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1990, pp. 189-199. https://doi.org/10.56577/FFC-41.189

in:

Tectonic Development of the Southern Sangre de Cristo Mountains, New Mexico, Bauer, P. W.; Lucas, S. G.; Mawer, C. K.; McIntosh, W. C.; [eds.], New Mexico Geological Society 41st Annual Fall Field Conference Guidebook, 450 p. https://doi.org/10.56577/FFC-41

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PRECAMBRIAN ROCKS OF THE MORA-ROCIADA AREA, SOUTHERN SANGRE DE CRISTO MOUNTAINS, NEW MEXICO

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Abstract—Early Proterozoic crystalline rocks of the Mora-Rociada area consist of layered metasedimentary and metavolcanic rocks intruded by synkinematic mafic to intermediate rocks and postkinematic granite. The layered rocks are divided into three units: (1) a basal unit consisting of quartz-feldspar-mica gneiss and migmatite interlayered with minor knotted sillimanite schist and micaceous quartzite; (2) a middle unit consisting of quartz-muscovite schist and metabasalt and containing minor interlayers of quartzite, chlorite schist, quartz-biotite-andalusite schist and hornblende and biotite gneiss; and (3) an upper unit consisting of micaceous quartzite and felsic metavolcanic rock locally interlayered with metabasalt, calc-silicate rock, marble and iron formation. Poorly preserved crossbedding and graded bedding indicate that the section is upright. The supracrustal rocks are exposed in three large, southwest-plunging anticlines. Pervasive Precambrian shearing, isoclinal folding and penetrative southwest-plunging crenulation axes and mineral lineations characterize the lower part of the sequence and decrease in intensity upsection. Younger folds are present but are restricted to areas adjacent to younger intrusive bodies and structures of Laramide age.

The synkinematic intrusive rocks range in composition from noritic to tonalitic based on major element geochemistry. Small, coarse-grained norite plugs are closely associated with and locally gradational into hornblende-plagioclase gabbro. The gabbroic bodies are lenticular with their long dimensions subparallel to the foliation of the host rocks. They are commonly well-foliated, fine- to medium-grained near their margins, becoming more coarsely crystalline and locally pegmatoidal near their centers. Tonalitic rocks are locally gradational into gabbro and consist of quartz and plagioclase with variable amounts of hornblende and biotite. Middle Proterozoic postkinematic granite and pegmatite have intruded all rocks, locally refolding the layered sequence.

INTRODUCTION

The Sangre de Cristo Mountains of northern New Mexico consist of a series of west-tilted, north-trending basement blocks bounded on the east and west by high-angle, west-dipping reverse faults. Precambrian rocks are exposed along the strongly uplifted east edges of these blocks, as well as in valleys and canyons cut into the range. Precambrian rocks of the Mora-Rociada area are the easternmost exposures of crystalline rocks in the range and are exposed in and adjacent to a pronounced Neogene, north-trending valley. West of the valley, these rocks are unconformably overlain by Mississippian and Pennsylvanian sedimentary rocks; Precambrian rocks are mostly in fault contact with these younger sedimentary rocks on the east.

Precambrian rocks of north-central New Mexico are Proterozoic in age (see recent summary by Bauer and Williams, 1989). These rocks, divided into an older, Early Proterozoic, layered metasedimentary and metavolcanic sequence and a younger Middle Proterozoic felsic intrusive sequence, have been mapped and described from areas adjacent to Mora-Rociada in the higher parts of the Sangre de Cristo Mountains (Goodknight, 1976; Moench et al., 1988; Grambling et al., 1989; Robertson and Condie, 1989; Wobus, 1989). Rocks of both groups are present in the Mora-Rociada area and were mapped and described by Baltz and O'Neill (1984, 1986). These rocks are exposed mainly in the Mora and Rociada 7$^1/_2$' quadrangles; the reader is referred to these maps for details of distribution of rock types discussed in this report. These mapped areas extend from Mora on the north, southward 25 km, beyond the Sapello River, to the base of Hermit Peak, located directly south of the map boundary (Fig. 1). Precambrian rocks in the northern part of this area have been previously described by Budding and Cepeda (1979) and in unpublished theses by Reise (1969) and Schowalter (1969).

PRECAMBRIAN ROCKS

Rocks in the Mora-Rociada area consist of a well-layered sequence of granitic gneiss and migmatite, quartzites, metapelites, ortho- and para-amphibolites, layered quartz-feldspar-mica granofels and minor marble, calc-silicate rocks, magnetite-bearing quartzite, chlorite schist and metaconglomerate. These layered rocks have been grouped into three informal units; they are, from structurally lowest to highest: quartzofeldspathic gneiss and migmatite of El Oro; mica schist and amphibolite of Las Quebraditas; and micaceous quartzite and quartzofeldspathic gneiss of Rociada. The layered rocks locally show intense internal penetrative deformation and associated well-developed axial planar foliation, but the individual rock units are lithologically distinct, mappable, and do not appear to have been repeated by megascopic isoclinal folding or thrust faulting. Poorly preserved graded and cross-

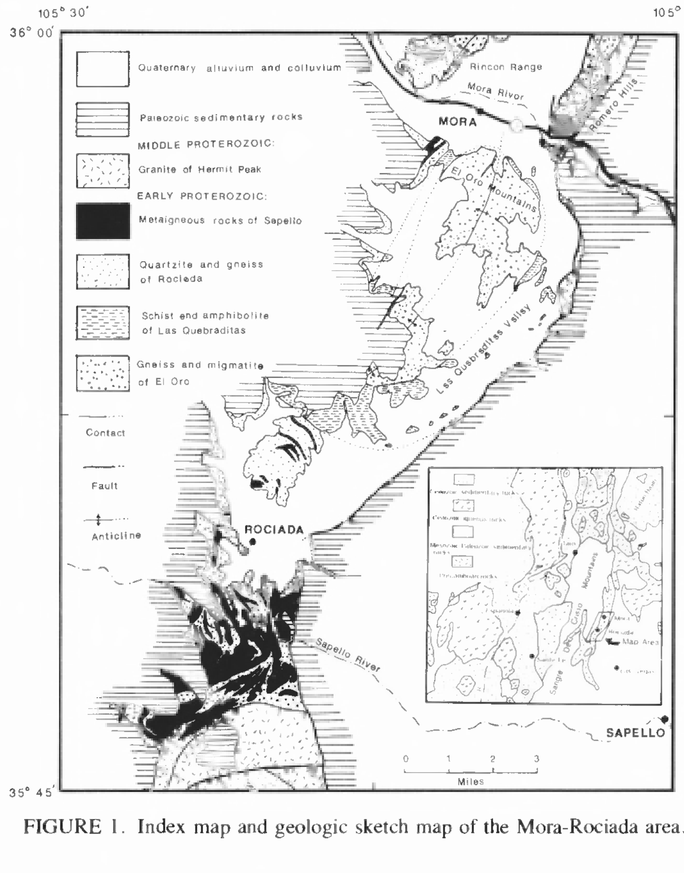

FIGURE 1. Index map and geologic sketch map of the Mora-Rociada area.

bedding suggest that the sequence is upright. Intruded into the layered rocks is an Early Proterozoic synkinematic sub-alkaline suite of mafic to intermediate metaigneous rocks of Sapello and a younger, Middle Proterozoic postkinematic granite of Hermit Peak, well exposed in the southernmost part of the area.

Metamorphic supracrustal rocks

Quartzofeldspathic gneiss and migmatite of El Oro

The structurally lowest and probably oldest rocks are best exposed in the broad, northeast-trending anticline that underlies the El Oro Mountains (Fig. 1). These rocks consist principally of quartz-feldspar-mica gneiss with minor interlayers of micaceous quartzite and thin, discontinuous lenses of knotted quartz-muscovite-sillimanite schist.

The gneissic rocks of El Oro are characteristically massive, well exposed and form steep slopes and cliff faces. The rock weathers pinkish- to yellowish-tan, is well foliated, migmatitic in its lower parts and locally very strongly sheared and folded. These granitic gneisses are informally divided into four mappable units, based on texture and composition. The first and structurally lowest unit, exposed in the core of the anticline, is a medium- to coarse-crystalline migmatitic quartz-plagioclase-microcline-mica gneiss. The base of the gneiss is not exposed. This lower unit is interlayered with, and locally gradational into, gray, dense micaceous quartzite and knotted mica schist. This lowermost migmatitic gneiss is overlain by two poorly defined gneissic units: the lower gneiss is distinguished from the underlying migmatite by a decrease in biotite content and by well-developed quartz-feldspar compositional banding; the upper of these two middle units is muscovite-rich and leucocratic. These two medial gneissic units are wedge-shaped, more than 1000 m thick in the El Oro Mountains, but are absent on the south. The great thickness of these gneisses on the north is in part the result of folding; tectonic thickening resulting from abundant isoclinal folding of gneiss in the El Oro Mountains gives way to weakly folded, well-foliated gneiss on the south. The medial gneissic units are overlain by, and locally interfinger with, the uppermost muscovite- and biotite-rich quartzofeldspathic gneiss. The upper contact of the gneissic rocks of El Oro is sharp and well defined, marked by the distinctive mica schist and amphibolite of Las Quebraditas.

