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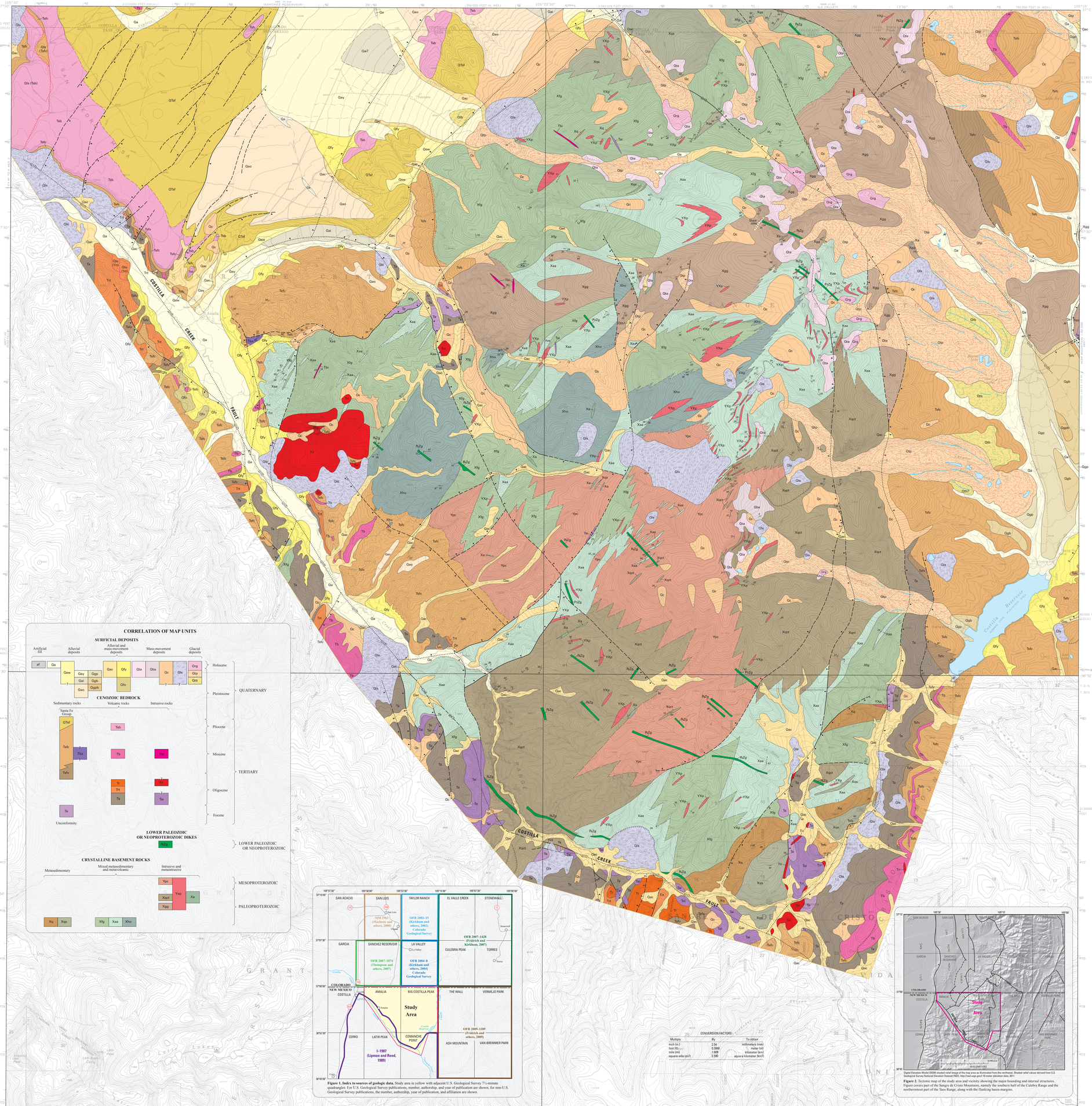

Figure 1. Index to sources of geologic data. Study area in yellow with adjacent U.S. Geological Survey 7½-minute quadrangles. For U.S. Geological Survey publications, number, authorship, and year of publication are shown; for non-U.S. Geological Survey publications, the number, authorship, year of publication, and affiliation are shown.

Figure 2. Tectonic map of the study area and vicinity showing the major bounding and internal structures. Figure covers part of the Sangre de Cristo Mountains, namely the southern half of the Culebra Range and the northermost part of the Taos Range, along with the flanking basin-margins.

