mediumgrained porphyritic basalt lava flows (50 wt. percent SiO₂). Phenocrysts include 5-7 percent euhedral to anhedral olivine, 0.2-0.5 mm, where

some grain boundaries are embayed and have minor to extensive iddingsite replacement. Xenocrysts of plagioclase are rare. Fine- to medium-grained groundmass with intergranular and rarely intersertal textures composed of plagioclase, subophitic pyroxene, olivine, opaque minerals, and minor glass. Only one lava flow is preserved capping Bighorn Peak. Unit is more extensive north of map area (Lipman, 1975b). Whole-rock ⁴⁰Ar/³⁹Ar age from sample north of the map area is 20.61±0.07 Ma (RGR–378; table 2) Tholeiitic basalt (Oligocene)—Gray to dark-gray, moderately to nonvesic-

ular, basalt lava flows (49–50 wt. percent SiO₂). Phenocrysts include olivine and plagioclase, however, due to the medium- to coarse-grained groundmass, modal plagioclase is difficult to distinguish from groundmass grains. Euhedral to subhedral olivine is 7–15 percent of rock, 0.1–1 mm, and slightly to completely iddingsitized; larger grains often have slightly rounded to embayed grain boundaries. Groundmass is intergranular, intersertal, and weakly diktitaxitic and composed of plagioclase, 0.1–2.4 mm, some grains as large as 4 mm; clinopyroxene, 0.05 to 0.2 mm, individual equant grains and subophitic grains up to 1 mm; 3–5 percent opaque minerals; and 0–7 percent glass, partially devitrified with intergrown opaque minerals. Rare orthopyroxene grains intergrown with olivine have thick clinopyroxene overgrowths and are up to 2 mm. Plagioclase grains with sieve-textured interiors are sparse. Outcrop trends southwesterly from northeast part of map area along the Rio de los Piños, where 7–10 flows are present. Number of lava flows decreases to the southwest suggesting lavas erupted from a source to the northeast of the map area. Flow thickness 5–8 m. Preferred whole-rock ⁴⁰Ar/³⁹Ar age is 25.67±0.20 Ma (RGR–456; table 2) from a sample west of the map area, which is significantly older than a previously reported K-Ar age of 15.0±0.8 Ma (Lipman and Mehnert, 1975). Sample RGR-148 (25.54±0.24 Ma) was collected near the sample of Lipman and Mehert (1975), therefore the K-Ar age is considered incorrect

Basaltic andesite (Oligocene)—Dark-gray to gray, sparsely phyric basaltic andesite lava flows (52–54 wt. percent SiO₂). Phenocrysts include olivine and most likely plagioclase; however, plagioclase grains larger than the groundmass are not observed. Subhedral to anhedral olivine 5–7 percent of rock, 0.1–0.5 mm, with completely iddingsitized cores but rims of grains are generally unaltered. Medium- to fine-grained groundmass has intergranular to intersertal, and weakly developed diktytaxitic textures and is composed of plagioclase, 0.2–1.0 mm; glass, dark brown to black mostly devitrified; clinopyroxene, 0.1 to 0.5 mm, equant to tabular grains; and opaque minerals. One grain with orthopyroxene core and thick clinopyroxene rim was observed. A single lava flow observed in most localities but possibly up to three lava flows present on Broke Off Mountain. Source unknown but may be east of the map area and buried by Pliocene volcanic rocks. Whole-rock ⁴⁰Ar/³⁹Ar age is 26.05±0.21 Ma (RGR-33; table 2) on a sample west of the map area on Broke Off Mountain.

