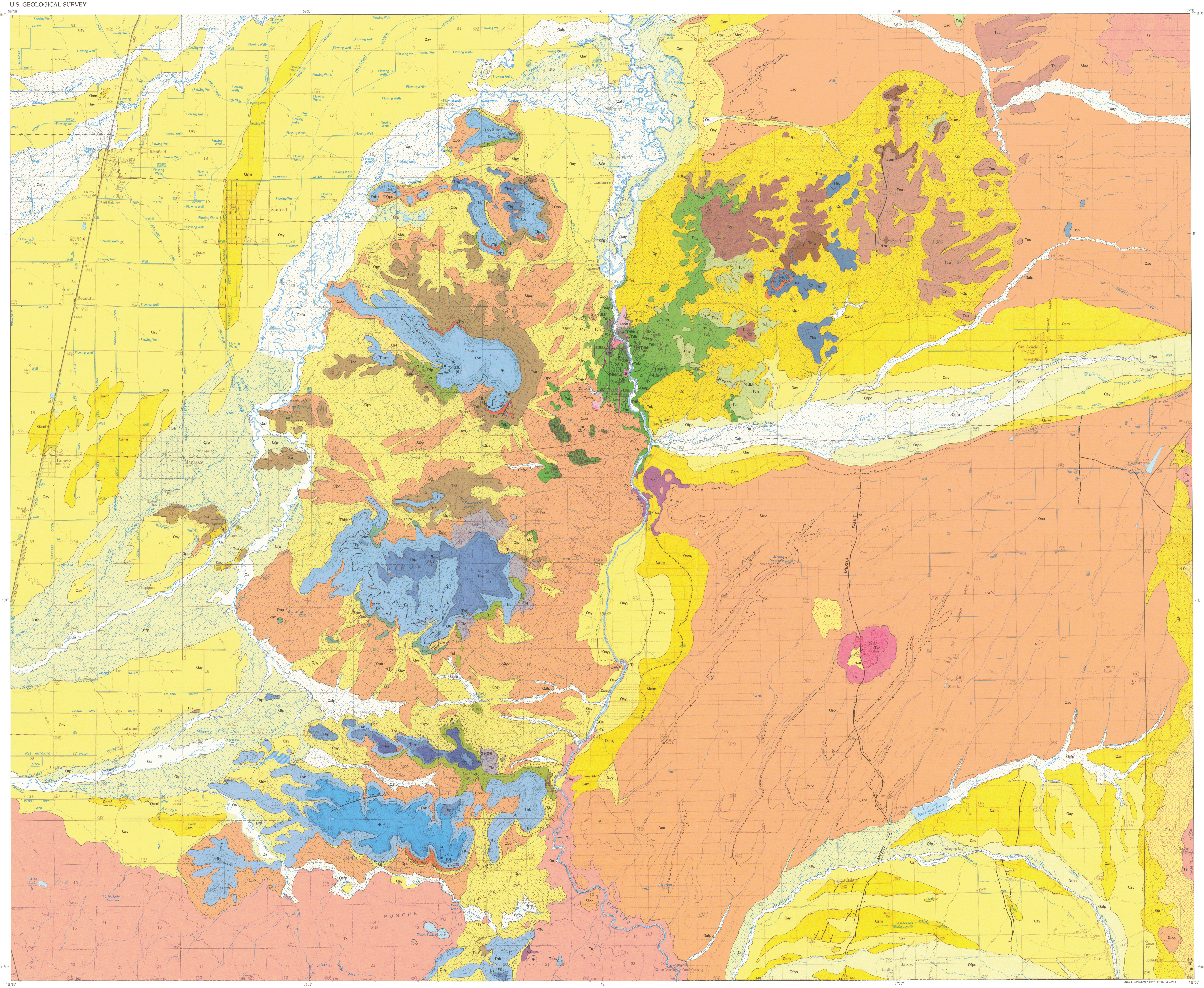

GEOLOGIC MAP OF THE SAN LUIS HILLS AREA, CONEJOS AND COSTILLA COUNTIES, COLORADO

By
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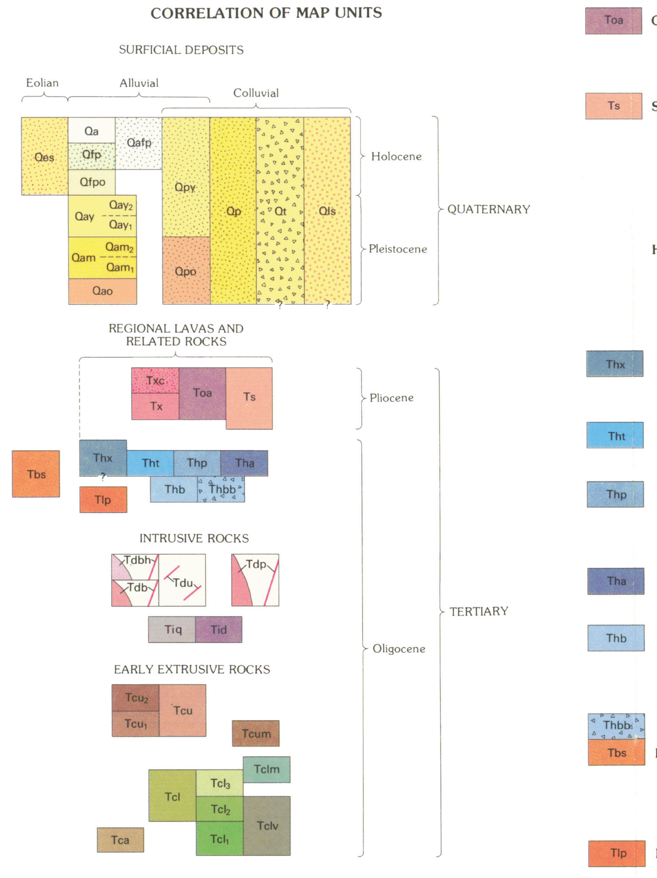
SCALE 1:50 000