CORRELATION OF MAP UNITS

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

af — **Artificial fill (latest Holocene)**—Engineered, compacted fill material composed of large angular rock fragments and finer material emplaced in a large earth-fill dam at the south end of Costilla Reservoir, near the southeast corner of the map area. Estimated thickness is 3–35 m.

Alluvial deposits

Qa — **Valley-floor alluvium (Holocene)**—Mostly sand and gravel in stream channels; silty sand, sandy silt, and gravel lenses beneath flood plains less than about 2 m above modern streams. Estimated thickness 1–5 m

Qaw — **Sheetwash alluvium (Holocene and late? Pleistocene)**—Mostly slightly pebbly, slightly silty to silty sand, forms alluvial aprons deposited by unconfined overland flow on gentle slopes. Estimated thickness 1–5 m

Stream alluvium (late and middle Pleistocene)—Fluvial deposits composed chiefly of interstratified pebbly sand and poorly sorted, clast-supported, cobbly pebble gravel that underlie alluvial surfaces along streams tributary to Costilla and Culebra Creeks in the western part of the map area. Clasts commonly are subangular to subrounded. Youngest unit (Qay) along Jarocito Creek locally includes outwash gravel (Qggo). Units locally may include debris-flow deposits. Estimated thickness 1–10 m

Qay — **Younger (lower) unit (late Pleistocene)**—About 4 m above modern stream level

Qai — **Intermediate unit (late and middle Pleistocene)**—About 3 m above Jarocito Creek where deposits are partly buried by unit Qay; about 12 m above Ute Creek

Qao — **Older (higher) unit (middle Pleistocene)**—About 37–110 m above modern stream level

Outwash gravel (late and middle Pleistocene)—Glaciofluvial deposits composed chiefly of slightly bouldery, cobbly, pebble gravel deposited by melt-water streams flowing from former glaciers in the central part of map area. Boulders are 25–30 cm in diameter; clasts typically are moderately rounded to subangular. Estimated thickness 3–10 m

Qgp — **Outwash gravel of Pinedale age (late Pleistocene)**—Underlies terrace remnants about 6 m above Casias Creek and about 12 m above Costilla Creek, near the eastern boundary of the map area. Probably coeval with nearby till deposited during the Pinedale glaciation (about 12–30 ka; Nelson and others, 1979; Benson and others, 2004, 2005). Deposits could be as old as 40–47 ka (Cole and others, 2007), and may have been deposited during an early advance of Pinedale ice (Sturchio and others, 1994).

Qgb — **Outwash gravel of Bull Lake age (late and middle Pleistocene)**—Underlies terrace remnants about 12 m above Casias Creek and about 24 m above Costilla Creek, near the eastern boundary of the map area. Probably coeval with nearby till deposited during the Bull Lake glaciation (about 120–170 ka; Sharp and others, 2003; Pierce, 2004).

Qgbp — **Outwash gravel of pre-Bull Lake age (middle Pleistocene)**—Underlies a single small isolated terrace remnant about 32 m above Casias Creek and about 57 m above Costilla Creek near the eastern boundary of the map area. Probably deposited during a glacial episode that predated the Bull Lake glaciation.

Alluvial and mass-movement deposits

Qac — **Alluvium and colluvium, undivided (Holocene and late Pleistocene)**—Undifferentiated valley-floor alluvium (Qa), sheetwash alluvium (Qaw), and younger fan deposits (Qfy); includes small deposits of colluvium (Qc) along minor streams and on adjacent lower (toe) slopes. Estimated thickness 1–10 m

Fan deposits (Holocene to middle Pleistocene)—Mostly nonsorted to poorly sorted, slightly bouldery to bouldery, pebble and cobble gravel and locally pebbly and cobbly silty sand. Deposited chiefly by streams and debris flows in fan-shaped accumulations near base of moderate to steep slopes. Fan deposits locally include sheetwash deposits (Qaw), colluvium (Qc), and probably hyperconcentrated flow deposits. Estimated thickness 3–15 m

Qfy — **Younger (lower) unit (Holocene and late Pleistocene)**—Deposits commonly have well-preserved depositional morphology, and are at or near modern stream level

Qfo — **Older (higher) unit (middle Pleistocene)**—Deposits commonly have muted depositional morphology, and are about 12–90 m above modern stream level. Unit is equivalent to older alluvial fan deposits of Lipman and Reed (1989).

