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Reed, John C., Jr.

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PROTEROZOIC ROCKS OF THE TAOS RANGE, SANGRE DE CRISTO MOUNTAINS, NEW MEXICO

JOHN C. REED, Jr.
U.S. Geological Survey, Denver, Colorado 80225

INTRODUCTION

Proterozoic basement rocks in the core of the Taos Range are invadec by Tertiary plutons and are partly mantled by Tertiary volcanic rocks related to the Miocene Questa caldera. Laramide thrust faults and high-angle faults related both to the Rio Grande rift and to the Questa calden cut the basement rocks (Lipman, 1983). The Proterozoic rocks include supracrustal rocks of volcanic, volcaniclastic, and sedimentary origins and a variety of plutonic rocks, all of which have undergone amphibolite-grade regional metamorphism. Most of the rocks have conspicuous foliations; many have distinct mineral lineations produced by shearing and recrystallization during and after metamorphism.

Much of the Taos Range (Fig. 1) was mapped by McKinlay (1956, 1957) and Clark and Read (1972), but these studies did not focus on the Precambrian rocks. Condie (1980) made a reconnaissance of the Precambrian rocks in the southern part of the range, and McCrink (1982) and Condie and McCrink (1982) published a detailed description and geochemical study of the well-exposed sequence of supracrustal and intrusive rocks in the Gold Hill—Wheeler Peak area. Mapping of the Precambrian terrane by the U.S. Geological Survey began in 1980 in conjunction with a long-range study of the Questa caldera and as part of the evaluation of the mineral-resource potential of Wilderness and Wilderness Study Areas in the Tans Range. A nreliminary man of the southern part of the range has been published (Reed and others, 1983) and a map of the entire area is in preparation. A few preliminary lead—uranium ages are available on zircon from the Proterozoic rocks. All the ages quoted in this report are from Bowring and others (1984) except as noted. The uncertainties in the ages quoted are generally less than 10 m.y. A paper fully reporting the analytical results on which the ages are based is currently in preparation.

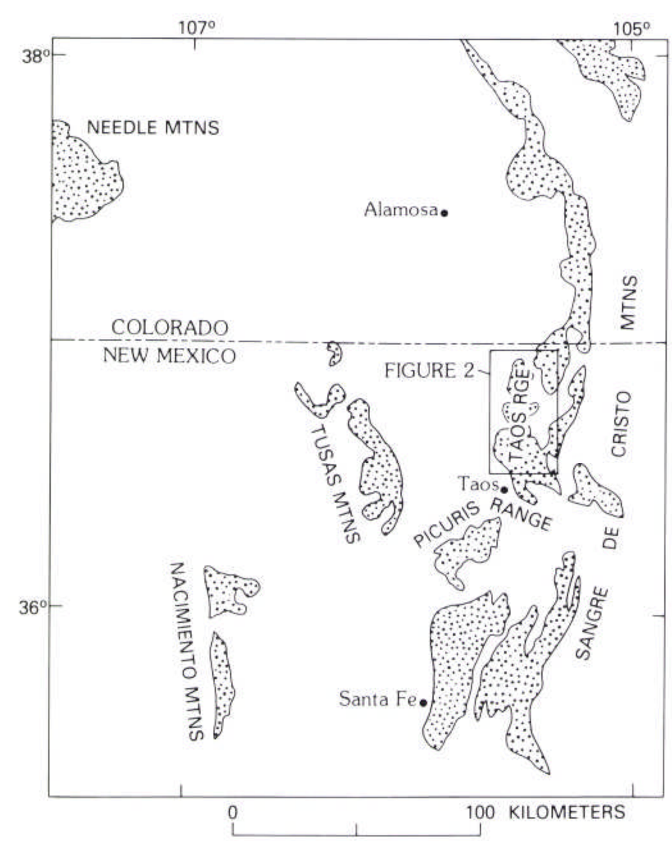

FIGURE 1. Index map showing location of the Taos Range and other areas of Precambrian outcrop in northern New Mexico and southern Colorado (stippled).

SUPRACRUSTAL ROCKS

Layered-gneiss Sequence

Interlayered feldspathic gneiss, biotite and hornblende gneiss, hornblende gneiss, and amphibolite comprise much of the Proterozoic terrane south of the Questa caldera, and similar rocks are widespread to the north and east (Fig. 2). The mafic gneisses are generally fine- to medium-grained and consist of various proportions of quartz, oligoclase—andesine, blue-green hornblende, smoky-brown biotite, epidote, and magnetite. Compositional layers range in thickness from a few millimeters to several meters and are generally parallel to foliation. In many places layers tend to be lens-shaped and discontinuous, suggesting that much of the layering represents transposed fold limbs. Locally, outcrop-scale isoclinal folds (Fig. 3) with limbs sheared off parallel to layering confirm this inference.