Quartzofeldspathic gneiss similar to that of El Oro is also present in the Rincon Mountains and the Romero Hills north of the Mora River (Fig. 1). In the Rincon Mountains, quartz-plagioclase-microcline-mica gneiss is massive, strongly sheared, isoclinally folded and locally interlayered with thin lenses of quartz-mica schist. These rocks are similar to the middle gneissic units in the El Oro Mountains. The base of the gneiss is not exposed. The upper contact is gradational into micaceous quartzites similar to those exposed near Rociada; the intervening mica schist-amphibolite sequence that marks the upper contact in El Oro Mountains is missing.

In the Romero Hills, gneiss similar to the lowermost migmatitic gneiss of El Oro is overlain by a thin, discontinuous lense of micaceous quartzite that pinches out northward; north of the pinchout, the gneiss of El Oro is overlain by thinly layered quartzofeldspathic gneisses, micaceous quartzites, and amphibolite similar in texture and composition to the gneiss of Rociada.

In thin section, the gneissic rocks of El Oro contain quartz, plagioclase (oligoclase-andesine), and microcline, minor and commonly variable amounts of muscovite, biotite, and opaque oxides, and trace amounts of garnet and sillimanite. Alteration products include limonite and chlorite. The rocks are granitic in composition, as shown by the modal analyses listed in Table 1.

Two thin lenses of gray quartzite are interlayered with quartzofeldspathic gneiss. These lenses attain a maximum thickness of about 75 m but pinch out southward. Contacts with the enclosing gneiss are commonly gradational. In thin section, quartz constitutes 85–90% of the rock. Grains are granoblastic elongate, strained and commonly show intergranular mortar texture. Muscovite makes up the bulk of the remainder of the rock; laths are evenly distributed, generally lepidoblastic, present as slightly bent crystals or as thin seams between quartz grains. Smaller laths are present in the mortar zones and are commonly shredded, bent or broken. Minor muscovite crystals are oriented at a large angle to the layering and locally these crystals are kinked or weakly bent around axes that lie in the plane of layering. Very minor, ragged laths of biotite are associated with well-formed, lepidoblastic muscovite. Seams of opaque oxides are present as anhedral, elongate grains subparallel to the layering, and as euhedral crystals that cut across grain boundaries. Trace amounts of epidote, zircon and sphene are present.

TABLE 1. Modal analyses (volume percent) for representative specimens of metamorphic rocks. Gneiss of El Oro: 1—lower member; 2—middle member; 3—upper member; 4—micaceous quartzite. Schist of Las Quebraditas: 5, 6 and 7. Gneiss of Rociada: 8 and 9, micaceous quartzite; 10 and 11, gneiss; —, not found; Tr, trace.

	Gneiss of El Oro				Schist of Las Quebraditas			Gneiss of Rociada			
	1	2	3	4	5	6	7	8	9	10	11
Quartz	48	42	40	90	40	33	61	42	59	30	39
Plagioclase	14	15	21	--	5	0	7	7.5	--	47	35
Microcline	33	33	25	--	0	25	3	12	--	12	23
Muscovite	1	9	13	8	48	26	27	28	39	8	2
Biotite	2.5	Tr	--	--	4	12	0	8	--	Tr	Tr
Opaque Oxides	2	1	1	1.5	3	3	1	Tr	2	2	--

Mica schist and amphibolite of Las Quebraditas

The metamorphic rocks of Las Quebraditas consist of lower, middle and upper quartz-muscovite schist members separated by layered, fine-crystalline amphibolites. Minor quartzofeldspathic gneiss, chlorite-tremolite schist and laminated magnetite-bearing quartzite are present.

Quartz-muscovite schist is the principal component of the layered metamorphic sequence of Las Quebraditas. Exposures are characteristically poor; where well exposed, the rock displays a pronounced silver-gray sheen and the schistosity commonly shows well-developed crenulations with axes oriented in two or more directions. Layering is defined by medium- to coarse-crystalline lepidoblastic muscovite interlayered with seams of fine- to medium-grained quartz. The relative percentages of quartz and muscovite are variable (Table 1); the combined volume percent ranges between 59 and 94 and many rocks contain more than 80 percent of these two minerals.

The quartz-muscovite schists are not lithologically homogeneous; these rocks include minor quartz-pebble conglomerate, and laminated quartz-plagioclase ± biotite ± hornblende gneiss.

In thin section, the rock contains mineral parageneses that are synkinematic and postkinematic. Synkinematic minerals are granoblastic equant to elongate or lepidoblastic and commonly show undulatory extinction. These minerals are, in addition to quartz and muscovite, minor plagioclase (oligoclase), biotite and opaque oxides. Postkinematic minerals are separated into two groups: minerals that show helicitic, porphyroblastic and poikiloblastic textures, that are not rolled or otherwise deformed, and that apparently formed during a phase of high temperature and non-directed stress (andalusite, garnet and biotite) and microcline and muscovite(?) related to potassium metasomatism.

The oldest and structurally lowest amphibolites are locally complexly interlayered with metapelites that rest directly above the quartzofeldspathic gneiss of El Oro. These rocks are well exposed in, and west of, the Las Quebraditas Valley; a partial section is exposed in the Romero Hills east of Mora. On the west the unit is much thinner and consists of thin metapelites interlayered with amphibolites and amphibole- and biotite-bearing quartzofeldspathic gneiss. This sequence is absent in the Rincon Mountains.

Two mappable amphibolitic units are present and are separated almost everywhere by a thick sequence of interlayered metapelitic rocks and micaceous quartzites. The lowermost amphibolite consists of complexly interlayered, fine-crystalline, laminated amphibolite generally less than 2 m in thickness, lenses of biotite-quartz-feldspar gneiss, thin seams of discontinuous quartzite less than 4 cm in thickness, and locally very quartz-rich lenses containing small sparse crystals of hornblende. The lowermost amphibolite also includes nonfoliate, coarse-crystalline hornblende-plagioclase amphibolite that probably represents younger gabbroic sills intruded into the layered sequence.

The structurally uppermost and youngest amphibolite is also characterized in part by interlayered fine-crystalline amphibolite and associated biotite-bearing gneiss and quartzite, but also includes thick, dark gray to black, fine-crystalline layered amphibolite that locally, on weathered surfaces, contains tabular to cylindrical cavities oriented parallel to layering. These vuggy amphibolites are always associated with discontinuous lenses of purplish, laminated, magnetite-rich quartzite. This upper amphibolite is locally associated with several minor lenses of chlorite-tremolite schist.

In this section, all rocks are seen to contain highly variable amounts of amphibole, quartz, plagioclase (oligoclase to andesine) and epidote, generally minor amounts of garnet, sphene and opaque oxides, and trace amounts of talc, apatite and zircon. Alteration products include clinozoisite and chlorite after hornblende and sericite after plagioclase. Microcline and epidote, where present, occur as thin veinlets, or as replacement products of plagioclase and hornblende, respectively. The variable mineralogy of these rocks is a function of both prograde and retrograde metamorphism; retrograde metamorphic minerals, mainly epidote and clinozoisite, are best developed in rocks adjacent to granite and granite gneiss of Hermit Peak.

Discontinuous lenses of greenish-tan to medium gray to purple quartzites are interlayered with the structurally higher sequence of amphibolites. Thickness of the lenses is variable, but is commonly 5 m or less. Most lenses are less than 0.5 km long, although some can be traced for more than 1 km. The rock is thin- to medium-bedded and in hand specimen contains conspicuous lamellae of opaque oxides. Quartz is the main constituent and occurs as granoblastic elongate grains showing locally well-developed mortar texture. Layering is defined by the subparallelism of quartz grains and associated seams and trains of opaque oxides. Quartz grains are typically anhedral, strained and show good evidence of grain growth. Contacts between grains are generally diffuse and irregular. Opaque oxides are present as small euhedra or as larger anhedral to subrounded grains, commonly partly altered to limonite. Minor amounts of biotite and muscovite are locally present.

Several lenses of chloritic schist are associated with the structurally higher sequence of layered amphibolites. In hand sample, these rocks are dark green, chlorite-rich and show well developed schistosity. In thin section, the specimens differ somewhat in mineralogy. One lens exposed east of the El Oro Mountains is a chlorite-talc-tremolite/actinolite schist, whereas a lens exposed on the south consists principally of hornblende, chlorite and quartz. In both specimens, chlorite is largely a retrograde alteration product of amphibole.

Micaceous quartzite and quartzofeldspathic gneiss of Rociada

Micaceous quartzite and quartzofeldspathic gneiss are interlayered with minor amphibolite, calc-silicate rock and marble. To the south, these rocks have been complexly intruded by synkinematic mafic to intermediate igneous plugs, sills and minor dikes and later intruded and hydrothermally altered by postkinematic granite. These rocks are divided into two units based on texture and composition. Rocks exposed north of Rociada consist principally of fine- to medium-crystalline, commonly thinly layered to fissile, micaceous, feldspathic quartzite. These rocks are mesoscopically distinct from a heterogeneous, generally pink, fine- to coarse-crystalline microcline-bearing quartz-feldspar-mica gneiss to the south. The contact between the two units, which is irregular, gradational and cuts across the compositional layering, is probably related to metamorphic and igneous processes rather than original lithology. In thin section, the units are less easily distinguished, as compositional and textural variations are peculiar to both.