Trachyandesite (Oligocene)—Black, sparsely phyric, trachyandesite lava flow (56–57 wt. percent SiO₂). Microphenocrysts likely include olivine and plagioclase but there is no distinction in size from groundmass. Fine grained to glassy with intersertal texture and composed of 50–60 percent tabular plagioclase, up to 0.4 mm; 30–35 percent glass that varies from fresh and light-brown with little to no devitrification to dark brown and highly devitrified; 3–5 percent equant and elongate clinopyroxene, up to 1 mm; 3–5 percent opaque minerals that often fill areas between plagioclase grains or are equant cubic grains; and trace equant olivine, 0.1 mm, with minor to no iddingsite replacement, or, rarely, as phenocrysts up to 1 mm that are highly iddingsitized. Trachyandesite occurs as a single lava flow up to 8-m thick with highly stretched vesicles. Lava flow is overlain by tholeitic basalt (Tht, RGR-456, 25.67±0.20 Ma; table 2), northwest of Laguna Larga, and basaltic andesite lavas (unit Thb, RGR-033, 26.05±0.21 Ma; table 2) in the area of Los Cerritos de la Cruz. Two vent areas are inferred. The first is northwest of Laguna Larga and west of western map boundary where sparsely phyric and highly oxidized scoriaceous deposits, inferred to represent near-vent pyroclastic deposits, are eroding from the slope below tholeitic basalts. A second vent is inferred west of the northern cone of Los Cerritos de la Cruz where two intersecting dikes are sparsely

Porphyritic basalt to trachybasalt (Oligocene)—Black to dark gray, porphyritic alkaline basalt to trachybasalt (48 wt. percent SiO₂) lava flow. Phenocrysts include 3–5 percent clinopyroxene, up to 1.5 mm; 3–5 percent euhedral to subhedral olivine, up to 2 mm; and 1 percent plagioclase, where phenocrysts are differentiated from groundmass grains based on more equant form and presence of mafic inclusions. Pyroxene is often in glomerocrysts with as many as 10 grains giving appearance in hand sample of larger phenocrysts. Groundmass is medium grained with intergranular texture and includes plagioclase, clinopyroxene, olivine, and opaque minerals. Groundmass plagioclase up to 2 mm in long dimension and groundmass clinopyroxene and olivine grains up to 0.5 mm. Lava occurs as a single flow up to 5-m thick. Source vent is unknown. Whole-rock ⁴⁰Ar/³⁹Ar age is 26.17±0.07 Ma (RGR-494; table 2) from a sample south of Rio San Antonio near the western map boundary

phyric and petrographically similar to outflow lavas

reasure Mountain Group, undivided (Oligocene)—Ignimbrite, air fall tuff, and volcaniclastic deposits associated with recurrent eruption and collapse of the Platoro caldera complex in the southeast San Juan Mountains. Within the map area, Treasure Mountain Group includes a distinct ledge of Chiquito Peak Tuff (Ttc) and a non-distinct, mostly covered slope stratigraphically between the Chiquito Peak Tuff and the underlying Conejos Formation. Undivided Treasure Mountain Group (Tt)

includes predominantly volcaniclastic tuffaceous sedimentary deposits. Thickness of slope-forming unit below Chiquito Peak Tuff up to 60 m **Chiquito Peak Tuff**—Pink to white, moderately welded, low-silica hyolite to trachydacite ignimbrite. In areas proximal to the Platoro caldera, phenocryst content is 40–50 percent, but within the map area, along the Rio de los Piños, phenocryst content varies from 10–20 percent. Phenocrysts include plagioclase, biotite, opaque minerals, and sanidine, ± augite (Lipman, 1975a; Lipman and others, 1996), Feldspar phenocrysts are equant to tablular and up to 1.5 mm. Biotite phenocrysts are up to 2 mm and are variably altered; grains with unaltered cores show pleochroism from light brown to greenish brown. Ignimbrite is only exposed along the Rio de los Piños in the northwestern part of map where it forms a single cooling unit up to 30 m thick. Single-grain, total-fusion age on sanidine from a sample collected along the Rio de los Piños is 28.94±0.31 Ma (RGR–466; table 2)

Conejos Formation (Oligocene)—Chiefly composed of gray matrix-supported olcaniclastic debris flows. Clasts are predominantly dark-brown, porphyritic pyroxene-bearing andesitic and light-gray dacitic lavas. Clasts are angular to subangular and range from 1–75 cm. Unit exposed along the Rio de los Piños, but exposures are discontinuous in part because of colluvial debris from overlying poorly resistant Los Pinos Formation deposits. Thickness of unit in map area as much as 50 m but base is not exposed. Colucci and others (1991) report hornblende and biotite ⁴⁰Ar/³⁹Ar ages from Conejos Formation in the southeast San Juan Mountains between 33.5 and 29.5 Ma

