U.S. Geological Survey

[Volcanic rock names listed in the unit descriptions below are based on geochemical data from volcanic rocks sampled in the map area and the classification scheme of Le Bas and others (1986). Phenocryst abundances listed in volcanic unit descriptions are based on visual estimates from one or more thin sections. Name classifications for both loose sediment (for example, sand) and their lithified equivalents (for example, sandstone) are listed together (separated by a forward slash, for example, sand/sandstone) in the descriptions below for the variably lithified Tertiary sedimentary map units]

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS dg Disturbed ground (Holocene)—Areas of human ground disturbance, including

quarries, excavation pits, and surface grading. Unit mapped just south of

city of Salida, Colo., in vicinity of large gravel quarry operation

Hill Gulch in southwest part of map area Ot Travertine deposits (Quaternary)—Pale-gray, laminated to massive, avertine deposits. Locally contains subangular bedrock fragments. Forms linear, partly eroded and collapsed, mound complex coincident with trace of Poncha fault and Poncha Hot Springs

af Artificial fill (Holocene)—Small earthen dam crossing channel of Round

ALLUVIAL AND MASS MOVEMENT Qa Alluvium (Holocene and latest Pleistocene)—Well-sorted, well-stratified to thick-bedded, subrounded to well-rounded, silty clay to silty sand and sandy pebble gravel to clast-supported cobble gravel. Present along the floors of wider stream canyons, and forming the floodplain of the South Arkansas River as much as about 5 meters (m) above river level. Floodplain surfaces are characterized by distinct bar-and-swale topography, and include relict, abandoned, braided channel networks. Floodplains subject to occasional flooding. Highest deposits above active channels commonly have a thin (<20 centimeters [cm]) loess mantle and a weakly developed A/Bw/C soil profile. Exposed sections commonly consist of sandy silt, silty sand, and clayey silt coarsening downwards to sand and pebble gravel. Along the north-sloping piedmont south of Salida, deposits generally have A/C soil profiles on older surfaces above active stream and wash channels. Locally soils are better developed, with weak argillic B horizons and stage I pedogenic carbonate visible as stringers in a bulk matrix that is HCl-reactive. Includes overbank deposits of organic-rich, fine-grained, silt and clay. Locally includes minor amounts of slopewash, recent landslide and colluvial debris, and reworked older fan gravels and till derived from adjacent slopes. Estimated thickness generally 1–5 m, but may exceed

10 m in some places Qac Alluvium and colluvium, undivided (Holocene and late and late middle? **Pleistocene**)—Poorly to moderately sorted, well-stratified to nonstratified, granule-pebble-boulder gravel in a sandy silt and silty clay matrix. Deposited primarily by ephemeral and discontinuous streams. sheetwash, slopewash, and mass wasting processes on moderate to gentle slopes and in ravines. Unit displays weak to strong soil development, with local stage III pedogenic carbonate locally developed where unit thinly mantles underlying middle Pleistocene gravel deposits Locally includes organic-rich, silty, sandy pebble stream-deposited gravel and clayey silt overbank deposits. Includes slopewash and sheetwash derived from underlying units of the Dry Union Formation. Clast lithology varies with local bedrock units from which it is derived Average thickness ranges from 1 to 3 m, but may locally exceed 5 m QIS Landslide deposits (Holocene and late and late middle?

Pleistocene)—Massive, poorly sorted to nonsorted, angular to subangular, granule to boulder gravel in a clayey silt and silty sand matrix. Landslide deposits have not been differentiated on map by process or age. Includes deposits formed by rock fall, rock slide, block slide, debris flow, and earth flow processes. More recent landslide deposits are generally characterized by well-expressed hummocky topography and bulging toes, with many exhibiting steep crown escarpments, and various extensional features across active surfaces. Includes recent debris flow deposits with well-expressed channeland-levee networks on active surfaces, locally with as much as 3 m of topographic relief. Older, inactive landslides have subdued and eroded surficial morphology, and pedogenic development, indicative of slope stability. In some places, substantial eolian silt and clay mantle older landslide deposits, promoting strong pedogenic carbonate formation. Generally, older, inactive landslides exist higher in landscape; more recent, active landslide deposits are generally in lower steep canyons of the active fluvial systems. Estimated thickness varies from 3 m to locally more than 10 m

ALLUVIAL/MASS MOVEMENT AND (OR) GLACIAL Diamicton (middle and early Pleistocene? and Pliocene?)—Pale-tan, -brown, -gray, -olive, and -ocher, friable, massive to crudely stratified, sandy gravel and sedimentary breccia. Contains rare intervals and lenses of pebbly sand and silty sand. Clasts are mostly poorly sorted to unsorted, angular to subangular pebbles, cobbles, and boulders of locally derived Proterozoic metamorphic and intrusive rocks, rarely accompanied by rounded pebbles and cobbles of Tertiary volcanic rocks. Maximum boulder lengths exceed 3 m. Clasts, which are both matrixand clast-supported, are commonly deeply weathered and oxidized. Unit commonly forms soft silty, sandy, and locally grussy soil. Deposits are typically poorly exposed, mantled by thick soil and bouldery colluvium, and typically expressed on the ground by large float boulders of Proterozoic rocks that protrude as much as 1 m above the soil surface. Diamicton unit underlies rounded ridge crests in erosionally dissected uplands surrounding O'Haver Lake and northwest of Little Cochetopa Creek in the western part of the map area. Origin of diamicton is uncertain. The deposits, which mostly lie on the east, downthrown side of south Sawatch fault, may represent proximal alluvial, rock avalanche, and other mass movement deposits (for example, debris flow) shed from the southern Sawatch mountain block as it was uplifted and exhumed along the fault. Alternatively, diamicton may represent old till deposited by middle Pleistocene glaciers that flowed out of southern Sawatch Range west of map area. Unit may be at least in part temporally correlative with the old alluvial deposits (unit QTa). Estimated thickness increases westward to a maximum of greater than 200 m

Young fan deposits (Holocene and late Pleistocene)—Unsorted to moderately sorted, stratified, angular to subrounded, pebble-boulder gravel commonly in a silty sand matrix. Locally includes stream, sheetwash, and recent landslide deposits too small to map separately Stratification defined by silty sand lenses interbedded with coarser gravels. Relict bar-and-swale topography is well expressed with commonly ≥1 m of topographic relief. Surfaces are locally characterized by channels and levees formed from episodic debris-flow events. Soils generally have discontinuous stage I pedogenic carbonate development. Along piedmont south of Salida, soils on older deposits of this unit have weak, discontinuous textural B horizons and more continuous stage I pedogenic carbonate development. Estimated thickness less than 5 m **Intermediate fan deposits (late middle Pleistocene)**—Deposits similar to young fan deposits (unit Qfy) in characteristics and mode of deposition, but are more dissected and incised. Soils are better developed than for unit Qfy, with moderate argillic textural B horizons and common stage I–II pedogenic carbonate development. Relative elevational difference between Qfy and Qfi deposits increases down drainages from source areas to local base levels, but generally **Qfi** deposits are less than 3 m

above Qfy deposits within map area. Estimated thickness less than 5 m Old fan deposits (middle and early? Pleistocene)—Generally crudely stratified, unsorted to moderately sorted, angular to subrounded, pebble-boulder gravel in a silty sand and clayey silt matrix. Deposits generally have well-developed argillic soils and common stage II–III pedogenic carbonate development. Clast composition is predominantly locally derived Proterozoic metamorphic and intrusive and Tertiary volcanic rock types, including clasts reworked from underlying deposits of the Dry Union Formation. Many clasts are weathered with iron staining and desert varnish. Mostly deposited as alluvium in fans and as pediment gravel veneers. Geomorphic upper surfaces of unit are commonly roughly planar and include thin eolian silt veneers. Thickness is generally 2 to 5 m but may locally exceed 10 m. Deposits flank southern and northern sides of the Poncha mountain block, south and southeast of Poncha Pass and on the north-sloping piedmont north of the Poncha fault, respectively. The old fan gravels flanking the northeast side of the Poncha mountain block are inferred to have been deposited as progradational fans representing a dropping base level associated with incision of the Arkansas River system. Unit divided into three age subunits based on degree of geomorphic preservation, inset relations, relative elevation of deposits, and correlation to fluvial deposits along the South Arkansas River, after Kellogg and others (2017): Youngest subunit—Deposits occupy lowest relative elevational position

Intermediate subunit—Deposits occupy intermediate relative elevational **Oldest subunit**—Deposits occupy highest relative elevational position. Subunit correlated with terrace gravels "No. 7" of Behre (1933) and Powers (1935) and "Qg1" of Kellogg and others (2017), who report lithologic and paleontologic evidence that the unit was deposited in a non-glacial environment Older alluvial deposits (early Pleistocene?)—Pale-tan, -yellow, -gray, and -ocher, friable, crudely to well-laminated and -stratified, sand, silty sand, gravelly sand, and sandy gravel. Clasts consist of mostly (75–95 percent)

locally derived, angular to subangular pebbles, cobbles, and small boulders

rounded pebbles and cobbles of mixed Tertiary volcanic rocks. Unit present

of Proterozoic basement rocks, and lesser (5–25 percent) subrounded to

in central and eastern parts of the northern piedmont where deposits

units of the Dry Union Formation below the base of the perched old

form remnant, dissected alluvial aprons that lap southward onto bedrock

alluvial deposits (unit QTa). Exposed thickness ranges from 10 to 15 m

Old alluvial deposits (early Pleistocene? and Pliocene?)—Pale-tan, paleolive-brown, pale-gray, and ocher, friable, massive to crudely stratified, sand, silty sand, gravelly sand, sandy gravel, and sedimentary breccia. Gravel lenses common. Clasts predominantly angular to subangular pebbles, cobbles, and boulders as long as 3 m of locally derived Proterozoic intrusive and metamorphic rocks; rarely unit includes clasts and local monomict sedimentary breccias of Tertiary volcanic rocks and Paleozoic(?) sedimentary rocks. Unit commonly forms soft, sandy, silty, and locally grussy soil. Deposits are typically poorly exposed, mantled by colluvium, and underlie strongly dissected uplands having steep slopes strewn with float blocks derived from unit. Old alluvial deposits present on northern, downthrown side of Poncha fault along margin of northern range-front piedmont. Unit inferred to have been deposited as proximal alluvial fans and rock-avalanche deposits shed from the adjacent mountain footwall block of the Poncha fault as it was uplifted and exhumed. Part or all of unit may be temporally correlative with diamicton unit (QTd). Maximum preserved thickness about 150 m. Deposits previously mapped as "Dry Union Formation, upper part" by Van Alstine (1975) and Taylor and others (1975). Deposits not mapped as part of Dry Union Formation in this report due to ubiquitous angular unconformity separating unit from underlying tilted strata of the Dry Union Formation, and due to markedly more consolidated and indurated nature of the Dry Union