Mass-movement deposits

Qta — **Talus deposits (Holocene and late Pleistocene)**—Deposits composed of virtually unsorted, granule- to boulder-sized angular rock fragments in steep, roughly angle-of-repose aprons below steep slopes and cliffs. Probably formed chiefly by rock fall, rock slide, and, perhaps, locally by debris flow. Locally may include block-slope and block-stream deposits (Qbs). Estimated thickness 1–10 m

Qbs — **Block-slope and block-stream deposits, undivided (Holocene and late Pleistocene)**—Blocky deposits on steep slopes near the crest of the Sangre de Cristo Mountains, in southeastern part of the map area, are composed chiefly of angular blocks of pegmatite (Ypc) and quartz monzonite (Xqzt). Block size probably decreases with increasing depth below the top of the deposits. Deposits of unit Qbs were probably formed chiefly by creep, freeze-thaw, and probably by periglacial processes during glacial episodes. Estimated thickness 1–10 m

Qc — **Colluvium, undivided (Holocene to middle? Pleistocene)**—Unsorted deposits formed by a variety of mass-wasting processes. Deposits consist of sand and fine material and angular clasts that range in size from granules to boulders. Unit includes material transported chiefly by creep, debris flow, sheetwash, hyperconcentrated flow, landslide, and by periglacial processes (such as solifluction) during glacial episodes. Thin deposits rich in eolian silt locally mantle frost-creep and solifluction deposits above tree line. The down-slope transport of these colluvial deposits may be locally due in part to the relatively high moisture-holding capacity of infiltrated eolian silt. Estimated thickness 3–15 m

Qls — **Landslide deposits (Holocene to middle? Pleistocene)**—Deposits of unsorted and unstratified debris that commonly have hummocky topography. Many younger landslides are bounded upslope by crescent-shaped headwall scarps and downslope by lobate toes. The unit locally includes material displaced chiefly by rock slides, debris slides, debris flows, earth slides, and earth flows, as defined by Varnes and Cruden (1996). Near the west boundary of the map area, relatively intact slide blocks of Servilleta basalt, alluvial facies of the Santa Fe Group, and Amalia Tuff are displaced by sliding. These slide blocks are designated Qlb (Tsb), Qls (QTsf), and Qls (Trt), respectively. Landslide scarps in Tertiary and Proterozoic bedrock indicate the upslope limits of deep-seated bedrock creep or incipient sliding that did not produce landslide deposits. Estimated thickness 5–45 m

Glacial deposits

Qrg — **Rock-glacier deposits (Holocene and latest Pleistocene)**—Bouldery, lobate and probably locally tongue-shaped masses that commonly have steep fronts and flanks, and form in cirques, and along valley walls, above tree line in areas of high talus production. Deposits probably consist of a veneer of angular boulders that overlies a thick mass of rock rubble that contains finer interstitial rock fragments. The lower part of the unit is ice-cemented or has an ice core. Unit Qrg locally may include minor talus deposits (Qta) displaced by post-depositional flowage, colluvium (Qc), and other mass-movement deposits. Estimated maximum thickness is 45 m

Till (late and middle Pleistocene)—Ice-deposited material composed chiefly of non-sorted and non-stratified, angular to subrounded boulders to granules in a sandy matrix. Probably locally includes stratified drift

Qtp — **Till of Pinedale age (late Pleistocene)**—Deposits commonly form large prominent, sharp-crested lateral moraines that are very bouldery and have distinct constructional morphology. Unit locally may include till of Bull Lake age (Qtb).

Radiocarbon (^{14}C) and cosmogenic surface-exposure ages for correlative deposits in Colorado suggest that Qtp is about 12–30 ka (Nelson and others, 1979; Benson and others, 2004). Some deposits of Qtp may be older than 30 ka, because uranium-series ages of travertine in the northern Yellowstone area suggest an advance of Pinedale ice occurred about 34–47 ka (Sturchio and others, 1994). Estimated thickness is 1.5–100 m

Qtb — **Till of Bull Lake age (late and middle Pleistocene)**—Deposits commonly form prominent lateral moraines that have rounded crests and that lie beyond the outer limit of till of Pinedale age (Qtp). Deposits near Jarocito, New Mex., are partly buried by stream alluvium of Qay. Unit Qtb locally may include till of Pinedale age (Qtp) and till of pre-Bull Lake age. K–Ar and $^{40}Ar/^{39}Ar$ analyses for correlative deposits in Wyoming suggest that Qtb is about 120–170 ka (Sharp and others, 2003; Pierce, 2004). Estimated thickness is 1.5–35 m

CENOZOIC BEDROCK

Sedimentary rocks

Santa Fe Group

Santa Fe Group (early Quaternary to Oligocene)—Syntectonic sedimentary and volcanic rocks deposited as fill in basins of the Rio Grande rift; everywhere divided into:

