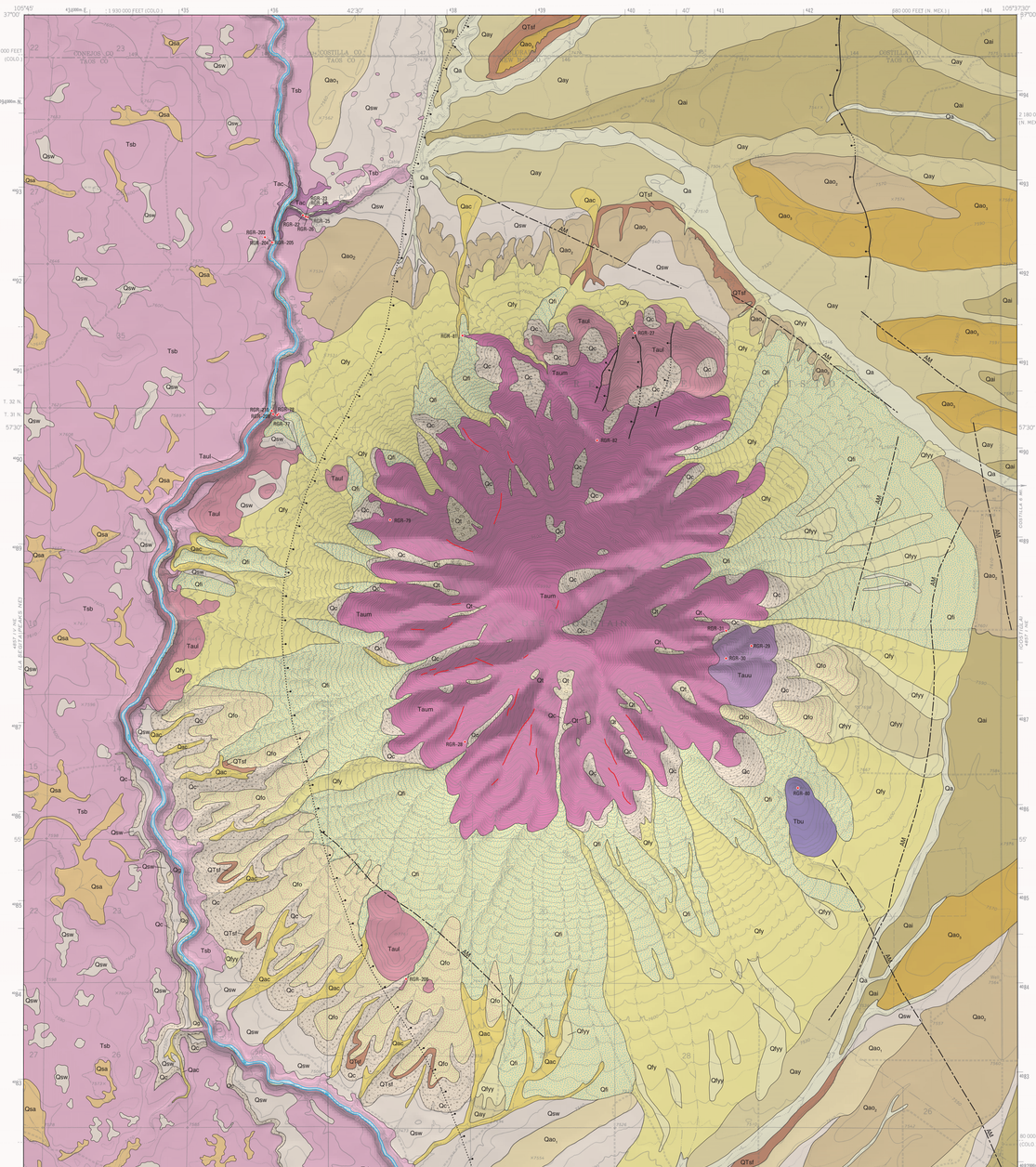
USGS
science for a changing world

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

Scientific Investigations Map 3284



Base from U.S. Geological Survey, Ute Mountain, New Mex-Colo., 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

