GEOLOGIC MAP OF THE LATIR VOLCANIC FIELD AND ADJACENT AREAS, NORTHERN NEW MEXICO

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DESCRIPTION OF MAP UNITS

[Ages for Tertiary igneous rocks are based on potassium-argon (K-Ar) and fission-track (F-T) determinations by H. H. Mehnert and C. W. Naeser (Lipman and others, 1986), except where otherwise noted. Dates on Proterozoic igneous rocks are uranium-lead (U-Pb) determinations on zircon by S. A. Bowring (Bowring and others, 1984, and oral commun., 1985). Volcanic and plutonic rock names are in accord with the IUGS classification system, except that a few volcanic names (such as quartz latite) are used as defined by Lipman (1975) following historic regional usage. The Tertiary igneous rocks, other than the peralkaline rhyolites associated with the Questa caldera, constitute a high-K subalkaline suite similar to those of other Tertiary volcanic fields in the southern Rocky Mountains, but the modifiers called for by some classification schemes have been dropped for brevity: thus, a unit is called andesite, rather than alkali andesite or high-K andesite. Because many units were mapped on the basis of compositional affinities, map symbols were selected to emphasize composition more than geographic identifier: thus, all andesite symbols start with Ta; all quartz latites with Tq, and so forth.]

SURFICIAL DEPOSITS

ds **Mine dumps (Holocene)**—In and adjacent to the inactive open pit operation of Union Molycorp. Consist of angular blocks and finer debris, mainly from the Sulphur Gulch pluton

Qal **Alluvium (Holocene)**—Silt, sand, gravel, and peaty material in valley bottoms. Locally includes small alluvial-fan and colluvial deposits **(Qf, Qc)** at margins of valley bottoms

Qc **Colluvium (Holocene)**—Poorly sorted silt- to boulder-sized material on slopes and in steep valleys. Locally includes small alluvial-fan, talus, landslide, and glacial-moraine deposits

Qf **Alluvial fan (Holocene)**—Unweathered gravel, sand, and silt in undeformed and little-dissected fans. Locally contain moderately rounded to well-rounded boulders. Mainly along mountain fronts

Qt **Talus (Holocene)**—Angular rock fragments as much as 1 m in diameter forming talus cones, talus aprons and scree slopes. Locally well sorted. Grades into colluvium **(Qc)** as sand and silt content increases

Qr **Rock glacier (Holocene)**—Lobate deposits of angular rock fragments, generally lacking fine-grained material on the upper surface. Locally includes protalus ramparts, block fields, and neoglacial moraines

Ql **Landslide deposits (Holocene and Pleistocene)**—Lobate accumulations of poorly sorted soil and rock debris on slopes marked by hummocky topography and downslope-facing scarps. Derived from bedrock and glacial deposits. Includes small earthflow, block-slump, and block-slide deposits; also, active landslides in glacial till east of Twinning. Locally intergrades with Quaternary block-slump features (indicated by hachured line)

Qfo **Older alluvial fan (Pleistocene)**—Dissected and partly weathered; commonly partly mantled by residual soils. Consists mainly of glacial outwash from Proterozoic source areas; deposited within present drainages and along range front. Locally deformed and faulted. Locally, map unit may include some conglomeratic units of the Santa Fe Group **(Tsc)**. Exposed thickness as much as 200 m

Qm **Moraine and till (Pleistocene)**—Terminal and lateral moraines, and thick valley-bottom till. Poorly sorted and generally unstratified clay, silt, and sand containing erratic boulders; characterized by hummocky or ridgey topography. Some till has been mapped with colluvium **(Qc)**

Qmo **Older moraine(?) (Pleistocene)**—Patches of poorly sorted silt and sand, containing erratic boulders as much as 2 m in diameter. On ridges southwest of Comanche Point at altitudes 50-75 m above present drainage

PLIOCENE AND MIOCENE ROCKS ASSOCIATED WITH THE RIO GRANDE RIFT

Tbs **Servilleta Basalt (Pliocene**)—Thin dark-gray pahoehoe flows of diktytaxitic olivine tholeiite (49–52 percent SiO_2). As many as 6 flows present on San Pedro Mesa northwest of Amalia. Dominant basalt type of the Taos Plateau volcanic field (Dungan and others, 1984). Best exposed in the Rio Grande Gorge, several kilometers west of map area. Age 3.6–4.5 Ma (Ozima and others, 1967; Lipman and Mehnert, 1975). Thickness 0–50 m

Td **Dacites of Guadaloupe Mountain and Cerro Negro (Pliocene)**—Dark-gray nearly aphyric rhyodacite (62–64 percent SiO_2). Erupted from two volcanoes along west margin of the map area. Age 4.6 Ma (Lipman and Mehnert, 1979)

Santa Fe Group (Pliocene and Miocene)—Tan to brown weakly indurated graben-fill sedimentary rocks. Tilted and deformed by regional extensional faults of the Rio Grande rift; largely unrelated to present drainage basins. Map unit locally includes some older alluvial-fan deposits **(Qfo)**

Ts **Fine-grained facies**—Silt and fine sand derived from Proterozoic sources. More extensive than indicated by mapped distribution, but obscured on most slopes by cobbly debris from intertongued conglomeratic facies

Tsc **Conglomeratic facies**—Conglomerates containing mainly clasts of Proterozoic rocks. White quartzite cobbles are conspicuous; boulders of granite and granitic gneiss are locally as much as 1 m in diameter. Grades into fanglomerate adjacent to fault scarps, especially in Comanche Point quadrangle. Thickness 0–300 m, variable due to deposition on irregular underlying faulted surfaces