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

[Surficial deposits are generally more than 2 m thick where mapped. In some places, thinner deposits are mapped to show areal distribution and stratigraphic relations. The distribution of surficial deposits west of the Rio Grande is based partly on geologic interpretation of soils mapped by the U.S. Soil Conservation Service (Yenter and others, 1980). The distribution of flood-plain and active stream-channel deposits is delineated from aerial photographs; their contacts are generally gradational and approximately located. Age estimates or correlations are based on preservation of original surface morphology, height of a unit's depositional surface above modern stream level, and the extent of soil development on units (*see* Machette, 1985, for a discussion of soils)]

Qes — **Eolian sand (Holocene)**—Light-brown, well-sorted, fine to medium sand. Forms embankments against bedrock and fills some small stream valleys of the San Luis Hills. East of the Rio Grande, eolian sand thinly covers most of the stable surface of the oldest alluvial unit (Qao), but only several patches of sand are thick enough (2 m) to show separately within the area mapped on units Qao and Qpo. Thickness 2–3 m

Alluvial deposits of the San Luis Basin—Light-gray to light-brown sand and sandy pebble to small-cobble gravel. Forms flood plains and terraces along the Rio Grande and along tributary streams to the east. Forms broad piedmont slopes west of the Rio Grande and between incised streams east of the Rio Grande. All deposits are relatively well sorted and were mainly deposited by perennial streams

Qa — **Alluvium of major, active stream channels (upper Holocene)**—Sandy pebble to cobble gravel within stream channels incised into older deposits. Only mapped along major streams. Thickness unknown, but probably 2–4 m; base covered

Qfp — **Flood-plain alluvium (upper Holocene)**—Moderately well sorted, fine-grained overbank alluvium and well-sorted sandy pebble to cobble gravel. Forms extensive, slightly undulating flood plains along most major streams in the area. Surface shows 1–2 m of bar-and-swale morphology. Soil has organic-rich A horizon and weakly oxidized C horizon. Thickness unknown, but probably 2–4 m; base covered

Qafp — **Undifferentiated alluvium (upper Holocene)**—Includes alluvium of major, active stream channels (Qa) and of adjacent flood plains (Qfp) where the two units overlap extensively or where restricted to narrow channels, especially along the Rio Grande and lower Conejos River. Thickness unknown; base covered

Qfpo — **Flood-plain alluvium (lower? Holocene)**—Sparse remnants of an older phase of flood-plain alluvium that are generally less than 2 m above the active flood plain and have subdued bar-and-swale morphology (1/2–1 m of surface relief). Soil has an A horizon and an oxidized, Cca (calcareous) horizon; clasts have thin, discontinuous calcium carbonate coatings of stage I morphology (stages of Gile and others, 1966). Largest remnants of this unit are along Culebra and Costilla Creeks, east of the Rio Grande. Thickness unknown, but probably 2–5 m; base covered

Qay (Qay2, Qay1) — **Young alluvium (upper Pleistocene)**—Extensive unit of alluvium that forms discrete terraces 5–10 m above the Rio Grande and a single terrace 2–4 m above its eastern tributaries. Terraces subdivided into Qay_1 (older) and Qay_2 (younger) along the Rio Grande, in central part of map area. West and north of San Luis Hills, unit forms broad, smooth surface at or just above stream level. Consists of well-rounded, well-sorted glacial outwash from the adjacent San Juan and Sangre de Cristo Mountains, west and east of the map area, respectively. Youngest major gravel deposit in the area. Soil on unit is different east and west of the Rio Grande owing to local climate and ground water level. West of the Rio Grande, soil has thick, organic-rich A horizon; weak, argillic, clayey B horizon; and oxidized to sparsely calcareous Cca horizon. Calcium carbonate has stage I morphology but shows irregular pattern of development. East of the Rio Grande, soil has a thin, less organic A horizon, a slightly thicker and more clayey B horizon, and a Cca horizon having stage I to weak stage II morphology. These soils show development similar to soils of uppermost Pleistocene age (15,000–25,000 yrs) elsewhere in the southern Rocky Mountains (Machette, 1985). Thickness 5–10 m along the Rio Grande, unknown elsewhere

Qam (Qam2, Qam1) — **Middle alluvium (uppermost middle Pleistocene)**—Extensive unit of alluvium that forms discrete terraces 18–22 m above the Rio Grande and 6–15 m above its eastern tributaries. Terraces subdivided into Qam_1 (older) and Qam_2 (younger) along the Rio Grande in central part of map area. West of San Luis Hills, unit has been mostly eroded and buried by younger alluvium; however, two outcrops near Sanford and La Jara show that unit was deposited as much as 3 m above modern stream level. Consists of well-rounded, well-sorted glacial outwash from the adjacent San Juan and Sangre de Cristo Mountains and an overlying mantle of loess. Soil below stable surface of alluvium east of the Rio Grande has a thick, organic-rich A horizon and a moderately to strongly developed, light-reddish-brown argillic (clayey) and calcareous (stage I) B horizon formed in 0.5–1.0 m of loess, whereas the underlying alluvium generally contains a Cca horizon. The Cca horizon has stage II to weak stage III morphology, but shows irregular pattern of distribution probably as a result of leaching during wet phases of the late Pleistocene. This soil is similar to soils of uppermost middle Pleistocene age (125,000–150,000 yrs) elsewhere in the southern Rocky Mountains (Machette, 1985). Thickness about 5–10 m along the Rio Grande, unknown elsewhere