Rocks exposed directly north of Rociada consist of thick, alternating layers of fine-grained, laminated, micaceous feldspathic quartzite and fine-grained, quartz-feldspar-mica granofels. Layers range in thickness from about 5 m to more than 30 m. The base of this sequence contains minor quartz-pebble conglomerate. The rock is typically equigranular, but locally contains larger (2–5 mm) ellipsoidal quartz and less commonly subhedral plagioclase grains. Layering is defined by subparallel compositional banding, lepidoblastic muscovite and thin seams of opaque oxides. Discontinuous lenses of larger quartz "eyes" and plagioclase crystals are parallel to the schistosity.

Correlative rocks are present west of the El Oro Mountains and in the Rincon Mountains (Fig. 1). In the Rincon Mountains the rock is less fissile, more coarsely crystalline and more quartz rich.

Modal analyses of the micaceous quartzites show them to be variable in composition (Table 1). In thin section, these rocks contain quartz, muscovite, opaque oxides and highly variable amounts of plagioclase, microcline and biotite. Plagioclase in these rocks varies in composition from north to south. Microprobe analyses of groundmass and porphyroblastic plagioclase in rocks directly north of Rociada show them to be albite, ranging in composition between $An_{0.3}$ to $An_{1.7}$; however, near the contact of these rocks with the more heterogeneous, microcline-bearing quartzofeldspathic gneiss on the south, these rocks contain both albite and sodic to calcic oligoclase. Trace amounts of garnet, apatite, epidote, sphene and zircon are present; biotite is locally altered to chlorite and plagioclase is partly altered to sericite.

Metamorphic rocks of Rociada also include minor layered amphibolite and calc-silicate rocks and marble. Hornblende-plagioclase amphibolites contain minor, variable amounts of biotite and quartz. Locally the amphibolites are associated with thin calc-silicate rocks rich in actinolite, tremolite, garnet, quartz, plagioclase and epidote. Fine-crystalline, thinly laminated marble is not common; where present it is interlayered with micaceous quartzites.

Quartz-feldspar-mica gneiss is a heterogeneous mixture of interlayered platy micaceous feldspathic quartzite, dense, massive feldspathic quartzite and coarse-crystalline granitic gneiss. These rocks are mesoscopically distinguished from the micaceous quartzites and granofels to the north by the greater abundance of microcline, a strong pink color, by a more dense and generally more coarsely crystalline fabric, and by more varied lithology. Along the Sapello River, large bodies of coarse-crystalline granitic gneiss were mapped separately.

Layering in these rocks is not well developed everywhere. Where the rock is more coarsely crystalline, the parallel alignment of biotite flakes and compositional layering define the foliation. In finer-grained varieties, layering is defined by thin alternating seams of quartz and muscovite. Locally the rock is so dense and massive that foliation is not obvious. Lineation, generally absent from these rocks, is defined by the fold axes of minute, crinkled muscovite grains.

In thin section, these rocks are similar in composition and texture to granofels in the north, but contain abundant microcline and less quartz. Plagioclase in these rocks is restricted to calcic oligoclase. Near the contact with the underlying quartzite and granulite, the rocks show well-developed plagioclase grain growth and myrmekite formation, replacement and recrystallization of quartz, and evidence of extensive alkali metasomatism.

Premetamorphic lithology

Metamorphic rocks of the Mora-Rociada area represent a supracrustal assemblage of interlayered sedimentary and volcanic rocks. This assemblage is composed mainly of metamorphosed pelitic and feldspathic to quartz-rich clastic rocks interlayered with minor carbonates, marl, iron-bearing quartzite and mafic tuffaceous deposits, all locally interbedded with probable felsic to mafic volcanic flows.

The protolith of the gneiss and migmatite of El Oro Mountains has been described as granite, but is more likely an altered and deformed metasedimentary-metavolcanic rock. Reise (1969) interpreted rocks in the southern Rincon Mountains as granites. In the El Oro Mountains, these rocks are layered and include a variety of rock types; compositional layering is subparallel to layering in the less strongly deformed, overlying metasedimentary and metavolcanic units. The lowest migmatite and gneiss are granitic in composition (Table 1), but are interlayered with micaceous quartzites and metapelites. Metamorphism and penetrative deformation have obscured all original textures. These rocks probably represent a metasedimentary and/or metavolcanic sequence that was locally potassium metasomatized during regional metamorphism.

The mica schists of Las Quebraditas are interpreted to originally have been a peraluminous clastic sedimentary sequence composed mainly of quartz, clays and minor feldspar. This interpretation is based on: (1) the quartz-muscovite mineralogy; (2) interlayering with thin, locally graded quartzite lenses; and (3) an association with minor quartz-pebble conglomerate.

The amphibolites associated with the mica schists of Las Quebraditas are of sedimentary and igneous parentages. The lower, thinly laminated quartz-feldspar-hornblende gneiss and schist associated with thin quartzite seams and lenses of quartz-plagioclase-biotite gneiss probably represent locally calcareous, argillaceous sedimentary deposits interlayered with minor quartz sand and possible reworked volcanic debris.

The upper dense, dark gray to black, vuggy, layered amphibolites and associated chlorite-tremolite schists may represent basalt flows and tuffs, respectively. The original fabric and mineralogy of these rocks has been altered and gives few petrographic clues to the original rock type. The homogeneity of the rock in outcrop, especially its finely crystalline, weakly laminated texture and the unique association with laminated magnetite-bearing quartzites, sets these rocks apart from the underlying, heterogeneous, layered hornblende gneiss and schist. Chemical analyses of a laminated vuggy amphibolite (1), a chlorite-tremolite schist (2), and a dense amphibolite adjacent to magnetite-bearing quartzite (3), all collected from the southernmost exposures in the area, as listed in Table 2.

TABLE 2. Chemical analyses and CIPW normative composition (wt %) of selected metamorphic rocks. Major oxide analyses performed by rapid rock methods described under "single solution" in Shapiro (1975). Analyses by K. Coates, H. Smith, Z. A. Hamlin and N. Skinner.

	Upper amphibolite of Las Quebraditas			Micaceous quartzite of Rociada				Average metarhyolite*	
	1	2	3	4	5	6	7	8	9
SiO_2	47.2	45.4	51.3	79.5	81.7	81.0	76.2	81.5	74.67
Al_2O_3	16.7	11.3	17.2	12.3	9.8	10.8	13.9	11.5	12.36
Fe_2O_3	3.0	4.0	6.0	1.2	2.2	1.5	1.2	1.6	1.84
FeO	9.1	9.3	6.2	0.28	0.08	0.28	0.28	0.32	0.68
MgO	6.3	16.1	3.8	0.08	1.1	0.29	0.38	0.19	0.18
CaO	11.7	9.2	9.0	0.29	1.1	0.3	0.1	0.4	0.7
Na_2O	2.4	1.2	2.5	6.0	2.7	1.1	0.93	0.44	3.14
K_2O	0.56	0.1	1.0	0.42	1.7	4.2	6.1	3.7	5.18
H_2O^+	0.74	2.2	1.2	0.55	0.33	0.98	0.98	1.2	0.56
H_2O^-	0.02	0.27	0.18	0.04	0.04	0.21	0.16	0.26	0.27
TiO_2	0.76	0.84	1.5	0.06	0.08	0.25	0.06	0.22	0.04
P_2O_5	0.10	0.13	0.29	0.05	0.04	0.09	0.04	0.05	0.05
MnO	0.15	0.26	0.20	0.01	0.02	0.06	0.02	0.04	----
CO_2	0.36	0.01	0.01	0.0	0.01	0.01	0.04	0.01	----
Total	99.09	100.31	100.38	100.78	100.87	100.07	100.39	101.03	99.67

*Barker and Friedman, 1974

Normative minerals (from normalized analyses)

	1	2	3	4	5	6	7	8	9
Q	----	---	9.88	42.83	55.33	57.84	47.20	63.83	35.43
C	----	----	----	1.80	1.63	4.15	5.81	6.19	0.46
or	3.31	0.59	6.03	2.48	9.99	24.82	36.34	21.87	30.98
ab	20.66	10.41	21.49	49.92	22.76	9.31	7.95	3.72	26.83
an	33.75	25.86	33.23	1.11	5.08	0.84	----	1.60	3.15
$\frac{100an}{(ab+an}$	An_{62}	An_{71}	An_{61}	An_2	An_{18}	An_8	An_0	An_{30}	An_{11}
di wo	9.35	8.40	4.24	----	----	----	----	----	----
di en	4.91	5.76	2.62	----	----	----	----	----	----
di fs	4.17	1.97	1.38	----	----	----	----	----	----
hy en	4.06	15.64	5.72	0.20	2.71	0.72	0.94	0.47	0.45
hy fs	3.44	5.34	3.01	----	----	----	----	----	----
ol fo	4.89	13.87	----	----	----	----	----	----	----
ol fa	4.57	5.22	----	----	----	----	----	----	----
mt	4.35	5.96	8.83	0.76	0.09	0.37	0.79	0.52	2.08
hm	----	----	----	0.67	2.13	1.24	0.66	1.24	0.43
il	1.46	0.66	2.89	0.11	0.15	0.47	0.11	0.42	0.08
mg	----	----	----	----	----	----	0.01	----	----
ap	0.23	0.30	0.67	0.12	0.09	0.21	0.09	0.12	0.12
cc	0.82	0.02	0.02	----	0.02	0.02	0.08	0.02	----

If major element chemistry reliably approximates the original chemical composition of these rocks, then these three specimens lie within the igneous rock field defined by van de Kamp (1969) (Fig. 2A). The trend line defined by these specimens, in conjunction with specimens of the metaigneous rocks of Sapello, is at a large angle to the compositional trend lines of sedimentary rocks; rather, it is closely aligned with that defined by the Karoo dolerites (Fig. 2B). If these rocks are metavolcanic assemblages, chemical analyses indicate that they are subalkaline and komatiitic (Table 2, Fig. 3), and closely related to the metaigneous rocks of Sapello (Figs. 2, 3). The magnetite-bearing quartzites that are associated only with these rocks may represent a poorly developed oxide facies of iron-formation formed by exhalative submarine volcanic activity.