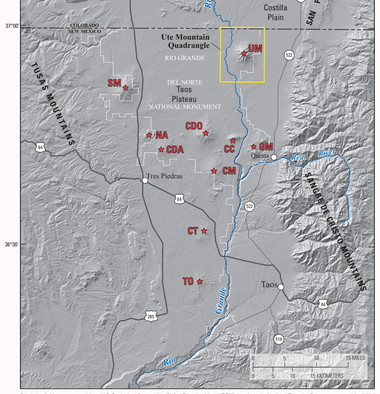
SCALE 1:24 000

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

QUADRANGLE LOCATION

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.H. 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



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/
Rio Grande del Norte National Monument boundary simplified from U.S. Bureau of Land Management at http://www.blm.gov/nm/st/en/prog/blm_special_areas/national_monuments/rio_grande_del_norte.html on Aug. 12, 2013.

Figure 1. Shaded-relief index map of the Taos Plateau and adjacent regions of southern Colorado and northern New Mexico showing outline of Ute Mountain geologic map area. Labeled physiographic volcanic features include: LM, Los Mogotes; UM, Ute Mountain; SM, San Antonio Mountain; CDO, Cerro de la Olla; NA, No Agua; CC, Cerro Chiflo; GM, north and south Guadalupe Mountain; CDA, Cerro del Aire; CM, Cerro Montoso; CT, Cerro de los Taoses; TO, Tres Orejas.

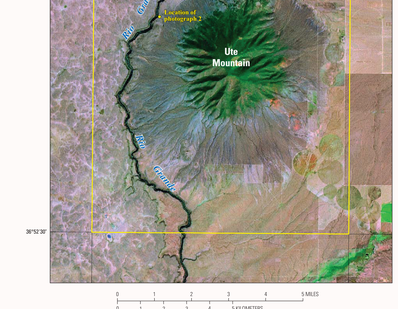


Figure 2. Landsat 7 satellite image (30-m band 7–4–2 merged with 15-m band 8) acquired on October 14, 1999, of Ute Mountain area, New Mexico (image clip from Sawyer and others, 2004), showing select geographic names. Volcanic rocks and sediments of the Taos Plateau volcanic field are visible throughout the image. Yellow rectangle is the boundary of the Ute Mountain 7.5' quadrangle. Yellow dots indicate the locations of photographs 1 and 2.

Table 1. *Approximate height, in meters, of tops of valley-floor, piedmont-slope, and gravelly alluvium above Costilla Creek and the Rio Grande inside and just south of the Ute Mountain 7.5' quadrangle.*
[North, indicates deposits near the northern boundary of the map area; South, indicates deposits near the southern boundary of the map area]

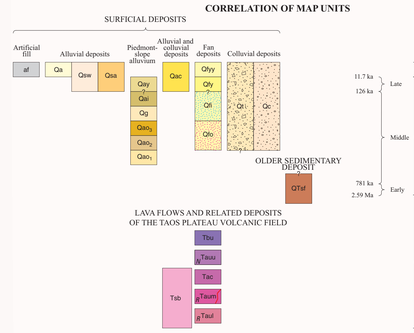
Map unit	Costilla Creek North	Costilla Creek South
Qa	1	--
Qay	3	--
Qai	6	--
Qg	--	46
Qao_3	12	37
Qao_2	32	44
Qao_1	46	55

DIVISION OF QUATERNARY AND NEOGENE TIME USED IN THIS REPORT

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

[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).

CORRELATION OF MAP UNITS



Black italics characters in boxes represent aeromagnetic polarity signature. N, normal; R, Reverse. Approximate eruption ages from table 3.

DESCRIPTION OF MAP UNITS

[The surficial units on this map are informal lithostratigraphic 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 (Qao, 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_3, Qao_2, and Qao_1 above the Rio Grande increase from north to south within, and south of, the map area. The southward increase in heights is due chiefly to the average gradient of the southward-flowing Rio Grande (1.5 m/km in the map area) 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 within the map area is about 42 m.