Qao — **Old alluvium (middle Pleistocene)**—Moderately oxidized, sandy pebble to cobble alluvium commonly overlain by a thin (<2 m) mantle of younger eolian silt and sand. As mapped, unit includes several alluvial subunits that have well-developed soils; however, because of limited exposures these subunits cannot be shown separately. Unit is only exposed east of the Rio Grande; presumably it is at shallow (25–100 m) depth west of the San Luis Hills. Generally, forms broad, slightly undulating, dissected surfaces 20–40 m above stream level in eastern part of map area; these surfaces become progressively higher above stream level to the west where they are 50–60 m above the Rio Grande. Soils below these surfaces may have a 0.5–1 m thick Cca or K horizon (stage III to incipient stage IV; see Gile and others, 1965, 1966) and (or) a thick, clayey, reddish-brown argillic B horizon and a thin, poorly organic A horizon. Locations of good exposures of soils on this surface are shown on the map. Unit probably includes alluvium that ranges in age from more than 200,000 to perhaps 600,000 yrs. Alluvium is at least 10 m thick along Culebra Creek and the Rio Grande; elsewhere base is covered and thickness is unknown

Piedmont-slope deposits of the San Luis Hills—Light-gray to light-brown pebble and cobble gravel having sandy matrix, although talus and landslides contain large blocks of bedrock. On broad piedmont slopes surrounding the San Luis Hills, poorly sorted colluvium grades laterally into coalesced fan- and piedmont-slope alluvium, which consist of moderately well sorted sandy gravel. Units fill broad valleys among resistant hills of Tertiary volcanic rocks. Also includes deposits along western toe of San Pedro Mesa. Thicknesses unknown, probably 2–10 m

Qpy — **Younger piedmont-slope alluvium (Holocene and upper Pleistocene)**—Colluvium and alluvium that form fairly broad but smooth surfaces. Unit is undivided and correlates with alluvial units Qafp, Qfpo, and Qay east of the Rio Grande. Soil on unit consists of weak A and B horizons and a stage I to stage II Cca horizon. Surfaces grade to low positions in valleys of San Luis Hills and to low flood plain west and north of San Luis Hills

Qpo — **Older piedmont-slope alluvium (middle Pleistocene)**—Colluvium and alluvium that form broad but moderately dissected surfaces. Unit is undivided and correlates with alluvial units Qam and Qao east of the Rio Grande. Contains soils that have moderately to strongly developed, reddish-brown argillic B horizons and stage II to III Cca horizons as much as 0.8 m thick. Soil development suggests that age of unit may range from 125,000 to perhaps 400,000 yrs (see Machette, 1985, for discussion of age estimates using soils)

Qp — **Undivided piedmont-slope alluvium (Quaternary)**—Includes younger and older alluvium and colluvium (units Qpy and Qpo) but is undivided in and around the San Luis Hills east of the Rio Grande and along the southeastern margin of the map area

Colluvial deposits—Includes talus, rockfall, landslide deposits, and associated undifferentiated colluvium that mantle slopes of 5° or more, in general

Qt — **Talus (Quaternary)**—Debris mantle of sandy to pebbly gravel and cobble- to boulder-size blocks of Tertiary volcanic rock derived from adjacent slopes. Only mapped along steep escarpments formed on bedrock of the San Luis Hills. Thickness unknown, probably 2–10 m

Qls — **Landslide debris (Quaternary)**—Includes large slumped blocks of volcanic rock in finer grained matrix. Localized in three areas: on the northeast and south sides of the Pinon Hills (0.4 and 0.1 km^2 in area, respectively) west of the Rio Grande, and widespread masses of debris that have slumped off the west margin of San Pedro Mesa in the southeastern part of the map area

BEDROCK

[Bedrock has been divided into four major packages based on potassium-argon age determinations, stratigraphic relationships, and correlation with regional units of volcanic and related rocks. The lowermost extrusive rocks comprise mafic to intermediate-composition lava flows, breccias, mudflows, and lava domes and are broadly correlated with the precaldera lavas and breccias in the southeastern San Juan Mountains that were assigned to the Conejos Formation (Cross and Larsen, 1935, p. 69). Individual volcanic centers are poorly defined, with the exception of early andesite centers, but appear to have erupted monotonous sequences of andesite and dacite. Intrusive activity was accompanied by contact metamorphism adjacent to large plutons and by extensive hydrothermal activity resulting in propylitic, argillic, and advanced argillic alteration of the overlying volcanic rocks (Bartlett, 1984). Subsequent erosion of the volcanic pile formed coalescing aprons of conglomerate of which only minor remnants are preserved along an unconformity beneath the overlying mafic rocks of the Hinsdale Formation. No rocks of Miocene age are present in the map area. Pliocene volcanic rocks are the youngest exposed bedrock units and are dominated by tholeiites of the Servilleta Formation but include subordinate olivine andesite and xenocrystic basaltic andesite]

Regional lavas and related rocks

Andesite of Mesita Hill (Pliocene?)—Xenocrystic basaltic andesite, occurs only at Mesita Hill in south-central part of map area and forms an isolated volcano consisting of basal lava flows and overlying cone composed of cinder and spatter agglutinate. Cone mostly removed by quarrying operations prior to 1986. Aphanitic to sparsely porphyritic and includes large, resorbed xenocrysts of quartz and plagioclase

Txc — **Cinder deposits**

Tx — **Flows**—1–3 m thick

Toa — **Olivine andesite (Pliocene)**—Sparsely to moderately porphyritic containing olivine phenocrysts and moderately to highly flattened vesicles. Present as remnants beneath Servilleta Formation shield in southern part of map area and forms a younger, isolated shield volcano in center of map area (Volcano de la Culebra of Burroughs, 1972). Flows, typically 2–5 m thick, form prominent escarpments in Rio Grande gorge