INTRODUCTION

This map summarizes the geology for the San Antonio Mountain area of northern New Mexico and approximately 10 square kilometers (km²) of southern Colorado. This geologic investigation was carried out with support from the U.S. Geological Survey (USGS) National Cooperative Geologic Mapping Program between 2012 and 2016. The map area is physiographically on the western edge of the Taos Plateau within the southern San Luis Valley. The San Luis Valley is the geomorphic expression of the San Luis Basin, an extensional basin of the northern Rio Grande rift. Approximately half of the map area is within the Rio Grande del Norte National Monument (fig. 1). The map area encompasses two full 7.5' quadrangles (see quad index on sheet); the San Antonio Mountain and Los Pinos, and three partial 7.5' quadrangles: Bighorn Peak, Pinabetoso Peaks, and La Segita Peaks. The partial quadrangles (Pinabetoso Peaks and La Segita) are included to the east to fully encompass the San Antonio Mountain volcano, and in the northwest area (Bighorn Peak) to include Pliocene volcanic rocks related to the Taos Plateau volcanic field. Previous work in the area included small-scale maps by Bingler (1968), Butler (1971), and Manley and others (1987). More detailed mapping included the Bighorn Peak 7.5' quadrangle (Manley, 1982a), San Antonio Mountain area (Eppler, 1976); San Antonio Mountain 7.5' quadrangle (Thompson and Lipman, 1994b), and Los Pinos 7.5' quadrangle (Thompson and Lipman, 1994a).

Deposits within the map area record volcanic, sedimentary, and tectonic processes over the last ~33 million years (m.y.). Oldest exposed deposits include Oligocene volcanic rocks associated with the southeast San Juan Mountains locus of volcanism within the Southern Rocky Mountains volcanic field. The Southern Rocky Mountains volcanic field is a composite mid-Tertiary volcanic field that covered parts of southern Colorado and northern New Mexico (Lipman, 2007), of which the San Juan Mountains are one locus of volcanism. Overlying deposits of the Southern Rocky Mountains volcanic field are volcaniclastic sedimentary rocks interbedded with predominantly basaltic lava flows of Oligocene to Miocene age. Basalt to rhyolite volcanic rocks of the Pliocene to Pleistocene Taos Plateau volcanic field unconformably overlie Oligocene to Miocene volcanic and sedimentary deposits. Superposed on the Tertiary deposits are Pleistocene to Holocene alluvial and colluvial deposits.

North- to northwest-trending faults displace rocks within the map area. Faults are assumed to have normal, chiefly dip-slip, displacement but are identified with varying degrees of certainty as their recognition within the map area is complicated by generally small displacements in young, brittle volcanic deposits that often lack an obvious fault scarp or in the poorly indurated Los Pinos Formation deposits that rarely preserve a prominent fault scarp and may not be exposed sufficiently to document offset. Normal faults attributed as 'accurate' or 'approximately located' were observed displacing map units where 'approximately located' indicates a lower degree of spatial certainty. Normal faults attributed as 'inferred' are associated with distinct topographic lineaments and cutoff ledges but lack direct observation of displaced lava flows.

Integrated Single grain total fusion Material

 3.88 ± 0.06

 4.1 ± 0.03

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0.66 sanidine

Magnitude of deformation is broadly correlative with age of the deposits inasmuch as Oligocene to Miocene rocks display a greater degree of fault displacement and east tilting than Pliocene volcanic rocks. Bedding attitudes recorded during field investigation