AXIAL FLUVIAL/ALLUVIAL Lag gravel deposits (middle and early Pleistocene?)—Subangular to wellrounded, sandy pebble-cobble gravel discontinuously perched above tributary canyons and drainages along basinward sloping interfluves and inset benches. Gravels are commonly thin, unconsolidated, winnowed, and clast supported. Deposits generally lie on abandoned fluvially scoured surfaces, with subsequent modification and erosion limited to local weathering and eolian processes. Soils generally are welldeveloped argillic textural B horizons with local stage II-III pedogenic carbonate development. Mapped within the Poncha Pass, Poncha Creek, Little Cochetopa Creek, and Pass Creek areas in the western part of map area, and on the western flank of Methodist Mountain between elevations of about 10,200–10,500 feet (ft). Highest mapped lag gravel deposits along Poncha Creek canyon grade southwestward to the base of unit QTd at an elevation of about 9,200 ft. Highest lag gravels and associated strath benches emanating from the Droz-Poncha Creek confluence and along Poncha Creek canyon grade northward to and below fan gravels of unit Qfo1 on the piedmont south of the town of Poncha Springs. Deposits interpreted to represent brief deposition, incision, and surface abandonment associated with the onset of middle Pleistocene glaciofluvial processes and resulting stream incision. Lag gravels are correlated with units Qg3 and Qg4 of Van Alstine (1969) and Kellogg and others (2017) in upper Arkansas River valley north of map area on the basis of topographic, geomorphic, and pedogenic relationships; all of these units are less than 640 ka (kilo-annum, thousand years) based on the presence of Lava Creek B in unit Qg3 (Kellogg and others, 2017). Estimated average thickness is less than 3 m

GLACIAL AND GLACIO-FLUVIAL Outwash gravel of Pinedale glaciation (late Pleistocene)—Massive to thinly bedded, moderately sorted to well-sorted, subrounded to wellterraces about 3–10 m above active stream level of the South Arkansas River. Sand lenses and cross bedding locally present. Deposit is locally clast supported with little to no matrix. Mainly deposited in streams sourced from glaciers of the southern Sawatch Range west of map area. Soils typically have a weak A/C development, but locally exhibit stage I pedogenic carbonate. Based on topographic position, pedogenic development, and correlation with deposits in adjacent regions, gravel inferred to have been deposited during the Last Glacial Maximum (Pinedale glaciation, about 22–21 ka). Higher-energy glacio-fluvial deposition represented by the outwash gravel likely waned or terminated by about 14–13 ka (Kellogg and others, 2017). Locally includes small, unmappable deposits of units Qac and Qls, and older glacial (Qtb) and glaciofluvial (Qgb) units. Thickness varies with geomorphic location within the basin; estimated to range from 3 to 10 m

Till of Pinedale glaciation (late Pleistocene)—Generally massive, unsorted, subangular to subrounded, pebble-boulder gravel with a silty sand and clayey silt matrix. Clasts are dominantly matrix supported. Unit forms sharp-crested lateral moraines on both sides of upper Little Cochetopa Creek. Unit locally includes small, unmappable mass-wasting deposits along steeper slopes of the moraines. Boulders are mostly unweathered, but till locally contains deeply weathered cobbles of metamorphic rock. Along moraine margin on southeast side of Little Cochetopa Creek, unit commonly contains deeply weathered granitic boulders derived from adjacent older units Qtb and (or) QTd. Soils are generally nonexistent on bouldery moraine crests, but weak argillic textural B horizons with spotty pedogenic carbonate stage I development are preserved in morainal depressions and swales. Till likely correlative with the early part of marine oxygen isotope stage (MIS) 2 glacial episode (Lisiecki and Raymo, 2005) (that is, Pinedale glaciation, about 31-13 ka) based on similarities with morainal deposits elsewhere in region (Kellogg and others, 2017). Estimated thickness increases along the lateral moraines westward towards the southern Sawatch range front from 5 m to as much as 70 m

Outwash gravel of Bull Lake glaciation (late? and late middle

to well-sorted, subrounded to rounded, pebble-boulder gravel in a silty sand matrix. Generally similar to deposits of unit Qgp, but soils have more developed pale-reddish brown to orange-brown argillic textural B horizons (A/Bt/C). Clasts chiefly composed of various Proterozoic rock types and Tertiary volcanic rocks derived from surrounding bedrock. Mainly deposited in streams sourced from glaciers of the southern Sawatch Range west of the map area. Estimated thickness ranges from 3 to 10 m Till of Bull Lake glaciation (late middle Pleistocene)—Subangular to subrounded, pebble-boulder gravel in a silty sand and clayey silt matrix. Unit is massive and has little to no sorting or stratification. Large boulders at surface are generally partly buried, and primary depositional morphology of till is subtle. Exposed granitic boulders are generally rounded and weathered with gruss on their outer surfaces. Clasts of other rock types are also weathered, locally including iron staining. Till forms relatively dissected and subdued lateral moraines adjacent to, and outboard of, the

Pinedale lateral moraines (unit Qtp) along upper Little Cochetopa

on correlative geomorphic surfaces of Bull Lake till in the northern

upper Arkansas River Basin (Schweinsberg and others, 2016; Kellogg

Creek. Based on the overall spread of cosmogenic nuclide exposure ages

Pleistocene)— Stratified to massive, clast-supported, moderately sorted

and others, 2017), an age of 167-95 ka is assigned to these deposits (that is, MIS 6 of Lisiecki and Raymo, 2005). Estimated thickness 10–70 m **Qgpb** Outwash gravel of pre-Bull Lake glaciation (middle **Pleistocene**)—Pale-gray to pale-gray-brown, subangular to wellrounded, pebble-cobble gravel in a silty sand matrix. Unit only preserved near mouth of Little Cochetopa Creek in northwesternmost part of map area. Soils have discontinuous stage II–III pedogenic carbonate development. Outwash gravel correlated with units Qg3 and Qg4 of

Kellogg and others (2017). Thickness less than 5 m **BASIN-FILL DEPOSITS** Dry Union Formation (Pliocene? and Miocene)—Basin-fill alluvial,

mass-movement, and lacustrine, variably lithified mudstone, sand/sandstone, gravel/conglomerate, and sedimentary breccia present in southwestern, western, northern, and northeastern parts of map area where they unconformably lap onto the Eocene–Oligocene volcanic and Proterozoic basement rocks. Generally poorly exposed; exposures primarily limited to channels and small cliffs of arroyos and canyons. Age range of formation inferred from middle and late Miocene ⁴⁰Ar/³⁹Ar ages on sanidine of air-fall(?) tuff layers in map area (9.30±0.04 Ma [mega-annum, million years] and 15.6±0.3 Ma) (see table of argon age data) and previously reported Miocene and questionable Pliocene ages of Mammalian vertebrate fossils (Van Alstine and Lewis, 1960; Van Alstine, 1974; MacKenzie and Sertich, 2016). Estimated maximum thickness of Dry Union deposits ≥2,500 m in northeast, north, and northwest parts of map area; thickness likely <500 m in southwest part Deposits previously mapped as Dry Union Formation by Van Alstine (1974; 1975), Scott and others (1975), Taylor and others (1975; "lower part"), Shannon and McCalpin (2006; "South Arkansas graben sequence"), and Kellogg and others (2017). Deposits in map area correlated with deposits of the type Dry Union Formation as originally defined by Tweto (1961) near Leadville at north end of upper Arkansas River Basin; generally, deposits in map area resemble type Dry Union deposits in terms of appearance, age, and mode(s) of deposition. The Dry Union Formation is regionally equivalent to basin-fill deposits of the Santa Fe Group in the Rio Grande rift of northern New Mexico and southern Colorado. Subunits of the Dry Union Formation are differentiated in map area primarily based on dominant clast composition or inferred depositional environment; all mapped subunits grade or interfinger laterally and up-down section into adjacent subunits. Subunits

consist of the following: **Polymict deposits**—Pale-tan, -brown, -gray, and -greenish gray, friable to rell-consolidated, mostly moderately to well-stratified, interbedded mudstone/claystone, silt/siltstone, silty sand/sandstone, sand/sandstone, pebbly sand/sandstone, sandy gravel/conglomerate, gravel/conglomerate, and sedimentary breccia. Layers of coarser-grained sediments are commonly lenticular or channelized. Locally sands and gravels are cemented with carbonate or, more rarely, silica or other minerals. Gravels, conglomerates, and breccias are characteristically polymict, with most clasts composed of variable mixtures of intermediate- to silicic-composition Tertiary volcanic rocks and Proterozoic metamorphic and intrusive basement rocks; clast proportions range from >90 percent volcanic rocks to >90 percent basement rocks, though most proportions range between 3:1 and 1:3; subordinate Paleozoic(?) quartzite and carbonate clasts accompany the volcanic and basement clasts in northwest part of map area, especially near unit's gradational contact with unit Tduz. Gravel and conglomerate clasts range from pebbles to boulders as long as 1 m and mostly range from subangular to well rounded; volcanic clasts tend to be somewhat more rounded than the

Proterozoic clasts, but in some exposures no noticeable difference in degree of rounding exists for different clast compositions. Gravels/ conglomerates and breccias are both matrix- and clast-supported. Larger elongate clasts in gravels and conglomerates are imbricated in places. Several thin (10–50 cm), conspicuously white-to-pale-gray, air-fall(?) ash tuff layers or lenses exist in subunit in northwest, north, and northeast parts of map area. Two such tuff layers have yielded Miocene radiometric ages (see general Dry Union description above). Mammalian vertebrate fossils of Miocene and questionable Pliocene age are scattered throughout subunit. Local concentrations of fossil wood fragments and logs also present. Subunit inferred to have been deposited as proximal to distal alluvium sourced both from nearby mountain block(s) cored by

Proterozoic basement rocks and from more distant volcanic terrane(s).