QTsf — **Alluvial facies, upper part (early Pleistocene to Pliocene)**—Pebble to cobble sand-matrix conglomerate, pebbly sandstone and siltstone; poorly consolidated; ochre-colored; overlies 4.4–4.8 Ma Servilleta basalt (Tsb)

Tafc — **Alluvial facies, lower part (Pliocene to Miocene)**—Pebble to boulder sand-matrix conglomerate, pebbly sandstone and siltstone; poorly to moderately consolidated; ochre-colored to light red; large clasts derived mainly from local Proterozoic bedrock and much lesser local volcanic and intrusive rocks—andesite (Ta), rhyolite lava (Tr), intrusive rhyolite porphyry (Tri), and Amalia tuff (Trt); underlies 4.4–4.8 Ma Servilleta basalt (Tsb); locally contains interbedded basalt or basaltic andesite flows yielding $^{40}Ar/^{39}Ar$ ages in the range of about 15 to about 11 Ma

Tsfv — **Volcaniclastic facies (early Miocene to late Oligocene)**—Boulder to pebble sand-matrix conglomerate of mainly volcaniclastic composition; clasts of local andesite, rhyolite, and tuff (Ta, Tr, and Trt), along with lesser intermixed clasts of local Proterozoic bedrock; includes minor tuffaceous layers which appear to be reworked rather than juvenile

Tbx — **Rock-avalanche breccia (Miocene?)**—Breccia composed of shattered Paleoproterozoic rocks, found as wedges locally interbedded within Santa Fe Group, alluvial facies, lower part (Tafc). Mapped only in a single locale near Amalia, New Mex.; however, float of this breccia is common throughout the area of Tafc to the north and east of this locale indicating it is more abundant than current mapping indicates

Ts — **Conglomerates, mainly pre-volcanic (lower Oligocene and Eocene)**—Boulder conglomerates with clasts of various local Proterozoic lithologies, especially quartzite; but including fewer clasts of andesites (Ta) in uppermost part only; boulders and cobbles are well rounded; matrix commonly consists of deep maroon colored red clay when locally (rarely) exposed; generally equivalent to "Prevolcanic sedimentary rocks" of Lipman and Reed (1989)

Volcanic rocks

Tsb — **Servilleta basalt (Pliocene)**—Tholeiitic basalt, thin dark-gray flows with small olive phenocrysts; not dated in map area but dated in vicinity at 4.4 to 4.8 Ma (whole rock, $^{40}Ar/^{39}Ar$; Thompson and others, 2007)

Tb — **Mafic lava flows (Miocene)**—Silica alkali-olivine basalt and basaltic andesite lava flows, dark-gray, fine-grained, with sparse plagioclase and olivine phenocrysts; dated at about 11 to about 15 Ma in the north of map ($^{40}Ar/^{39}Ar$, whole-rock; Kirkham and others, 2005); equivalent to Hinsdale Formation of Thompson and others (2007)

Tr — **Rhyolite lava (Oligocene)**—Rhyolite lava with <0.5 percent phenocrysts of feldspar and quartz in a light grayish-blue groundmass; locally aperolitic or reddened by oxidation. Directly overlies the Amalia Tuff (Tat) in most exposures, and is presumed to be genetically related to it

Trt — **Amalia Tuff (Oligocene)**—Peralkaline rhyolite ash-flow tuff; mainly densely welded, with 10 to 20 percent phenocrysts of quartz and alkali feldspar (transitional sanidine-anorthoclase), and sparse to rare pyroxene, fayalite and sodic amphibole; dated at 25.5 Ma ($^{40}Ar/^{39}Ar$, feldspar; Lipman and Reed, 1989)

Ta — **Andesites (Oligocene)**—Thick sequence of lava flows, tuffs, lahars, and lesser interbedded volcaniclastic conglomerates and sandstones; mainly of andesitic composition but includes some dacites and rhyolites; generally equivalent to Conejos Formation of the San Juan Mountains; equivalent rocks to south of map have been called "precaldera volcanic rocks," which Lipman and Reed (1989) divide into 15 map units ranging in age from about 30 to about 26 Ma

Intrusive rocks

Tbx — **Mafic dike (Miocene)**—Basaltic andesite dike with sparse plagioclase phenocrysts and quartz xenocrysts, presumed to be related to xenocrystic basaltic andesite (Tbx) of Lipman and Reed (1989), to south of map. If this proposed correlation is correct, Tbx is similar in age to the oldest of the (about 11 to 15 Ma) mafic lava flows (Tb) of northern part of map area, based on stratigraphic position