are sparse as a result of (1) poorly indurated and poorly exposed Los Pinos Formation; (2) lava flows that are sufficiently magnetic to deflect a compass arrow; and (3) lava flows that rarely preserve a measurable surface representative of the attitude of the flow. Within the map area, faults displace Oligocene to Miocene deposits 10–30 meters (m) with generally down-to-west offset, and the units dip eastward 3–7 degrees. However, west of the map area fault displacement is as much as 200 m down-to-west along the west side of Broke Off Mountain (fig. 2) (Manley, 1982b). Pliocene volcanic rocks exhibit shallower eastward dips inferred primarily from the slope of upper lava flow surfaces that dip eastward 1–3 degrees. However, proximal to vent areas, dips increase and dip in all directions away from the vent. Fault offset of Pliocene volcanic rocks is likely underrepresented on the map due to cover by unconsolidated surficial deposits, but exposed faults displace Pliocene lavas less than 5 m. The magnitude of post-emplacement tilting of Pliocene lava flows is difficult to constrain because the lavas are interpreted to have flowed predominantly down an east-dipping paleoslope. Flow directions shown on the map are inferred from vent locations and topographic expression, and display predominantly easterly flow directions.

Geology was mapped using a combination of remotely sensed data and field investigation. Natural-color, 1-m resolution imagery gathered by the U.S. Department of Agriculture National Agricultural Imagery Program (NAIP) from 2009 and 2014 for Rio Arriba and Taos Counties, New Mexico, and 2009 for Conejos County, Colorado, was used as an interpretive layer for new mapping and to evaluate previous mapping (later acquisition years of NAIP available as quarter quadrangle downloads from https://nationalmap.gov). New mapping utilized argon-argon (40Ar/39Ar) geochronology, geochemical data, and thin-section petrography to identify, correlate, and constrain the stratigraphic position and ages of volcanic units. Volcanic rock names are based on the standard International Union of Geological Sciences (IUGS) classification scheme of Le Bas and others (1986) using major element compositions recalculated as volatile-free with ferric/ferrous iron ratios as proposed by Middlemost (1989); a result of this calculation can cause a slight shift to higher concentrations in the major element values plotted in figure 3 relative to the original data reported in table 1. Geochemical analyses of select representative samples are presented in table 1 and 40 Ar/39 Ar ages are reported in table 2. The complete datasets that support these tables are available through ScienceBase (https://www.sciencebase.gov) as part of the data release that accompanies this report at https://doi.org/10.5066/F72N51M5 (Turner and others, 2018).

REFERENCES American Geological Institute, 1982, Grain-size scales used by American geologists, modified Wentworth scale, data sheets (2d ed.): Falls Church, Va., American Geological Institute, sheet 17.1.

Appelt, R.M., 1998, 40Ar/39Ar geochronology and volcanic evolution of the Taos Plateau volcanic field, northern New Mexico and southern Colorado: Socorro, New Mexico Tech. M.S. thesis, 58 p. Benson, L.V., Madole, R.F., Landis, G.P., and Gosse, J.C., 2005, New data for late Pleistocene Pinedale alpine glaciation from southwestern Colorado: Quaternary Science Reviews, v. 24, p. 49–65. Benson, L.V., Madole, R.F., Phillips, W.M., Landis, G.P., Thomas, T., and Kubic, P., 2004, The probable importance of snow and sediment shielding on cosmogenic ages

of north-central Colorado Pinedale and pre-Pinedale moraines: Quaternary Science Reviews, v. 23, p. 193–206. Bingler, E.C., 1968, Geology and mineral resources of Rio Arriba County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 91, 158 p., 7 pl. Breese, R., 1984, Rhyolite domes and flows at No Agua Peaks, New Mexico, in Baldridge, W.S., Dickerson, P.W., Riecker, R.E., and Zidek, J., eds., Rio Grande Rift— Northern New Mexico: New Mexico Geological Society, Guidebook 35, p. 373–374. Butler, A.P., Jr., 1971. Tertiary volcanic stratigraphy of the eastern Tusas Mountain southwest of the San Luis Valley, Colorado-New Mexico, New Mexico Geological

Society Fall Field Conference Guidebook: New Mexico Geological Society, v. 22, Chamberlin, R.M., and Barker, J.M., 1996, Genetic aspects of commercial perlite deposits in New Mexico, in Austin, G.S., Hoffman, G.K., Barker, J.M., Zidek, J. and Gilson, N., eds., Proceedings of the 31st forum on the geology of industrial minerals—The Borderland Forum: New Mexico Bureau of Mines and Mineral