The micaceous quartzite of Rociada probably represents a thick succession of argillaceous sandstones. They commonly show graded bedding and crossbedding and are associated with minor quartz-pebble conglomerate, calc-silicate rock and marble. Interlayered with the quartzites are quartz-rich rocks that have a strong pink color, are laminated and contain conspicuous ellipsoidal quartz and plagioclase grains. These rocks are bimodal in grain size, do not contain any sedimentary structures and are texturally very similar to aphanitic porphyritic volcanic rocks.

Chemical analyses of these rocks are listed in Table 2. Specimens 4 and 5 show bimodal grain size; 6 is a micaceous quartzite closely associated with amphibolite and iron formation; 7 is a laminated quartz-feldspar-muscovite gneiss; and 8 is a micaceous quartzite. These rocks

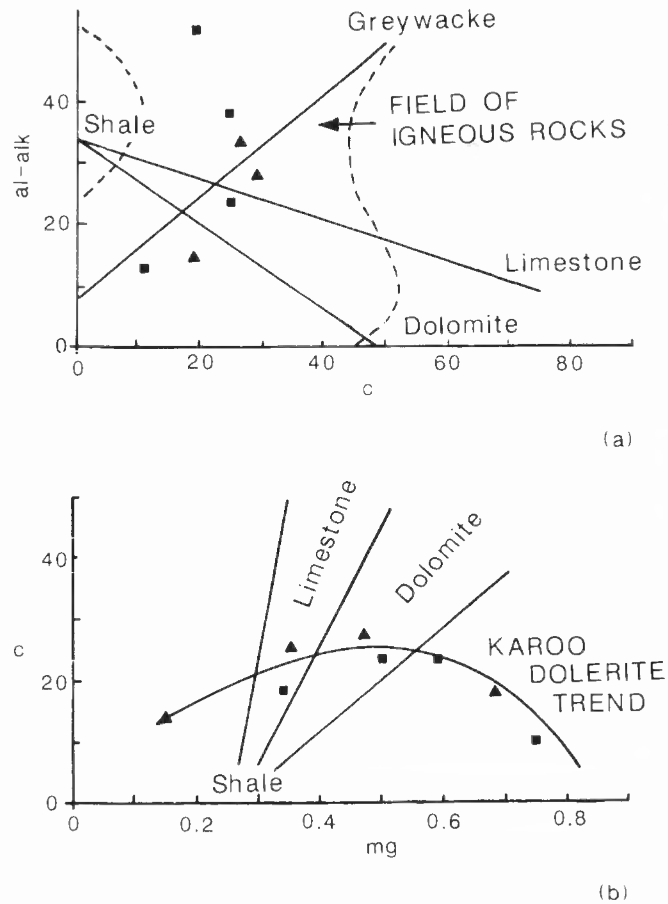

FIGURE 2. A, plot of Niggli c versus al-alk values for two amphibolites and one chlorite-tremolite schist of Las Quebraditas (triangles) and for metaigneous rocks of Sapello (squares). The solid lines show compositional trends for greywacke and for shale to carbonate sedimentary rock mixtures (after van de Kamp, 1969); B, plot of Niggli c versus mg values for two amphibolites and one chlorite-tremolite schist of Las Quebraditas (triangles) and for metaigneous rocks of Sapello (squares). Trend lines for shale to carbonate sedimentary rock mixtures and for the Karoo dolerites (after Leake, 1964).

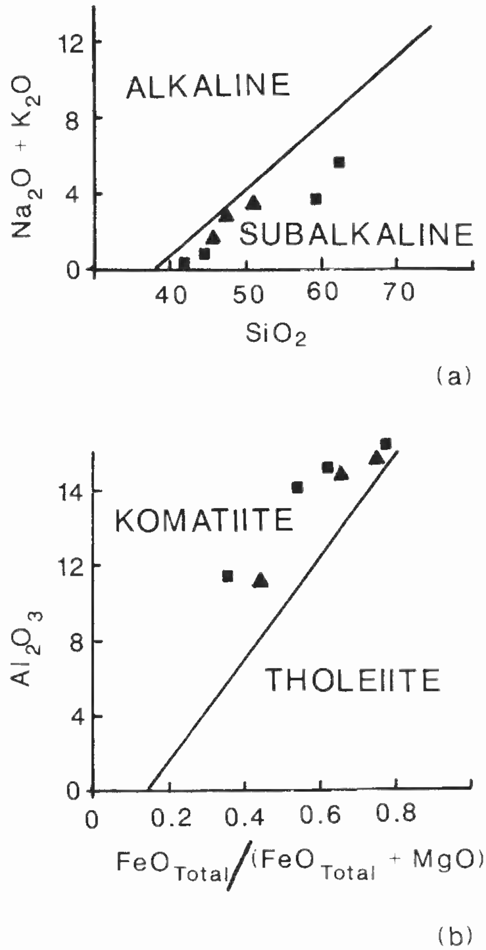

FIGURE 3. Igneous rock classification of two amphibolites and one chlorite-tremolite schist of Las Quebraditas (triangles) and for metaigneous rocks of Sapello (squares). A, after Irvine and Baragar (1971); B, after Arndt (1976).

are extremely silica rich, with SiO_2 values ranging between 76.2 and 81.7%. Total alkalies vary from 4.14 to 7.03%, and there is no consistent relationship between K_2O and Na_2O. Al_2O_3 ranges between 9.8 and 13.9%. These analyses are significantly different from the average of 10 analyses of Precambrian metarhyolites from north-central New Mexico (Table 2, column 9) (Barker and Friedman, 1974). Perhaps many of the Rociada rocks were originally quartzites that contained minor, variable amounts of clays and detrital feldspar; however, those rocks with bimodal grain size whose fabric is suggestive of volcanic rock cannot be chemically distinguished from nearby quartz-rich rocks that lack that texture. Alteration of felsic volcanic rocks to quartz muscovite schist has been documented and described from similar Proterozoic rocks exposed in north-central New Mexico (Barker, 1958; Bingler, 1965; Gresens, 1971, 1972; Gresens and Stensrud, 1974); platy quartz muscovite schist, that could be interpreted to be a metasedimentary rock containing rounded, relict quartz "eyes," has been shown to be an altered volcanic rock that grades laterally into metarhyolite. Hydrogen metasomatism (Hemley and Jones, 1964) probably drives this alteration process.

Igneous rocks

Intrusive rocks are present throughout the map area and are divided into two groups: (1) an older metaigneous, synkinematic rock sequence that ranges in composition from mafic to tonalitic; and (2) postkinematic pegmatite and granite. The rocks of the mafic sequence are most abundant south of Rociada and are best exposed along the Sapello River. Granite is present throughout the map area; the largest body is well exposed in the southernmost part of the map area, north of Hermit Peak.

Metaigneous rocks of Sapello

Foliated, chlorite-tremolite plug-shaped bodies, irregular plugs, sills, and minor dikes of coarsely crystalline foliated amphibolite, and concordant quartz + plagioclase ± hornblende ± biotite gneiss are common along the Sapello River. Contacts between these rocks and the well-layered metamorphic rocks are sharp. The margins of all intrusive bodies are generally finely to medium-crystalline, foliated and grade inward to a coarsely crystalline, non-foliated core. The layering at the margins of the bodies is subparallel to that of the enclosing host rocks. Chlorite-tremolite schist in irregular plugs is locally gradational into coarse-crystalline hornblende-plagioclase amphibolite. Amphibolite-to-tonalite contacts are gradational over several meters or more.

Four chemical analyses of specimens collected from continuously exposed rock ranging from chlorite-tremolite schist to gray-colored felsic gneiss, listed in Table 3 (columns 1 through 4), show these rocks to range in composition from norite to tonalite. The local plug-like, discordant character of these rocks, their gradational contacts with one another, and the subparallelism of their fabric with that of the host rocks, sugests that these bodies represent a consanguineous, late synkinematic intrusive rock suite.