Tri — **Felsic-composition intrusions (Oligocene?)**—Hypabyssal stocks and smaller bodies of rhyolite porphyry; most of these intrusions are probably related to rhyolite (Tr), but some may be younger

Tai — **Intermediate-composition intrusions (Oligocene?)**—Hypabyssal sills and dikes of andesite (diorite porphyry) composition; most of these intrusions are probably related to andesites (Ta), but some may be younger

LOWER PALEOZOIC OR NEOPROTEROZOIC DIKES

PzZg — **Gabbro (early Paleozoic or Neoproterozoic)**—Dikes of nonfoliated quartz-bearing pyroxene gabbro, which cut foliated Paleoproterozoic and Mesoproterozoic rocks throughout the Sangre de Cristo Mountains, but do not cut overlying upper Paleozoic sedimentary rocks. A Rb-Sr isochron on a gabbro dike near the confluence of the Rio Costilla and Latir Creek (near the center of the southwest border of the map) gave an age of 670 Ma (data from Z.E. Peterman, U.S. Geological Survey, 1984, published by Lipman and Reed, 1989)

CRYSTALLINE BASEMENT ROCKS

[Note on coarse sawtooth-pattern contacts: Throughout the map area, many contacts within the Proterozoic crystalline basement rocks are depicted with a coarse sawtooth pattern to indicate very large-scale interfingering or gradation between adjacent map units. This type of contact is particularly appropriate for the pegmatite sheeted sill complex (Ypc), which interfingers so extensively with its host rocks that it cannot be shown as having definite boundaries at the scale of the map. In general, this pegmatite sheeted sill complex (Ypc) is mapped as solid where the sills constitute ≥ 90 percent of the rock, and the sawtooth are used in those zones where sill concentration declines from about 90 percent of the rock to ~ 25 percent. Outlying pegmatite sills that are peripheral to the main mass of this intrusive complex are generalized, as are enclosed selvages of host-rock, and both are mapped mainly on ridge-tops above tree line, where exposures are best. Sawtooth boundaries are also used locally for contacts between the five compositional assemblages of mixed metavolcanic and metasedimentary Paleoproterozoic rocks, because the mixtures of different interbedded metamorphic rocks commonly are too complex to be portrayed at map scale.

The orientation of the sawtooth in all cases indicate the overall trend of compositional bedding in the Proterozoic rocks. In contrast, the width of the sawtooth generally increases with the uncertainty in location of the highly gradational "contact," and that uncertainty is largely a function of the extent of cover by humic and colluvial soils]

Intrusive and metaintrusive

Ypc — **Pegmatite sheeted-sill complex (Mesoproterozoic)**—granitic pegmatite found as a large complex of sills that have locally intruded so densely that remnant selvages of the host rock are rare; consists of quartz and two feldspars in eutectic proportions, along with minor to rare biotite and magnetite

YXp — **Isolated pegmatites (Mesoproterozoic to Paleoproterozoic)**—small pegmatite bodies that primarily are outliers of the pegmatite sheeted sill complex (Ypc); locally includes older (about 1.6–1.7 Ga) pegmatites related to local granitoid plutons (Xqg and Xqzt)

Xa — **Amphibolite (Paleoproterozoic)**—Hornblende-plagioclase gneiss (meta-gabbro); locally found as small intrusions emplaced within granitoid plutons (Xqg and Xqzt)

Xqzt — **Quartz monzonite of Costilla Creek (Paleoproterozoic)**—Gneissic biotite quartz monzonite, coarse-grained, moderately to strongly foliated; containing conspicuous augen of microcline 0.5 to 5 cm long; locally includes masses of pegmatite; an age of 1.644 Ga (U-Pb, zircon) was reported by Lipman and Reed (1989)

Xqg — **Gneissic granite of Jarosa Creek (Paleoproterozoic)**—Monzogranite with a weak to strong superimposed gneissic foliation; locally includes masses of pegmatite; $^{206}Pb/^{238}U$ SHRIMP dating of zircons from this granite yielded ages of 1.688 Ga and 1.689 Ga (analyst W.R. Premo, U.S. Geological Survey, reported in Kirkham and others, 2005)

Metasedimentary

Xq — **Quartzite (Paleoproterozoic)**—Orthoquartzite, well-bedded with minor interbeds of muscovite schist; locally contains trace amounts of specular hematite