Resources Bulletin 154, p. 171–186. Cole, J.C., Mahan, S.A., Stone, B.D., and Shroba, R.R., 2007, Ages of Quaternary Rio Grande terrace-fill deposits, Albuquerque area, New Mexico: New Mexico Bureau of Geology and Mineral Resources, New Mexico Geology, v. 29, no. 4, p 122–132. Colucci, M.T., Dungan, M.A., Ferguson, K.M., Lipman, P.W., and Moorbath, S., 1991, Precaldera lavas of the southeast San Juan volcanic field—Parent magmas and crustal interactions: Journal of Geophysical Research, v. 96, p. 13413–13434. Cruden, D.M., and Varnes, D.J., 1996, Slope movement types and process, in Schuster, R.L., and Krizek, R.J., eds., Landslide investigation and mitigation: Washington, D.C., National Academy Press, Transportation Research Board Special Report 247,

Drenth, B.J., Turner, K.J., Thompson, R.A., Grauch, V.J.S., Cosca, M.A., and Lee, J.P., 2011, Geophysical expression of elements of the Rio Grande rift in the northeast Tusas Mountains—Preliminary interpretations, in Koning, D.J., Karlstrom, K.E., Kelley, S.A., Lueth, V.W., Aby, S.B, eds., Geology of the Tusas Mountains and Ojo Caliente, New Mexico Geological Society Guidebook 62: New Mexico Geological Society, p. 165–176. Dungan, M.A., 1987, Open system magmatic evolution of the Taos Plateau volcanic

Dickens, A.K., 2007, Obsidian hydration and its consequences for the Ar-Ar dating

method: Socorro, New Mexico Institute of Mining and Technology, M.S. thesis, 182 p.

field, Northern New Mexico: II. The Genesis of Cryptic Hybrids: Journal of Petrology, v. 28, p. 955–977. Dungan, M.A., Lindstrom, M.M., McMillan, N.J., Moorbath, S., Hoefs, J., and Haskin, L.A., 1986, Open system magmatic evolution of the Taos Plateau volcanic field, northern New Mexico—1. The petrology and geochemistry of the Servilleta Basalt: Journal of Geophysical Research, v. 91, p. 5999–6028. Eppler, D., 1976, Geology of the San Antonio Mountain area, Tres Piedras and Rio Arriba Counties, New Mexico: Albuquerque, University of New Mexico, M.S. thesis, 76 p.

scale 1:24.000.

Stratigraphy, 2010, Formal ratification of the Quaternary System/Period and the Pleistocene Series/Epoch with a base at 2.58 Ma: Journal of Quaternary Science, v. 25, p. 96–102. Gile, L.H., Peterson, F.F., and Grossman, R.B., 1966, Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, p. 347–360. Hilgard, E.W., 1892, A report on the relations of soil to climate: U.S. Department of Agriculture, Weather Bureau Bulletin 3, 59 p. Kuiper, K.F., Deino, A.L, Hilgen, F.J., Krijgsman, W., Renne, P.R., and Wijbrans, J.R.,

Gibbard, P.L., Head, M.J., Walker, M.J.C., and the Subcommission on Quaternary

2008, Synchronizing rock clocks of Earth history: Science, v. 320, p. 500–504, doi:10.1126/science.1154339. Le Bas, M.J., Le Maitre, R.W., Streckeisen, A., and Zanettin, B., 1986, A chemical classification of volcanic rocks based on the total alkali-silica diagram: Journal of Petrology, v. 27, p. 745–750. Lee, J.-Y., Marti, K., Severinghaus, J.P., Kawamura, K., Yoo, H.-S., Lee, J.B., and Kim, J.S. 2006, A redetermination of the isotopic abundances of atmospheric Ar: Geochimica et Cosmochimica Acta, v. 70, p. 4507–4512, doi: 10.1016/j.gca.2006.06.1563. Lipman, P.W., 1975a, Evolution of the Platoro caldera complex and related volcanic