Tsv **Volcaniclastic facies**—Conglomerates containing mainly clasts of Miocene volcanic rocks. Boulders of gray porphyritic quartz latite are abundant; in northwestern part of map area, contains fragments of Amalia Tuff **(Trt)** and associated rhyolitic lava **(Tr)**. Locally well indurated where weakly hydrothermally altered in association with potassium metasomatism. Thickness 0–100 m

Trg **Rhyolite of Gonzales Ranch (Miocene)**—Lava dome of light-gray, low-silica rhyolite (70–72 percent SiO_2), containing 10–20 percent small phenocrysts of plagioclase, sanidine, biotite, and hornblende. Commonly gray and massive due to vapor-phase crystallization; locally faintly flow layered. Erupted from vent near major buried fault at west flank of Costilla Mountains. Vent area marked by chaotic breccias, containing sparse fragments of Proterozoic rocks. Preferred K-Ar age of 10–12 Ma indicates emplacement concurrently with older volcanic rocks on Taos Plateau within Rio Grande rift to west

Miocene basalt flows—Flows from several centers in northern part of map area

Tb **Silicic-alkalic basalt and basaltic andesite**—Dark-gray flows (50–55 percent SiO_2) that are the dominant young basalt type within the mountainous areas; contain a few percent olivine phenocrysts. Locally intermixed with xenocrystic basaltic andesite **(Tbx)**. Along Costilla Creek about 5 km southeast of Amalia, four of these flows **(Tb_1–Tb_4)** intertongue with conglomeratic facies of the Santa Fe Group **(Tsc)** on flanks of a small shield volcano that is marked by agglutinated spatter and scoria. Individual flows are as thick as 20 m. Sequence is as thick as 150 m in upper Costilla Valley, where 8–10 flows are present. Whole-rock K-Ar dates at Costilla and Amalia localities are 15–16 Ma

Tbb **Basanitic basalt**—Dark-greenish-gray alkalic basalt flow (45 percent SiO_2) near Amalia. Characterized by crumbly spheroidal weathering and by ellipsoidal segregations of fine-grained leucocratic minerals 1–2 cm across (ocelli). Whole-rock K-Ar date is 16 Ma.

Tbx **Xenocrystic basaltic andesite**—Dark-gray flow containing sparse resorbed xenocrysts of quartz and plagioclase; Powderhouse Canyon area

Tbm **Basaltic mixed lavas**—Dark-gray hornblende- and olivine-bearing lava flows characterized by variable textures and compositions indicative of magma mixing. In places, dark-gray sparsely porphyritic clots or rounded inclusions of basaltic material are surrounded by light-gray to tan silicic matrix containing plagioclase and biotite phenocrysts. Recognized only on ridge crests east and west of Ballejas Creek. Whole-rock K-Ar age is 15 Ma

ROCKS OF THE QUESTA MAGMATIC SYSTEM
(MIOCENE AND OLIGOCENE)

Fine-grained intrusions—Dikes, sills, laccoliths, and irregular porphyritic intrusions associated with the composite granitic batholith that accumulated beneath the Questa caldera and adjacent areas to the south during Latir volcanism (Lipman, 1983). Trends of many poorly exposed dikes inferred by analogy with nearby better exposed dikes

Trp **Porphyritic rhyolite**—Light-tan to light-gray porphyritic rhyolite (74–77 percent SiO_2), typically containing 5–20 percent phenocrysts of quartz, sanidine, and sparse plagioclase and biotite. Occurs as dikes 1–10 m wide and local more irregular intrusions. Constitutes dominant dike type in the major northwest-trending swarm along crest of the Rio Hondo granodiorite pluton and also in the east-west swarm along the Red River, generally following the south margin of the Questa caldera. Many large masses of mapped porphyritic rhyolite in these areas constitute coalesced aggregates of dikes in which intervening country rocks are absent, poorly exposed, or too small to show at map scale. A large mass of porphyritic rhyolite along the east side of the Red River intrusive cluster, between the forks of upper Mallette Creek, consists of a single sparsely porphyritic intrusion transitional between porphyritic rhyolite and aplite. Some other large bodies mapped as porphyritic rhyolite in lower Mallette Creek and south of the Red River are transitional into porphyritic granite.

Trpx **Coarsely porphyritic rhyolite**—Dikes and small irregular intrusions of silicic rhyolite containing phenocrysts of quartz and alkali feldspar as much as 2 cm in diameter. Occurs mainly within and adjacent to the Red River intrusive cluster

Tri **Rhyolite**—Aphanitic to sparsely porphyritic rhyolite (76–77 percent SiO_2) containing less than 5 percent phenocrysts. Distribution and structural relations generally similar to those of intrusive rhyolite porphyry **(Trp)**

Trpp **Peralkaline rhyolite**—Dikes and irregular intrusions of alkali rhyolite and granite porphyry (76–77 percent SiO_2) chemically similar to the Amalia Tuff **(Trp)** and associated caldera-related rhyolitic lava flows **(Tr)**. Contains 1–25 percent phenocrysts of quartz and sodic alkali feldspar. Locally contains small phenocrysts of arfvedsonite and acmite, especially in the caldera-margin ring dike along Jaracito Canyon and in the Virgin Canyon-Virsylvia Peak area, where the peralkaline rhyolite forms marginal facies of metaluminous biotite-bearing intrusions of granite porphyry within the caldera (section *B*–*B′*). Some peralkaline intrusions may have been mapped with intrusive rhyolite or porphyritic rhyolite **(Trp, Tri)**, but all identified peralkaline rhyolite is confined to the interior of the caldera. Dated by K-Ar and F-T methods at about 26 MA