Occasional lenses a few centimeters to several meters thick of thinly laminated ferruginous quartzite, magnetite ironstone, and quartz—epidote—calcite marble are interleaved with the mafic gneisses. South of Gold Hill a lens of chert and chert breccia 20 m thick and 200 m long occurs in mafic gneiss of the layered gneiss sequence. In a few places lenses of muscovite or muscovite—biotite schist a few meters thick are interleaved with the biotite and hornblende gneisses south of the caldera. Some of these layers contain kyanite, sillimanite, and staurolite, but the paragenetic relations among these minerals have not been established.

Between Rio Hondo and the south margin of the caldera much of the supracrustal sequence is fine-grained, light-gray, greenish-gray or pink felsic gneiss which contains scattered 2-5 mm ovoid grains of bluish-gray quartz and 1-5 mm laths of feldspar. The rocks consist of a microcrystalline groundmass of granoblastic quartz, plagioclase (An, ,,), potassic feldspar, epidote, and scattered flakes of brown biotite partly altered to chlorite. The large quartz grains consist of single, optically continuous crystals or subgrains with nearly parallel orientations. The rounded and embayed shapes of the grains suggest that they are partly resorbed phenocrysts (Gresens and Stensrud, 1974). The feldspar laths are either well-twinned cloudy plagioclase (An,,,_,,) or grid-twinned microcline with irregular blotches of albite. In some rocks, biotite flakes and sphene aggregates in 1-2 mm irregular clots give the rock a spotted appearance.

The felsic gneiss contains layers of amphibole—biotite gneiss, amphibole gneiss, and calc-silicate gneiss. In a few places, thinly layered felsic gneiss displays tangential crossbeds with individual laminations marked by heavy mineral concentrations. Irregular blocks of amphibolite, some with relict basaltic textures and chilled margins, are locally common. These may represent volcanic bombs, boulders, or fragments of mafic dikes or sills dismembered during deformation. Near their contacts, felsic and mafic gneisses are interlayered on all scales and in