Ts — **Servilleta Formation (Pliocene)**—Thin flows of tholeiitic basalt characterized by small olivine phenocrysts, diktytaxitic texture, and local vesicle pipes and segregation veins. Potassium-argon age of flow in slump block in southeast corner of map area is 4.3 Ma (Lipman and others, 1986). Potassium-argon ages of flows southeast of map area range from 3.6 to 4.5 Ma (Ozima and others, 1967; Aoki, 1967; Lipman and Mehnert, 1979). Only exposed vent in map area is a low shield in southern part of map area, 0.5 km north of state boundary and 3 km west of the Rio Grande. Maximum exposed thickness is about 50 m in Rio Grande gorge in south-central part of map area

Hinsdale Formation (Oligocene)—Basaltic lava, associated breccia, and near-vent pyroclastic deposits. Includes fine-grained silicic alkali-olivine basalt, basaltic andesite, tholeiitic basalt and minor andesite and xenocrystic basaltic andesite. Sparse small olivine phenocrysts partly altered to iddingsite are typical, and xenocrysts of quartz and feldspar are locally abundant. Potassium-argon ages of flows range from 25.7 to 26.4 Ma within map area but range from 4.4 to 26.8 Ma to the west in the southeastern San Juan Mountains (Lipman, 1975). Thickness 0–300 m

Thx — **Xenocrystic basaltic andesite flows**—Aphanitic to sparsely porphyritic; contains large, resorbed xenocrysts of quartz and plagioclase. Clinopyroxene xenocrysts are abundant locally. Remnants cap mesas, and isolated outcrops occur in north-trending belt on west side of the Rio Grande in northeastern part of map area

Tht — **Tholeiitic basalt flows**—Characterized by small olivine phenocrysts, diktytaxitic texture, and local vesicle pipes and segregation veins. Restricted to uppermost part of section at South Piñon Hills. No source vents were identified. Potassium-argon age on basal flow is 25.7 Ma (table 1)

Thp — **Silicic alkali-olivine basalt flows**—Moderately porphyritic, massive flows of Piñon Hills with 10–15 percent phenocrysts of plagioclase (60 percent), clinopyroxene (20 percent), iron-titanium oxides (15 percent), and minor olivine (<5 percent). Elsewhere basalt flows are sparsely porphyritic containing phenocrysts of clinopyroxene (>40 percent), olivine, and, in places, plagioclase

Tha — **Andesite flows**—Massive, restricted to north end of South Piñon Hills. Base of thickest flow contains euhedral hornblende phenocrysts which are progressively altered and recrystallized to clinopyroxene in middle to upper parts of flow

Thb — **Silicic alkali-olivine basalt flows and near-vent pyroclastic deposits**—Sparsely porphyritic, containing phenocrysts of olivine and clinopyroxene as much as 40 percent. Vent areas characterized by steeply dipping accumulations of reddish-brown cinders and spatter agglutinate, commonly deeply eroded and overlain by lava flows. Flows range in thickness from 3 to >10 m

Thbb — **Silicic alkali-olivine basalt, monolithic flow breccias, and subordinate spatter agglutinate**—Local accumulation only

Tbs — **Eolian sediments (Oligocene)**—Fine-grained, light-tan to buff eolian sediments, interbedded with basaltic lava flows; some fluvial reworking locally. Highly variable in thickness and lateral extent. Forms discontinuous marker beds between major packages of basalt flows. Composed principally of reworked volcanic ash. Baked zones at the base of overlying basalt flows commonly contain thin zones of admixed sediments and basaltic glass, which indicate locally moist conditions at the time of eruption

Tlp — **Los Pinos Formation (Oligocene)**—Mostly bedded conglomerate and minor sandstone containing dacite clasts derived locally from underlying lava flows and domes. Contains a few Precambrian cobbles derived from the Sangre de Cristo Mountains to the east. Discontinuous lenses mark the unconformity between volcanic rocks of the Conejos Formation and the overlying basalts of the Hinsdale Formation

Intrusive rocks

Tdbh — **Biotite-hornblende dacite porphyry (Oligocene)**—Northeast-trending dikes and small stocks of coarsely porphyritic dacite. Phenocrysts consist of plagioclase, sanidine (as much as several centimeters long), biotite, hornblende, iron-titanium oxides, and minor quartz and resorbed oligoclase xenocrysts. Southernmost stock (2 km northeast of Kings Turquoise Mines) hosts extensive quartz-alunite alteration. Potassium-argon ages on unaltered dike northeast of alunite locale range from 26.0 to 28.9 Ma (Bartlett, 1984).

Tdb — **Biotite dacite porphyry (Oligocene)**—Dikes and small stocks of porphyritic dacite. Phenocrysts of plagioclase, biotite, iron-titanium oxides, in some places clinopyroxene, and minor sanidine and hornblende. Confined to Fairy Hills and Brownie Hills area. Potassium-argon age of 29.1 Ma (Bartlett, 1984)

Tdu — **Dacite porphyry, undivided (Oligocene)**—Dikes of porphyritic dacite. Includes units Tdbh and Tdb. Phenocrysts of plagioclase, biotite, iron-titanium oxides, in places clinopyroxene, hornblende, and sanidine. Present throughout Brownie Hills. Thickness 1–3 m

Tdp — **Andesite porphyry (Oligocene)**—Dikes of sparsely porphyritic to porphyritic andesite commonly containing plagioclase, clinopyroxene, in places olivine; contain plagioclase crystals in which sieved cores are common. At three localities west of the Rio Grande, dikes intrude (1) andesite (Tca) vent complex 3 km west of Lasauses at north end of prominent hills, (2) andesite (Tca) and dacite (Tcl) flows on south side of the mesa Flat Top, and (3) unit Tcl_2 1.7 km south of Lasauses cemetery. Thickness ≤ 1 m