Two plug-like bodies of noritic gabbro composed of chlorite-tremolite schist are exposed in the valley drained by the Sapello River. They are circular to elliptical in plan with a maximum dimension of about 200 m. The plugs are exposed in an area that is complexly intruded by tonalite and coarse-crystalline gabbro; both plugs are in contact with

TABLE 3. Chemical analyses and CIPW normative composition (wt %) of intrusive igneous rocks. Major oxide analyses performed by rapid rock methods described under "single solution" in Shapiro (1975). Analyses by K. Coates, H. Smith, Z. A. Hamlin and N. Skinner.

	Metaigneous rocks of Sapello				Granite of Hermit Peak		
	1	2	3	4	5	6	7
SiO_2	63.0	60.2	51.2	42.9	73.6	71.6	75.6
Al_2O_3	15.7	15.1	13.9	11.7	13.9	15.1	11.5
Fe_2O_3	1.7	1.5	2.1	2.1	1.7	1.5	2.1
FeO	4.2	5.4	7.6	10.3	0.36	0.64	0.64
MgO	1.8	4.0	8.2	21.9	0.23	0.29	0.10
CaO	5.1	7.5	9.9	5.7	0.32	1.1	0.89
Na_2O	4.0	2.9	2.2	0.50	4.5	4.3	2.3
K_2O	1.7	0.94	0.60	0.08	4.4	4.8	5.1
H_2O^+	0.73	0.72	1.3	4.9	0.63	0.46	0.32
H_2O^-	0.01	0.04	0.15	0.04	0.10	0.01	0.13
TiO_2	0.86	0.78	0.85	0.24	0.04	0.07	0.19
P_2O_5	0.41	0.44	0.30	0.17	0.03	0.05	0.05
MnO	0.10	0.11	0.16	0.16	0.02	0.06	0.04
CO_2	0.08	0.06	0.02	0.01	0.02	0.01	0.02
Total	99.39	99.69	98.48	100.7	99.85	99.99	98.98
Normative minerals (from normalized analyses)							
Q	19.49	17.70	3.07	----	29.97	25.73	41.48
C	----	----	----	0.91	1.28	0.90	0.76
or	10.16	5.61	3.66	0.47	26.24	28.48	30.61
ab	34.27	24.79	19.21	4.40	38.42	36.55	19.72
an	20.15	25.68	27.08	28.48	1.27	5.12	4.01
$\frac{100an}{(ab+an)}$	An_{37}	An_{51}	$An_{58.5}$	An_{90}	An_{59}	An_{56}	An_{39}
di wo	0.94	3.62	8.92	----	----	----	----
di en	0.43	1.98	5.46	----	----	----	----
di fs	0.49	1.51	2.97	----	----	----	----
hy en	4.10	8.08	15.59	21.97	0.57	0.72	0.25
hy fs	4.66	6.16	8.47	6.88	----	----	----
ol fo	----	----	----	24.52	----	----	----
ol fa	----	----	----	8.47	----	----	----
mt	2.49	2.20	3.13	3.18	1.11	2.06	1.67
hm	----	----	----	----	0.95	0.09	0.97
il	1.65	1.50	1.67	0.47	0.08	0.13	0.36
ap	0.97	1.02	0.72	0.42	0.07	0.12	0.12
cc	0.18	0.14	0.05	0.02	0.05	0.02	0.05

these rock types. The small plug north of Sapello River grades from chlorite-tremolite facies (norite) to coarse-crystalline hornblende-plagioclase (gabbro), to quartz-plagioclase-hornblende gneiss, to quartz-plagioclase-biotite gneiss (tonalite).

In hand specimen, the rock is dense, dark green and coarsely crystalline. The plug on the south side of the river is strongly schistose; layering is parallel with the foliation in the host rocks, whereas the plug north of the river is very coarsely crystalline and massive. Mineralogy is mainly amphibole partly or wholly altered to chlorite. Garnet is locally abundant in the southernmost exposure only. In thin section, the rock is seen to contain colorless to pale green tremolite-actinolite which is partly altered to prochlorite. Minor garnet, opaque oxides and sphene are present as well as trace amounts of apatite.

Coarse-grained amphibolitic rocks of gabbroic composition are present throughout the map area and are especially common from Rociada south towards Hermit Peak. These rock units are both concordant and discordant, lensoid to irregular in shape and consist principally of hornblende and plagioclase. Coarsely crystalline, massive textures are characteristic of the cores of the bodies whereas medium-crystalline, schistose textures predominate near the margins. Locally, finely crystalline, strongly contorted zones within the masses are commonly associated with vuggy, coarse-crystalline mafic pegmatoid. Less common but widespread are fine-crystalline, concordant amphibolites similar to those interlayered with metapelites of Las Quebraditas area; however, because of the difficulty in distinguishing between metasedimentary and metaigneous amphibolites, all amphibolites not interlayered with mica schists of Las Quebraditas are included in this map unit. Most of these rocks are thought to represent metaigneous rocks—either volcanic flows or plutonic sills and dikes.

The coarsely crystalline gabbro contains variable amounts of hornblende, plagioclase and epidote and minor amounts of quartz, biotite, pyroxene and opaque oxides. Microcline, where present, occurs in thin veinlets. Trace amounts of sphene, apatite, tourmaline and calcite are present. Alteration products include epidote, clinozoisite and chlorite.

Massive, generally foliated, light-to-medium-gray bodies of tonalite containing quartz + plagioclase ± biotite ± hornblende are exposed north and south of the Sapello River. These rocks are present as generally concordant lenses that thin and pinch out northward. Layering, where present, is defined by thin seams of lepidoblastic biotite that are subparallel to the fabric of the host rocks. Locally, exposures show a continuous gradation from biotite- to hornblende-rich rock.

These rocks contain abundant plagioclase, commonly zoned from sodic andesine to oligoclase, and quartz, variable amounts of biotite and hornblende and minor amounts of muscovite and epidote. Sphene, apatite and opaque oxides are present in trace amounts and alteration products include chlorite, sericite and minor microcline. Like the layered amphibolites and associated chlorite-tremolite schist of Las Quebraditas, these rocks are also subalkaline and show komatiitic affinities (Fig. 3). The ortho-amphibolite of Las Quebraditas and the synkinematic intrusive rocks of Sapello appear to share a common genesis (Figs. 2, 3).

Pegmatite and granite

Granitic to almost pure quartz pegmatite is present throughout the area as sills, minor dikes, and small plug-like bodies in the mica schist and amphibolite of Las Quebraditas. These intrusive rocks range in size from equigranular, concordant to discordant quartz-feldspar lenses 1–2 cm thick, to massive, mainly concordant lenses more than 100 m thick. Most are granitic in composition, although some are composed almost exclusively of white, coarsely crystalline quartz. Most pegmatites have finely crystalline margins and coarsely crystalline cores; the cores of the larger bodies may contain abundant feldspar crystals as much as 1 m long, local biotite and muscovite books 6–8 cm in diameter, amphibolite crystals up to 4 cm long, and smaller crystals of garnet and tourmaline, and less common seams rich in magnetite.

Pegmatites intruded into the gneisses of El Oro are generally less than 5 cm thick, are locally folded and in the lower part of the sequence are associated with 2–4-cm-diameter knots of plagioclase or plagioclase and quartz that are strung out and elongate parallel to the foliation. In more schistose rocks of Las Quebraditas, pegmatite injection appears to have deformed the host rocks, resulting in small amplitude folds restricted to rocks adjacent to the intrusion. Surfaces of these pegmatites are commonly marked by grooves or mullion structure that are subparallel to the crenulation and mineral lineations in the rocks. Abundant granitic pegmatites are also present in rocks adjacent to the granite of Hermit Peak.

At least two generations of pegmatites are distinguished. Thin, concordant, locally knotted quartz-feldspar pegmatites in the lower gneissic units of El Oro appear to have formed by metamorphic differentiation and mineral segregation during regional metamorphism; these bodies did not deform or alter host rock, but are passively intercalated within the layered sequence. Large, mainly concordant, coarse-crystalline quartz and quartz-feldspar pegmatites intrude all rocks in the area. These pegmatites, most abundant in the schist and amphibolite of Las Quebraditas which directly overlies the gneissic rocks of El Oro, are synkinematic; whether they are related to partial melting of the underlying rocks or related to synkinematic intrusive rocks of Sapello is not certain. The pegmatites located around the periphery of the granite of Hermit Peak are probably related to this Middle Proterozoic postkinematic intrusive phase.

A large, elliptical intrusive body of granite is present in the southern part of the map area (Fig. 1), underlying the north slopes of Hermit Peak which is located directly south of the map boundary. The region of granitic exposure shown in Figure 1 can be divided into two parts (Baltz and O'Neill, 1986): nonfoliated to weakly foliated granite, not associated with pegmatite, is present on the east; on the west, granite encloses numerous slivers and irregular slices of host rocks that are strongly migmatized, partly assimilated, and closely associated with coarse-grained, semiconcordant granite pegmatite. Enclosed metamorphic rocks locally are intricately penetrated by thin dikes and veins of fine- to medium-grained, nonfoliate granite. Contact of the main intrusive body on the east cuts across the regional foliation, suggesting that the granite was emplaced during a postkinematic intrusive event. Chemical analyses of these rocks (Table 3) show them to be granitic in composition, and distinctly different in major element chemistry than the subalkaline suite of older, synkinematic rocks of Sapello.