Trr **Rhyolite of Relica Peak**—Light-tan high-silica rhyolite (75–76 percent SiO_2) forming a large irregular laccolith or plug in upper Red River. Contains 1–3 percent small phenocrysts of sanidine, quartz, and biotite. Locally characterized by faintly developed flow layering, which is parallel to more easily discernable closely spaced joints that dip steeply

Tqi **Quartz latite**—Gray to greenish-gray porphyritic quartz latite (63–66 percent SiO_2) containing 15–30 percent phenocrysts of plagioclase, biotite, augite, and (or) hornblende (generally altered), and local sparse quartz and sanidine. Commonly contains chlorite, epidote, and calcite as alteration minerals; is associated with propylitic alteration. Occurs generally as dikes 2–25 m wide and constitutes the dominant dike type in the southern and eastern parts of the map area away from intense swarms of rhyolite porphyry and rhyolite dikes. Large irregular laccolithic masses of intrusive quartz latite south and east of the town of Red River occur near the Proterozoic-Tertiary contact; additional structural control in this area is by northwest-trending graben faults; these intrusions were previously mapped mainly as lava flows (Clark and Read, 1972). Some intrusive quartz latite is difficult to distinguish from petrologically similar extrusive rocks, especially where extrusive quartz latite occurs as megabreccia clasts within the Questa caldera. Criteria for intrusive origin, in addition to locally exposed contact relations, are lack of flow breccia, flow layering, and other textural features that characterize eruptive Latir Peak Quartz Latite **(Tq)**. Northeast of the town of Red River, some intrusive quartz latite is texturally transitional toward porphyritic granodiorite **(Tgd)**, similar to that in the Rio Hondo pluton

Tqk **Potassium-feldspar quartz latite**—Coarsely porphyritic light-gray quartz latite (67–70 percent SiO_2), containing K-feldspar phenocrysts as long as 5 cm. Occurs mainly as large dikes 5–25 m thick

Tai **Andesite**—Small dikes of fine-grained dark-gray andesite and some basalt (49–61 percent SiO_2). In places, contains small phenocrysts of plagioclase and altered mafic minerals. Mostly occurs as dikes 1–2 m wide within and adjacent to the Rio Hondo pluton. A sill of olivine-bearing basaltic andesite, as thick as 200 m, is semiconformable within a sequence of volcanic mudflows for about 8 km along upper Costilla Creek; the tuff of Tetilla Peak **(Tt)** is baked along the intrusive upper contact of the sill at the northern end of the map area. Poorly exposed vesicular upper parts of the body further downstream may represent portions that reached the surface

Tapi **Porphyritic andesite and some dacite**—Intrusive dark-gray porphyritic rocks (56–65 percent SiO_2) of diverse mineralogy and texture. Mostly occurs as small dikes and sills, but includes a few large bodies. A semiconcordant body of hornblende andesite is intrusive into the steeply dipping volcanic sequence along Lemos Creek. Distinctive porphyritic andesite containing 5-mm phenocrysts of hornblende and plagioclase forms irregular bodies near the base of the volcanic section in lower Cabresto Creek. Small east-trending dikes of porphyritic andesite, containing 10–20 percent small tabular phenocrysts of plagioclase, are especially common along the south margin of the Questa caldera east of the Sulphur Gulch pluton

Granitic rocks—Compositionally diverse phases of a composite batholith emplaced at shallow depth in the Questa area during volcanism and caldera formation

Tgy **Younger granite and aplite (Miocene)**—Medium- to fine-grained biotite granite, locally grading into large masses of aplite and aplite porphyry. Typically massive and structureless; SiO_2 commonly 76–77 percent. The granitic rocks comprise several compositionally and texturally diverse plutons, emplaced at 22–23 Ma as indicated by K-Ar and F-T dating

Granites of the Bear Canyon and Sulphur Gulch plutons and the Red River intrusive cluster are fine grained, contain large masses of intergradational aplite, and are associated with intense pyritic, argillic, and potassic alteration. Granite of the Red River cluster locally grades into porphyritic rhyolite **(Trp)**. Each pluton hosts major economic and subeconomic molybdenum mineralization along its contacts. These three bodies occur along the southeast margin of the Questa caldera, are probably interconnected at shallow depth, and are interpreted as high points on an irregular ring intrusion (section *C–C′*)

The Lucero Peak pluton, in southern parts of map area, consists of medium- to coarse-grained equigranular granite characterized by rounded quartz grains resembling resorbed phenocrysts. The main body is unaltered massive rock, but an eastern area in the South Fork of Rio Hondo is cut by dikes and hosts Mo mineralization (Ludington, 1981; Jones and Norris, 1984)

Tg **Older biotite granite (Oligocene)** —Emplaced in the Questa area at about 26 Ma, during volcanism and caldera formation

Granitic roof phases of the Rio Hondo pluton (74–76 percent SiO_2) are medium grained, equigranular, and contain only sparse aplite; hornblende is absent. The granitic roof rocks grade irregularly downward into granodiorite. Locally intense pyritic alteration is associated with the roof zone in Manzanita and Yerba Canyons

Granite of the Rito del Medio pluton is distinctive light-colored medium-to coarse-grained rock (76 percent SiO_2) characterized by miarolitic cavities and magmatic white mica. This granite and intergradational granite porphyry of Canada Pinabete and Virgin Canyon plutons are interpreted as a resurgent pluton in the core of the Questa caldera (section *F–F′*)

Granite of the Cabresto Lake pluton (71–73 percent SiO_2) is equigranular and contains sparse hornblende in addition to biotite; it is compositionally intermediate between the contemporaneous Rito del Medio pluton to the north and the Rio Hondo batholith south of the Questa caldera. Aplite is abundant in an eastern outlier of the Cabresto Lake pluton, west of the mouth of Italian Canyon. The Cabresto Lake and associated bodies occur within a structurally uplifted mass of Proterozoic rocks. These resurgent granites are not associated with major alteration or mineralization at presently exposed levels