Subunit mapped in southwest, west, northwest, north, and northeast parts

of map area, where it is intercalated with and grades into the other Dry Union subunits throughout the full stratigraphic range of formation. Estimated maximum thickness of polymict deposits ≥2,000 m **Proterozoic-clast deposits**—Tan, pale-brown, pale-olive-gray, and ocher, friable to well-consolidated, massive to well-stratified, interbedded silty sand/sandstone, sand/sandstone, pebbly sand/sandstone, sandy gravel/ conglomerate, gravel/conglomerate, and sandy sedimentary breccia. Rare interbeds and intervals of laminated sandy silt and mudstone. Clasts predominantly angular to rounded pebbles, cobbles, and boulders as long as 2 m of locally derived Proterozoic intrusive and metamorphic rocks; locally in Pass Creek area, unit includes rare clasts of Paleozoic sedimentary rocks. Gravels, conglomerates, and breccias are both matrix- and clast-supported. Subunit inferred to have been deposited as proximal to medial alluvium sourced from nearby mountain block(s) cored by Proterozoic basement rocks. Subunit is present in the northwestern part of map area where it is estimated to range in thickness from about 1,000 m to >2,000 m. Subunit distinguished from deposits of the unconformably overlying diamicton (unit QTd) by its generally greater consolidation and lithification, greater abundance of sand beds, better-

developed stratification, and greater stratal dips (20–40°) Volcanic-clast deposits—Pale-tan, -gray, and -brown, friable to wellconsolidated, massive to well-stratified, interbedded silty mudstone/ claystone, silt/siltstone, silty sand/sandstone, sand/sandstone, pebbly sand/sandstone, sandy gravel/conglomerate, gravel/conglomerate, and sedimentary breccia. Some layers of coarser-grained sediments are lenticular or channelized. Gravels, conglomerates, and breccias are characteristically monomict, with most clasts composed of mixtures of intermediate- to silicic-composition Tertiary volcanic lavas and lesser welded tuffs; in places, clasts include rare to sparse (<3 percent) clasts of Proterozoic basement rocks or, very rarely, Paleozoic sedimentary rocks. Clasts typically consist of matrix-supported, subangular to well-rounded, pebbles, cobbles, and small boulders. Sedimentary breccias are commonly composed of angular monolithologic blocks of locally derived lava as much as 2 m long with negligible matrix. Subunit present in southwest, west, and northeast parts of map area; in southwest, deposits form most or all of the exposed Dry Union section, whereas in the west and northeast, they form lower or lowest part of section and grade upwards into the polymict deposits (subunit Tdup). Coarse sedimentary breccia that is chiefly derived from directly underlying dacitic lava of the Conejos Formation (unit Tcd) makes up most of lower part of volcanic-clast subunit in the west. Subunit inferred to have been deposited as proximal to medial alluvium and mass movement debris sourced from local intermediate lavas and as distal alluvium derived from more distant intermediate to silicic volcanic terrane(s). Estimated maximum thickness about 850 m

reddish brown, friable to indurated, finely bedded to laminated, generally well-sorted, interbedded claystone, mudstone, silt/siltstone, and finegrained clayey/silty sand/sandstone. Rare to common interbeds and lenses of pale-gray and -green-gray and buff, locally tuffaceous sand/ sandstone, pebbly sand/sandstone, and gravel/conglomerate, and rare beds of beige, tabular, silty, sandy limestone and dark-brown peaty shale. Mudstone and claystone gypsiferous in places. Sandstone and gravel beds locally cemented with silica(?). Subunit comprises two separate inferred lacustrine facies in middle part of exposed Dry Union section, one in northeast part of map area and one in northwest part. Gravel and conglomerate clasts of northeast facies are predominantly composed of volcanic rocks, whereas such clasts of northwest facies are variable mixtures of Proterozoic basement and Paleozoic sedimentary rocks. Large (tens of meters long) pervasively fractured and brecciated stratabound lenses and masses of Paleozoic carbonate rocks (equivalent to subunit sb; see unit description listed below for details) are present in stratigraphically lower part of northwestern facies. White, thin (about 1 m), bedded, air-fall(?) tuff layer present in subunit about 1 kilometer (km) west of confluence of Pass and Little Cochetopa Creeks. The northwest lacustrine facies stratigraphically overlies and interfingers with the Paleozoic-clast subunit (Tduz) just west of lower Little Cochetopa Creek. Deposits inferred to have been deposited in lacustrine depocenters due to dominant fine-grained, muddy-silty nature of sediments, presence of limy and gypsiferous layers, and the common presence of blocks and masses of Paleozoic carbonate rocks that presumably slid into a closed basin (Van Alstine, 1970). Maximum exposed thickness about 750 m for northwest facies and about 500 m for northeast facies

Lacustrine deposits—Pale-brown, -gray, -olive-green, and -olive-tan and

aleozoic carbonate slide blocks—Gray to tan-gray, large (tens of meters long), pervasively fractured and brecciated stratabound lenses and masses of Paleozoic carbonate rocks with local, minor clastic rock components. Disturbed carbonate rock ranges from crackle or shatter breccia, containing angular "clasts" that have experienced little or no rotation or displacement relative to adjacent clasts, to completely disaggregated but intact, carbonate-cemented rock. Blocks and masses present throughout subunit Tduz and stratigraphically lower part of overlying Idul subunit in northwest part of map area; mapped separately only where large enough to depict at map scale. Carbonate lenses and masse inferred to be paleo-landslide blocks that were internally fractured and brecciated as they were emplaced into lacustrine or alluvial depositional basin (Van Alstine, 1970). Estimated maximum thickness of individual slide masses about 7–10 m Paleozoic-clast deposits—Pale-gray, -brown, -brownish gray, -pinkish

gray, and -greenish gray and reddish brown, friable to indurated, interbedded silty sand/sandstone, sand/sandstone, pebbly sand/sandstone, sandy gravel/conglomerate, gravel/conglomerate, and sedimentary breccia; subordinate interbeds of mudstone, silty mudstone, and conglomeratic mudstone. Gravels, conglomerates, and breccias typically contain abundant clasts (75 percent to >90 percent) of Paleozoic sedimentary rocks, which are mostly carbonates, sandstones, and quartzites; other clasts consist of variable proportions of Proterozoic basement rocks and Tertiary volcanic rocks; blocks of Proterozoic rocks as long as 2.5 m are present in some sedimentary breccia intervals. Clasts, which are both matrix- and clast-supported, mostly consist of angular to subrounded pebbles, cobbles, and small boulders. Large (tens of meters long) pervasively fractured and brecciated stratabound lenses and masses of Paleozoic carbonate rocks (equivalent to subunit sb; see unit description below for details) are present throughout subunit. Subunit inferred to have been deposited as proximal to distal alluvium and mass-movement debris sourced from nearby elevated exposures of Paleozoic and Proterozoic rocks, as well as more distant volcanic terrane(s). Subunit present in northwest part of map area mostly east of Little Cochetopa Creek. Maximum exposed thickness about 765 m Lower Proterozoic-clast deposits—Tan, tan-gray, and reddish tan, massive to stratified, intercalated silty sand/sandstone, sand/sandstone,

pebbly sand/sandstone, sandy gravel/conglomerate, and sedimentary breccia. Clasts are predominantly angular to subangular pebbles, cobbles, boulders, and blocks (as much as several meters long) of Proterozoic basement rocks, but in places include rounded pebbles and cobbles of Tertiary(?) volcanic rocks. Mapped subunit forms basal Dry Union section where formation laps onto Proterozoic basement rocks (unit YXvs) southwest of Poncha Pass (southwest part of map area) and along the Poncha range-front fault system near mouth of Poncha Creek canyon (north part of map area). In latter area, some Proterozoic-clast gravels and breccias near basal contact are characterized by wispy, sinuous, discontinuous, micaeous shears and thin layers with a weak phacoidal fabric that are subparallel to stratification. Subunit inferred to have been deposited chiefly as proximal alluvium and mass movement debris shed from adjacent elevated mountain blocks cored by Proterozoic basement rocks. Maximum exposed thickness about 100 m

Bonanza Tuff (lower Oligocene)—Pale-tan to -tannish brown, lithic-rich, crystal-poor, platy, partly welded, dacitic-to-rhyolitic ignimbrite. Crystal fragments composed of sanidine (about 5 percent), plagioclase (about 2 percent), and biotite (about 1 percent) in a devitrified, to oxidized, glass matrix. Lithic fragments (as long as 1 m) chiefly consist of andesitic rocks. Source of tuff is Bonanza caldera (Lipman and others, 2015), whose northern topographic wall overlaps southern border of map area. In map area, tuff exposures limited to three small, thin, outflow remnants: (1) talusforming remnant plastered on Conejos dacitic lava (unit Tcd) in northwest map area; (2) remnant plastered against Proterozoic basement rocks in southeast area; and (3) remnant plastered against caldera topographic wall on southwest border of map area. Lipman and others (2015) reported a mean ⁴⁰Ar/³⁹Ar (sanidine) age of 33.12±0.03 Ma for outflow Bonanza Tuff. Mapped as lower and upper welded tuff by Van Alstine (1975) Rhyolitic lava (lower Oligocene)—Pale-gray, conspicuously flow-layered and -folded, crystal-poor rhyolitic lava. Contains phenocrysts of sanidine (10 percent), plagioclase (3 percent), biotite (2 percent), and Fe-Ti (irontitanium) oxides set in a glassy, intersertal groundmass. Forms plug-shaped extrusion between confluence of Poncha and Silver Creeks along southwest border of map area. Lipman and others (2015) reported a ⁴⁰Ar/³⁹Ar (sanidine) age of 33.05±0.09 Ma for the lava. Exposed thickness

Volcanic rocks of Bear Creek (lower Oligocene?)—Thin, localized sequence of intermediate-composition lava flows, flow breccias, and minor interflow sediments exposed in a small area (0.1 km²) at north end of Bear Creek near northeast corner of map area. Lavas lap onto Proterozoic basement rocks (units YXvs and Xgd) and are unconformably overlain by deposits of the Dry Union Formation. No radiometric ages available for Bear Creek volcanic rocks, but their similarity to other intermediate lavas in region stratigraphically below Dry Union Formation (for example, Conejos Formation lavas) suggest they are early Oligocene in age. Volcanic rocks of Bear Creek previously mapped as andesite at Waugh Mountain by Taylor and others (1975). The following lavas of unit are separately mapped:

Phyric trachyandesite lava—Purple-gray (weathered), gray (fresh), vesicular, conspicuously porphyritic trachyandesite lava flow. Phenocrysts consist of plagioclase (about 25 percent), tabular clinopyroxene (about 15 percent; readily visible on weathered surfaces), Fe-Ti oxides (about 7 percent), and rare, strongly altered biotite. Phyric trachyandesite lava flow likely overlies andesitic lava (subunit Ta). Flow about 10 m thick Frachyandesite lava—Gray, vesicular, nearly aphyric trachyandesite lava flow. Groundmass coarsely holocrystalline, composed of plagioclase (about 80 percent), Fe-Ti oxides (about 10 percent), and biotite (about 8 percent). Partly amygdaloidal, with vesicles containing zeolite(?) minerals. Trachyandesite lava flow stratigraphically overlies thin (about 15 m) interval of tuffaceous (palagonitic?) sediments that, in turn, overlie

dacitic lava (subunit Td). Flow about 15 m thick Frachydacitic lava—Pale-purple-gray, porphyritic dacitic (transitional trachydacite-trachyandesite compositionally) lava flow. Phenocrysts consist of plagioclase (about 20 percent), biotite (about 10 percent). Fe-Ti oxides (about 5 percent) set in a glassy groundmass. Dacitic lava flow laps onto Proterozoic basement rocks. Flow <15 m thick Conejos Formation (lower Oligocene and upper Eocene)— Predominantly intermediate-composition, lava flows, flow breccias, associated lahar and pyroclastic deposits, and interflow sediments present in southwest and west parts of map area. Lavas range in age from about 34.2 Ma to 33.4 Ma based on several new ⁴⁰Ar/³⁹Ar (whole-rock and biotite) ages (see tabl of argon age data). Lavas temporally and compositionally closely resemble regionally extensive, intermediate lavas of the Conejos Formation that crop out south and southwest of map area (for example, Colucci and others,