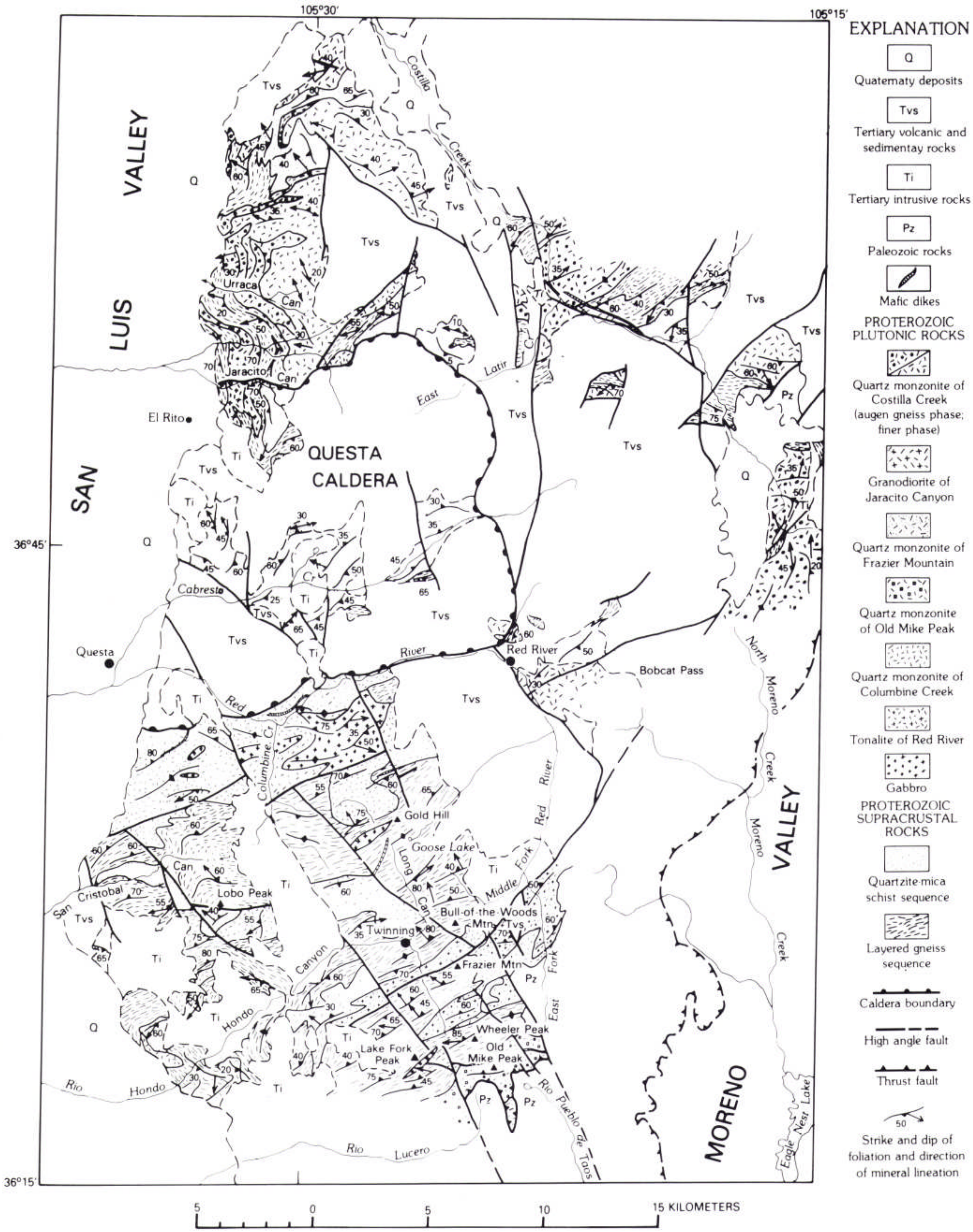

FIGURE 2. Simplified geologic map of the Precambrian rocks of the Taos Range.

FIGURE 3. Breccia along Tertiary fault zone in layered mafic gneiss on ridge 2.5 km southwest of Twinning. Note rootless isoclinal-fold noses in gneiss indicated by arrows. Scale is 18 cm long.

all proportions, and thin layers and lenses of porphyritic felsic gneiss occur locally throughout the supracrustal succession.

Between Gold Hill and Bull-of-the-Woods Mountain mafic and felsic gneisses are interlayered with lustrous, fine-grained phyllitic schist composed chiefly of quartz, muscovite, and chlorite. The schist commonly contains abundant irregular sieve-textured aggregates of rusty-weathering calcite or dolomite surrounded by aggregates of biotite. A few irregular grains of albite can be identified in some of the schist. The schist contains interbeds a few centimeters to several meters thick of fine-grained, very thinly laminated specularite ironstone, greenish-gray to white calcareous quartzite, and white siliceous marble. A few layers in the schist contain small angular fragments of fine-grained felsic rocks some of which resemble flattened lapilli. The schist also contains lenses of massive, fine-grained calcareous greenstone as much as 200 m thick. Most of the greenstone consists of a felted mosaic of actinolite, chlorite, epidote, and calcite with scattered aggregates of quartz and albite.

The layered gneisses are believed to represent a sequence of predominantly volcaniclastic rocks interlayered with flows, tuffs, and sedimentary rocks. Compositions of many of the amphibolite layers are basaltic, and some have well-preserved basaltic textures. Locally, amygdaloidal volcanic breccia is preserved (Fig. 4). The porphyritic felsic gneiss has a composition close to that of rhyolite. Some of it may represent flows or hypabyssal intrusives, but, in many places, the porphyritic felsic gneiss has features suggesting that it is a reworked tuff or tuff-breccia (Fig. 5). Many of the biotite—hornblende gneisses have compositions similar to that of andesite, but no volcanic textures have been identified. Some of these rocks have indistinct graded bedding, which indicates that they may have been derived from graywackes.

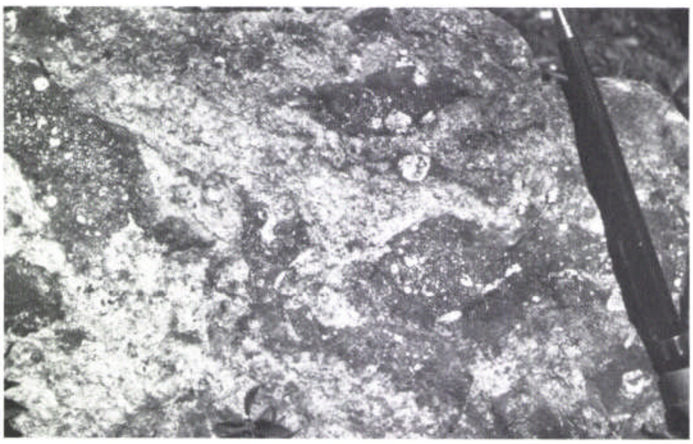

FIGURE 4. Mafic volcanic breccia in layered-gneiss sequence on ridge about 2 km south of Gold Hill. Dark fragments are amygdaloidal greenstone; matrix is epidote-rich greenstone. Amygdules are filled with quartz and albite. Note fine-grained nonamygdaloidal borders on many fragments. Pencil is 15 cm long.

Reliable indicators of facing directions are rare in the layered-gneiss sequence, and nowhere has the stratigraphic order been clearly established. There is a suggestion of a coherent stratigraphy in the area between Gold Hill and Bull-of-the-Woods Mountain where detailed mapping by McCrink (1982) shows no major repetition of stratigraphic units. He concluded that the sequence faces north, on the basis of scour-and-fill structures in one outcrop and the occurrence of fragments of felsic rocks in adjacent mafic layers. On the other hand, crossbedding and graded bedding in the felsic volcaniclastic rocks north of Gold Hill suggest that the sequence faces south. Relict cumulus layers along the northwest contact of the metagabbro sill west of Gold Hill also suggest a south-facing sequence. Study of oriented thin sections of the graded laminations in the chert lens and the ironstone layers may yield further evidence of facing direction.