Tgp **Granite porphyry (Oligocene)—**Fine-grained porphyritic biotite granite and aplite, texturally transitional between mapped bodies of granite **(Tg)** and intrusive porphyritic rhyolite **(Trp)** or rhyolite **(Tri)**, especially in the Rito del Medio and Canada Pinabete areas

Tp **Granitic pegmatite (Oligocene)—**Local pods of coarsely intergrown quartz and feldspar near roof zones of Tertiary granitic intrusions. Mapped separately only in Proterozoic roof rocks of Rito del Medio pluton; similar pegmatite occurs locally within granitic roof phases of Rio Hondo pluton. Distinguished from Proterozoic pegmatite by absence of coarse muscovite

Tgd **Granodiorite and granite (Oligocene)**—Medium-grained porphyritic biotite-hornblende granodiorite of the Rio Hondo pluton, widely characterized by orthoclase phenocrysts as much as 5 cm across. SiO_2 is 62–70 percent; accessory sphene is conspicuous. Generally massive; obscure foliation, rounded mafic inclusions, and mafic schlieren are discernable locally. Contact relations indicate that exposed areas of granodiorite represent the southern roof zone of a batholith at least 15 × 30 km in plan dimensions and elongate northwest-southeast (Lipman, 1983). Batholith roof dips gently over large area; steeply-dipping linear contact on the northeast side is probably fault controlled (section *D–D′*). In tributaries of Rio Hondo and over large area to the north in Columbine Creek, granodiorite locally grades irregularly upward into lighter-colored nonporphyritic granite near the roof. Multiple K-Ar, F-T, and Rb-Sr determinations indicate emplacement at about 26 Ma; dates variably reset by younger intrusions at 22–23 Ma

Tm **Monzonite (Oligocene)**—Fine-grained equigranular intrusive rocks (64–66 percent SiO_2), which are poorly exposed within and adjacent to more silicic rocks of the Red River intrusive complex. Consist of feldspar, augite, and sparse biotite, all variably propylitically altered. May represent intrusive core of precaldera intermediate-composition stratocones, partly truncated by more silicic caldera-related intrusions

Tr **Rhyolitic lava flows (Oligocene)—**Light-gray to buff flow-laminated alkali rhyolite (77 percent SiO_2) containing 5–10 percent phenocrysts of quartz and alkali feldspar. Similar in composition to the Amalia Tuff **(Trt)** and the peralkaline rhyolitic intrusions **(Trpp)** within the Questa caldera. Overlies Amalia Tuff locally in northeastern part of map area; in places, grades downward into the Amalia ash-flow tuff and represents rheomorphic flow of densely welded tuff. Small erosional remnants of petrologically similar rhyolite, which cap hills in the upper Red River area, are tentatively considered correlative. Boulders of similar rhyolite are common in volcaniclastic facies of the Santa Fe Group north of the Questa caldera, indicating that such rhyolite flows were formerly more extensive

Amalia Tuff (Oligocene)—Single cooling unit of alkali rhyolite ash-flow tuff erupted from the Questa caldera (Lipman, 1983)

Trt **Main unit**—Weakly to densely welded silicic alkalic ash-flow tuff, containing 10–20 percent phenocrysts of quartz and alkali feldspar (transitional sanidine-anorthoclase). Rare vitrophyric basal tuff contains sparse ferrohedenbergite and fayalite; sodic amphibole phenocrysts are locally preserved in upper part of tuff. SiO_2 contents of devitrified rocks are 77–80 percent, indicating some secondary silicification. Occurs as erosional remnants of regional ash-flow sheet 20–50 m thick, especially in northern part of map area, and as masses of welded tuff ponded within the Questa caldera to a thickness of 1–2 km or more. Lenticular masses of older volcanic rocks, as much as 1 km across and enclosed by intracaldera Amalia Tuff (section *C–C′*), are interpreted as caldera-collapse megabreccia. Radiometric dates are variable, 23–26 Ma (K-Ar feldspar); only older dates are considered reliable, and unit is no longer considered partly Miocene

Trtl **Lithic-rich lower facies**—Nonwelded to partly welded tuff up to 30 m thick, containing as much as 5 percent fragments of andesitic volcanic rocks; sparse fragments of Proterozoic rocks present locally. Generally grades upward into main unit, which is characterized by lower lithic content and greater degree of welding. In places, difficult to distinguish from older tuff of Tetilla Peak **(Tt)**

PRECALDERA VOLCANIC ROCKS (OLIGOCENE)

[Described in general stratigraphic sequence as exposed north of the Questa caldera. Andesitic rocks are subdivided north of the caldera and locally elsewhere]

Tvs **Volcanic sedimentary rocks**—Relatively well-bedded and well-sorted volcanic sedimentary rocks of andesitic to rhyolitic composition at many levels in the volcanic sequence, especially in the northern and northeastern areas; dominantly fluviatile and deltaic deposits. These rocks commonly directly overlie the prevolcanic sedimentary rocks **(Tes)**, but generally similar fine-grained fluviatile volcaniclastic rocks also interfinger with andesitic lava flows **(Ta)**. The volcanic sedimentary rocks are locally tuffaceous and interfinger and intergrade in places with the tuff of Tetilla Peak **(Tt)**; also included are local air-fall and reworked silicic tuff underlying the Amalia Tuff **(Trt)**. In comparison with the andesitic sediments **(Tac)**, mudflow deposits are sparse, and more silicic sources—including rhyolite—are represented. Exposed thickness nowhere more than about 50 m