1991; Lipman and others, 2015), and are herein correlated with this

formation. Conejos volcanic rocks, and locally pre-Conejos gravels, lap

onto Proterozoic basement rocks (unit YXvs) in Round Hill, Poncha Pass

Poncha Creek canyon, and Cleveland Mountain areas, and volcanic rocks are unconformably overlain by deposits of the Dry Union Formation. Conejos Formation in map area differentiated into following subunits: Frachydacite lavas and breccias—Pale-to-dark-gray, pale-brown, palepurple-gray, and pinkish gray (weathered), gray (fresh), blocky, flowbanded, -foliated, -lineated, and -jointed, porphyritic trachydacite lava flows and subsidiary flow breccias. Phenocrysts consist of plagioclase (15–35 percent; 2–5 millimeters [mm] long), biotite (2–7 percent; 0.5– 3 mm long), pyroxene (mostly clinopyroxene; 0–7 percent; 0.5–2 mm long), and Fe-Ti oxides (1–3 percent; <0.5 mm long) set in an intergranular to intersertal groundmass. Lavas locally vesicular, especially near flow tops. At least three separate trachydacite flows distinguished in map area, from south to north: (1) flow centered at Round Hill, (2) flow in O'Haver Lake vicinity and its probable faulted equivalent in Poncha Creek canyon-Cleveland Mountain area, and (3) flow in hills about 3 km southwest of Poncha Springs. Uncertain relative age relations exist among trachydacite lava(s) in Murphys Hole area (southwest corner of map area), Round Hill, and O'Haver Lake. Northern flow (near Poncha Springs) is hydrothermally altered, and markedly so in area of prospects at northern limit of its exposure. In most of their southwestern extent, trachydacite lavas overlie Conejos trachyandesite lava (subunit Tca); whereas at Round Hill and north of Poncha Creek canyon in Cleveland Mountain area, lavas lap onto, and locally fill paleochannels cut into, Proterozoic basement (unit YXvs). 40 Ar/39 Ar biotite ages were obtained from two trachydacite lavas: 33.4±0.4 Ma (Round Hill lava) and 33.6±0.4 Ma (Cleveland Mountain-Poncha Creek canyon lava) (see table

of argon age data). Trachydacite lavas and breccias previously mapped as Squirrel Gulch rhyodacite flow by Van Alstine (1975). Maximum estimated flow thickness about 350 m Trachyandesite lavas and breccias—Pale-to-dark-gray, pale-brown, pale-olive-gray, and pinkish gray (weathered), gray (fresh), locally platy or blocky, flow-foliated, flow-folded, and jointed porphyritic trachyandesite lava flows and subsidiary flow breccias. Common salmon-pinkweathering, interflow, pyroclastic agglomerate and (or) lahar deposits composed of angular to spindle-shaped andesitic lava clasts in a clayey/ silty matrix. Phenocrysts consist of plagioclase (10–45 percent; 0.5– 4 mm long), pyroxene (mostly clinopyroxene; 3–10 percent; 0.5– 2 mm long), and Fe-Ti oxides (3–7 percent; <0.5 mm long) set in an intersertal to intergranular groundmass. Lavas commonly vesicular and rubbly, especially near flow bottoms and tops, and in places amygdaloidal. Uppermost transitional (trachyandesite to trachydacite) flow(s) present in upper Poncha Creek canyon area (southwest of Mears Junction); transitional flow(s) differ from underlying trachyandesite flows by containing a greater proportion of larger plagioclase phenocrysts and sparse (1–2 percent) biotite phenocrysts. Three ⁴⁰Ar/³⁹Ar whole-rock ages obtained from trachyandesite lavas exposed in Poncha Creek canyon southwest of Mears Junction: 34.14±0.08 Ma, 33.92±0.08 Ma and 33.92±0.08 Ma (see table of argon age data); an additional ⁴⁰Ar/³⁹Ar whole-rock age of 33.9±0.4 Ma obtained for upper "transitional" flow exposed in same area (see table of argon age data). Trachyandesite lavas and breccias previously mapped as Rawley (lower and upper) trachyandesite flows by Van Alstine (1975). Individual trachyandesite lava flows range in thickness from about 15 m to more than 30 m. Estimated cumulative thickness of trachyandesite flows about 500 m in upper Poncha Creek canyon area. Relatively thick and abundant flows and agglomerate and (or) lahar deposits in canyon near Shirley town site deposits in Clover Creek area near southwest corner of map area may

suggest that at least some trachyandesite flows and related deposits were emplaced in this area. Cumulative thickness of trachyandesite lavas and exceed 500 m, but base of sequence is not exposed. Clover Creek trachyandesite lavas form part of northern paleo-topographic wall of Bonanza caldera (Lipman and others, 2015) Interflow sediments—Poorly exposed interbedded gravel and sedimentary breccia. Clasts, mostly observed as float, consist of angular to rounded pebbles, cobbles, and boulders of primarily Tertiary mixed intermediateto-silicic volcanic lavas and welded ash-flow tuff(?) and rare to sparse Proterozoic basement rocks; local monomict concentrations of dacitic(?) lava blocks. Sediments form laterally extensive lenticular interval between upper and lower lavas of Conejos trachyandesite subunit (Tca) in upper Poncha Creek canyon southwest of Mears Junction. Maximum exposed thickness about 80 m **Rhyolitic lava**—Beige to pale-tan (bleached), hydrothermally altered, crystal-poor, massive rhyolite lava. Forms eroded plug-like extrusion at

mouth of canyon of Clover Creek near southwest corner of map area.

Part of "pre-caldera lavas" of Lipman and others (2015) forming northern paleo-topographic wall of Bonanza caldera. Age relation of rhyolitic lava with surrounding trachyandesite lavas uncertain. Exposed thickness about 120 m Pre-Conejos Formation gravels (upper Eocene)—Pale-olive-green, paleolive-yellow, and tan-gray, well-consolidated, crudely bedded silty to sandy conglomerate with subordinate conglomeratic sandstone layers and rare mudstone partings. Clasts consist of angular to subrounded pebbles, cobbles, and boulders of primarily Tertiary(?) mixedcomposition volcanic rocks and sparse Proterozoic basement rocks, but in places Proterozoic clasts outnumber volcanic clasts. Some of the more rounded Proterozoic cobbles and boulders do not resemble basement rocks exposed in map area and may be derived from more distant source(s). Pre-Conejos gravels are exposed south and southwest of Mears Junction where they lap onto Proterozoic basement rocks (unit YXvs) and possibly fill a broad paleochannel cut into basement rocks; to the west and south, overlying Cone os trachyandesite lavas (unit Tca) overlap and bury gravel-basement contact. Maximum exposed thickness

of gravels about 150 m Rhyolite dikes (Late Cretaceous)—Phenocryst-poor, microcrystalline, rhyolite dikes, 1-to-5 meters wide, massive to strong internal flow foliation. Locally altered to clay minerals. Dikes intrude Proterozoic basement rocks (unit YXvs) and are spatially associated with two zones of fluorite veins, one just southeast of Poncha Hot Springs and the other about 6 km to the south, near Camp Rock Gulch (compare with Wallace, 2010). Based on float, additional dikes are present in these two areas beyond those mapped. Associated fluorite veins locally cut one of the dikes as well as basal Dry Union Formation deposits (subunit TduXI) in the vicinity of Poncha Hot Springs. One rhyolite dike just above Poncha Fluorspar Mine, on Poncha Mountain range front in north-central part of map area, intrudes a fault zone and appears to have been brecciated by subsequent fault movement. Rhyolite dikes yield zircon U-Pb (uraniumlead) laser-ablation inductively coupled mass spectrometry (LA-ICP-MS) ages of circa (ca.) 65 Ma, ca. 67 Ma, and 68.6±0.6 Ma (see table of U-Pb data)

PALEOZOIC SEDIMENTARY ROCKS Carbonate rocks (Paleozoic)—Dark-gray, thin-bedded carbonate sedimentary rocks (limestone?) of uncertain Paleozoic formational identity. Rocks cut by numerous fractures and small-displacement faults. Exposed only in westernmost part of map area in upper Droz Creek drainage on east, downthrown side of south Sawatch fault. Carbonate rocks either represent large allochthonous block translated from adjacent Sawatch fault escarpment or rooted down-dropped block of Sawatch fault system. Thickness unknown

BASEMENT METAMORPHIC AND INTRUSIVE ROCKS **Pegmatite (Mesoproterozoic?)**—Light-colored, massive, nonfoliated, commonly steeply dipping, pegmatite dikes. Typically, several meters wide, and less commonly as larger, more irregular-shaped intrusive bodies. Feldspars are chunky, fist-sized and larger, commonly euhedral crystals; many are perthitic. Quartz is generally clear to slightly smoky, and typically intergrown with feldspar as graphic granite. Locally bearing fist-sized books of euhedral muscovite crystals, and very rarely small, clear to light blue beryl crystals. Pegmatite intrusions are wellexposed, appear to crosscut all other Proterozoic units exposed in map area, and may be associated with other 1.4-billion years (giga-annum, Ga) pegmatites observed throughout Sangre de Cristo Mountains (for example, Jones and Connelly, 2006; Fridrich and others, 2012) Intrusive complex of Methodist Mountain-Simmons Peak (Paleoproterzoic) —Plexus of stocks and large (up to tens of meters wide) dike-like intrusions in central and southeast parts of map area with four distinct,

separately mapped compositional "facies": **Granodiorite**—Dominantly (about >90 percent) pale- to dark-gray, massive, medium- to coarse-grained granodiorite composed chiefly of potassium feldspar, sodic plagioclase, quartz, biotite, hornblende, and Fe-Ti oxides. Also includes minor contiguous and isolated, related intrusions of quartz monzonite, quartz diorite, and amphibolitic metagabbro. Granodiorite, generally exposed in isolated outcrops, forms large, irregular, stock- to plug-shaped intrusive bodies with sporadic apophyses and associated satellitic dikes and dike swarms. Intrusions are compositionally heterogeneous and locally transition into amphibolitic metagabbro, especially at some intrusive margins and in smaller dikes that radiate out from major stocks. Exhibits primary igneous textures and lacks metamorphic foliation, but possible magmatic flow foliation present locally along intrusive margins. Outcrops in central Sand Gulch, at Methodist Mountain, along ridges to the southeast, and in lower Bear Creek area near northeast corner of map area. Granodiorite yields zircon U-Pb, LA-ICP-MS ages of 1,722.3±9.5 Ma and 1,737.9±7.2 Ma (see table of U-Pb data). Unit also yields zircon U-Pb, sensitive high resolution ion microprobe (SHRIMP), common Pb-corrected, ²⁰⁷Pb/²⁰⁶Pb weighted average age of 1,736.4±6.6 Ma (Premo and Moscati, 2019; their sample SGC-120)