Zircon from a felsic volcaniclastic rock near Gold Hill has an age of 1,750 Ma. This is probably a good estimate of the depositional age of the layered-gneiss sequence.

Quartzite—Mica-schist Sequence

Quartzite interlayered with mica schist and mica gneiss comprise most of the exposed floor of the Questa caldera, and similar rocks are extensive to the north and northeast. Quartzite with little or no associated micaceous rocks crops out in a narrow belt in the layered gneisses between the mouth of San Cristobal Canyon and Lobo Peak, and in several small areas to the south. Similar quartzite is mapped and described by Clark and Read (1972) and Condie (1980) in the upper reaches of the Rio Pueblo de Taos and between Bobcat Pass and North Moreno Creek, but neither of these areas was accessible during the present study.

FIGURE 5. Layered felsic gneiss about 2 km northeast of Gold Hill. Coarser layers contain abundant laths of white feldspar and ovoid grains of blue quartz. A few of the finer layers are crossbedded. Scale is 18 cm long.

The quartzite is white to blue-gray, sugary to vitreous, and ranges from massive to well layered on scales of a few centimeters to several meters. Layering is marked by differences in color, grain size, or mica content and is parallel to bedding as indicated by heavy mineral streaks. Near the mouth of San Cristobal Canyon the quartzite contains a 2-m-thick layer of quartz-pebble conglomerate. Pebbles are angular to subrounded and are as much as 10 cm in diameter; the pebbles consist entirely of gray, brown, or white quartz or quartzite. Pebble layers have not been found elsewhere.

Rocks interleaved with the quartzite are coarse-grained mica schist, medium-grained mica gneiss, and, very locally, gray calcite marble. The mica schist and gneiss are strongly foliated and rudely to well layered. Typically, they consist predominately of quartz, biotite, and muscovite. Most lack plagioclase, but some contain as much as 20% oligoclase—andesine (An,,_„). Some of the schist in the caldera south of El Rito contains abundant disseminated graphite. Mica schists and gneisses in and north of the caldera contain sillimanite, andalusite, and cordierite in apparent equilibrium. Similar rocks south of the caldera contain various combinations of kyanite, staurolite, sillimanite, and cordierite, but the paragenetic relations between these minerals are not clear.

Layering in the micaceous rocks is defined by differences in color, grain size, and proportions of quartz and micaceous minerals. In several areas the schist contains conspicuous, randomly oriented porphyroblasts of light-green muscovite as much as 5 cm in diameter. Muscovite in the porphyroblasts is only slightly warped and has sieve-textured margins containing abundant poikilitic inclusions of matrix minerals.

Contacts between the layered gneisses and the quartzite and mica-schist sequence are generally conformable. Although intrusive rocks rarely cut the quartzite sequence, perhaps due to differences in mechanical properties, there is no conclusive evidence for an intrusive event predating deposition of the quartzite sequence. Neither is there any apparent difference in structural or metamorphic history between the layered-gneiss sequence and the quartzite—mica-schist sequence. These relations suggest that no major unconformity separates the two sequences. Because indicators of facing direction are sparse in both sequences, their relative age cannot be definitely established. Where dips of layering are gentle and structure is relatively simple, the layered-gneiss sequence generally underlies the quartzite sequence. Basement rocks in the downdropped block within the Questa caldera consist almost entirely of quartzite and mica schist, which also suggests that this sequence once overlay the layered gneisses in an extensive area. These relations, although tenuous, suggest that the quartzite—schist sequence is the younger.

The only place where facing indicators are relatively common is in the narrow belt of quartzite between the mouth of San Cristobal Canyon and Lobo Peak where crossbedding faces consistently south. The structure of the area has not been worked out in detail. The quartzite may occupy the trough of a complex syncline with the south limb structurally removed. A simpler interpretation is that the quartzite represents a large interbed within the layered-gneiss sequence. If so, the facing direction is consistent with that inferred for the layered gneisses at Gold Hill along strike to the east.

PLUTONIC ROCKS

The supracrustal rocks are invaded by a diverse array of plutonic rocks ranging in composition from pyroxenite to granite. All the plutonic rocks are of calc-alkaline affinity; the felsic rocks are all weakly peraluminous, and the intermediate and mafic rocks are generally metaluminous. In the following discussion the plutonic rocks are described using igneous-rock names, although all the rocks have been deformed and regionally metamorphosed along with the supracrustal rocks and most display conspicuous foliation.