Tiq — **Quartz monzonite (Oligocene)**—Stocks, fine to medium grained, equigranular to slightly porphyritic, and gray to light tan; contains potassium feldspar, plagioclase, quartz, variably altered biotite, iron-titanium oxides, and minor clinopyroxene. Present at several areas as steep-sided stocks along north-trending belt in south-central part of map area. Similarity in mineralogy and composition suggest that the stocks may be connected at depth. Commonly intruded by aplitic dikes <0.5 m wide. Potassium-argon ages from stock at South Piñon Hills range from 28.9 to 29.2 Ma (Burroughs, 1972).

Tid — **Diorite (Oligocene)**—Stock, medium grained, equigranular, and grey; contains plagioclase, clinopyroxene, olivine, and iron-titanium oxides. Olivine variably altered to iddingsite. Forms small stock on southeast side of South Piñon Hills. Isolated occurrence suggests unit is a satellitic intrusion from the main intrusive body of unit Tiq

Early extrusive rocks

Conejos Formation (Oligocene)—Includes mafic to intermediate-composition vent facies rocks, consisting of lava flows, flow breccias, explosion breccias, and volcaniclastic rocks, principally mudflow breccias. Divided into an upper sequence (units Tcu_2, Tcu_1, Tcu, Tcum) and a lower sequence (units Tcl, Tcl_3, Tcl_2, Tcl_1, Tclm, Tclv, Tca) on the basis of observed stratigraphy and variations in flow morphology and mineralogy. Thickness varies considerably throughout San Luis Hills; maximum exposed thickness of 250 m on east side of Flat Top, base not exposed. Potassium-argon ages on intrusive quartz monozonite (Tiq) provide a minimum age for overlying volcanic rocks of approximately 29 Ma

Upper sequence

Tcu_2 — **Upper dacite**—Gray, sparsely porphyritic lava flows containing plagioclase, clinopyroxene, iron-titanium oxides, biotite, and minor quartz phenocrysts. Distinguished as separate unit only at Music Mesa. Minor occurrences interfinger with andesite flows near southern extent of unit Tcu

Tcu_1 — **Upper andesite**—Dark-brown to brownish-gray, moderately porphyritic andesite flows and flow breccias containing plagioclase, clinopyroxene, iron-titanium oxides, and, in places, olivine and biotite phenocrysts

Tcu — **Upper andesite, undivided**—Dark-brown to reddish-brown, moderately porphyritic andesite flows and flow breccias containing plagioclase, clinopyroxene, iron-titanium oxides, and, in places, minor olivine phenocrysts. Plagioclase crystals commonly have sieved cores and resorbed rims. Forms subdued rounded hills in northeastern part of map area. Flows thicken and become more abundant to the west. Maximum observed thickness 170 m

Tcum — **Upper mudflows**—Light-gray to tan volcaniclastic mudflows and debris flows composed of matrix-supported clasts predominantly of unit Tcu. Occurs only in northeastern part of map area

Lower sequence

Tclm — **Lower mudflow**—Monolithologic dacite mudflow, confined to base of section at Piñon Hills. Contains clasts (<1 cm–>2 m) of coarsely porphyritic dacite vitrophyre containing phenocrysts of plagioclase, biotite, minor sanidine, and iron-titanium oxides. Moderately well developed columnar cooling joints common. Maximum exposed thickness 60 m at south end of John James Canyon

Tcl_3 — **Upper part**—Gray to light-gray, moderately to coarsely porphyritic, massive dacite flows containing plagioclase, variably altered biotite, clinopyroxene, and euhedral iron-titanium oxides in glassy to pilotaxitic groundmass. Glomerocrysts of plagioclase, clinopyroxene, and iron-titanium oxides, and, in places, biotite is common. Similar in field appearance to unit Tcl_2 but distinguished by lack of hornblende and field relationships that suggest flows resulted from a discrete volcanic event. At north end of Brownie Hills, flows traversed more than 50 m of erosional relief

Tcl_2 — **Middle part**—Gray to light-gray, moderately porphyritic, massive dacite flows containing plagioclase, variably altered clinopyroxene and biotite, hornblende, and iron-titanium oxides in a felty to pilotaxitic groundmass. Glomerocrysts of plagioclase, hornblende, clinopyroxene, and iron-titanium oxides common

Tcl_1 — **Lower part**—Gray to brown, sparsely porphyritic, thin andesitic to dacitic flows, flow breccias, and intercalated volcaniclastic deposits. Contains euhedral plagioclase, altered biotite, iron-titanium oxides, and, in places, clinopyroxene phenocrysts. Breccias and volcaniclastic debris are subordinate in upper part of unit

Tcl — **Lower dacite, undifferentiated**—Moderately to coarsely porphyritic dacite flows and lava domes containing plagioclase, variably altered biotite, clinopyroxene, minor orthopyroxene, in places hornblende, and iron-titanium oxides phenocrysts. Includes all dacite occurrences west of the Rio Grande. Correlation with units Tcl_3 and Tcl_2 based on petrographic and chemical similarity and on stratigraphic relationship to unit Tca observed at Flat Top

Tclv — **Volcaniclastic deposits**—Local accumulations of volcaniclastic debris intercalated with flows of units Tcl_1 and Tcl_2. Principally composed of andesite to dacite clasts in matrix-supported mudflows; breccias predominate in upper part of section. Mapped as a separate unit only in the Fairy Hills and western Brownie Hills. Corresponds to unit Tllv of Bartlett (1984)