Microgranitoid—Pale-tan to -pink, poorly exposed, massive, very finegrained granitoid (granite-to-granodiorite). Contains potassium and plagioclase feldspars, quartz, minor biotite, and rare muscovite. Commonly very weathered, punky, and altered; mainly observed as float. Generally exhibits primary igneous textures and lacks metamorphic foliation. Microgranitoid intrudes Proterozoic metamorphic rocks (unit Xgd) and amphibolite (unit Xam) observed within the main microgranitoid body. Microgranitoid yields zircon U-Pb LA-ICP-MS age of 1.714.0±22 Ma (see table of U-Pb data). Unit also yields zircon, SHRIMP, common Pb-corrected, ²⁰⁷Pb/²⁰⁶Pb weighted average age of 1,740.9±6.2 Ma (Premo and Moscati, 2019; their sample SGC-88)

mphibolite—Dark-green to dark-brown-black, foliated to massive, fineto coarse-grained hornblende-plagioclase metagabbros, metadiorites, and intrusive metabasalts with complex spatial associations. Locally strongly altered to chlorite; alteration rarely includes tremolite and (or) actinolite. Includes dark-gray-green, largely nonfoliated and massive, medium- to coarse-grained, pyroxene-plagioclase gabbro forming poorly exposed Simmons Peak pluton centered just southeast of, and continuing into, southeast part of map area (Taylor and others, 1975); large swarm of medium to large (tens of meters across) associated dikes (and some sills) emanate northwestward from the pluton within map area. Amphibolite present throughout exposed extent of Proterozoic intrusive and metamorphic rocks, but mapped separately only where bodies are large enough to be depicted at map scale. Variably mottled, pale- to dark-gray, amphibolite in central part of map area characterized by hybrid intrusives consisting dominantly of amphibolitic metagabbro, locally foliated, with sparse to abundant centimeter- to meter-scale blobs of more felsic, generally dioritic composition; hybrid intrusives likely represent magma mixing processes. In northwest part of map area and at numerous mapped and unmapped outcrops in the vicinity of lower Poncha Creek canyon are well-foliated, tabular, compositional-layer-parallel, amphibolite sill-like bodies and irregular to tabular layer-cutting dikes. These sills and dikes are generally a few to several meters thick. The amphibolites are dominantly composed of sodic amphibole and plagioclase, and are quartz poor. In some places, amphibolite sills are

mylonitized, particularly within tightly folded metasedimentary rocks (unit YXvs) in northwestern part of map area Interleaved intrusives—Mixed composition unit composed of closely spaced, interleaved and hybrid intrusive bodies of granodiorite (unit Xgd), amphibolite/gabbro (unit Xam), and microgranitoid (unit Xmg). Contact relations are very poorly exposed among different lithotypes in the larger intrusive bodies. A well-exposed about 6-square kilometers (km²) plexus of large northwest-trending dikes (and some sills) between Methodist Mountain and Simmons Peak (located 1.7 km southeast of map area) have compositions ranging from granodiorite to gabbro, varying both between adjacent dikes and within single dikes

orphyroblastic sillimanite gneiss and schist (Mesoproterozoic? and **Paleoproterozoic**)—Gray to pale-brown, quartz-biotite-plagioclasemuscovite gneiss and schist with distinctive pea- to fist-sized porphyroblasts of quartz, sillimanite, and biotite (compare with Snyder and others, 1988). Pea-sized porphyroblasts commonly cored by biotite-quartz clots. Foliation defined by compositional layering of biotite and quartz with sillimanite-rich porphyroblasts that are generally symmetric, layerparallel oblate spheres. Porphyroblastic gneisses and schists are a subsidiary component of metavolcanic and metasedimentary rocks (unit YXvs) and are mapped as a separate unit only in a single location on west flank of Poncha Mountain where they form a map-scale body. Porphyroblastic gneiss and schist generally have thicknesses of a few meters where exposed in small unmapped outcrops. Sample of porphyroblastic rock from possible slide block in unit TduXl yielded zircon U-Pb LA-ICP-MS age of ca. 1,745 Ma, with a single concordant age as young as 1,061 Ma (see table of U-Pb data)

Metavolcanic and metasedimentary rocks, undifferentiated (Mesoproterozoic? and Paleoproterozoic)—Tan to pale-to-dark-gray, foliated to locally massive, fine- to medium-grained, feldspar-rich metarhyolite, metadacite, metavolcaniclastic rocks, metagreywacke, psammite, quartzite, and felsic paragneiss. Excluding the quartzites, most rocks have similar mineralogy dominated by plagioclase, potassium feldspars, quartz, and biotite; sillimanite, muscovite, magnetite, maghemite(?), and almandine garnet are locally present. Feldspar and sporadic relict quartz phenocrysts and glomerocrysts are present in some foliated and nonfoliated units. Complex interlayering of calculates, some with hand-sized sprays of actinolitic hornblende, and schistose units with felty sillimanite and andalusite, exist in places. Includes units and lenses of porphyroblastic sillimanite gneiss and schist that are equivalent to map unit YXpod but are too small to show separately at map scale. Map unit also includes, particularly in lower canyon of Poncha Creek, distinctive compositional-layer-parallel and lesser layer-cutting units of foliated amphibolite that are too small to map separately as unit Xam. Distinctive, but spatially limited, meters-thick units and lenses of white orthoquartzite with minor intergranular muscovite are present within metavolcanic and psammite intervals. Transpositional foliation is defined by complete recrystallization of mineral grains destroying primary textures or features, discrete to clotty biotite layering, and variations in grain size of compositional layering. Metavolcanic rocks may be distinguished from metavolcaniclastic and metasedimentary rocks based on mineralogy and texture; for example, plagioclase porphyroclasts in the former versus sillimanite, muscovite porphyroblasts, and garnets in the latter; thin interlayers of calculates with hornblende sprays is also interpreted to be evidence of sedimentary protoliths. Metavolcanic and metasedimentary rocks are widespread, but generally poorly exposed except where outcrops are abundant in the lower canyon of Poncha Creek; unit forms main Proterozoic basement core of Poncha mountain block in central and southeast parts of map area; unit also exposed near mouth of Bear Creek in northeasternmost part of map area. Thickness at least 500 to 600 m. Representative samples in map unit yield zircon U-Pb LA-ICP-MS ages of 1,706.2±7.4 Ma, 1,717±24 Ma, 1,741±11 Ma, and

1,770.0±22 Ma. One sample with a poor zircon yield appears to be as

Summary of 40Ar/39Ar ages for volcanic rocks in the Poncha Pass map area.

Sample Number	UTM Northing*	UTM Easting*	Map Unit Symbol	Lithology	Geochronologic Method	Age (Ma)	\pm Age 2σ	MSWD	P
RGB12102	4262731	410817	Tdup	air-fall(?) tuff	SAN-SCTF	9.30	0.04	0.74	0.53
PP15147B	4262300	414908	Tdup	air-fall(?) tuff	SAN-SCTF	15.6	0.3	1.23	0.19
PP13016	4250525	407305	Tcd	phyric dacitic lava	BT-SH	33.4	0.4	0.7	0.59
PP13037	4259320	403028	Tcd (in Qls slide mass)	phyric dacitic lava	BT-SH	33.6	0.4	1.36	0.24
PP14158	4254530	402758	Tca (upper)	transitional andesitic- dacitic lava	SAN-SH	33.9	0.4	1.32	0.24
RGB12077	4254956	402161	Tca	andesite lava	WR-SH	33.92	0.08	0.66	0.75
RGB12079	4254418	401844	Tca	andesite lava	WR-SH	33.92	0.08	1.58	0.15
RGB12075	4255206	402426	Tca	andesite lava	WR-SH	34.14	0.08	1.33	0.22

young as ca. 1,398 Ma (see table of U-Pb data). Other samples yield zircon SHRIMP, common Pb-corrected, ²⁰⁷Pb/²⁰⁶Pb weighted average ages of 1,735.5±7.2 Ma and 1,729.4±5.7 Ma (Premo and Moscati, 2019; their samples WRP 03–8 and SAG–47, respectively)

INTRODUCTION

This report presents a 1:24,000-scale geologic map, cross sections, and descriptive and interpretative text for the Poncha Pass area in central Colorado. The map area is irregular in shape, covering all of one 7 ½' quadrangle (Poncha Pass) and parts of five others (Mount Ouray, Maysville, Salida West, Salida East, and Wellsville). The map boundaries were drawn to cover all of the "Poncha mountain block," our designation for the approximately 15-kilometer-long northwestern end of the Sangre de Cristo Mountains. The map conveys the areal distribution of (1) Proterozoic basement rocks forming the core of the Poncha mountain block, (2) overlying Eocene and Oligocene volcanic rocks, (3) Miocene and younger basin-fill deposits, (4) Quaternary surficial glacial and alluvial deposits, and (5) faults and folds affecting all of the above units. The Poncha mountain block, which lies within the Rio Grande rift, is topographically and geologically distinctive. Generally, the Rio Grande rift is internally characterized by subsided structural basins or grabens and subdued, low-relief topography rather than elevated mountain blocks. The intrarift, topographically high Poncha mountain block spans the axial part of the rift and separates the low-lying basins of the west-tilted upper Arkansas River half graben and east-northeast-tilted San Luis half graben. These distinctive aspects of the Poncha mountain block were the primary motivations to conduct geologic mapping in the area. Important questions addressed by geologic mapping and related studies in the Poncha Pass area include (1) what were the structural controls and tectonic mechanism(s) that resulted in development of the Poncha mountain block in an intrarift environment; (2) did surface uplift of the Poncha block occur during rift development in the Neogene and Quaternary, and at what rate(s); (3) how was extensional strain accommodated and relayed across the Poncha block between the opposite-polarity rift basins and flanking mountain blocks; (4) is there a clear Laramide deformational signal in rocks of the map area; and (5) have earlier Laramide contractional structures, if they exist, influenced later rift-related extensional deformation through reactivation or strain localization. Prior to our mapping, the geology of much of the Poncha Pass area had only been mapped in reconnaissance fashion, reflecting the area's poor bedrock exposures, poor access due to the rugged terrain, and geologic complexity. The map presented here provides new details of the geology of this difficult area and helps elucidate the development of the Poncha block and improves understanding of the geologic framework and geologic history of the area. This mapping effort was made possible through the support of the "Rio Grande

Mineral Resources Program. GEOGRAPHIC AND PHYSIOGRAPHIC SETTING The Poncha Pass area in central Colorado straddles the northern end of the Sangre de Cristo Mountains where it separates the broad San Luis Valley to the south from the narrower upper Arkansas River valley to the north. The city of Salida (population 5,400) and town of Poncha Springs are situated near the northern map boundary and two major highways (U.S. 50 and U.S. 285) traverse the area. The northern edge of the map area approximately coincides with the east-flowing South Arkansas River, which joins the main Arkansas River at the northeast corner of the area. The west border of the map area follows the lower part of the eastern flank of the southern Sawatch Range. The southern edge of the map area crosses the northern end of the San Luis Valley. From this valley, the eastern border heads northward across the crest of the northern Sangre de Cristo area overlaps parts of three counties (Chaffee, Fremont, and Saguache), two national forests (Rio Grande and San Isabel), and, near its eastern border, a wilderness area

Basins" and successor "Cenozoic Landscape Evolution of the Southern Rocky Mountains"

Program. Additional funding and support was provided by the U.S. Geological Survey's

projects of the U.S. Geological Survey's National Cooperative Geologic Mapping

The dominant physiographic feature in the map area is the Poncha mountain block. which forms the northern end of the Sangre de Cristo Mountains and projects northwestward across the central part of the area. The Poncha mountain block is markedly stream dissected and has significant topographic culminations at Methodist Mountain (11,707 ft elevation), Poncha Mountain (10,134 ft), and Cleveland Mountain (9,704 ft). Near its northwest termination, the Poncha block is deeply incised and segmented by antecedent Poncha Creek that flows northward across the entire mountain block to the South Arkansas River. In contrast, the relatively subdued and low Poncha Pass (9,019 ft) separating the Poncha Creek drainage system from the south-flowing drainage system of San Luis Creek is located well south of the crest of the Poncha mountain block. In the north part of the map area, a moderately elevated, strongly dissected piedmont lies between the northern front of the mountain block and the South Arkansas River floodplain. This piedmont is incised by numerous north-flowing intermittent streams that drain the north flank of the mountain block and empty into the South Arkansas River along the north edge of the piedmont.