Xqs — **Muscovite- quartz schist (Paleoproterozoic)**—Interbedded muscovite-quartz schist and lesser quartzite; locally contains feldspar, biotite, sillimanite, and garnet; interbeds of other rocks types, including felsic gneiss (meta-rhyolite) and amphibolite, are mostly minor except near sawtooth contacts

Mixed metasedimentary and metavolcanic

Xfg — **Felsic gneiss assemblage (Paleoproterozoic)**—Mixed unit of compositionally layered metamorphic rocks dominated by gneisses composed of quartz and two feldspars, along with a trace to abundant biotite or muscovite. Mica-poor facies is probably meta-rhyolite based on preserved very-fine-grained equigranular texture and massive character, along with local remnant fabrics resembling flow-banding and phenocrysts. Mica-rich facies commonly have compositional bedding defined by variations in mica and quartz contents and appear metasedimentary. Interbeds of other rocks types, including amphibolites and mica schist are minor except near sawtooth contacts. Thin interbeds of banded iron formation (composed of quartz and specular hematite) are rare

Xaa — **Amphibolite assemblage (Paleoproterozoic)**—Mixed unit composed dominantly (about 50 percent) of amphibolite (metabasalt) interbedded with a mixture of metavolcanic and metasedimentary rock types, including quartzites, mica-quartz schists, felsic gneiss, hornblende-orthoclase gneiss, and rare banded iron formation. Includes abundant pegmatite bodies too small to map separately. Not related to "Mixed unit of felsic gneiss and amphibolite" on the map to the northeast (Fridrich and Kirkham, 2007), which is entirely metavolcanic; instead correlative with "Bimodal and meta-sedimentary unit (Xb)" of that map, and to unit Xfa of the map to the east (fig. 1; Fridrich and others, 2009). "Mixed unit of felsic gneiss and amphibolite" of Lipman and Reed (1989) is mainly Xaa; however, greater discrimination is made on our map between areas dominated by felsic gneiss (Xfg) and ones dominated by amphibolites (Xaa)

Xhoz — **Hornblende-orthoclase gneiss assemblage (Paleoproterozoic)**—Mixed unit composed dominantly of hornblende-orthoclase gneiss (interpreted as meta-trachyte), with minor to moderately abundant interbeds of amphibolite, felsic gneiss, and mica schist

EXPLANATION

Contact—Dashed where approximately located; short dash where uncertain and (or) queried

Gradational contact—Large-scale interfingering or gradation between adjacent Proterozoic crystalline basement rocks represented using a coarse sawtooth pattern. The orientation of the sawtooth indicates the general trend of compositional bedding in the Proterozoic rocks. The width of the sawtooth generally increases with the uncertainty in location of the highly gradational contact

Crest line of moraine

Landslide scarp—Hachures at base of scarp

Erosional scarp—Hachures at base of scarp

Fault—Dashed where approximately located; dotted where concealed

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

Strike-Slip fault—Right lateral offset. Dashed where approximately located; dotted where concealed

Vertical bedding—Showing strike

Inclined bedding—Showing strike and dip

Overturned bedding—Showing strike and dip

Inclined foliation in metamorphic rock—Showing strike and dip; with foliation arrow showing bearing and plunge

Inclined foliation in igneous rock—Showing strike and dip

Lineation—Showing bearing and plunge

Minor syncline—Showing bearing and plunge

Fault attitude—Showing strike and dip

Rake on fault—Showing bearing and rake

Shear zone

INTRODUCTION

This map covers the Big Costilla Peak, New Mex.–Colo. quadrangle and adjacent parts of three other 7½-minute quadrangles: Amalia, New Mex.–Colo.; Latir Peaks, New Mex.; and Comanche Point, New Mex. (fig. 1). The study area is in the southwesternmost part of that portion of the Sangre de Cristo Mountains known as the Culebra Range. The Taos Range part lies to the southwest of Costilla Creek and its tributary, Comanche Creek. This study fills a gap in detailed bedrock geologic mapping in the Sangre de Cristo Mountains between previous maps, listed clockwise from northwest by the authors (see fig. 1): Machette and others, 2008; Kirkham and others, 2003; Kirkham and others, 2004; Fridrich and Kirkham, 2007; Fridrich and others, 2009; Lipman and Reed, 1989; Kirkham and others, 2004; and Thompson and others, 2007. Nearly all of the mapping presented is new original detailed work; however, a thin strip of geologic mapping along Costilla Creek was modified from Lipman and Reed (1989) in order to show the evidence for two major late Tertiary faults that are largely concealed under alluvium of the river valley.