Tc **Comendite of Ortiz Peak**—Thick flows of dark-red-brown to gray porphyritic lava (70–71 percent SiO_2), containing 10–20 percent phenocrysts of alkali feldspar as much as 1 cm across. Groundmass is oxidized; mafic phenocryst phases are altered. Rock is typically massive; boundaries between flows are obscure. Confined to an area about 8 km in diameter, just northeast of the Questa caldera. As thick as 250 m on ridge crests east of Latir Creek

Taf **Alkali andesite and dacite**—Flows of distinctive aphyric dark-gray andesitic-dacitic lava (64–66 percent SiO_2), in northern part of area, containing closely spaced sheet joints that break rock into slabs and prisms 5–10 cm thick. Interiors of thick flows locally characterized by irregular mottled texture and color. More alkalic in chemistry, and transitional toward the comendite of Ortiz Peak (Tc), in comparison with other precaldera andesites of the area 0–75 m thick

Tab **Basaltic andesite**—Dark-gray andesite flows (54–56 percent SiO_2) containing 5–10 percent phenocrysts of altered olivine. Present only in northwestern part of map area; as many as 6 flows in Cedro Canyon. Flow margins are vesicular, locally scoriaceous; vesicles are filled by calcite and other secondary minerals. 0–30 m thick

Tax **Xenocrystic andesite and dacite**—Dark-gray flows (63–64 percent SiO_2) containing a few percent resorbed xenocrysts of quartz and plagioclase. Tops and bottoms of flows are scoriaceous. Most common in northern part of map area; as many as three flows are present north of Lemos Creek. 0–50 m thick

Tap **Pyroxene andesite**—Dark-gray aphyric to finely porphyritic andesite flows (63–64 percent SiO_2); consists largely of augite and plagioclase. Small altered phenocrysts of olivine locally conspicuous. Single flows are as much as 50 m thick; maximum exposed thickness exceeds 300 m

Tah **Hornblende andesite and dacite**—Dark-gray flows and breccias of porphyritic andesite and rhyodacite (59–66 percent SiO_2) containing 5–20 percent phenocrysts of hornblende, plagioclase, and sparse biotite. Thick accumulations are present between Comanche Creek and Cabresto Park, and in the upper Red River drainage; probably more widespread than mapped. K-Ar and F-T dates of two flows are about 27 Ma. Individual flows are more than 100 m thick; maximum thickness is at least 400 m

Ta **Andesitic lava flows, undivided**—Compositionally variable intermediate-composition dark-gray to greenish-gray lava flows, ranging in texture from aphanitic to porphyritic. Some sparsely porphyritic andesite is similar to the pyroxene andesite **(Tap)**. Common porphyritic types include plagioclase andesite, hornblende-plagioclase andesite, and sparsely biotite-bearing silicic andesite or rhyodacite. Biotite is absent or sparse, and phenocrysts are typically smaller than in Latir Peak Quartz Latite **(Tq)**. Silica content 55–66 percent. Much propylitic alteration, especially within and near the Questa caldera. Boundaries between flows commonly obscure due to alteration and poor exposure; flow breccias or volcanic sediments are locally present along contacts. Within the caldera, structure of the andesite is chaotic and flow contacts and attitudes can rarely be determined; much of the intracaldera andesite occurs as megabreccia slide debris derived from the caldera walls. Individual flows are about 10–100 m thick

Tac **Andesitic sedimentary rocks**—Mudflow deposits and interlayered fluviatile andesitic sedimentary rocks, locally interbedded with andesitic flows, especially in the upper Red River and Comanche Creek areas. Mudflow deposits are poorly sorted and crudely stratified volcanic conglomerates, containing clasts as much as 0.5 m in diameter. Volcaniclastic rocks are mostly moderately indurated and green gray, due to propylitic alteration; locally they are reddish brown. Thought to represent alluvial aprons around flanks of andesitic volcanoes, mostly centered in the caldera area. Maximum thickness, interlayered with andesitic flows, may be 300–400 m in the upper Red River area

Latir Peak Quartz Latite—Lava flows and pyroclastic deposits of porphyritic quartz latite (62–66 percent SiO_2)containing 20–35 percent phenocrysts of plagioclase, biotite, augite, hornblende, and local sparse quartz and K-feldspar. Plagioclase phenocrysts larger and more blocky, and biotite more abundant, than in andesitic flows **(Ta)**. Quartz and sanidine phenocrysts sparse or absent and plagioclase phenocrysts more abundant than in rhyolite flows. Essentially the same unit as the Latir Peak Latite of McKinlay (1956)

Tq **Lava flows and domes**—Massive quartz latite, locally flow layered. Commonly gray to greenish gray, especially where propylitically altered in interiors of thick flows; tops of less altered flows are light red brown or light gray. Intrusive quartz latite **(Tqi)** locally is difficult to distinguish from flow rocks. Maximum thickness is at Latir Mesa, where sections through seemingly single flows or domes exceed 500 m

Tqc **Volcaniclastic rocks**—Tuff breccia and flow breccia consisting of angular fragments of quartz latite flow rock in a fragmental matrix. Probably represents marginal breccias of lava flows and local interlensing pyroclastic flows of small volume. Quartz latite pyroclastic-flow deposits occur mostly in the Cordova Creek area. 0–50 m thick