rocks, southeastern San Juan Mountains, Colorado: U.S. Geological Survey Professional Paper 852, 128 p. [Available at https://pubs.er.usgs.gov/publication/pp852.] Lipman, P.W., 1975b, Geologic map of the lower Conejos River canyon area, southeastern San Juan Mountains, Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I–901, scale 1:48,000. Lipman, P.W., 2007, Incremental assembly and prolonged consolidation of Cordilleran

magma chambers—Evidence from the Southern Rocky Mountain volcanic field: Geosphere, v. 3, p. 42–70. [Available at https://ngmdb.usgs.gov/Prodesc/proddesc_9794.htm.] Lipman, P.W., Dungan, M.A., Brown, L.L., and Deino, A., 1996, Recurrent eruption and

subsidence at the Platoro caldera complex, southeastern San Juan volcanic field, Colorado—New tales from old tuffs: Geological Society of America, Bulletin, v. 108, p. 1039–1055.

Lipman, P.W., and Mehnert, H.H., 1975, Late Cenozoic basaltic volcanism and development of the Rio Grande depression in the southern Rocky Mountains, in Curtis, B.F., ed., Cenozoic history of the southern Rocky Mountains: Geological Society of America, Memoir 144, p. 119–154. Lipman, P.W., and Mehnert, H.H., 1979, The Taos Plateau volcanic field, northern Rio Grande Rift, New Mexico, in Riecker, R.W., ed., Rio Grande Rift: Tectonics and magmatism, International Symposium on the Rio Grande Rift: American

ophysical Union, p. 289–312. Machette, M.N., 1985, Calcic soils of the southwestern United States, in Weide, D.L., ed., Soils and Quaternary geology of the southwestern United States: Geological Society of America, Special Paper 203, p. 1–22. Manley, K., 1981, Redefinition and description of the Los Pinos Formation of northcentral New Mexico: Geological Society of America Bulletin, v. 92, no. 12, p. 984–989 Manley, K., 1982a, Geologic map of the Bighorn Peak quadrangle, Rio Arriba County,

New Mexico and Conejos County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF–1451, scale :24,000 scale. [Available at https://ngmdb.usgs.gov/Prodesc/proddesc_7202.htm.] Manley, K., 1982b, Geologic map of the Broke Off Mountain quadrangle, Rio Arriba County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map

MF-1450, 1:24,000 scale. [Available at https://ngmdb.usgs.gov/Prodesc/proddesc_7201.htm.] Manley, K., Scott, G.R., and Wobus, R.A., 1987, Geologic map of the Aztec 1°×2°

quadrangle, northwestern New Mexico and southern Colorado: U.S. Geological Survey Miscellaneous Investigation Series Map I-1730, 1:250,000 scale. [Available at https://ngmdb.usgs.gov/Prodesc/proddesc_9899.htm.] Merrill, G.P., 1897, A treatise on rocks, rock-weathering and soils: New York, Macmillan Company, 411 p. Middlemost, E.A.K., 1989, Iron oxidation ratios, norms and the classification of volcanic

rocks: Chemical Geology, v. 77, p. 19–26.

Min, K., Mundil, R., Renne, P.R., and Ludwig, K.R., 2000, A test for systematic errors in ⁴⁰Ar/³⁹Ar geochronology through comparison with U/Pb analysis of 1.1-Ga rhyolite: Geochimica et Cosmochimica Acta, v. 64, p. 73–98, doi: 10.1016/S0016-7037(99)00204-5. Neart, K.A., Wright, L.A., and Thornton, C.P., 1980, Geology of the perlite deposits of the No Agua Peaks, Taos County, New Mexico: New Mexico Bureau of Mines and

Mineral Resources Open-file Report 162, 88 p. Nelson, A.R., Millington, A.C., Andrews, J.T., and Nichols, H., 1979, Radiocarbon-dated upper Pleistocene glacial sequence, Fraser Valley, Colorado Front Range: Geology, v. 7, p. 410–414. North American Commission on Stratigraphic Nomenclature, 2005, North American Stratigraphic Code: American Association of Petroleum Geologists Bulletin, v. 89, p. 1,547–1,591, doi: 10.1306/07050504129. Rogers, K.L., Repenning, C.A., Luiszer, F.G., and Benson, R.D., 2000, Geologic history, stratigraphy, and paleontology of SAM Cave, north-central New Mexico: New