Field work for this map was carried out by the authors during the summers of 2007 through 2009. The map was compiled using a photogrammetric plotter and recent aerial photography (1:40,000-scale black-and-white National Aerial Photography Program (NAPP) photographs taken in 1999; available at http://ngpc.usgs.gov/ngdb/pubs/doqs/aerial/aerial.html), in conjunction with Global Positioning System (GPS) measurements taken in the field.

GEOLOGIC SUMMARY

The map area extends over all but the northernmost part of the Big Costilla horst (fig. 2), a late Cenozoic uplift of Proterozoic rocks that is largely surrounded by down-faulted Cenozoic rocks exposed at significantly lower elevations. This horst is bounded on the northwest side by the San Pedro horst and Culebra graben, on the northeast and east sides by the Devils Park graben (Fridrich and Workman, 2009), and on the southwest side by the Latir volcanic field (fig. 2). The area of this volcanic field has undergone significantly greater extension than the area to the north of Costilla Creek (Fridrich and Workman, 2009). The horst and grabens discussed above are all peripheral structures on the eastern flank of the San Luis basin, which is the axial part of the about 26 Ma-to-present Rio Grande rift at the latitude of the map (fig. 2; Fridrich and Workman, 2009). The Laramide-age (about 70 to about 40 Ma) Raton basin lies to the east of the Culebra segment of the Sangre de Cristo Mountains (fig. 2).

Cenozoic strata in the map area include: (1) Eocene to lower Oligocene boulder conglomerates (Ts) that predate the Rio Grande rift; (2) about 30 to about 26 Ma volcanic rocks of the Latir volcanic field (Ta, Tri, and Trt), which were erupted shortly before or at the advent of rifting; and (3) the Santa Fe Group, which represents syn-rift basin-fill sedimentary strata, and is divided into three map units (Tafc, Tafv, and QTsf). The oldest subunit of the Santa Fe Group (Tafc) is overwhelmingly volcaniclastic and has strongly fanning (diminishing-upward) strata dips. The overlying remainder of the Santa Fe Group consists predominantly of alluvial conglomerates, with clasts mainly of Proterozoic rocks, and is divided into two parts, subunits Tafc and QTsf, that predate and postdate the 4.4–4.8 Ma Servilleta basalt (Tsb), respectively. An older group of interbedded volcanic rocks locally found within the middle map unit of the Santa Fe Group (TaTc) consists of flows of basalt or basaltic andesite (Tb) and lesser dacite (northeast of the map), ranging in age from about 11 to about 15 Ma (Thompson and others, 2007).

Subvolcanic Cenozoic intrusions in the map area include basaltic (Tbi), rhyolitic (Tri), and andesitic (Tai) stocks and dikes, which are interpreted as being related to Cenozoic extrusive rocks of the same three compositions (Tb, Tr, and Ta), and probably are approximately the same in age; however, younger ages for some of the intrusions are possible. The vast majority of the intrusions in the map area were emplaced along or in the immediate vicinity of the Costilla Creek fault, a large fault with predominantly strike-slip offset that intervenes between the Big Costilla horst and the structural block immediately to the southwest that hosts the Latir volcanic field (fig. 2).

The western range-front fault system of the Sangre de Cristo Mountains shows evidence of recent activity as close as 1 kilometer north of the map area (Kirkham and others, 2003, 2004; Thompson and others, 2007); however, there is no evidence of recent offset on range-front faults in the map area itself. An array of small (about 2 to about 10 m) offset northeast-striking normal faults in the northwestern part of the map cut Santa Fe Group strata (QTsf) that overlie the Servilleta basalt. Whereas the youngest of the QTsf strata may locally be as young as early Pleistocene, these northeast-striking faults lack discernable primary geomorphic expression and thus probably are no younger than middle Pleistocene. Whereas the post-about 4.5 Ma offsets on these faults are very small, exposures on the steep north slope of Costilla Creek valley show that at least one of these is a sizeable fault at deeper levels where it cuts Miocene and older rocks. This array of small-offset northeast-striking normal faults in the northwestern part of the map may reflect minor non-seismogenic reactivation of Miocene faults.

The Proterozoic rocks of the Culebra Range part of the Sangre de Cristo Mountains can be grouped into five major packages. (1) an oldest package of mixed metasedimentary and metavolcanic (mainly meta-andesite) rocks, which are not exposed in the map area. (2) an overlying sequence of interbedded metasedimentary and bimodal metavolcanic rocks, (3) plutonic meta-intrusive rocks of mainly granitoid composition, (4) a sheeted-sill complex of pegmatite, and (5) non-foliated gabbro dikes.