Gabbro and Ultramafic Rocks

Gabbro, now metamorphosed to coarse-grained amphibolite and amphibole gneiss, forms several irregular bodies enclosed by younger quartz monzonite south of the Red River and numerous dikes and sills cutting the layered gneisses. The two largest sills are the sill west of Gold Hill and the sill south of Lake Fork Peak, the former 500 m thick and the later about 200 m thick. Ultramafic rocks occur as layers and lenses in gabbro, as isolated pods and lenses in the supracrustal rocks, and as small dikes and sills cutting the supracrustal rocks. McCrink (1982) reported that ultramafic rocks cut dikes and sills of gabbro near Gold Hill, but that deformed bodies of ultramafic rocks are cut by gabbro near Wheeler Peak.

The gabbro is generally a medium- to coarse-grained, dark-green to greenish-gray rock composed of rudely equidimensional clots of blue-green hornblende set in a mosaic of plagiocase (An,,„_5„), epidote, and quartz with a few flakes of chestnut-brown biotite and minor amounts of calcite. In smaller bodies the rock is medium- to fine-grained and displays chilled margins against enclosing supracrustal rocks. Foliation is best developed in the finer-grained gabbro; coarse-grained gabbro is commonly massive or only very rudely foliated. Original ophitic or intergranular textures are faintly preserved in some rocks, and a few have relict cumulus layering (Fig. 6). A few ultramafic rocks contain relict grains of olivine. Zircon from gabbro in the sill west of Gold Hill has an age of about 1,741 Ma.

Tonalite of Red River

Medium- to coarse-grained, strongly foliated biotite—hornblende tonalite forms several elongated northeast—southwest trending bodies in the headwaters of the East Fork of Red River north and east of Frazier (Frazer) Mountain and Wheeler Peak. The tonalite typically consists of a mosaic of recrystallized plagioclase, quartz, and biotite, studded with 0.5—I cm ovoid porphyroclasts of well-twinned and faintly zoned plagioclase (An_{30-35}). Hornblende forms large, irregular, sieve-textured grains and scattered smaller grains in the mosaic. In a few rocks traces of the original igneous texture are preserved. Locally the tonalite grades imperceptibly into gabbro which closely resembles the main masses of gabbro previously described. Contacts of the tonalite with the layered mafic gneiss are generally sharp. Slabs and blocks of layered gneiss are locally abundant in the tonalite, and a few dikelets of tonalite cut the enclosing gneiss.

Zircon from tonalite northeast of Frazier Mountain has an age of about 1,750 Ma. The gradation from tonalite to gabbro suggests that the rocks may be essentially of the same age, and uncertainties in the age determinations (S. A. Bowring, personal comm. 1983) do not preclude this possibility.

Quartz Monzonite of Columbine Creek

Gray to pink, gneissic quartz monzonite crops out in a large pluton south of the Red River between the town of Red River and the mountain front to the west. Similar rock makes up a number of smaller plutons which cut the supracrustal rocks as far south as Rio Hondo. The rock

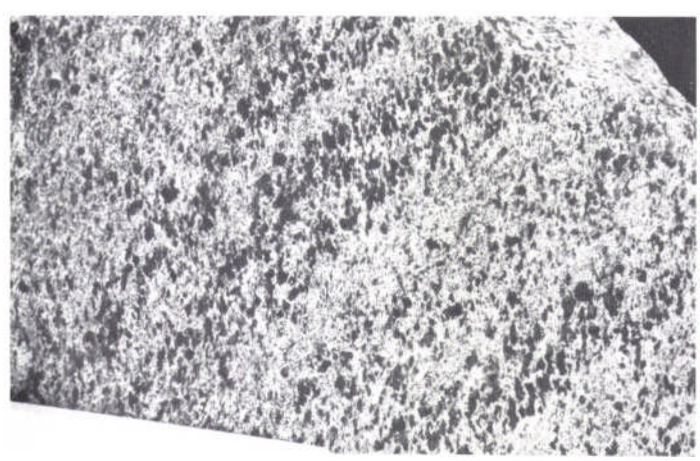

FIGURE 6. Cumulus layering in gabbro (now metamorphosed to amphibolite). Foliation transects layering at about 60°. Specimen from unmapped body about 5 km east of confluence of East Latir Creek and Costilla Creek. Height of specimen shown is about 18 cm.

is weakly to moderately well foliated and in outcrop appears medium- to coarse-grained. It consists of a fine-grained inequigranular mosaic of sutured quartz, plagioclase (An$_5$_,,), and grid-twinned microcline, with scattered irregular dark clots about 5 mm in diameter. The clots consist of crudely aligned, undeformed flakes of chloritized biotite and skeleton grains of epidote. The distribution of biotite—epidote clots and quartz segregation lenses in the generally fine-grained mosaic gives the impression that the rock is medium- or coarse-grained. Near Tertiary plutons recrystallization has locally destroyed the foliation, resulting in a vaguely mottled, light-gray to pink, massive sugary rock.