METAMORPHISM

Precambrian rocks of the Mora-Rociada area were regionally metamorphosed to amphibolite-grade and subsequently modified by thermal, dynamic and metasomatic events (Table 4). Gneissic rocks of El Oro display mineral parageneses indicative of the middle subfacies of amphibolite-grade metamorphism; the mineral assemblage characteristic of these rocks is quartz + muscovite + biotite + plagiclase + sillimanite. Overlying rocks of Las Quebraditas are apparently slightly lower grade, containing the assemblage quartz + muscovite + biotite + plagioclase + andalusite ± sillimanite. Flow folding and ductile shearing accompanied regional metamorphism, resulting in locally strong internal deformation and development of a pervasive extension lineation. Formation of the El Oro, Rincon and Romero Hills anticlines overlapped with a thermal event.

Regional metamorphism was followed by a period of elevated temperature and nondirected stress. Mica-bearing rocks show randomly oriented poikiloblasts of biotite or andalusite, or laths of biotite and muscovite that grew with their long axes at a high angle to the tectonite fabric. In amphibolites, green to brown pleochroic, uniformly oriented hornblende crystals are crosscut by randomly oriented blue-green amphibole.

In the gneiss of El Oro and schist of Las Quebraditas, randomly oriented crystals are locally bent or broken, suggesting a minor, geographically restricted dynamic event. Evidence of this phase of deformation was not observed in the gneiss of Rociada.

Metamorphism and deformation were followed by a period of alkali metasomatism that is spatially dispersed around the granite of Hermit Peak and which most severely altered the gneissic rocks of Rociada. The gneisses of El Oro, the lowermost and northernmost rocks of the

TABLE 4. Summary of metamorphic, deformational and intrusive events that affected the Precambrian rocks of Mora-Rociada area.

	Gneiss and migmatite of El Oro		Mica schist and amphibolite of Las Quebraditas		Micaceous quartzite and gneiss of Rociada	
History of Deformation	Quartzofeldspathic Gneiss	Quartzite	Amphibolite	Quartz-muscovite Schist	Micaceous Quartzite	Calc-silicate Rock
Protolith	Sedimentary and probably volanic rocks	Argillaceous quartz sandstone	Calcareous, argillaceous sedimentary rocks and mafic volcanic rock	Argillaceous quartz sandstone	Argillaceous, feldspathic sandstone and felsic volcanic rocks	Siliceous limestone and marl
Regional Metamorphism	Granoblastic texture Prograde mineral parageneses Granitization	Granoblastic elongate texture Mortar texture between grains Strained quartz	Granoblastic elongate to equant texture Dimensional alignment of green-brown amphibole Amphibole shingled about fold axes	Lenses of opaque oxides folded into isoclines Dimensional orientation of muscovite laths	Granoblastic-elongate texture	Granoblastic-elongate texture Tremolite/actinolite shingled about fold axes
Thermal Metamorphism	Randomly oriented crystalloblasts of biotite and muscovite	Randomly oriented muscovite laths	Randomly oriented blue-green amphibole	Randomly oriented biotite and muscovite Poikiloblasts of biotite and andalusite	Randomly oriented muscovite laths	Randomly oriented pyroxene, amphibole, and muscovite
Dynamic Event	Fracturing of plagioclase	Kinked to bent randomly oriented muscovite	No evidence	Bent biotite and broken andalusite poikiloblasts	No evidence	No evidence
Alkali Meta-somatism (Retrograde)	No evidence	No evidence	Microcline veinlets cut rock or replaces plagioclase Epidote replaces plagioclase and amphibole	No evidence	Microcline replaces plagioclase Albite rinds on plagioclase grains Quartz recrystallization and grain growth	Microcline replaces plagioclase Albite rinds on plagioclase grains
Pegmatite Intrusion	No thermal effects	No thermal effects	Garnet replaces epidote	Poikiloblasts of garnet Crystalloblasts of tourmaline	Crystalloblasts of garnet	Crystalloblasts of garnet

area do not record this late stage alkali metasomatic event that alters or cuts across the tectonite fabric developed during regional metamorphism; microcline in the rocks of El Oro is clearly a prograde metamorphic mineral phase related to early regional metamorphism. The effects of strong, postkinematic alkali metasomatism are best developed in the heterogeneous, microcline-bearing gneisses south of Rociada that are adjacent to the granite of Hermit Peak; alkali metasomatism decreases northward, away from this area. Metasomatism is marked by anhedral crystals of microcline that have partly to wholly replaced small, granoblastic, elongate crystals of plagioclase; plagioclase is present as ragged inclusions in anhedral microcline and shows strong preferential replacement along twin planes. Relict crystal outlines of plagioclase are commonly preserved within microcline crystals. Farther away from the intrusive granite body, in rocks near the town of Rociada, plagioclase is not ubiquitously replaced by microcline, but rather rimmed by a thin, clear albite rind only where it is in contact with microcline. Farther north, in schistose rocks of Las Quebraditas, alkali metasomatism is restricted to areas directly adjacent to microcline veinlets; veinlets commonly cut across the tectonite fabric, plagioclase adjacent to these veins is partly to wholly replaced by microcline, and contiguous hornblende is replaced by epidote. A final, localized, thermal event is marked by the presence of poikiloblasts of garnet and crystalloblasts of tourmaline in host rocks adjacent to postkinematic garnet- and tourmaline-bearing granite pegmatites.

REGIONAL CORRELATION

Proterozoic rocks of the Mora-Rociada area have been given informal names because they are not easily correlated with well-studied, more extensively exposed sequences described elsewhere in north-central New Mexico. Informal nomenclature was also used because of the somewhat indefinite status of several Proterozoic metamorphic and plutonic sequences in the region (Bauer and Williams, 1989). The complexity of these rocks is perhaps best appreciated when one examines previous reports on these rocks, beginning with Evan Just's pioneering work in 1937, and realizes that nearly every subsequent study has modified the previously suggested stratigraphic and structural framework of this Proterozoic terrain (see references cited in Bauer and Williams, 1989).

The rocks exposed in the El Oro anticline between Mora and Rociada are an upright succession of Proterozoic supracrustal rocks consisting mainly of quartzofeldspathic gneiss derived from a siliciclastic and probable felsic volcanic sequence, interlayered in the middle part with pelitic rocks and mafic volcanic flows of probable submarine origin. Bauer and Williams (1989) correlate the lower, gneissic rocks of El Oro in this structure with the Vadito Group; the schist and amphibolite of Las Quebraditas and the lower part of the micaceous quartzite of Rociada were correlated with their overlying Hondo Group.

Quartzofeldspathic gneiss in the Rincon Mountains and the Romero Hills in the northern part of the map area, although similar to the gneiss of El Oro, is not necessarily equivalent. The absence of the schist and amphibolite of Las Quebraditas in the Rincon Mountains and the tectonic juxtaposition of quartzofeldspathic gneiss with the sequence of Las Quebraditas in the Romero Hills may indicate that the quartzofeldspathic rocks on the north represent a fundamentally different, albeit lithologically similar, sequence.

The strongly metasomatized quartzofeldspathic gneiss of Rociada and the metaigneous rocks of Sapello that intrude this gneiss have been included in the Pecos Complex by both Bauer and Williams (1989) and Robertson and Condie (1989). Rocks that comprise the Pecos Complex, a basalt-dominated bimodal volcano-sedimentary succession (Robertson et al., 1990), are among the oldest known rocks in New Mexico. This correlation, if correct, requires that a major fault separate the underlying micaceous quartzites of Rociada from the overlying older rocks. This fault is not exposed but would be buried beneath the alluvium of Rociada Valley and, farther west, beneath the Proterozoic cover rocks. Several problems must be reconciled if such a correlation is made: (1) the metaigneous rocks of Sapello, the postulated subvolcanic intrusive sequence related to the greenstone belt, appear to be synkinematic igneous intrusions emplaced during regional metamorphism that, in this area, is younger than the formation of the greenstone belt; and (2) they are present as gabbroic sills and small plugs north of the postulated fault that must separate these two rock packages. The question reduces to whether the quartzofeldspathic gneiss of Rociada can be included in an otherwise well-defined basalt-dominated greenstone belt. If they can, then perhaps the lower micaceous quartzite of Rociada that also contains gabbroic sills and the underlying metapelitic and mafic volcanic rocks of Las Quebraditas should be included in the Pecos Complex. The strong southward thinning of the upper quartzofeldspathic gneiss of El Oro (Baltz and O'Neill, 1984) may reflect an erosional unconformity between older basement rocks and the overlying Pecos Complex. The intrusion of the granite of Hermit Peak is considered to have been coeval with the latest Early Proterozoic granitic plutonism present throughout much of the southern Sangre de Cristo Mountains (Robertson and Condie, 1989).