Mexico Bureau of Mines and Mineral Resources, New Mexico Geology, v. 22, Sawyer, D.A., Mullins, K.F., Dohrenwend, J., and Isbrecht, J.A., 2004, Processed Landsat 7 satellite imagery of the Española Basin region, New Mexico: U.S. Geological Survey Open-File Report 2004–1040–A. Shroba, R.R., Thompson, R.A., and Ruleman, C., 2007, Possible role of eolian sediment in the genesis of bouldery debris-flow deposits on the lower flanks of Ute Mountain northern Taos Plateau volcanic field, New Mexico, chap. I of Machette, M.N., Coates, M.-M., and Johnson, M.L., eds., 2007 Rocky Mountain Section Friends of the Pleistocene field trip—Quaternary geology of the San Luis basin of Colorado

and New Mexico, September 7–9, 2007 [guidebook]: U.S. Geological Survey Open-File Report 2007–1193, p. 181–185. [Available at https://pubs.usgs.gov/of/2007/1193/.] Steven, T.A., 1975, Middle Tertiary volcanic field in the Southern Rocky Mountains, in Curtis, B.F., ed., Cenozoic History of the Southern Rocky Mountains: Geological Society of America Memoir 144, p. 75–94. Sturchio, N.C., Pierce, K.L., Murrell, M.T., and Sorey, M.L., 1994, Uranium-series ages of travertines and timing of the last glaciation in the northern Yellowstone area, Wyoming-Montana: Quaternary Research, v. 41, p. 265–277. Thompson, R.A., and Lipman, P.W., 1994a, Geologic map of the San Antonio Mountain

quadrangle, Rio Arriba County, New Mexico: U.S. Geological Survey Geologic

Quadrangle Map GQ-1750, 1:24,000 scale. [Available at https://ngmdb.usgs.gov/Prodesc/proddesc_1235.htm.] Thompson, R.A., and Lipman, P.W., 1994b, Geologic map of the Los Pinos quadrangle, Rio Arriba and Taos Counties, New Mexico, and Conejos County, Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1749, 1:24,000 scale. [Available at https://ngmdb.usgs.gov/Prodesc/proddesc_1234.htm.] Thompson, R.A., Shroba, R.R., Machette, M.N., Fridrich, C.J., Brandt, T.R., and Cosca, M.A., 2015, Geologic map of the Alamosa 30'×60' quadrangle, south-central, Colorado: U.S. Geological Survey Scientific Investigations Map 3342, 23 p., scale 1:100,000, accessed Jan. 14, 2016, at https://pubs.er.usgs.gov/publication/sim3342.

Turner, K.J., Thompson, R.A., Cosca, M.A., Shroba, R.R., Chan, C.F., and Morgan, L.E. 2018, Data release of geospatial map database, argon geochronology and geochemistry data for geologic map of the San Antonio Mountain area, northern New Mexico and southern Colorado: U.S. Geological Survey data release, https://doi.org/10.5066/F72N51M5.

U.S. Geological Survey Geologic Names Committee, 2018, Divisions of geologic time-Major chronostratigraphic and geochronologic units: U.S. Geological Survey Fact Sheet 2018–3054, 2 p., accessed September 17, 2018 a https://doi.org/10.3133/fs20183054.

Whitson, D., 1982, Geology of the No Agua deposit at No Agua Peaks, New Mexico, in Austin, G.S., compiler, Industrial rocks and minerals of the Southwest: New Mexico Bureau of Mines and Mineral Resources, Circular 182, p. 89–95. Zimmerer, M.J., and McIntosh, W.C., 2012, The geochronology of volcanic and plutonic rocks at the Questa caldera: Constraints on the origin of caldera-related silicic magmas: Geological Society of America Bulletin, v. 124, p. 1394–1408.



2000). Fossils were excavated from sediments preserved in the lava as early as the 1950s (Rogers and others, 2000). Photograph by K. Turner, July 21,