The first and oldest package of rocks is exposed to the northeast of the map, in the Culebra Peak area, and is strictly metavolcanic consisting mainly of meta-andesite and meta-dacite (Fridrich and Kirkham, 2007).

The second package of rocks is the oldest exposed group of rocks in the map area, and it is divided into five map units based on composition (see Correlation of Map Units and Description of Map Units). These five map units include two fairly pure lithologies: quartzite (Xq) and quartz-muscovite schist (Xqs), as well as three mixed assemblages, each dominated by a particular lithology: amphibolite (meta-basalt; Xaa), felsic gneiss (mixed meta-rhyolite and meta-sedimentary quartz-feldspar-mica gneiss; Xfg), and hornblende-orthoclase gneiss (meta-trachyte; Xhoz).

The third package of rocks, which consists mainly of two granitoid plutons, intrudes the mixed metasedimentary and metavolcanic rocks of the map area (Xq, Xqs, Xaa, Xfg, and Xhoz). The gneissic granite of Jarosa Creek (Xqg) is exposed in the northern part of the map and has been dated in the adjacent La Valley, Colo., 7½-minute quadrangle at 1.688 Ma (U-Pb, zircon; whole rock, $^{40}Ar/^{39}Ar$; Thompson and others, 2007)

The quartz monzonite of Costilla Creek (Xqzt) is exposed in the southern part of the map and has been dated at 1.644 Ma (U-Pb, zircon; Lipman and Reed, 1989). This third package (meta-intrusive rocks) also includes a minor unit consisting of amphibolite (Xa; meta-basaltic) rocks that are emplaced within the plutonic granitoid intrusions.

The fourth package of Proterozoic rocks consists of a large sheeted sill complex of pegmatite (Ypc) that is exposed throughout the south-central part of the map area. This complex intrudes the quartz monzonite of Costilla Creek (Xqzt) and its host rocks. The sheeted sill complex is nonfoliated, whereas the rocks it intrudes (typically are strongly foliated and lineated, including some older pegmatite that is locally part of the about 1.7-Ga host rocks. U-Pb dating of the sheeted sill complex (Ypc) has yielded only a very rough estimate of its age, about 1.400 Ma, owing to the strongly metamict nature of the zircons found in it (W.R. Premo, written commun., U.S. Geological Survey, 2011). Isolated pegmatites (YXp) of the map area consist mainly of outliers related to the sheeted sill complex, but may also include some older pegmatites that may be related to the about 1.640–1.690-Ma granitoid plutons.

The fifth and youngest package of Proterozoic (or early Paleozoic) rocks consists of non-foliated gabbro dikes (PzZg) that are predominantly subvertical and northwest-striking. Whereas stratigraphic constraints in the Sangre de Cristo Mountains only bracket these dikes between about 1.400 Ma and the Pennsylvanian period (about 320 Ma), a Neoproterozoic age is most likely based on a Rb-Sr isochron of a gabbro dike near the confluence of Costilla Creek and Latir Creek (near the center of the southwest border of the map; Lipman and Reed, 1989). However, these dikes may possibly be as young as early Paleozoic (Larson and others, 1985).

Metamorphic fabrics in the Paleoproterozoic rocks are complex. Map data gathered in this study indicate that there are at least four different foliations in the rocks and at least three lineations reflecting a complex, multi-stage tectonic history. Because of these complex structural fabrics, the best developed foliation and the best developed lineation in single locales are not necessarily coplanar.

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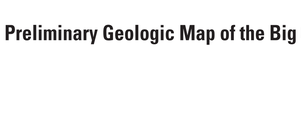

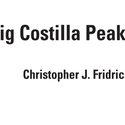

Base from U.S. Geological Survey Big Costilla Peak, New Mex.–Colo.,1983; Amalia, New Mex.–Colo., 1983; Latir Peak, New Mex., 1983, and Comanche Point, New Mex. 1983, 1:24,000.

Polyconic projection. North American Datum of 1927 (NAD 27)

10,000-foot grids based on New Mexico coordinate system, central zone, and Colorado coordinate system, south zone

1000-meter Universal Transverse Mercator grid ticks, zone 13

GIS files projected in Universal Transverse Mercator

Field work was carried out by C.J. Fridrich, R.R. Shroba, and A.M. Hudson in the summers of 2007–2009. A thin strip of geologic mapping along Costilla Creek was modified from Lipman and Reed (1989)

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