Tca — **Lower andesite**—Moderately to sparsely porphyritic andesite containing plagioclase, olivine, and clinopyroxene phenocrysts; plagioclase xenocrysts with sieved cores are common. Includes flows and breccias, the latter being predominant. Near-vent accumulations of steeply dipping (as much as 25°) spatter agglutinate and explosion breccias occur 2 km west and 1.8 km east of Lasauses. Primary dips and indications of bedding become less pervasive away from vent complexes, and the proportion of flow to breccia material increases. Maximum thickness 250 m, base covered

Contact—Dashed where approximately located, dotted where concealed

Fault—Ball and bar on downthrown side; dashed where approximately located; dotted where concealed beneath younger deposits (some small deposits unmapped). Number indicates amount of surface offset, in meters

Strike and dip of beds

Strike and dip of flow foliation

Trend and slope of geomorphic surface, in degrees

Soil exposure—Indicates good exposures of calcic soils on relict surface of unit Qao (southeast one-quarter of map area)

Fluvial scarp—Formed on alluvial units Qay, Qay_1, Qay_2, Qam, Qam_1, and Qam_2. Locally subdivides units into two terrace subunits. Hachures on downslope side

Landslide escarpment—Prominent vertical escarpment either at the headwall of large landslide or within the landslide mass. Hachures on downdropped side

Dike—Showing map unit; dotted where concealed

Interflow marker bed—Prominent to discontinuous lenses of eolian sediments separating major packages of basalt flows

Collapse feature in Servilleta Formation

Known volcanic vent location

Horizontal basalt flow of Hinsdale Formation

Generalized location of extensive hydrothermal alteration

25.7 [8] **Locality of sample for potassium-argon age determination**—Unbracketed number is potassium-argon age; bracketed number is map number in table 1

GEOLOGIC AND TECTONIC HISTORY OF THE SAN LUIS HILLS AND SURROUNDING AREA

MESITA FAULT

The Mesita fault is a major down-to-the-west fault that records demonstrable movement in Pliocene(?) to upper Quaternary deposits and is the only exposed major fault that has moved during the latest Quaternary (past 25,000 yrs) in the vicinity of the San Luis Hills. The fault is marked by scarps ranging in height from less than 1.5 m on latest Pleistocene alluvium (unit Qay) to scarps as high as 8 m on the broad piedmont that surrounds Mesita Hill, in the east-central part of the map area. The fault cuts the western flank of the cone and displaces local basalt flows (unit Tx) 8–10 m. These flows are undated, but probably are coeval with basalt of the Servilleta Formation (unit Ts) to the southwest and north. If unit Tx is Pliocene, as suspected, then the fault seems to have had an accelerated rate of slip in the middle and late Quaternary. The decreasing offset recorded by progressively younger deposits along the fault demands a history of repeated movement on the fault. The morphology of scarps on the youngest faulted alluvium (unit Qay, upper Pleistocene) suggests that the fault was most recently active in the latest Pleistocene (this data revises an estimate of late Pleistocene by Personius and Machette, 1984). The broad undisturbed flood-plain deposits along Costilla Creek (units Qfp, Qfpo, and locally Qay) suggest that the fault has not been active in the Holocene (past 10,000 yrs).

GEOLOGIC HISTORY

The San Luis Hills are the surface expression of a major intrarift horst within the central depression of the San Luis Valley part of the northern Rio Grande rift. For most of its length, the horst is confined to the subsurface (Kleinkopf and others, 1970); two additional surface exposures are at Brushy Mountain and a locality 10 km to the south in northern New Mexico (Thompson and others, 1986). At all three localites exposures are formed entirely of middle Tertiary volcanic rocks. The San Luis Hills are bounded by undissected basin-fill sediments of the San Luis Valley that terminate to the east at a major bounding fault system along the west side of the Sangre de Cristo Mountains (Cordell, 1978; Personius and Machette, 1984) and to the west through intersection with eastward-dipping middle-Tertiary volcanic and sedimentary rocks of the San Juan Mountains.

The oldest volcanic rocks exposed in the San Luis Hills correlate with the intermediate-composition Oligocene lavas and breccias of the Conejos Formation in the San Juan Mountains and Tusas Mountains to the west and southwest, respectively, despite a 1 m.y. younger age for them than reported for the 30 Ma uppermost Conejos Formation (Lipman and others, 1970). In addition, coeval intermediate-composition volcanic and volcaniclastic rocks in the Sangre de Cristo Mountains to the east and southeast (Lipman and others, 1986), although not specifically designated as Conejos Formation, are an extension of pre-rift volcanism believed to be part of a once nearly continuous volcanic field extending over much of the southern Rocky Mountains in Oligocene time (Steven, 1975). These volcanic rocks were deposited on the post-Laramide erosional surface of the Uncompahgre Arch. Basement rock is not exposed in the San Luis Hills, but Precambrian crystalline rocks have been found at a depth of 1,675 m (Tweto, 1979) in a subsurface section of the horst 50 km north of the map area. Precambrian crystalline basement is exposed in the southeastern San Juan Mountains (Lipman, 1975) and extensively in the Tusas Mountains to the southwest. To the east, mid-Tertiary volcanic rocks are underlain by extensive Precambrian crystalline rocks which have been elevated as much as 2 km above the San Luis Valley floor (Lipman and others, 1986).

Whereas intermediate-composition volcanism in the San Juan Mountains and the Sangre de Cristo Mountains was followed by major silicic ash-flow eruptions, no such history is recorded in the San Luis Hills. Andesitic to dacitic eruptions appear to have been followed closely in time by subvolcanic intrusions of cogenetic plutons (table 1). Emplacement of quartz monzonite plutons and diorite stocks was accompanied by dike-swarm intrusions offset from the main quartz monzonitic intrusions 8 km to the northeast in the Fairy Hills. These shallow intrusions were accompanied by extensive hydrothermal hot springs alteration, but little mineralization of economic value (Bartlett, 1984).