PREVIOUS MAPPING

The earliest medium- to large-scale geologic maps focusing on portions of the Poncha Pass map area were published in the 1970s. Normand (1972) completed a regional 1:62,500-scale geologic map of the northern part of the Sangre de Cristo Mountains (including the Poncha mountain block area) that focused on the Proterozoic rocks. U.S. Geological Survey (USGS) geologist Richard Van Alstine published a 1:24,000-scale geologic map of the Salida West quadrangle overlapping the northwest part of the Poncha Pass map area and the reconnaissance-level (1:62,500-scale) geologic map of the Bonanza NE quadrangle (same area as Poncha Pass 7½ quadrangle) (Van Alstine, 1974; 1975). At the same time, reconnaissance-level geologic maps were also published for the Poncha Springs and Howard 15' quadrangles overlapping the northwest and northeast parts of the present map area, respectively (Scott and others, 1975; Taylor and others, 1975). No further geologic mapping was published in the area until 2006 when the Colorado Geological Survey published a map of the Maysville 7½' quadrangle that overlaps the northwesternmost part of the present map area (Shannon and McCalpin, 2006). In 2009 and 2011, aeromagnetic geophysical surveys of the Poncha Pass region were conducted, which included coverage for much of the present map area and allowed for new interpretations of faults and other geologic features in the shallow subsurface (Grauch and Drenth, 2009; Brown and Grauch, 2019). A new geologic map of the upper Arkansas River valley region, extending southward into the northernmost part of the Poncha map area, was recently compiled by Kellogg and others (2017) at a scale of 1:50,000.

PRESENT MAPPING Following early field reconnaissance of the Poncha map area in 2011, individual responsibilities for mapping various parts of the area were identified for coauthors. Caine and Fridrich focused on mapping the Proterozoic basement rocks in the central core of the Poncha mountain block, whereas Minor concentrated on mapping the Tertiary volcanic rocks and sedimentary deposits in the north, west, and southwest parts of the map area. Ruleman joined the mapping team beginning in 2013 to map the Quaternary surficial deposits. Field mapping continued through 2016 intermittently during the summer months. The field phase of the mapping effort consisted primarily of making geologic site observations, including structural measurements, and collecting GPS waypoints (about 5 m horizontal accuracy) along traverses, roads, and at isolated exposures scattered throughout the map area. Approximately 3,000 observations with waypoints were recorded primarily on handheld digital tablets. Georeferenced imagery loaded onto the tablets were used to aid mapping; imagery consisted of light detection and ranging (lidar) hillshades with 1 m horizontal accuracy, color and gray-scale aerial photography. topographic maps, and aeromagnetic maps from Grauch and Drenth (2009) and Brown and Grauch (2019). The lidar imagery was especially beneficial for identifying and mapping surficial units and youthful fault and landslide scarps. Rocks and sediments were sampled at selected sites for eventual geochemical, mineralogical, petrographic, microstructural, geochronologic, thermochronologic, cosmogenic, and paleontologic analyses. Minor, Caine, and Ruleman digitally compiled their respective field map data at 1:24,000-scale level of detail using ArcGIS. The geologic map geodatabase and associated metadata generated from this compilation are available at the USGS ScienceBase website (Minor and others, 2019). Geologic cross sections were constructed by Minor and Caine with the assistance of Grauch, who provided aeromagnetic constraints for subsurface structure based on recent geophysical surveys (Grauch and Drenth, 2009; Brown and Grauch, 2019). Caine, Fridrich, and Minor examined and described thin sections of rocks they mapped. Chan assisted with geologic mapping during the 2016 field season, prepared samples for geochemical and geochronologic analyses and thin sectioning, examined and described thin sections of the Tertiary volcanic rocks, and analyzed geochemical data from these rocks. Brandt populated, edited, and managed the map geodatabase and made some lidar-based interpretations of Quaternary geologic features in ArcGIS. Morgan and Cosca performed ⁴⁰Ar/³⁹Ar geochronology of volcanic rock samples collected in the map area (Morgan and Cosca, 2017). Holm-Denoma completed mineral separations and laser-ablation inductively coupled mass spectrometry (LA-ICP-MS) zircon U-Pb geochronology on samples of metamorphic and igneous basement rocks (Holm-Denoma and others, 2019). Approximately 700 measurements o magnetic susceptibility were made by Caine at Proterozoic rock outcrops and the data were used in preliminary geophysical modeling by Grauch for cross-section construction.

GEOLOGIC SUMMARY STRATIGRAPHY The oldest rocks in the map area, forming the elevated high-relief basement core of the Poncha mountain block, consist of Paleoproterozoic and possibly Mesoproterozoic metavolcanic and metasedimentary rocks and amphibolitic, gabbroic, granodioritic, and granitoid intrusive rocks (map units YXvs, YXpod, Xgd, Xmg, Xam, and Xgag). These basement rocks are cut by scattered pegmatite intrusions (unit Ypeg) of possibly Meso-

Symbol

Kri (subcrop in YXvs)

YXpod (roadcut in TduX

Summary of zircon U-Pb ages for basment metamorphic and igneous rocks in the Poncha Pass map area.

Data are available at https://doi.org/10.5066/P96HNSNL (Holm-Denoma and others, 2019)

406271

415967

412230

411691

412598

Sample UTM* UTM*

92117–2A 4260672 406512

4262577

4255585

4256516

4257786

4258544

91411–15A 4261648 406386

91511–19A 4260368

51812–11A 4259059

92112–28A 4253885

*Datum: North America 1983

92117–9A

92217-4A

83016-6A

72215-2A

72215-3A

90811-1A

Northing (m) Easting (m)

4261015 406350

4256580 411161

proterozoic age. Similar basement rocks also form (1) the upthrown footwall block of the southern Sawatch Range along the west border of the map area, (2) a smaller faultbounded block near the southwest corner of the map area, and (3) the southwestern

Arkansas Hills along the northeastern border of the map area. The metavolcanic and metasedimentary units consist of interlayered gneissic and schistose rocks dominated by metarhyolites, metadacites, metagraywackes, metapsammites, quartzites, metapelites, and amphibolites. The mineral assemblages in the quartzofeldspathic and amphibolitic rocks are consistent with dynamothermal, amphibolite facies, and sillimanite zone metamorphism. Evidence for a second episode of local amphibolitefacies metamorphism consists of euhedral amphiboles and micas that consistently cut the dominant foliation at moderate angles. Stratigraphic relations among these units are not generally mappable. A contact of uncertain origin is apparent in the well-exposed lower canyon reaches of the west side of Poncha Creek. The rock assemblage below the contact is dominated by metavolcanic and metasedimentary units and the assemblage above it is dominated by nondescript gneissic rocks of unknown protolith. However, the contact is not exposed on the east side of the canyon and thus was not mapped. The thick (>500 m) section of penetratively foliated metavolcanic and metasedimentary rocks is intruded by a complex of mafic to intermediate stocks, plugs, and dike swarms in the central and southeastern parts of the Poncha mountain block. These intrusive rocks vary greatly in the degree to which they are foliated, lineated, and recrystallized, which probably reflects the timing of their emplacement relative to metamorphism and associated deformation. Inadequate exposure results in poorly defined map-scale contact relations, exacerbated by significant overlap in zircon U-Pb geochronology among metavolcanic, metasedimentary, and intrusive rocks. Such aspects highlight the difficulty in definitively interpreting the metamorphic and intrusive history of the basement rocks. Medium- to small-scale compositional heterogeneities are common in most of the intrusions, which may either reflect multiple intrusions of different magmas or compositional zonation resulting from differentiation or magma mixing. Based on the geometries of individual intrusions, their dominantly fine-grained textures, and the abundance of small-scale apparent magmamixing features, the basement intrusive complex appears to be high-level epizonal in character, perhaps even locally hypabyssal. The intrusive complex may represent an intrusive feeder zone for the abundant Proterozoic volcanic (now metavolcanic) rocks of dominantly felsic composition that are exposed farther south in the Sangre de Cristo Mountains and to the north in the southern part of the Mosquito Range (Reed, 1988; Kellogg and others, 2017). The compositionally immature nature of the quartzofeldspathic metasedimentary

rocks is indicative of likely nearby source rocks of uncertain origin. The interlayered intermediate-to-felsic metavolcanic rocks and amphibolites form a bimodal suite also recognized in the region by Boardman (1986), but the rock assemblage in the Poncha block is of higher metamorphic grade. The inferred protoliths of these rocks are, perhaps indicative of an island-arc to back-arc depositional setting or, perhaps, discontinuous extensional basins of continental affinity. Rocks nearby to the west and north of the map area form similar sequences, and have similar overlapping, largely Paleoproterozoic ages and metamorphic mineral assemblages (compare with Bickford and Boardman, 1984; Jones and others, 2010). Such rocks were also recognized in the northern Park Range (Snyder and others, 1988), more than 275 km north of the map area, suggesting possible genetic links over a broad region. The only Paleozoic rocks exposed in the map area consist of a large panel or block of fractured sedimentary carbonate rocks (unit Pzc) on the downthrown side of the south Sawatch fault near the western border of the map area. These rocks either represent a large allochthonous block that slid from the south Sawatch fault escarpment or a rooted down-dropped block of the Sawatch fault system. A nonconformity separates the

Proterozoic basement rocks from the Tertiary (latest Eocene and younger) section on the west and southwest flanks of the Poncha mountain block. The lack of Paleozoic rocks along this nonconformity suggests that any Paleozoic rocks that may have been deposit on the Poncha basement rocks were erosionally removed before the end of the Eocene The nonconformity likely correlates with a late Eocene erosional surface that developed throughout the southern Rocky Mountain region following the Laramide orogeny when elevated sedimentary and basement rocks were stripped and exhumed during a period of relative tectonic quiescence (Epis and Chapin, 1975; Abbey and others, 2017). A suite of variably porphyritic rhyolite dikes (unit Kri) are found near the northern terminus of the Poncha mountain block in the vicinity of the Poncha fluorspar mine.