Tt **Tuff of Tetilla Peak**—Quartz-rich light-colored weakly welded rhyolitic ash-flow tuff (73–75 percent SiO_2) containing abundant small volcanic fragments. Phenocryst content 10–30 percent; mainly quartz, sanidine, plagioclase, and sparse chloritized biotite. Lithic fragments mostly andesite and quartz-bearing rhyolite; where the tuff is altered, lithic fragments are main indicator of original pyroclastic character. Unit ranges from light gray to buff in northeastern part of area, to dark-gray dense rocks of obscure texture where baked and otherwise altered by granitic intrusions within the caldera. Tuff of Tetilla Peak is closely associated in areal and stratigraphic position with large rhyolite flow-dome complexes **(Trc)**; the tuff probably represents pyroclastic eruptions associated with emplacement of the rhyolite flows. In places several ash-flow units, each 10–30 m thick, are separated by thin interbeds of rhyolitic ash-fall tuff or reworked tuffaceous sedimentary rocks equivalent to the volcanic sedimentary unit **(Tvs)**. Within the Questa caldera, tuff of Tetilla Peak is locally difficult to distinguish from the lithic-rich lower part of the Amalia Tuff **(Trtl)**. Tuff of Tetilla Peak is as much as 300 m thick; substantial local thickness variations are due to pre-eruption topography and in places to subsequent structural complications

Trc **Rhyolite of Cordova Creek**—Light-tan to light-gray rhyolitic lava flows and domes (74–77 percent SiO_2) containing about 5 percent phenocrysts of quartz, alkali feldspar, plagioclase, and biotite. Commonly massive and devitrified; locally flow laminated. Large domes centered at Cordova Creek, Van Diest Peak, and Italian Creek also appear to be sources for main accumulations of tuff of Tetilla Peak. As thick as 250 m at head of Cordova Creek

Twt **Treasure Mountain(?) Tuff**—Densely welded purplish-brown welded quartz latitic tuff (64 percent SiO_2), exposed locally west of Amalia, containing about 10 percent phenocrysts of plagioclase, biotite, and altered augite. Thickness as much as 30 m, but variable because of relief on prevolcanic surface. Petrographically similar vitrophyric welded tuff 5–10 m thick present locally in upper Costilla valley. Petrology and stratigraphic position suggest correlation with Ra Jadero Member of Treasure Mountain Tuff, erupted at 30 Ma from the Platoro caldera 90 km northwest in the San Juan Mountains of Colorado (Lipman, 1975)

PREVOLCANIC SEDIMENTARY ROCKS
(LOWER OLIGOCENE OR EOCENE)

Tps **Shale, sandstone, and conglomerate**—Discontinuous lenses of weakly indurated sedimentary rocks derived from Proterozoic sources. Commonly expressed mainly by reddish-brown silty soil; cobbles of green quartzite are locally distinctive. Outcrops rare, except where baked near granitic intrusion along the Red River. Indurated Tertiary sedimentary rocks, which have been correlated with Permian and Pennsylvanian Sangre de Cristo Formation (McKinlay, 1956; Clark and Read, 1972), occur only within areas of Tertiary thermal metamorphism and lack limestone interbeds characteristic of the Sangre de Cristo in adjacent areas. Probably correlative with the Vallejo Formation of Upson (1941) in the Sangre de Cristo Mountains in southern Colorado, and with the Blanco Basin Formation and Telluride Conglomerate in the San Juan Mountains. Thickness 0–100 m

SEDIMENTARY ROCKS (PALEOZOIC)

Pz **Sangre de Cristo Formation, Magdalena Group, Tererro Formation, and Espiritu Santo Formation**

Sangre de Cristo Formation (Permian and Pennsylvanian)—Red-brown arkosic sandstone, shale, and local conglomerate. Exposed only in Little Costilla Creek in northeast part of map area (McKinlay, 1956). Exposed thickness greater than 100 m

Magdalena Group (Pennsylvanian)—Interbedded coarse-grained arkosic sandstone, drab-brown to gray or black shale, and gray limestone containing detrital grains of glassy quartz and brown feldspar. Exposed in upper reaches of East Fork of Red River in southeastern part of map area. Total thickness in region at least 1500 m; maximum thickness in map area probably 750 m (Clark and Read, 1972)

Tererro Formation (Upper Mississippian)—Pale-green to olive limestone, thin-bedded sandstone, and calcareous shale overlying a distinctive but discontinuous breccia bed (Macho Member) as thick as 6 m that consists of angular fragments of limestone and chert in a sandy matrix. Exposed near Wheeler Peak and in upper reaches of Rio Lucero in the southeastern part of map area. Thickness 0–6 m (Clark and Read, 1972)

Espiritu Santo Formation (Lower Mississippian)—Gray sandy limestone, dark-gray siltstone, and light-brown medium-grained arkosic sandstone. Exposed in the vicinity of Wheeler Peak and in upper reaches of Rio Lucero in the southeastern part of map area. Thickness 0–20 m (Clark and Read, 1972)

INTRUSIVE ROCKS (EARLY PALEOZOIC

OR LATE PROTEROZOIC?)

d **Diabase—**Dark-gray-green medium- to fine-grained rock having well-preserved diabasic (ophitic) texture; weathers distinctive chocolate brown. Dikes are 10 cm to 20 m thick and commonly have chilled margins. Calcic plagioclase is locally partly altered and sericitized; pyroxene is jacketed with or replaced by green hornblende, sphene, and carbonate. Nonfoliated; some dikes are sheared along Tertiary faults. Similar in petrology and trend to early Paleozoic dikes in southern Colorado (Larson and others, 1985)

g **Gabbro—**Dark-grayish-green medium- to coarse-grained rock, having well-preserved gabbroic texture, in dikes as thick as 60 m north of Costilla Creek. Rock consists principally of partly altered calcic plagioclase and pyroxene, and contains minor biotite, green hornblende, microperthite, chlorite, epidote, and magnetite. Dikes are unsheared and display chilled margins. Preliminary whole-rock Rb-Sr isochron on gabbro from dike near confluence of Costilla and Latir Creeks indicates an age of about 670 Ma (Z. E. Peterman, written comm., 1984)