Subsequent uplift and erosion of the volcanic carapace unroofed the intrusive bodies and provided the irregular topography onto which basalts of the Hinsdale Formation were erupted. The 26 Ma age reported for three basaltic units (Thb, Thp, and Tht) corresponds to the oldest ages for basalts of the Hinsdale Formation in the San Juan Mountains (Lipman and Mehnert, 1975). Although basalts of the Hinsdale Formation in the San Juan Mountains are intimately associated with alkali rhyolites as a biomodal assemblage, no Hinsdale-age rhyolites are found in the San Luis Hills. Additionally, the San Luis Hills assemblage of basaltic volcanic rocks represents the largest and compositionally most diverse assemblage of basalts in the Hinsdale Formation. The general lack of Los Piños-age (Oligocene) basin-fill sediments beneath or interbedded with basalts of the Hinsdale Formation suggests that the horst may have been a topographic high within the early Rio Grande rift during the Oligocene. Drill-hole data from the subsurface in the rift indicate a thinner sequence of Echo Park Alluvium (Eocene) on the horst than in the downdropped eastern part of the graben (Tweto, 1979). This suggests that the horst may have been structurally as well as topographically high prior to the Oligocene.

After emplacement of the Hinsdale Formation and related eolian units, the area was uplifted to form the San Luis Hills. Subsequent erosion and deposition in the surrounding southern San Luis Basin largely buried the older rocks. Deposition continued to fill the slowly aggrading basin, as evidenced by at least 150 m of intercalated basalts of the Servilleta Formation and sediments that are now exposed in the Taos gorge of the Rio Grande, 50–75 km south of the San Luis Hills. Faunal and floral evidence from the Alamosa Formation of Siebenthal (1910), exposed in Hansen Bluff (Rogers and others, 1985) along the east side of the Rio Grande just north of the map area, suggests that the Rio Grande was still largely aggrading 700,000 yrs ago. The Alamosa Formation probably correlates with the Sierra Ladrones Formation in central New Mexico and the Camp Rice Formation of Strain (1966) in southern New Mexico. In New Mexico, these units are considered be the youngest part of the Santa Fe Group.

This aggradational mode changed during the early(?) middle Pleistocene, and since then it appears that the Rio Grande has been progressively downcutting through and south of the Fairy Hills part of the San Luis Hills. In the southeastern part of the map area, the surficial deposits record at least five successively lower depositional levels of the Rio Grande and major tributary streams. On the basis of similar stratigraphic and geomorphic relations along the Rio Grande to the south, it appears that deposition of the surficial deposits is largely related to changes in climate and in the carrying capacity of streams debouching from adjacent mountain ranges.

West and north of the San Luis Hills, depositional regimes have been much different in the middle and late Quaternary. Streams in this area have been primarily aggrading, so that mainly Holocene and latest Pleistocene alluvium are exposed. The bedrock of the San Luis Hills has been, and continues to be, an effective barrier to headward entrenchment of the Rio Grande and streams of the Conejos River system.

REFERENCES

Aoki, Ken-Ichico, 1967, Petrography and petrochemistry of latest Pliocene olivine-tholeiites of Taos area, northern New Mexico, U.S.A.: Contributions to Mineralogy and Petrology, v. 14, p. 190–203.

Bartlett, R.D., 1984, Geology of an Oligocene-age acid hot spring, San Luis Hills, Conejos and Costilla Counties, Colorado: Colorado State University, M.A. thesis, 111 p.

Burroughs, R.L., 1972, Geology of the San Luis Hills, south-central Colorado: Albuquerque, University of New Mexico, Ph.D. dissertation, 139 p.

Cordell, Lindreth, 1978, Regional geophysical setting of the Rio Grande rift: Geological Society of America Bulletin, v. 89, p. 1073–1090.

Cross, C.W., and Larsen, E.S., 1935, A brief review of the geology of the San Juan region of southwestern Colorado: U.S. Geological Survey Bulletin 843, 138 p.

Gile, L.H., Peterson, F.F., and Grossman, R.B., 1965, The K horizon—Master soil horizon of carbonate accumulation: Soil Science, v. 99, no. 2, p. 74–82.

________1966, Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, no. 5, p. 347–360.

Kleinkopf, D.M., Peterson, D.L., and Johnson, R.B., 1970, Reconnaissance geophysical studiés of the Trinidad quadrangle, south-central Colorado: U.S. Geological Survey Professional Paper 700B, p. B78–B85.

Lipman, P.W., 1975, Evolution of the Platoro caldera complex and related volcanic rocks, southeastern San Juan Mountains, Colorado: U.S. Geological Survey Professional Paper 852, 128 p.

Lipman, P.W., and Mehnert, H.H., 1975, Late Cenozoic basaltic volcanism and development of the Rio Grande depression in the southern Rocky Mountains, *in* Curtis, B.F., ed., Cenozoic history of the Southern Rocky Mountains: Geological Society of America Memoir 144, p. 119–154.

________ 1979, The Taos Plateau volcanic field, northern Rio Grande rift, New Mexico, *in* Riecker, R.E., ed., Rio Grande rift—Tectonics and magmatism: Washington, D.C., American Geophysical Union, p. 289–311.

Lipman, P.W., Mehnert, H.H., and Naeser C.W., 1986, Evolution of the Latir volcanic field, northern New Mexico, and its relation to the Rio Grande rift, as indicated by potassium-argon and fission track dating: Journal of Geophysical Research, v. 91, p. 6329–6345.