Stages of secondary calcium carbonate morphology (referred to as stages I and II 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 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 young fan deposits (Qfy) 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 "clasts" refers to particles larger than 2 mm in diameter, whereas all finer material is called "matrix." 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 hue, colors on the List of Map Units and the Correlation of Map Units may not exactly match unit colors on the map]

SURFICIAL DEPOSITS

Artificial-fill deposits

af — **Artificial fill (latest Holocene)**—Earth-filled dam composed of rock fragments and finer material that impounds a small reservoir near the southwest corner of the map area. Estimated thickness is less than 5 m

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. Top of unit Qa is about 1 m above of Costilla Creek and about 2 m below the top of unit Qay (table 1). Unit Qa locally includes a minor amount of the youngest fan deposits (Qfyy) 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)**—Chiefly slightly pebbly to pebbly, slightly silty to silty sand in aprons that have accumulated 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). 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 is 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

Six 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 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) and 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 because of uplift along faults of units Qao_2 and Qao_1 preclude stream 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_2, Qao_1, and Qao_0 may have accumulated under pluvial climatic conditions associated with glacial advances in the Sangre de Cristo Mountains prior to about 440 ka (Ruleman and others, 2013). Deposits of map units Qg, Qao_3, Qao_2, Qao_1, and Qg 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 Costilla Creek and about 3 m below the top of unit Qai (table 1). On the southeast side of Ute Mountain, deposits of unit Qay appear to be graded to deposits of unit Qfy. Stage I and weak stage II carbonate morphology on clasts in unit Qay suggests that unit Qay 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 is about 6 m above Costilla Creek and about 6 m below the top of unit Qao_3 (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

Qg — **Gravelly alluvium (middle Pleistocene)**—Four small deposits of gravelly stream alluvium underlie remnants of a discontinuous terrace about 46 m above the Rio Grande (table 1), a few meters below the top of the Rio Grande gorge near the southwest corner of the map area. Deposits of unit Qg consist of pebbly sand and cobbly pebble gravel that are locally overlain by deposits of sheetwash alluvium (Qsw). Estimated thickness is 10 m

Qao_3 — **Lower older piedmont-slope alluvium (middle Pleistocene)**—Near the northern boundary of the map area, the top of unit Qao_3 is about 12 m above Costilla Creek, about 37 m above the Rio Grande, and about 7 m below the top of unit Qao_2 (table 1). About 5 km south of the map area, the top of unit Qao_3 is about 56 m above the Rio Grande. In this area, deposits of unit Qao_3 are preserved on both the east and west sides of the Rio Grande gorge (Cafton del Rio Grande). Estimated thickness is 1–3 m

Qao_2 — **Higher older piedmont-slope alluvium (middle Pleistocene)**—Near the northern boundary of the map area, the top of unit Qao_2 is about 32 m above Costilla Creek, about 44 m above the Rio Grande, and about 11 m below the top of unit Qao_3 (table 1). About 2 km south of the map area, the top of unit Qao_2 is about 63 m above the Rio Grande, and about 7 m above the top of unit Qao_3. Estimated thickness is 2–3 m

Qao_1 — **Highest older piedmont-slope alluvium (middle Pleistocene)**—Near the northern boundary of the map area, the top of unit Qao_1 is about 46 m above Costilla Creek, about 55 m above the Rio Grande, and about 11 m above the top of unit Qao_2 (table 1). Near the southern boundary of the map area, unit Qao_1 is about 70 m above the Rio Grande, and about 7 m above the top of unit Qao_2. Estimated thickness is 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 younger fan deposits (Qfyy). Unit 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