The quartz monzonite contains abundant inclusions of layered mafic gneiss, amphibolite, and gabbro, and a few inclusions of felsic volcanic rocks. Dikes of quartz monzonite cut the gabbro body east of the mouth of Columbine Creek. A 30-m-thick concordant body of felsic gneiss in the quartzite sequence just south of the summit of Lobo Peak is interpreted as a sheared sill of quartz monzonite.

Zircon from the quartz monzonite along the mountain front south of Questa has an age of 1,730 Ma.

Quartz Monzonite of Old Mike Peak

Pink, medium- to coarse-grained, weakly to moderately well-foliated quartz monzonite forms an elongate pluton that extends southwest from the headwaters of the East Fork of Red River into the valley of Rio Lucero. The map by Condie (1980) shows that the pluton is extensively exposed in the lower reaches of the valley of Rio Lucero, but this area is currently inaccessible as it lies within the lands of the Taos Pueblo. The rock consists of 0.5-1 cm crystals of untwinned, faintly perthitic potassic feldspar and altered zoned plagioclase (cores AN,,; rims near AO in a mosaic of recrystallized feldspar and quartz. The rock is slightly less silicic and more potassic than the quartz monzonite of Columbine Creek and differs from it chiefly in its weaker foliation, in the character of the potassic feldspar, and in the conspicuous zoning of the plagioclase.

The contact of the quartz monzonite north and west of Old Mike Peak is generally sharp and parallel to layering in the adjacent layered gneiss. A few discordant dikes of quartz monzonite cut the wallrocks, and the intrusive contains scattered blocky inclusions of layered gneiss that contain internal folds. An attempt to date the quartz monzonite was only partly successful due to a very small yield of zircon. The results show that the age of the rock is about 1,700 Ma, but do not establish the place of the quartz monzonite in the intrusive sequence.

Quartz Monzonite of Frazier Mountain

Fine-grained, strongly foliated, pink to gray felsic intrusive rocks form several semiconcordant plutons in a belt extending southwestward from the lower part of the East Fork of Red River to the mountain front near the mouth of Hondo Canyon. Similar rocks form dikes and sills ranging in thickness from a few centimeters to several meters in both the surrounding mafic gneiss and in the tonalite of Red River. The rocks in these bodies are chiefly quartz monzonite, but range from granite to granodiorite. The rocks typically consist of porphyroclasts of untwinned perthitic potassic feldspar and strongly zoned plagioclase (An,$_5$_,, cores; An,_,„ rims) in a mosaic of recrystallized quartz, albite, epidote, and postkinematic biotite.

The rocks in these bodies resemble the quartz monzonite of Old Mike Peak in mineralogy and major-element chemistry. The character of the potassic feldspar and the zoning of the plagioclase are also similar. They differ in grain size, texture, degree of development of foliation, and in the common occurrence of allanite and muscovite as accessories in the Frazier Mountain rocks. The two rocks probably were comagmatic and their minor compositional and textural differences have been emphasized by cataclasis and recrystallization. A dike of the quartz monzonite cutting tonalite along the East Fork of Red River has an age of about 1,699 Ma.

Granodiorite of Jaracito Canyon

Fine- to coarse-grained, strongly foliated gray granodiorite forms a semiconcordant pluton along the mountain front east and north of El Rito. The granodiorite commonly contains abundant inclusions of the enclosing gneisses, some of which display internal foliation discordant to foliation in the granodiorite. The granodiorite consists of equidimensional grains of zoned plagioclase (An,„ cores; An„ rims) in a mosaic of smaller recrystallized plagioclase, potassic feldspar, and quartz. Ragged undeformed flakes of dark smoky-brown biotite and irregular poikilitic grains of olive to grass-green hornblende are aligned parallel to the foliation. The granodiorite has an age of about 1,678 Ma, appreciably younger than the tonalite of Red River. Similar granodiorite from one of a number of small unmapped bodies near the mouth of Hondo Canyon has an age of 1,689 Ma. Analytical uncertainties (S. A. Bowring, personal comm. 1983) are large enough that the rocks could be contemporaneous.

Quartz Monzonite of Costilla Creek

Gneissic quartz monzonite comprises a considerable part of the exposed basement north and northeast of the Questa caldera. Because the basement rocks are broken by numerous Tertiary faults and are extensively mantled by Tertiary rocks, it is not clear whether the various isolated outcrop areas of quartz monzonite are parts of a single large pluton or represent several independent plutons. The quartz monzonite has two textural phases. The most extensive phase is fine- to medium-grained, light gray to pink, and weakly to moderately foliated; the other phase is coarse-grained, moderately to strongly foliated, and is studded with large potassic-feldspar augen. Both phases contain small concordant lenses of pegmatite composed chiefly of quartz and gray potassic feldspar and containing 1-5 cm aggregates of magnetite. Contacts between the finer-grained quartz monzonite and the augen gneiss are gradational over distances of a few meters to several tens of meters; the two phases are interleaved on scales of a few centimeters, and the augen gneiss becomes finer-grained and contains progressively fewer augen until the two phases become indistinguishable.