Lipman, P.W., Steven, T.A., and Mehnert, H.H., 1970, Volcanic history of the San Juan Mountains, Colorado, as indicated by potassium-argon dating: Geological Society of America Bulletin, v. 81, p. 2329–2352.

Machette, M.N., 1985, Calcic soils of the southwestern United States, *in* Weide, D.L., ed., Soils and Quaternary geology of the southwestern United States: Geological Society of America Special Paper 203, p. 1–21.

Ozima, Minoru, Kono, M., Kaneoka, I., Kinoshita, H., Kobayashi, Kazuo, Nagata, Tokesi, Larsen, E.E., and Strangeway, D.W., 1967, Paleomagnetism and potassium-argon ages of some volcanic rocks from the Rio Grande gorge, New Mexico: Journal of Geophysical Research, v. 72, no. 10, p. 2615–2622.

Personius, S.F., and Machette, M.N., 1984, Quaternary and Pliocene faulting in the Taos Plateau region, northern New Mexico, *in* Baldridge, W.S., Dickerson, P.W., Riecker, R. E., and Zidek, Jiri, eds., Rio Grande rift—northern New Mexico: New Mexico Geological Society Guidebook, 35th Field Conference, p. 83–90.

Rogers, K.L, Reppening, C.A., Forester, R.M., Larson, E.E., Hall, S.A., Smith, G.R., Anderson, Elaine, and Brown, T.J., 1985, Middle Pleistocene (late Irvingtonian—Nebraskan) climatic changes in south-central Colorado: National Geographic Research, v. 1, no. 4, p. 535–563.

Siebenthal, C.E., 1910, Geology and water resources of the San Luis Valley, Colorado: U.S. Geological Survey Water-Supply Paper 240, 128 p.

Steven, T.A., 1975, Middle Tertiary volcanic field in the southern Rocky Mountains, *in* Curtis, B.F., ed., Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir, 144, p. 75–94.

Strain, W.S., 1966, Blancan mammalian fauna and Pleistocene formation, Hudspeth County, Texas: University of Texas at Austin, Texas Memorial Museum Bulletin 10, 55 p.

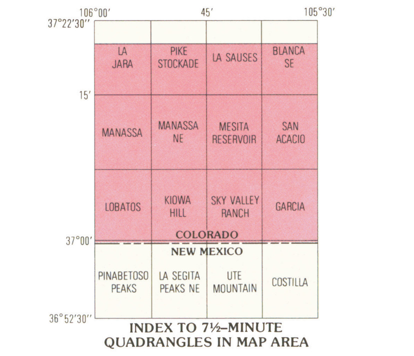
Thompson, R.A., Dungan, M.A., and Lipman, P.W., 1986, Multiple differentiation processes in early-rift calc-alkaline volcanics, northern Rio Grande rift, New Mexico: Journal of Geophysical Research, v. 91, p. 6046–6058.

Tweto, Ogden, 1979, The Rio Grande rift system in Colorado, *in* Riecker, R.E., ed., Rio Grande rift—Tectonics and magmatism: Washington, D.C., American Geophysical Union, p. 33–56.

Yenter, J.M., Schmitt, G.J., Johnson, W.W., Jr., and Mayhugh, R.E., 1980, Soil survey of Conejos County area, Colorado: U.S. Soil Conservation Service in cooperation with the Colorado Agricultural Experiment Station, 144 p., and 17 maps at 1:24,000 scale.

Table 1.—*Age determinations of volcanic and intrusive rocks in the map area*

Map no.	Type of determination and material dated	Age (Ma)	Map unit and sample locality	Rock type	Reference	Sample no.
1	K-Ar (biotite).	29.2±0.6	Tiq, stock of South Piñon Hills.	Quartz monzonite	Burroughs (1972)	KA 71–52.
	K-Ar (biotite).	28.9±0.6	--do------------	--do--------	--do----------------	--do-----.
2	K-Ar (biotite).	29.1±1.8	Tdb, stock in Fairy Hills.	Dacite	Bartlett (1984)	SP–11–2.
	Fission track (sphene).	30.9±2.4	--do------------	--do--------	--do----------------	--do-----.
	Fission track (zircon).	28.4±1.5	--do------------	--do--------	--do----------------	--do-----.
3	K-Ar (hornblende).	28.9±1.5	Tdbh, dike in Fairy Hills.	--do--------	--do----------------	SP–11–8.
	K-Ar (biotite).	26.0±2.7	--do------------	--do--------	--do----------------	--do-----.
	Fission track (zircon).	25.6±1.5	--do------------	--do--------	--do----------------	--do-----.
	Fission track (sphene).	25.3±3.2	--do------------	--do--------	--do----------------	--do-----.
4	K-Ar (alunite).	25.1±1.0	Tcl_1 (outcrop too small to show at map scale).	Quartz-Alunite replacement vein.	--do----------------	SP–231.
5	K-Ar (whole rock).	26.4±1.2	Thb, flow at Flat Top.	Basalt	Thompson and Mehnert (unpub. data, 1986).	T84098.
6	K-Ar (whole rock).	26.1±1.2	--do------------	Andesite	--do----------------	T84150.
7	K-Ar (whole rock).	26.0±1.1	Thp, flow at Piñon Hills.	Basalt	--do----------------	T84163.
8	K-Ar (whole rock).	25.7±1.8	Tht, flow at South Piñon Hills.	--do--------	--do----------------	T84089.
9	K-Ar (whole rock).	4.3±0.8	Ts, block in Qls at San Pedro Mesa.	--do--------	Lipman and others (1986)	77LRG107.



INDEX TO 7½-MINUTE QUADRANGLES IN MAP AREA