METAMORPHIC ROCKS (EARLY PROTEROZOIC)

Metasedimentary rocks

Xq **Quartzite—**White vitreous quartzite, commonly massive and nonlayered, but locally displaying conspicuous bedding and crossbedding defined by dark-blue heavy-mineral streaks. Quartzite from San Cristobal Canyon contains two populations of detrital zircon: dark rounded grains yielding a ^{207}Pb/^{206}Pb date of 1,775 Ma, and clear euhedral grains yielding a ^{207}Pb^{206}Pb date of 1,713 Ma (Aleinikoff and others, 1985). The 1,775 Ma date is interpreted as the age of the source terrane for the quartzose sediments, and the 1,713 Ma date is regarded as the age of volcaniclastic input during sedimentation

Xqs **Muscovite-quartz schist and gneiss**—Medium- to coarse-grained thinly layered to massive muscovite-feldspar-quartz schist and gneiss, commonly containing abundant sillimanite and minor garnet and biotite. In part gradational with felsic gneiss **(Xfg)** and biotite-muscovite schist and gneiss **(Xms)**

Xms **Biotite-muscovite schist and gneiss**—Medium- to coarse-grained thinly layered to massive lustrous quartz-mica schist and gneiss, locally containing abundant disseminated graphite. Commonly contains sillimanite; locally contains garnet, andalusite, and cordierite. Some schist contains porphyroblasts of muscovite as long as 4 cm that may be pseudomorphs of andalusite or kyanite. On the slopes 1.6 km S 50° E of the outlet of Cabresto Lake, a 3-m-thick layer of gray calcite marble is interleaved with mica schist and gneiss

Interlayered metavolcanic and metasedimentary rocks

Xph **Phyllite—**Lustrous gray, gray-green, and blue phyllite and phyllitic schist composed chiefly of quartz, sericite, and chlorite. Exposed only in southern parts of the map area. Commonly contains irregular sieve-textured aggregates of rusty-weathering calcite or dolomite surrounded by aggregates of biotite. Contains interbeds a few centimeters to several meters thick of thinly laminated ironstone, greenish-gray quartzite, and white siliceous marble. A few layers contain small angular fragments of dark chloritic rock resembling flattened lapilli

Xi **Iron-formation**—Thinly laminated fine-grained magnetite ironstone and magnetite quartzite

Xc **Chert—**White massive to thinly laminated chert and chert-breccia composed of microcrystalline quartz and minor topaz. Locally contains small angular quartz aggregates that resemble silicified lapilli or phenocrysts, suggesting that the chert may have been produced by silicification of felsic volcanic rocks

Xg **Greenstone**—Massive fine-grained calcareous greenstone in Bull of the Woods Mountain area; composed of a felted mosaic of actinolite, chlorite, epidote, and calcite containing scattered small aggregates of quartz and albite. Probably derived from basalt flows or sills, but no igneous textures or structures are preserved

Xvm **Mafic metavolcanic rocks—**Greenstone and greenschist composed of actinolite or hornblende, epidote, chlorite, albite, and quartz; commonly a few flakes of biotite. Locally displays well-preserved fragmental textures and amygdules filled with quartz, calcite, and albite. Derived from basalt flows, tuffs, and tuff breccia

Xvf **Felsic metavolcanic rocks**—Fine-grained light-gray, greenish-gray, or pink massive to strongly foliated felsic blastoporphyritic gneiss containing conspicuous 2- to 5-mm ovoid grains of bluish-gray quartz and 1- to 5-mm laths of white feldspar. Groundmass consists of a microcrystalline mosaic of quartz, plagioclase, K-feldspar, epidote, and scattered flakes of biotite. Quartz aggregates have probably replaced original embayed phenocrysts. Feldspar porphyroblasts include both plagioclase (oligoclase) and grid-twinned microcline with irregular blotches of albite, the latter probably derived from original sanidine phenocrysts. Composition is similar to rhyolite or rhyodacite; widespread layering and local graded bedding show that a large part of the unit is derived from tuffs or volcaniclastic rocks. Zircon from volcaniclastic rock northeast of Gold Hill give an upper-intercept concordia age of 1,765 Ma

Xlg **Layered gneiss—**Conspicuously layered and well-foliated fine- to medium-grained biotite gneiss, biotite-hornblende gneiss, hornblende gneiss, and amphibolite. Rocks consist of various proportions of quartz, oligoclase-andesine, blue-green hornblende, brown biotite, epidote, and magnetite. Layers range in thickness from a few centimeters to several meters and commonly display rootless isoclinal fold noses and variations in thickness due to ductile deformation. Thin lenses and layers of ferruginous quartzite, magnetite ironstone, and quartz-epidote-calcite marble are commonly interleaved. Compositions suggest that many of the layers could have been derived from intermediate volcanic or volcaniclastic rocks. Local graded bedding suggests derivation from graywackes, perhaps with a significant volcanic component

ROCKS OF MIXED OR UNCERTAIN ORIGIN

Xfg **Felsic gneiss—**Fine- to medium-grained weakly to moderately foliated light-gray to pink gneiss consisting of subequal amounts of strained quartz, microcline, oligoclase, and scattered crudely aligned flakes of biotite. Some rocks mapped as felsic gneiss contain abundant muscovite and locally grade to muscovite schist or gneiss. Commonly interlayered with amphibolite and amphibole gneiss and locally with quartz-pebble metaconglomerate **(Xcg)**. Most rocks mapped as felsic gneiss are probably metamorphosed felsic volcanic or volcaniclastic rocks; some are metamorphosed sedimentary rocks, and some may be metamorphosed felsic intrusive rocks. Zircon from felsic gneiss in Jarosa Canyon east of Urraca Ranch gives an upper-intercept concordia age of 1,643 Ma; zircon from felsic gneiss along dirt road 2.8 km southeast of Urraca Ranch gives an upper-intercept concordia age of 1,585 Ma. The significance of these ages is uncertain