Fan deposits

Fan deposits of four age groups form an extensive (about 40 km^2) apron that surrounds Ute Mountain. The fan apron commonly is about 0.5–3 km wide, has average slopes of about 35–120 m/km and was deposited by ephemeral streams that radiated outward from Ute Mountain. Fan deposits consist of clast-and-matrix supported, locally bouldery, pebbly and cobbly gravel with a silty sand matrix. Near the lower part of the fan apron, individual deposits are about 0.5–3 m thick. Locally they consist of pebbly and cobbly, slightly silty sand that contains gravel lenses. Rock fragments in the fan deposits are composed of andesite (Taurp) eroded from Ute Mountain as well as a minor amount of olivine andesite (Taul) eroded from several small outcrops that locally protrude through the fan deposits near the base of Ute Mountain. Fan deposits commonly form fan-shaped and lobate masses of sediment deposited at and below the mouths of narrow valleys. Sediments in these units were deposited by debris flows and by sediment-charged ephemeral streams. Lenses that contain cobbles and boulders are formed locally at the margins of some debris flows. Eolian sediment may have played an important role in the genesis of these debris flows (Shroba and others, 2007). Small, unmapped deposits of sheetwash alluvium (Qsw) and alluvium and colluvium, undivided (Qac) locally, overlie fan deposits. Low-lying areas adjacent to stream channels are prone to periodic stream flooding and debris-flow deposition. Fan deposits were identified and mapped based chiefly on relative height above modern stream channels and topographic relationships with other fan deposits.

Qfyy — **Youngest fan deposits (Holocene)**—Top of unit Qfyy is slightly higher than adjacent stream channels. Deposits of unit Qfyy are inset into and slightly lower than lower deposits of unit Qfy. There is little or no erosional modification of original surface morphology in areas between washes. Washes have steep sides that are only slightly modified by erosional processes. Unit Qfyy locally overlies valley-floor alluvium (Qa). Estimated thickness is 1–10 m

Qfy — **Younger fan deposits (late Pleistocene)**—Top of unit Qfy is about 3–12 m above channels of ephemeral streams. Deposits of unit Qfy are inset into and slightly lower than deposits of unit Qfi. Matrix of deposits is locally rich in silty very fine to medium sand, which may be eolian in origin (Shroba and others, 2007). Silt-rich sheetwash alluvium (Qsw), derived from loess or silty sediment of the Santa Fe Group, are locally exposed in washes near the upper limit of the fan apron. Stage I and weak stage II carbonate morphology on clasts in deposits of unit Qfy suggests that these deposits accumulated during the Pinedale glaciation (table 2 in Machette, 1985). There is minor erosional modification of original surface morphology in areas between washes. Washes have steep sides that are only slightly modified by erosional processes. On the southeast side of Ute Mountain, deposits of unit Qfy appear to be graded to deposits of unit Qay. These fan deposits probably formed under pluvial climatic conditions associated with these glaciations, which occurred about 12 to >30 ka and 120–170 ka, respectively (Pierce, 2004, and references cited therein). Maximum thickness possibly about 50 m

Qfi — **Intermediate fan deposits (late? and middle Pleistocene)**—Top of unit Qfi is slightly higher than the top of unit Qfy. Deposits of unit Qfi are inset into, and locally are as much 10 m lower than, deposits of unit Qfo. Original surface morphology is mated in areas between washes. Washes have slightly rounded sides, due to erosion of fan deposits from the convex-shaped top of the slope of washes. Maximum thickness possibly about 50 m

Qfo — **Older fan deposits (middle Pleistocene)**—Top of unit Qfo is as much as 10 m higher than the top of unit Qfi. Original surface morphology is not preserved in areas between washes. Washes have very rounded sides, due to significant erosion of fan deposits along the upper and lower slopes of washes. Deposits of unit Qfo may have formed under pluvial climatic conditions associated with one or more pre-Bull Lake glaciations. They locally overlie highest older piedmont-slope alluvium (Qao$_3$). Deposits of unit Qao_3, as well as those of units Qao_2 and Qao_1, predate major downcutting of the Rio Grande gorge (Thompson and Shroba, 2007), which began after about 440 ka (Machette and others, 2007; 2013). Maximum thickness possibly about 50 m