based on zircon U-Pb geochronology. These dikes everywhere strike northwest and dip Latest Eocene and earliest Oligocene (34.6–33 Ma) intermediate-composition (trachyandesite-to-trachydacite) lavas, breccias, and associated local pyroclastic and sedimentary deposits (units Tcd, Tca, Tcs, and Tcr), correlated with the regionally extensive Conejos Formation (Lipman and others, 2015), lap onto the basement rocks on the west and southwest flanks of the Poncha block. These volcanic rocks become thicker and more extensive towards the southwest corner of the map area where they obtain a maximum cumulative thickness of about 800 m, and some of the lavas may have vented in that area. A thin sequence of similar intermediate-composition, Conejos-like lava flows (units Tpa, Ta, and Td) are preserved where they rest on the basement rocks at the northern end of Bear Creek near the northeast corner of the map area. These lavas, however, may have greater affinities with intermediate volcanic rocks present in the Howard area several kilometers southeast of the map area (Taylor and others, 1975). Small remnants of Bonanza Tuff (unit Tbt) that directly overlie the intermediate lavas are preserved in the southernmost part of the map area (overlies unit Tca) as well as in the northwest part about 3 km southwest of Poncha Springs (overlies unit Tcd). This rhyolitic-to-dacitic and welded ignimbrite erupted out of the Bonanza caldera, centered about 10 km south of the map area, at 33.12 Ma (Lipman and others, 2015). A small, localized, and plug-like rhyolitic lava flow (unit Tbr) erupted at 33.05 Ma immediately

following emplacement of the Bonanza Tuff (Lipman and others, 2015). Unit Tbr is

present near the confluence of Poncha and Silver Creeks at the southwest border of the

The Miocene–Pliocene basin-fill deposits of the Dry Union Formation (Tweto,

These exclusively intrude the Proterozoic basement rocks and yield Late Cretaceous ages

1961) unconformably (but concordantly) lap onto the volcanic rocks on the outer wes and southwest flanks of the Poncha mountain block. Similar Dry Union sediments underlie the dissected older piedmont along the northern mountain flank. These sediments at the eastern end of the piedmont in the Bear Creek area lap directly onto the Proterozoic basement rocks. The Dry Union in the map area consists of several subunits or facies distinguished by their dominant provenance or mode of deposition. Alluvial, mass-movement, and lacustrine mudstone, sand/sandstone, gravel/conglomerate, and sedimentary breccia are typical. Clasts in the stratigraphically older Dry Union deposits are locally derived from one of three dominant sources: (1) Proterozoic basement rocks mainly from near mouth of the canyon of Poncha Creek (subunit TduXI), (2) Paleozoic sedimentary rocks northwest of Cleveland Mountain that are not exposed in the map area (subunit Tduz), or (3) Tertiary volcanic rocks generally to the south of Cleveland Mountain and Bear Creek (subunit Tduv). Throughout the exposed section of the Dry Union Formation, mixed-provenance deposits (subunit Tdup) are common, whereas fine-grained lacustrine sediments (subunit Tdul) are limited to two laterally restricted stratigraphic members in the middle of the section in the northeast and northwest areas. The northwestern lacustrine deposits and underlying coarser sediments include large inferred paleo-landslide blocks (subunit sb) composed of Paleozoic carbonate rocks (Van Alstine, 1970). These slide blocks may have been detached and transported eastward into the map area from Paleozoic terranes located in the southern Sawatch Range that presently contain Paleozoic strata (Shannon and McCalpin, 2006). The probable lack of Paleozoic rocks in the Poncha mountain block area by the end of the Eocene precludes a more local source for the slide blocks. The uppermost facies of the Dry Union east of the south Sawatch fault (northwest map area) is dominated by gravels and sedimentary breccias rich in locally derived Proterozoic basement clasts (subunit TduX). Overall, the Dry Union Formation in the map area is inferred to represent an unroofing sequence that records the Miocene–Pliocene synrift uplift and exhumation history of the Poncha mountain block and adjacent southern Sawatch Range block. The Dry Union also records the formation of small, closed lake basins presumably in areas of localized, pronounced subsidence flanking, and coeval with, the Poncha block uplift. Gently dipping, coarse, locally derived, Proterozoic-clast alluvial (unit QTa) and diamicton (unit QTd) deposits of probable Pliocene–Pleistocene age unconformably overlie moderately tilted deposits of the Dry Union Formation along the piedmont north of the Poncha mountain front and along the eastern base of the south Sawatch Range. These deposits likely represent later episode(s) of mountain-block surface uplift and exhumation associated with movement along the Poncha and south Sawatch range-front fault systems. Units QTa and QTd record concomitant proximal-to-medial deposition of basement detritus shed from the uplifting blocks. At least some of the boulder-rich diamicton in the downthrown block of the south Sawatch fault (northwest map area) may represent older glacial till associated with early glacial advances in the middle Pleistocene. Sequences of variably dissected early-to-middle Pleistocene pediment and fan deposits (units Qfo1, Qfo2, Qfo3, and Qfi) are concentrated along the northern piedmont and in the south part of the map area at the northern end of San Luis Valley. Γhin lag gravels (unit Qlg) of probable early-to-middle Pleistocene age that rest on old relict erosional surfaces are scattered through upland parts of the west map area. Bull Lake- and Pinedale-age glacial moraines (units Qtb and Qtp) and outwash gravels (units Qgb and Qgp) are preserved in the Little Cochetopa Creek drainage (northwest map area) at and below the south Sawatch Range front, and similar outwash gravels are also preserved in the nearby Pass Creek drainage. Late Pleistocene-to-Holocene fan (unit Qfy), alluvial (unit Qa), mixed alluvial and colluvial (unit Qac), and landslide (unit Qls) deposits floor larger stream channels, valleys, and mantle slopes throughout the map area.

STRUCTURE Deformation in the map area is diverse, ranging from ductile folds to brittle faults, joints, and mineralized veins that range in age from pre-Tertiary to Quaternary. Ductile geologic structures are restricted to the Proterozoic basement rocks chiefly in the central

Comments on Age

Mainly inherited analyses of ca. 1.7 and ca. 1.4 Ga. Few analyses

Mainly inherited analyses of ca. 1.7 and ca. 1.4 Ga. Two concordant

Minimum age, very low zircon yield, multiple analyses on 3 grains

Intercept age, modern Pb-loss apparent, unimodal age population.

Peak unimodal age population at 1,745 Ma, single concordant

Weighted average of ²⁰⁶Pb/²³⁸U ages of most concordant analyses.

Weighted average of ²⁰⁷Pb/²⁰⁶Pb ages.

nalyses as young as 1,061 Ma.

1770 22 Intercept age, modern Pb-loss apparent, unimodal age population

Weighted average of ²⁰⁷Pb/²⁰⁶Pb ages.

± Age (Ma)

ca. 65 NA

ca. 67

Age (Ma)

ca. 1398

1714

1722.3

1737.9

1741

rhyolite dike

rhyolite dike

rhyolite porphyry

porphyritic metadacite

metarhyolite

microgranitoid

orthoquartzite

granodiorite

granodiorite

metarhyolite

rphyroblastic quartz, sillimanite, mica gnei

quartz, mica, garnet schist

core of the Poncha mountain block, whereas the brittle structures affect rocks and deposits of all ages located throughout the map area. Geologic structures in the Proterozoic basement rocks include major north- to northwest-trending, generally upright, tight-to-open antiformal and synformal folds of the penetrative foliation. These folds are derived from foliation measurements (n=1,050) concentrated in the west, southwest and central parts of the Poncha mountain block where exposures allowed for structural observations. One of the better-exposed basement folds is a north-northeast-trending antiform that has an axis coincident with the canyon of lower Poncha Creek. Complex, outcrop-scale folds are observed particularly where there are rock competency contrasts, such as between units YXvs and Xam. There is little evidence of refolding in outcrops; however, at the map scale, it appears there may be refolding consistent with northwest-southeast shortening, as also observed regionally (compare with Kellogg and others, 2008). Flattening fabrics are dominant throughout the folded basement section. Flattening is particularly evident in gneisses and schists containing conspicuous (up to fist-size) sillimanitic porphyroblasts that are symmetric. layer parallel, and form oblate spheres. Some amphibolite units show local evidence of shear, such as asymmetric porphyroblasts, but evidence for thick, widespread, ductile shear zones with large-displacement in the basement rocks is largely absent in the map area. Lineations are dominantly formed by foliation and compositional layering intersections with joint and rock-face surfaces. Other linear features, such as rodding or

minor outcrop-scale fold axes, are rare in the Proterozoic rocks. Only one known major fault, the northeast-striking Sand Gulch fault, cuts through the Poncha mountain basement block. This fault cuts across the entire northwest part of the Poncha mountain block and continues to the southwest into onlapping Tertiary rocks and deposits. The fault exhibits nearly 1 km of dextral separation of intrusive Proterozoic units near the northeast end of its trace. However, the juxtaposition of southwest-dipping Tertiary volcanic rocks on the northwest side of the fault farther to the southwest could have also resulted from primarily normal movement. Thus, the Sand Gulch fault either had a complex movement history that included both dextral and normal episodes of slip, or it experienced dextral-normal oblique movement during much of its evolution. A few shorter-trace-length northwest-striking, steeply dipping faults cut the basement rocks in the northwestern part of the Poncha mountain block. The largest of these faults is a northnorthwest-striking, mineralized, extensionally reactivated, reverse fault on the north flank of Poncha Mountain that intersects the basement-bounding Poncha normal fault. Numerous small-displacement (meters-to-centimeters) brittle faults exist in the basement rocks near this mountain-front Poncha fault, and there is a measurable increase in small fault intensity as the Poncha fault is approached from the south. Many of these small faults host concentrated argillic hydrothermal alteration, providing an ancient analog for the plumbing system associated with the modern hot springs located along the Poncha

fault zone, about 400 m east of where it crosses Poncha Creek. The Poncha fault separates tilted strata of the Dry Union Formation underlying the piedmont north of the fault from the Proterozoic basement rocks forming the steep northern Poncha mountain front south of the fault. This fault was named the Maysville-Salida fault by Shannon and McCalpin (2006) and Kellogg and others (2017), but herein we rename it the Poncha fault since it does not pass through or near the city of Salida, and since the fault bounds the Poncha mountain block along most of its length within the map area. The curving Poncha fault trace strikes west to northwest and forms right steps and jogs. This fault strand, and its subparallel splays, in part have relatively gentle northward dips (40–50°). The fault's curvilinear trace may partly reflect a broadly corrugated or undulating subsurface fault geometry. Near the mouth of Poncha Creek canyon, the Poncha fault branches into several splays, all basinward of the main, southern strand and all with down-to-north apparent displacement. A short distance west of Poncha Creek, the main Poncha fault strand abruptly steps at least 2 km basinward (northward) along a north-striking, down-to-east fault. West of this step fault, the side of the South Arkansas River floodplain. A series of small-displacement, unmappable west-striking faults (possibly associated with the main strand) cut pre-Bull Lake outwash gravels (unit **Qgpb**) where they are exposed in a quarry near the mouth of Little

Fault kinematic measurements indicate that the Poncha mountain-front fault system has experienced mainly dextral-normal oblique movement (Minor and others, 2016). Data include measurements of slip surfaces associated with the main fault zone, as well as measurements of small-displacement (outcrop-scale) faults within deposits of the Dry Union to the north in the piedmont area and the small Quaternary faults in the Little Cochetopa Creek quarry. Small-displacement normal-oblique faults similar to those observed north of the main Poncha fault trace are also distributed for several kilometers south of the fault within the basement rocks. The intensity of these basement

faults decreases southward. Based on the fault geometries, kinematics, and spatialtemporal patterns, the Poncha frontal fault system is inferred to be a broad, normaloblique, relay zone that developed in the late Neogene to transfer extensional strain across the left step between the Sawatch and Sangre de Cristo rift-bounding fault zones (Minor and others, 2016). The subordinate dextral strike-slip component along the relay zone probably reflects how the regional east-west-trending minimum principal stresses associated with the surrounding rift were perturbed near, and resolved onto, the west-northwest-striking faults making up the zone. Progressive surface uplift of the Poncha mountain block and basinward migration of active normal faults likely accompanied development of the relay.