Contacts of the quartz monzonite with the enclosing rocks are concordant with layering in the wallrocks and foliation in the plutonic rock. Contacts of the augen-gneiss phase with wallrocks are generally sharp, but those of the finer phase are less well defined because the enclosing rocks commonly consist of amphibolite and amphibole gneiss interleaved with fine-grained, pink, felsic gneiss, much of which probably represents sills of quartz monzonite, but some of which may represent felsic volcanic rocks or arkosic sediments. The finer-grained quartz monzonite consists of an inequigranular mosaic of strained quartz, grid-twinned microcline, zoned plagioclase (An,,,, cores; An$_5$_,,, rims), and crudely aligned flakes of deep-smoky-brown biotite. The augen gneiss is very similar except for the presence of large porphyroclasts of microcline (many of which are now aggregates of grain fragments), and for the concentration of slightly coarser biotite flakes into anastomosing folia that enclose lenses of recrystallized quartz and feldspar; these lenses give the rock a coarse-grained appearance in hand specimen.

The augen-gneiss phase has an age of about 1,644 Ma; several samples of the finer phase have been collected but have not yet been analyzed.

MAFIC DIKES

Mafic dikes cut the foliated Proterozoic rocks throughout the range, but are truncated by the unconformity at the base of Mississippian strata near Wheeler Peak. Many of the dikes have approximately east—west trends and some can be traced for several kilometers. Most of the dikes are medium- to fine-grained diabase, but a 60-m-thick dike north of Costilla Creek is hornblende—pyroxene diorite. This dike has margins and apophyses of diabase similar to the diabase in the other mafic dikes. Most of the dikes have chilled margins and display diabasic or ophitic textures. Three whole-rock samples of the diorite dike along Costilla Creek fit closely on a rubidium—strontium isochron indicating an age of about 500 Ma, but a fourth sample of somewhat altered rock from the dike margin falls significantly off the isochron (Z. E. Peterman, personal comm. 1984).

METAMORPHIC AND STRUCTURAL HISTORY

All the basement rocks were regionally metamorphosed and deformed during the Early or Middle Proterozoic. Effects of shearing during the

Laramide orogeny and contact metamorphism and brecciation during the mid-Tertiary are superimposed on the Proterozoic mineral assemblages and structures.

Mineral assemblages in the pelitic metasedimentary rocks and in the mafic gneisses and intrusive rocks indicate Proterozoic metamorphism in the lower-grade part of the amphibolite facies. Particularly significant are the occurrence of kyanite, staurolite, sillimanite, and cordierite in pelitic rocks south of the caldera, the occurrence of the possible equilibrium assemblage sillimanite–andalusite–cordierite in the pelitic rocks in and north of the caldera, and the equilibrium assemblage of blue-green hornblende–calcic plagioclase–biotite in the mafic rocks throughout most of the range. The phyllitic schist and associated mafic rocks between Gold Hill and Bull-of-the-Woods Mountain contain chlorite-actinolite–albite–epidote assemblages, indicating that in this area metamorphism was only to greenschist facies.

The earliest period of deformation of the supracrustal rocks produced the isoclinal folds now preserved as small intrafolial fold noses and sheared out limbs in the supracrustal rocks. The principal foliation is parallel to layering except very locally in the noses of these isoclines. The foliation and mineral lineation in both supracrustal and plutonic rocks are marked by flattened, elongate lenses of recrystallized quartz and feldspar and crudely aligned but undeformed grains and aggregates of micaceous minerals and hornblende. The mineral lineation lies on the foliation planes at various angles to the axes of the early isoclines. The foliation and lineation are inferred to be the results of cataclasis and recrystallization. The lack of deformation of the metamorphic minerals (Fig. 7) indicates that the climax of regional metamorphism post-dated significant movement along foliation planes. Because the youngest dated plutonic rock, the quartz monzonite of Costilla Creek, displays the same foliation and lineation, these structures, most of the isoclinal folds, and the regional metamorphism must be younger than 1,644 Ma. However, folds contained in blocky inclusions in the quartz monzonite of Old Mike Peak and rotated foliated inclusions in the granodiorite of Jaracito Canyon show that some folds and some of the foliation formed earlier. Wobus and Hedge (1982) have dated a post-tectonic granite porphyry stock at Tusas Mountain, about 50 km west of the Taos Range, at between 1,500 and 1,430 Ma. This age provides a younger limit for metamorphism and formation of the principal foliation.

More open folds, probably of several generations (Norman and Nielsen, 1982), are superimposed on early isoclines, but superimposed folds are rarely seen in single outcrops. It is these later folds that are responsible for much of the complexity of the pattern of foliation and lineation trends (Fig. 2). Some of the open folds have poorly developed crenulation cleavage with recrystallized mica parallel to the axial planes, which suggests that they formed during the waning stages of regional metamorphism.