Colluvial deposits

Qt — **Talus deposits (Holocene to middle? Pleistocene)**—Deposits composed mostly of angular tabular blocks of andesite of Ute Mountain middle unit (Taurm) deposited chiefly by rock fall and rock creep on steep slopes of the upper flanks of Ute Mountain. Some deposits have ridges and furrows due to downslope creep that remobilized these deposits. Talus deposits composed of fragments of Servilleta Basalt (Tsb) are mapped in the Rio Grande gorge near the southern boundary of the map area. Unit locally may include small rock-glacier deposits. Maximum thickness possibly about 15 m

Qc — **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 Varnes (1978) and Cruden and Varnes (1996). Unit locally includes deposits of sheetwash alluvium (Qsw) and alluvium and colluvium, undivided (Qac) that are too small to map separately. Unit Qc locally may include talus deposits (Qt) on the flanks of Ute Mountain and in the Rio Grande gorge, and periglacial deposits near the summit of Ute Mountain formed during glacial episodes. 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 few 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 (Puzzaglia 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 2,500-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 breached 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, subsaliaitic 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, now dissected vents. Dacitic lavas form lava domes and large composite centers, often with poorly preserved stratigraphy. 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 fluxgate determinations 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 include 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 cinder deposits used in unit descriptions were determined by comparison with a Geological Society of America Rock-Color Chart (Munsell Color, 2009).

Tbu — **Trachybasalt of Ute Mountain (Pliocene)**—Light-gray near-vent trachybasalt lava flows (49 weight percent SiO_2) and associated red to dark gray cinder, spatter and scatter agglutinate deposits on the southeast flank of Ute Mountain. Groundmass with intersertal and trachytic texture composes 95 percent of rock and includes plagioclase, completely altered olivine, opaque minerals, and glass. Phenocrysts only of olivine (Fo_{70-74}), grain size: 0.1 mm to 0.6 mm, euhedral to subhedral and highly skeletal with iddingsitized rims. Quartz xenocrysts present. $^{40}Ar/^{39}Ar$ date (whole rock) of 3.05 ± 0.07 Ma (RGR–80; table 3)

$_yT_{tau}$ — **Upper basaltic trachyandesite of Ute Mountain (Pliocene)**—Light- to dark-gray lava flows (54–56 weight percent SiO_2) and at least one dike on east flank of Ute Mountain, includes basaltic trachyandesite and trachyandesite compositions that occasionally contain quartz xenocrysts. Groundmass from 60 to 70 percent glass, 25–35 percent plagioclase, and 2–5 percent olivine, pyroxene, and opaque minerals. Phenocrysts absent in some samples, where present consist of olivine ranging in size from 0.6 to 1.2 mm that are highly skeletal, some grains atmosphere dendritic pattern, with rims altered to opaque minerals. $^{40}Ar/^{39}Ar$ date (whole rock) of 3.17 ± 0.04 Ma (RGR–29; table 3). Also distinguished by normal aeromagnetic polarity and fluxgate determinations

Ttsb — **Servilleta Basalt (Pliocene)**—Black to dark-gray tholeiitic basalt (49–50 weight percent SiO_2), lava flows in western map area. Contains isolated vesicles, vesicle pipes and segregation trains; intergranular, seriate, weakly defined trachytic and diktytaxitic groundmass textures common with plagioclase, clinopyroxene, olivine and oxides. Plagioclase (An_{70-85}) 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 ($En_{0.69}$ $Fs_{0.07}$ $Wo_{0.24}$) composes 15–20 percent of rock as phenocrysts, groundmass and as late stage ophitic to subophitic grains, ranging from 0.01 to 0.3 mm, generally light green to colorless, often with iddingsitized rims. Olivine ($Fo_{0.65}$) composes 5–15 percent of rocks as euhedral to anhedral phenocrysts (0.3–0.4 mm) commonly altered to iddingsite and subhedral to anhedral microphenocrysts (less than 0.2 mm). $^{40}Ar/^{39}Ar$ geochronology on sample west of Ute Mountain along the Rio Grande gorge indicates age of 3.43 ± 0.12 Ma (RGR–78; table 3) but locally overlies and underlies lava flows of unit Tac near the confluence of the Costilla Creek and the Rio Grande. 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 to the south (>10 m), where exposed in the Rio Grande gorge near Taos, New Mexico