STRUCTURAL GEOLOGY

Folds

The Precambrian layered rocks of the Mora-Rociada area were deformed into megascopic, northeast-trending folds that extend from the southern part of the map area to at least 20 km north of Mora. The strata within these structures are interpreted to be upright, hence the folds are termed anticlines and synclines; the folds are asymmetric, overturned to the east-southeast. In the map area, three major anticlines are exposed in the cores of the El Oro Mountains, the Romero Hills, and the Rincon Mountains. There is no evidence of megascopic isoclinal folding as each mappable unit is distinct and not repeated. Many of the lowermost map units, however, show strong penetrative deformation and axial planar foliation or schistosity (S_1) that is subparallel to major lithologic boundaries. Hence, the foliation or schistosity in the lowermost units is regarded as subparallel to the original compositional layering (S_0). In the structurally higher and apparently younger part of the section, S_1, where present, is subparallel to S_0.

El Oro anticline

Layered rocks in the El Oro Mountains define a noncylindrical, doubly plunging, northeast-trending anticline (Figs. 1, 4). The crest of the fold extends from the northern tip of the El Oro Mountains more than 20 km south to the Rociada area. The northeast-plunging nose of the fold is gently to steeply inclined and is associated with small amplitude warps and crinkles. The transition zone from gently to steeply north-plunging is marked by a west-northwest-trending synclinal sag located about 1.5 km south of the northernmost exposures in the El Oro Mountains. The limbs of the fold are asymmetric with respect to the crest line. The limb east of the crest line initially dips gently eastward, then is marked by a sharp flexure where the layered rocks become nearly vertical to overturned. The west limb, over much of the length of the fold, dips moderately west, becoming steeper farther away from the crest line. The geometry of the fold limbs suggests that the trace of the axial surface is located east of the crest line and is marked by the sharp change from moderate to steep easterly dip (see Baltz and O'Neill, 1984) and that the axial surface dips moderately westward and is concave downward.

The quartz-feldspar-mica gneiss exposed in much of the El Oro anticline is typically strongly folded and deformed. Foliation in these rocks is axial planar. The folds are similar, disharmonic and isoclinal; commonly the axial surfaces define the loci of shear zones. Where shearing predominates, the rocks are characterized by pseudocrossbedding structures that represent the limbs of sheared-out folds. Where folding predominates, appreciable tectonic thickening occurs, as on the southeast side of the El Oro Mountains.

The minor mesoscopic structures present in these rocks, principally the hinges of isoclinal folds, crenulation hinges in muscovite-rich layers, and dimensional alignment of prismatic minerals, in general coincide with the trend of the axis of the southern part of the anticline (Figs. 5E, F). A random pattern of these linear features is present where the El Oro anticline becomes a gently to steeply northeast-plunging structure (Fig. 5C); the random orientation of these linear fabric elements only in this area suggests that these minor tectonite features formed early in the deformational evolution of these rocks, and were locally reoriented during the somewhat later formation of the larger folds. Sequential fold development is also indicated by mesoscopic isoclinal folds that consistently show eastward-directed vergence, regardless of which limb of the anticline they are found; they are not drag folds formed during megascopic folding. However, the general colinearity and the similar southeast-verging aspect of the mesoscopic and megascopic structural elements suggest that the smaller scale folds were followed closely in time by major warping and folding, both of which probably formed in response to the same phase of shortening.

On the northwest side of the El Oro Mountains, metapelites and associated rocks show as many as five differently oriented linear features that include closely spaced crenulations, widely spaced monoclinal bends, prismatic mineral alignment, mineral streaking and slickensided

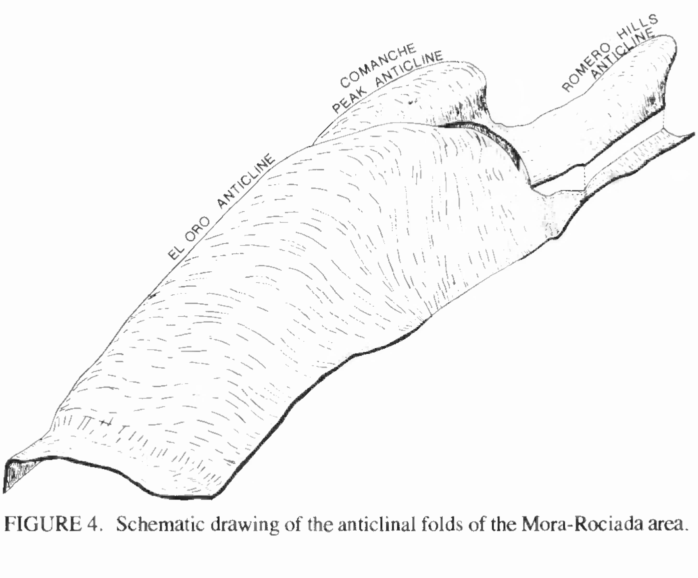

FIGURE 4. Schematic drawing of the anticlinal folds of the Mora-Rociada area.

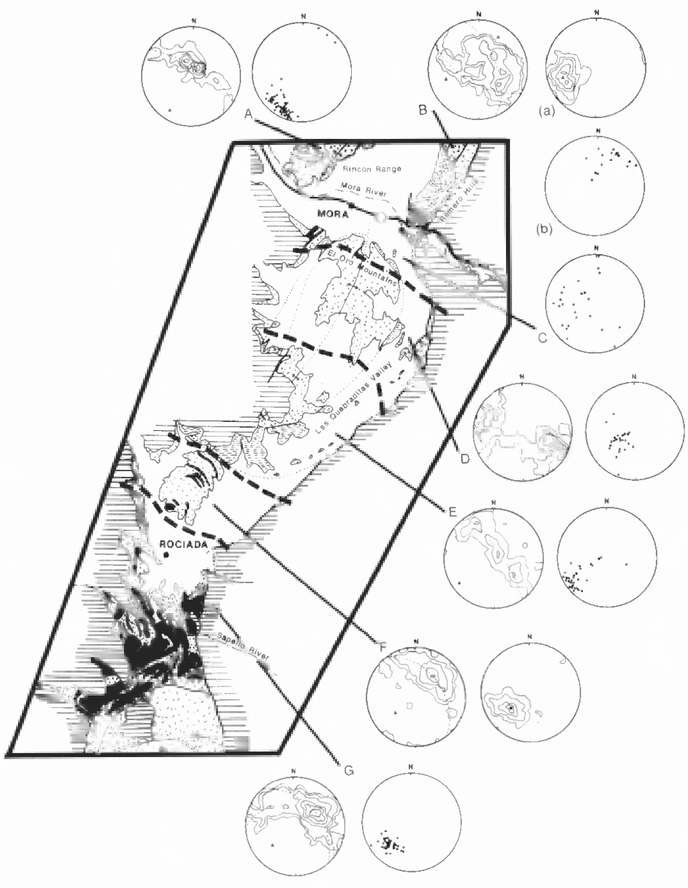

FIGURE 5. Generalized geologic map of Mora-Rociada area showing structural domains defined by orientation diagrams of Precambrian tectonites: Diagrams are equal area, lower hemisphere, sterographic projections. Contours show density of data for each domain: poles to foliation on left, lineations on right. Triangles in pi diagrams represent the normals to the great circle girdles defined by poles to foliation in that domain. Domain A—Pi diagram: 67 pts, contours 1, 3, 6, 9 and 15%; lineations: 52 pts; Domain B—Pi diagram: 245 pts, contours 0.5, 1, 3, 5 and 7%; (a) older mineral lineations and crenulations: 103 pts, contours 1, 3, 5, 9 and 13%; (b) younger fold axes: 15 pts; Domain C—older mineral lineations and crenulations: 24 pts; Domain D—Pi diagram: 101 pts, contours 0.5, 2, 4 and 6%; older lineations, 23 pts; Domain E—Pi diagram: 110 pts, contours 1, 4 and 8%; lineations: 31 pts; Domain F—Pi diagram: 222 pts, contours 0.5, 1, 4, 11 and 20%; lineations: 80 pts, contours 1, 4, 11 and 21%; Domain G—Pi diagram: 172 pts, contours 0.5, 1, 3, 5, 7 and 11%; lineations: 33 pts.

surfaces. Of the three best developed sets of crenulations, the oldest plunge southwest, parallel to the lineations in nearby metamorphic rocks, the intermediate plunge northeast, and the youngest plunge south-southwest. The origin of these crenulations is not clear: the oldest appears to be related to the pervasive southwest-plunging penetrative deformation present in all rocks of the area; the northeast-plunging crenulation appears to represent slightly younger folding related to the crumpling of stratigraphic units along the steeply northeast-plunging nose of the El Oro anticline, for nowhere else in the metapelitic sequence is this lineation attitude so pervasive and well developed; the youngest, widely spaced, south-southwest-plunging crinkles are present only along the west side of the El Oro Mountains and may be related to a small fault of Laramide or younger age that passes through this area.