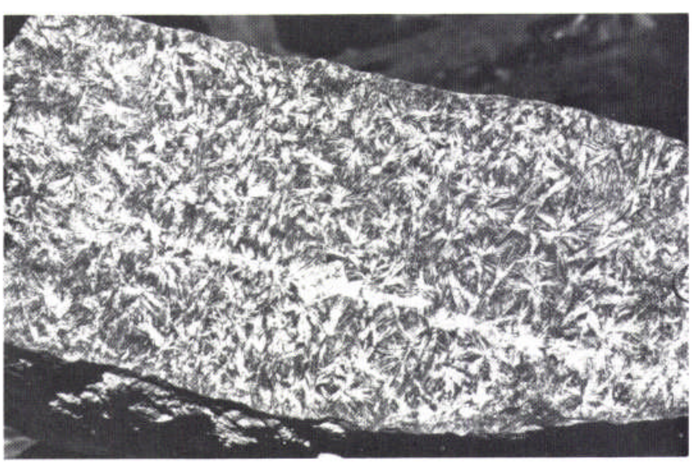

FIGURE 7. Sillimanite rosettes on foliation plane in micaceous quartzite. Rosettes are about 3 cm in diameter. White streak is a scratch. Specimen from about 4 km east of confluence of East Latir Creek and Costilla Creek.

It has been suggested (Reed and others, 1983) that the broad belt of steeply dipping, northeast-trending foliation south of the Questa caldera is an expression of the Jemez zone, a northeast-trending zone of crustal weakness of Precambrian ancestry that has been an important control of late Cenozoic volcanism and tectonism (Mayo, 1958; Lipman and Mehnert, 1979). Most of the foliation in the belt is not related to a younger crosscutting shear zone, but local zones of phyllonite and silicified blastomylonite a few meters to a few tens of meters thick lie parallel to the steep foliation and apparently mark ductile shear zones. Thus, the broad belt of steep foliation may be due to rotation of the earlier regional foliation during movement along narrower and more local shear zones related to the Jemez zone.

Tertiary faults in the basement rocks are marked by zones of shattered rocks, breccia (Fig. 3), and microbreccia. The breccias consist of angular fragments of wallrock in a dark-green to gray mortar of quartz, feldspar, chlorite, sericite, and limonite. Fragments in the microbreccia include individual grains of plagioclase—some with warped, broken, and offset twin lamellae.

CONCLUSIONS

The principal conclusions of the present investigation of the Precambrian rocks of the Toas Range are:

(1) The supracrustal rocks include a sequence of layered mafic and felsic gneisses derived from volcanic, volcaniclastic, and associated sedimentary rocks, and a sequence of quartzite and pelitic schist derived from nonvolcanic shelf sediments. In general, the quartzite–schist sequence overlies the volcanic sequence, but, locally, quartzite and schist are interlayered in the volcanic sequence.

(2) The protoliths of the layered gneisses are of Early Proterozoic age (about 1,750 Ma) and included volcanic and volcaniclastic rocks ranging in composition from rhyolite to basalt. Volcanic rocks of intermediate composition have not been identified, but many of the mafic gneisses have bulk compositions close to andesite and may have been derived from graywacke with an appreciable volcanic component.

(3) Calc-alkaline plutonic rocks, the oldest of which were essentially contemporaneous with the volcanic rocks, were emplaced in the supracrustal rocks over a span of only about 120 m.y., a span comparable to that required for emplacement of the various plutons of the central Sierra Nevada batholith (Bateman, 1983). The plutonic rocks include large volumes of quartz monzonite, smaller volumes of granodiorite and tonalite, and still smaller volumes of granite, gabbro, and ultramafic rocks. There seems to be no simple relation between age of emplacement and composition, although there is a general progression from ultramafic and mafic rocks through intermediate compositions to potassic quartz monzonite. There is a general decrease in age of emplacement from south to north, counter to the regional trend noted by Condie (1982), perhaps due to local structural complexity or to the small size of the area investigated. No major body of post-tectonic Proterozoic granite exists in the Taos Range as suggested by Condie and McCrink (1982), although the possibility of dikes or very small, poorly exposed plutons cannot be excluded.

(4) Isoclinal folding of the supracrustal rocks and cataclasis and recrystallization of both plutonic and supracrustal rocks to form the principal regional foliation took place during the early stages of regional metamorphism between 1,644 and 1,430 Ma. Regional metamorphism of most of the rocks took place at temperatures near the aluminum-silicate triple point. The occurrence of kyanite in the rocks south of Questa caldera suggest that PT gradients were lower there than in the rocks now exposed in and north of the caldera, where andalusite occurs (Grambling, 1981).

(5) Notation of the regional foliation into near parallelism with narrow northeast-trending zones of ductile shear post-dated regional metamorphism. These shear zones may be related to the Jemez zone.

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Taos Plaza, northeast corner, at the July Fiesta, ca 1938. Photographer unknown.