Xcg **Metaconglomerate**—Composed of closely packed 0.5- to 4-cm angular to subrounded white, blue-gray, and red-brown quartz pebbles in a fine-grained arkosic matrix. Interlayered with muscovitic felsic gneiss south of Lama Canyon

Xfa **Mixed unit of felsic gneiss (Xfg) and amphibolite (Xa) interlayered in subequal proportions**

Xa **Amphibolite—**Thinly layered to massive fine- to coarse-grained amphibolite and amphibole gneiss, locally containing layers of calc-silicate gneiss, biotite-hornblende gneiss, felsic gneiss, and muscovite-biotite schist. Most rocks mapped as amphibolite are probably metamorphosed mafic volcanic or volcaniclastic rocks; some are metamorphosed mafic intrusive rocks, and a few may be metamorphosed calcareous sedimentary rocks

Xbg **Biotite gneiss**—Fine-grained weakly foliated nonlayered medium- to dark-gray gneiss consisting of quartz, sodic plagioclase, biotite, hornblende, and opaque minerals. Locally contains sparse staurolite. Probably largely derived from metamorphism of volcaniclastic sedimentary rocks

PLUTONIC ROCKS

Xp **Pegmatite**—Coarse-grained quartz-K-feldspar-plagiocase pegmatite, locally containing muscovite, biotite, tourmaline, and (or) magnetite

Xqct **Quartz monzonite of Costilla Creek—**Coarse-grained moderately to strongly foliated gray gneissic biotite quartz monzonite containing conspicuous augen of grid-twinned microcline 0.5-5 cm long. Commonly contains a few percent hornblende and abundant accessory sphene, allanite, and zircon. Zircon from quartz monzonite along Costilla Creek 1.4 km northwest of junction with Latir Creek gives an upper-intercept concordia age of 1,644 Ma, interpreted as the age of emplacement

Xgd **Granodiorite of Jaracito Canyon—**Fine- to coarse-grained, strongly foliated, gray biotite-hornblende granodiorite, commonly containing abundant inclusions of the enclosing rocks. Ragged undeformed flakes of biotite and irregular poikilitic grains of green hornblende are aligned parallel to foliation. Zircon from granodiorite along Latir Creek 1.4 km east of gaging station gives an upper-intercept concordia age of 1,678 Ma; zircon from small unmapped body of granodiorite in amphibolite **(Xa)** along road in Hondo Canyon gives an age of 1,689 Ma. These are intepreted as emplacement ages; analytical uncertainties are large enough that the rocks may be coeval

Xqo **Quartz monzonite of Old Mike Peak—**Medium- to coarse-grained weakly to moderately foliated mottled pink and green quartz monzonite consisting of 0.5- to 1-cm crystals of pink K-feldspar and clots of green chloritized biotite set in a matrix of gray to green plagioclase and gray recrystallized quartz. Finer grained phases in abundant dikes and sills in surrounding gneisses described as quartz monzonite of Frazier Mountain by Reed (1984). Zircon from fine-grained pink quartz monzonite cutting amphibolite on east side of East Fork of Red River gives an upper-intercept concordia date of 1,699 Ma, interpreted as the emplacement age

Xqc **Quartz monzonite of Columbine Creek—**Gray to pink weakly to moderately foliated biotite quartz monzonite. Appears medium- to coarse-grained in outcrop, but actually consists of lenses of fine-grained inequigranular quartz, plagioclase, and grid-twinned microcline interleaved with folia of scattered partly chloritized biotite and skeleton grains of epidote. Near Tertiary plutons recrystallization has locally destroyed foliation, resulting in a vaguely mottled light-gray to pink massive sugary rock. Zircon from quartz monzite 5.2 km S 16° E of Questa yields an upper-intercept concordia date of 1,730 Ma, interpreted as the emplacement age

Xtr **Tonalite of Red River**—Gray to green medium- to coarse-grained strongly foliated biotite-hornblende tonalite (quartz diorite). Consists of a mosaic of recrystallized quartz, plagioclase, and biotite studded with 0.5- to 1-cm ovoid porphyroclasts of faintly zoned andesine. Hornblende forms large irregular sieve-textured grains and scattered small grains in the mosaic. Locally grades into gabbro. Slabs and blocks of layered gneiss are locally abundant as inclusions. Zircon from tonalite along road to Middle Fork Lake gives an upper-intercept concordia date of 1,750 Ma, interpreted as the emplacement age

Xmi **Mafic and ultramafic rocks**—Medium- to coarse-grained dark-green to greenish-gray weakly foliated gabbro and serpentinized ultramafic rocks. Gabbro consists of equant clots of hornblende in a matrix of calcic plagioclase, epidote, and sparse quartz. In smaller bodies the gabbro is medium to fine grained, distinctly foliated, and displays chilled margins. Original ophitic or intergranular textures are locally preserved and a few bodies display relict cumulus layering. Utramafic rocks are similar to gabbro, except that quartz is absent and plagioclase sparse. Mapped only where intrusive into supracrustal rocks; similar rocks are widespread as inclusions in plutonic rocks where they are mapped as amphibolite **(Xa)**. Age of most bodies undetermined, but zircon from gabbro sill west of Gold Hill gives an upper-intercept concordia date of 1741 Ma, interpreted as the emplacement age

Xu **Supracrustal and plutonic rocks**—Diverse lithologies. Shown in cross sections and in areas not mapped in detail

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