Ttac — **Basaltic trachyandesite of Costilla Creek (Pliocene)**—Light-gray to reddish brown basaltic trachyandesite (51–52 weight percent SiO_2) lava flows exposed in the Costilla Creek drainage near the confluence with the Rio Grande. Lava flows here are intercalated with lava flows of Servilleta Basalt (Tsb). Intersertal to intergranular or weakly trachytic texture in coarse-grained groundmass composed of plagioclase, subophitic pyroxene, and olivine. Plagioclase composes 70 percent of rocks with elongate grains most common and subordinate equant grains; elongate grains 0.8–1.2 mm in length and 0.05–0.12 mm width and equant grains 0.6–0.8 mm occasionally up to 1.5 mm. Clinopyroxene composes 15–20 percent of rock as subophitic grains (up to 1 mm) and isolated grains 0.04–0.2 mm. Olivine composes 8–10 percent of rock as smaller groundmass-sized grains (0.05–0.2 mm) and larger commonly skeletal phenocrysts (up to 1 mm) that have iddingsitized rims or are completely replaced by iddingsite. Fine-grained oxides more abundant than in Servilleta Basalt and compose up to 2 percent of rock. Preliminary $^{40}Ar/^{39}Ar$ geochronology on uppermost flow where Costilla Creek joins Rio Grande yielded an interpreted age of 3.52 ± 0.03 Ma (RGR–26; table 3). Likely reflects distal lava flow deposits of a low-relief shield volcano (RGR–207; table 2) located approximately 6 km to the northwest of the confluence of Costilla Creek and the Rio Grande, near the border of Colorado and New Mexico (Thompson and Machette, 1989). Lava flow thickness 10–12 m

$_yT_{taum}$ — **Middle trachyandesite of Ute Mountain (Pliocene)**—Gray to black trachyandesite to trachyte (59–64 weight percent SiO_2), commonly vesicular lava flows and flow dome remnants. Groundmass with intersertal texture composed of glass, plagioclase microlites, pyroxene, and opaque minerals; phenocrysts vary from 1 to 16 percent of rock and include plagioclase and pyroxene, both enstatite and augite, with enstatite being more common. Enstatite ($En_{0.68}$ $Fs_{0.30}$ $Wo_{.02}$) composes 6 percent to less than 1 percent of rock, grains are euhedral to subhedral, range in size from 0.1 to 1 mm, often slightly pleochroic from light brown to light green, found as isolated grains and in glomerocrysts consisting of both pyroxenes ± plagioclase. Augite ($En_{0.40}$ $Fs_{0.10}$ $Wo_{0.50}$) composes up to 2 percent of rock but absent in less phyric varieties; grains found as both isolated grains and in glomerocysts; largest grains (up to 2 mm) are larger than enstatite grains but most are similar in size to enstatite; grains are colorless to light green with no pleochroism and are often strongly embayed but euhedral grains do exist. Plagioclase from 8 percent of rock to absent in less phyric varieties; when present grains are concentrically zoned, mostly elongate with fewer equant grains and vary in size from 0.1 to 1.6 mm (in long direction). Locally intruded by feeder dikes of similar composition and mineralogy as lava flows and dome remnants. Ages for dikes are inferred to be similar to those reported here. $^{40}Ar/^{39}Ar$ dates (whole rock) of 3.86 ± 0.13 Ma (RGR–82; table 3) and 3.84 ± 0.07 Ma (RGR–79; table 3). Reverse aeromagnetic polarity. Flow thickness from 30–40 m