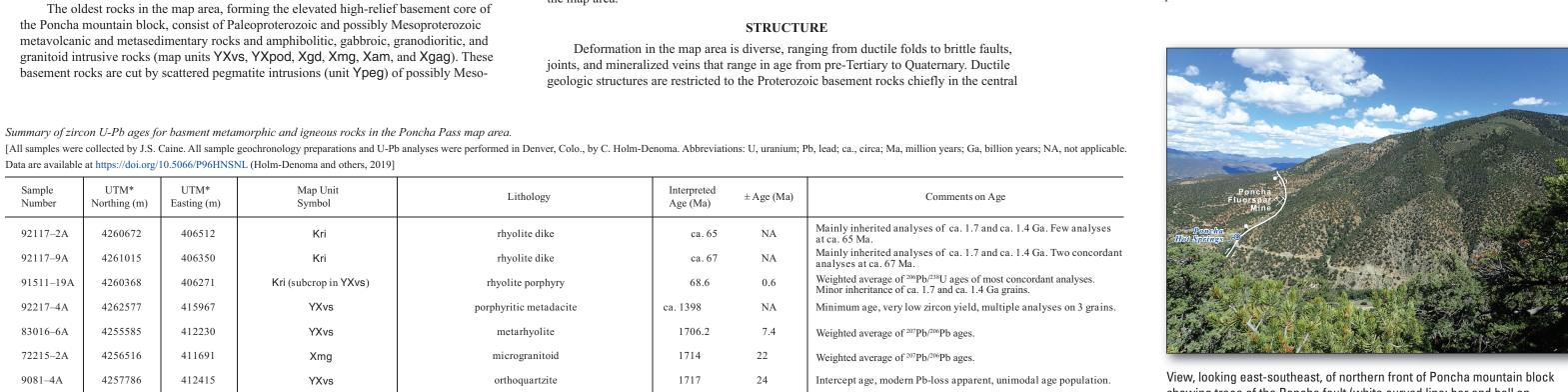
The south Sawatch range-front fault is a north-northwest-striking, down-to-east, normal fault. It forms the western terminus of the Poncha mountain block and cuts deposits as young as middle Pleistocene (Bull Lake moraines, unit Qtb). The Sand Gulch fault curves into a westerly strike and is slightly disrupted by some crosscutting faults in the upper Poncha Creek canyon area. It then continues west into the Droz Creek drainage where it terminates at the southern Sawatch fault. This western Sand Gulch fault segment exhibits significant down-to-north apparent displacement, juxtaposing Paleozoic sedimentary rocks (unit Pzc) and Eocene–Oligocene volcanic cocks (units Tcd and Tca) against Miocene–Pliocene deposits of the Dry Union (units TduX and Tdup) and Pliocene–Pleistocene diamicton (unit QTd). South of this fault, similar, westerly striking faults cut units as young as the Dry Union Formation in and west of the Poncha Pass area. One inferred large-displacement, west-striking fault just north of Clover Creek (southwest corner of map area), juxtaposes Proterozoic basement rocks on the north against Conejos Formation andesitic volcanic rocks on the south. This may be part of an outer ring fault associated with the Bonanza caldera located just south of the map area (Lipman and others, 2015). A set of north-to-northwest-striking normal faults, also present in and west of the Poncha Pass area, exhibit mutually crosscutting and abutting age relations with respect to the westerly striking faults. Included in this north-northwest-striking fault set are some discontinuous normal faults west of Round Hill and San Luis Creek that are partly coincident with the modern, western, range front. The faults cut early-to-middle Pleistocene fan deposits (units Qfo1 and Qfo2), and locally have fault scarps preserved along them.

The Tertiary volcanic rocks and the Dry Union strata flanking the Poncha basement block are both tilted 10° to 35°, mostly to the west and southwest. These same, dominant, stratal-tilt directions and magnitudes exist both along the northern piedmont and in the west and southwest parts of the map area. This stratal dip pattern probably reflects Miocene–Pliocene tilting and increased subsidence of early basinal deposits towards the south Sawatch fault, and associated branching faults in and near the southwest part of the map area. In this view, the broad area of deposits of the Dry Union Formation west of Cleveland Mountain as far south as the Droz Creek drainage represents an early, southern extension of the upper Arkansas River Basin half graben (compare with Van Alstine, 1968) that was abandoned, uplifted, and partly exhumed relative to the modern upper Arkansas River valley basin floor to the north, presumably as movement along the Poncha mountain-front fault system increased.

MINERAL OCCURRENCES AND ENERGY RESOURCES Economic mineral deposits are sparse in the map area with the exception of the Poncha Springs fluorspar mining district (Van Alstine, 1969; Wallace, 2010). A now inactive, primarily surface mine of this district, the so-called "Poncha Fluorspar Mine," is located on the east side of lower Poncha Creek canyon. The fluorspar deposits there are hosted in a major north-northwest-striking, steeply dipping, brittle-contractional (but extensionally reactivated) fault near its intersection with the Poncha fault zone. Veins in Proterozoic bedrock near the mine, as much as several centimeters thick, commonly consist of botryoidal-to-colloform fluorspar locally associated with chalcedony and (or) carbonate. The veins locally penetrate into overlying, poorly lithified sediments of the Dry Union Formation. Many of the veins near the mine are located along fault slip surfaces and are undeformed. These mineral assemblages, bedrock-fault permeability features (such as fault veins and associated fractures), and presence in Dry Union deposits suggest the fluorspar was precipitated in association with hot springs that became active during and after extensional faulting. Such hot springs are also likely associated with recent travertine mounds (unit Qt) as well as the currently active "Poncha

A few shows of sulfide mineralization, particularly chalcopyrite, as well as chrysocolla were observed in basement rocks in the southern map area north of Camp Rock Gulch and east of Murphys Hole. Oxides, only locally observed, include manganese oxide coatings on fractures and hematite on some fault slip surfaces. Clay minerals are common in discrete zones of argillic alteration along faults, particularly in association with the Poncha fault zone. Several prospects, most notably those between Camp Rock Gulch and Poncha Pass, were observed in basement pegmatites (unit Ypeg) in the southern map area where muscovite and possibly beryl were excavated in the past.

Hot Springs' located along the Poncha fault (compare with Wallace, 2010).



showing trace of the Poncha fault (white curved line; bar and ball on downthrown block, opposing arrows show strike-slip component of movement) where it juxtaposes deposits of the Miocene–Pliocene Dry Union Formation (units TduXI and Tdup) on the left against relatively upthrown Proterozoic basement rocks (unit YXvs) on the right. Visible Poncha Hot Springs and Poncha fluorspar mine are coincident with Poncha fault trace, and reverse fault zone and rhyolite dikes in its footwall are located in area of pale-gray outcrop at center skyline. Mouth of Poncha Creek canyon is visible just above trees in foreground, and summit of Poncha Mountain is in upper right of photo. Arkansas River, where it exits the upper Arkansas River Basin, is just visible at left edge.

Gravel and sand deposits are abundant in the map area, particularly along the northern piedmont and South Arkansas River floodplain (compare with Van Alstine, 1974). Pleistocene alluvial fan gravels are currently being extracted at a large quarry located about 1.5 km south of Salida. Geothermal water issuing from the previously mentioned Poncha Hot Springs is currently being diverted through pipe to Salida where it provides hot water for the city's

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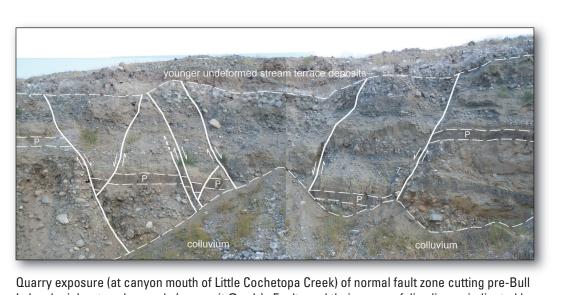
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Lake glacial-outwash gravels (map unit Qgpb). Faults and their sense of dip slip are indicated by unbroken white lines and opposing arrow pairs, respectively. "P" indicates distinctive paleosol layer offset by faults. View looking east, parallel to overall fault strike. Faults are roughly coincident with, and likely represent Pleistocene reactivation of, the Poncha frontal fault zone. Pick next to right-most fault about 0.65 meter long.



Outcrop of metavolcanic rocks (map unit YXvs) along US 285 in Poncha Creek canyon, Colo., about 500 meters (m) south of the Poncha mountain front fault. Rocks in outcrop are cut by numerous conjugate fractures and small-displacement faults kinematically related to the Poncha fault. Rock hammer at lower center about 0.3 m long.

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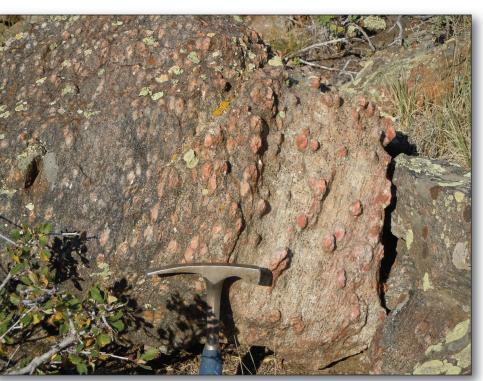
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Outcrop of porphyroblastic, sillimanite gneiss typical of map unit YXpod, colloquially known as pod rock. Outcrop located on hillslope east of US 285, midway between Poncha Creek and summit of Poncha Mountain. Head of rock hammer about 20 centimeters long.



Outcrop of rhyolite dike (map unit Kri) intruding, and brecciated by, a brittle fault zone above the Poncha fluorspar mine. Scale 12 centimeters long.



*Datum: North America 1983

unit Xam) intruded into metavolcanics rocks (unit Xvs).





0.3–1.0 meter thick, are relatively compacted and (or) weakly cemented.



kilometer north of Poncha Hot Springs.



in northeastern map area 1 kilometer south of the Arkansas River. Here, pale-brown mudstone intervals (smooth slopes) are intercalated with subordinate, ledge-forming buff sandstone beds and a 15.6-million years (mega-annum, Ma) air-fall tuff layer (white thin, about 1-meter [m] -thick ledge in left center). Largest trees in foreground are about 4 m in

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derived clasts of Proterozoic metamorphic (gray clasts) and intrusive (large boulders)

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