$_yT_{taul}$ — **Lower trachyandesite of Ute Mountain (Pliocene)**—Predominantly light-gray to black porphyritic trachyandesite (57 weight percent SiO_2) lava flows and flow remnants associated with the early eruptive phase of Ute Mountain. Exposed along lower flanks of northern Ute Mountain, and as isolated exposures topographically elevated above alluvial fan apron (units Qfo, Qfi, and Qfy) on western and southwestern flanks and in the Rio Grande gorge west of Ute Mountain. Likely represents eroded volcanic complex unconformably overlain by main eruptive phase deposits of unit Taum. Phenocrysts vary from 2 to 16 percent of rock and include plagioclase, olivine, and pyroxene. Plagioclase composes 7 percent to less than 1 percent in sample with coarse-crystalline groundmass; concentrically zoned grains are elongate and equant and vary in size from 0.4 to 2.0 mm in length for elongate grains and 0.3–1.2 mm for more equant grains. Pyroxenes appear black in hand sample and compose 6 percent to less than 1 percent of rock in sample with coarse-crystalline groundmass; includes both enstatite ($En_{0.68}$ $Fs_{0.30}$ $Wo_{.3}$) and augite ($En_{0.47}$ $Fs_{0.10}$ $Wo_{0.43}$); petrographically, both pyroxenes are light green, euhedral grains to anhedral fragments ranging in size from 0.5–2.4 mm, found as isolated grains and in glomerocrysts ± plagioclase. Olivine ($Fo_{0.66}$) grains are light green to yellow in hand sample, colorless with slightly iddingsitized rims in thin section, compose no less than 2 percent of rock, and consist of highly embayed subhedral grains to anhedral fragments ranging in size from 0.6 to 2.0 mm. Groundmass with intersertal to intergranular texture comprises plagioclase, pyroxene, opaque minerals, and glass ranging from fine to coarsely crystalline with plagioclase and pyroxene grains up to 0.4 mm. Locally exposed in the Rio Grande gorge as the lowest of three distinct flow packages with Taum and Ttac. Basaltic trachyandesite lava flows characterized by poorly developed pahoehoe flow morphology and increased olivine and decreased pyroxene phenocryst abundances. $^{40}Ar/^{39}Ar$ date (whole rock sample from the west side of Ute Mountain near the Rio Grande gorge rim) of 3.91 ± 0.06 Ma (RGR–77; table 3). Reverse aeromagnetic polarity. Flow thickness ranges from 10 to 20 m, base not exposed

EXPLANATION

Contact

Normal fault—Dotted where concealed; bar and ball on apparent downthrown side

Dike—Feeder dikes that locally intrude unit Taum

AM — Lineament located by aeromagnetic survey

RGR–32 — 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)

Publishing support provided by:
Denver Publishing Service Center
Manuscript approved for publication Nov. 19, 2013

For more information concerning this publication, contact:
Center Director, USGS Geosciences and Environmental Change Science Center
Box 25046, Mail Stop 980
Denver, CO 80225
(303) 236-5344

Or visit the Geosciences and Environmental Change Science Center Web site at:
http://gec.cr.usgs.gov/

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Although this information product, for the most part, is in the public domain, it also contains copyrighted materials as noted in the text. Permission to reproduce copyrighted items must be secured from the copyright owner.

This database, identified as SIM 3284, has been approved for release and publication by the U.S. Geological Survey (USGS). Although this database has been subjected to rigorous review and is substantially complete, the USGS reserves the right to revise the data pursuant to further analysis and review. Furthermore, it is released on condition that neither the USGS nor the U.S. Government may be held liable for any damages resulting from its authorized or unauthorized use.

This and other USGS information products are available at
http://store.usgs.gov/
U.S. Geological Survey
Box 25286, Denver Federal Center
Denver, CO 80225
To learn about the USGS and its information products visit
http://www.usgs.gov/
1-888-ASK-USGS
This report is available at:
http://pubs.usgs.gov/sim/3284

ISSN 2329-132X (online)
http://dx.doi.org/10.3133/sim3284

INTRODUCTION

The