Romero Hills anticline

An anticline, which is exposed over almost the entire 10 km length of the Romero Hills, plunges gently south-southwest and is strongly asymmetric, overturned to the east-southeast. Like the El Oro anticline, the oldest rock exposed in the core of the fold is quartzofeldspathic gneiss; the south end of the fold is truncated by a major fault which juxtaposes metapelite and amphibolite of Las Quebraditas with quartzofeldspathic gneiss. The sterographic projection (Fig. 5B) shows this area to be the most complex structure of the Mora-Rociada area; these rocks have experienced at least two major episodes of folding. The main girdle on the sterogram defines the southwest-plunging aspect of the fold, similar to the structural architecture of the El Oro fold; however, a second girdle defines a northeast-plunging fold. Lineation diagram (b) shows the orientation of the youngest fold axes observed from the micaceous schists exposed in the southern part of the Romero Hills and in rocks exposed directly south of the Mora River. The azimuth and plunge of these younger fold axes are roughly coincident with the normal to the less well-defined girdle of the poles to foliation. All these rocks are in an allochthonous thrust plate of Laramide age that has been thrust up to the northeast. The folding defined by the less well-developed girdle apparently owes its origin to refolding and thrusting of these rocks in Laramide time.

Comanche Peak anticline

The Comanche Peak anticline exposed in that part of the Rincon Mountains present in the northern map area represents the southernmost part of a very large anticlinal structure that extends from Mora north at least 20 km. The fold is a broad structure; the crest line defines a gently dipping west limb and a gently to very steeply inclined east limb. Like the El Oro anticline, the trace of the axial surface lies some distance to the east of the crest line, and is located near the abrupt increase in dip of the layered rocks. The geometry of the fold is nearly identical to that of the El Oro anticline and suggests that the axial plane of the fold dips west, is curviplanar, and concave downward. Like the Romero Hills and El Oro anticlines, this geometry indicates east-southeastward-directed tectonic transport. The southern part of the fold is broad, plunges gently southwest, and shows gentle undulations in the upper limb (Baltz and O'Neill, 1984).

The layered rocks that compose the core of the anticline are quartzofeldspathic gneisses similar to those rocks exposed in the El Oro Mountains and are overlain by micaceous quartzites that appear to be equivalent to those rocks exposed directly north of Rociada. The intervening metapelite-amphibolite exposed elsewhere in the map area is absent; however, this sequence is quite thin along the entire exposed west limb of El Oro anticline and may not have been deposited in the Rincon Mountains area. In the Rincon Mountains there does not appear to be a fault separating the two units; locally the two units are gradational.

Rocks exposed in the core of the anticline show strong shearing, isoclinal folding and axial planar foliation parallel to the regionally defined S_0. The hinges of the isoclines are colinear with the hinges of crenulations and prismatic mineral alignment present in the overlying micaceous quartzites, and all coincide with the trend of the axis of the anticline, as determined by poles to foliation collected from this area (Fig. 5A).

Younger folds

Folds of Proterozoic age that are younger than the genetically related mesoscopic and macroscopic folds described above are present only in the Sapello Creek area. Here, the southwest-plunging El Oro anticline has been weakly refolded. Refolding, shown on equal area projections (Fig. 5G), is superimposed on the regional southwest-plunging fold, and appears to be noncylindrical, marked by a small circle girdle of poles to foliation (long dashed line). Refolding is most pronounced in the area of strongest alkali metasomatism and suggests that granitic rocks of Hermit Peak were forcefully emplaced, dilating the host rocks and reorienting the original attitude of the original fabric elements.

Origin of anticlines

The largest fold in this area, the El Oro anticline, was interpreted by Budding and Cepeda (1979) to be a gneiss dome that formed in response to gravitational instabilities between a less dense, granitic substratum (the gneiss of El Oro) and an overlying, dense, mafic mantle (schist and amphibolite of Las Quebraditas). The presence of two additional anticlinal structures in this area that lack the mantling schists and amphibolites above the granitic core (Fig. 1), and that likely formed in response to the same regional metamorphic and tectonic conditions that formed the El Oro structure (Fig. 5), suggests that these anticlines did not form in the classical sense of the diapiric mantled gneiss domes originally described by Eskola (1949). Rather, these folds are southeast-verging structures that may be related to a regionally recognized Proterozoic tectonic event that is characterized in part by southeast-directed tectonic transport of rocks over a postulated subhorizontal detachment surface (Grambling et al., 1989; Robertson et al., 1990).

Faults

Faults that cut Precambrian rocks in the Mora-Rociada area are of at least three different ages. Precambrian age faults are present in the El Oro Mountains and the Romero Hills. Laramide-age high-angle reverse and thrust faults mark the eastern boundary of the map area. Normal faults which cut Pliocene basalt flows north of the map area and appear to cut Quaternary alluvial-fluvial deposits near Mora are superimposed on the older Laramide structures. Normal faults of uncertain age are present along the west side of the map area; these faults offset Precambrian metamorphic rocks as well as the overlying Mississippian and Pennsylvanian strata.

Precambrian faults

The El Oro anticline is cut by one Precambrian-age fault that appears to be related to the formation of the anticline. The trace of the fault is oriented at a small angle to the crest line of the fold; it intersects the crest line at the northernmost exposure of the fold and can be traced southwest for approximately 3 km. The fault dips west at an angle slightly greater than the dip of the foliation, and is marked by a thin, 30-cm-thick mylonite and by well-developed, gently northwest-plunging mullion structures. The fault appears to have minor displacement related to shortening during folding.

A high-angle fault truncates the southern end of the Romero Hills anticline. The trace of the fault trends east on the west side of the Romero Hills, there turns northeast where it is intersected by the major Laramide-age fault at an acute angle about 1.5 km to the north. The fault is covered by Quaternary alluvium on the west. Northeast-striking rocks similar to the gneiss of El Oro are present on the north and abut against the northeast-striking metapelite and amphibolite of Las Quebraditas to the south. The fault is cut by numerous Precambrian quartz-feldspar pegmatites, and fabric elements in rocks in both sides of the fault are colinear, suggesting that faulting is either pre- or synkinematic with respect to the regional metamorphism of these rocks. If the quartzofeldspathic gneiss exposed in the cores of the Romero Hills and Comanche Peak anticlines is not equivalent to similar gneiss in the El Oro anticline, then this Precambrian-age fault is a major east-trending structure that separates fundamentally different, but lithologically similar, gneissic terrains.

On the south, the strongly metasomatized, structurally higher quartzofeldspathic gneiss of Rociada has been included in the Pecos greenstone terrain (Robertson and Condie, 1989; Pecos Complex of Bauer and Williams, 1989). These rocks, which appear to rest on micaceous quartzites of Rociada that may be correlative with the younger Hondo Group (Bauer and Williams, 1989), are everywhere separated from these quartzites by alluvium. If an older-on-younger relationship truly exists, a major east-trending fault must be present beneath the alluvium of the Rociada Valley. This fault would be the eastward continuation of the large, south-dipping ductile shear zone that bounds the northern edge of the greenstone belt to the west, in the higher parts of the Sangre de Cristo Mountains (Robertson and Condie, 1989). Rocks on both sides of the postulated fault were deformed during the same regional metamorphic event that affected the entire Mora-Rociada area (Fig. 5); thus faulting must also be of Precambrian age.

Laramide faults

Laramide-age faults mark most of the eastern boundary of the map area and have deformed the Precambrian rocks. High-angle reverse faults, that locally flatten to thrust faults, juxtapose a variety of Precambrian rock types against upper Proterozoic sedimentary rocks. The character of the fault zone is variable along strike. In the Romero Hills, upper Paleozoic sedimentary rocks are draped over the nearly vertical edge of the uplifted Precambrian block; the resulting fault zone is narrow and poorly exposed. Minor faults that are at an acute angle to this zone outline distinct, ridged blocks of Precambrian rock. Linear fabric elements collected from these blocks show minor deviations from the overall southwestern plunge characteristic of the Mora-Rociada area, and suggest minor rotation during Laramide deformation (Fig. 5B).

South of the Mora River, Precambrian amphibolites are strongly fractured near low-angle Laramide-age faults. The hinges of young, minor folds here, and in the metapelites north of the gap, plunge northeast (Fig. 5B) and appear to be related to this period of faulting. Drag folds indicate predominantly vertical slip with a component of right-lateral displacement along these faults. The fault south of the Mora River is mainly of high-angle reverse sense and is marked by pervasive shearing and shattering of quartzofeldspathic gneiss along a zone as much as 100 m thick. Sedimentary rocks are draped over the edge of the uplifted block and locally have been tectonically removed.

Directly north of Sapello Creek, the Laramide faults are marked by a narrow zone, generally less than 3 m thick, of dense green, finely comminuted, cohesive rock derived principally from Precambrian amphibolite and quartz-feldspar-mica gneiss. The fault is of high-angle reverse sense, is locally associated with minor imbricate tectonic slices, and is accompanied by draping and local tectonic removal of the overlying sedimentary section.

Late Cenozoic normal faults

The north-trending Las Quebraditas and Mora Valleys, in which most of the Precambrian rocks of this area are exposed, is the southern part of a narrow, 100-km-long depression filled with Neogene sedimentary and volcanic rocks (Ray and Smith, 1941; Clark and Read, 1972). The southern part of the valley is bounded on the east by normal faults that are generally buried by alluvium (Baltz and O'Neill, 1984, 1986) that thickens to the east, adjacent to the fault (Mercer and Lapala, 1970), and pinches out to the west. North of Mora, these faults offset Pliocene basalt flows that once extended across the valley; down-to-the-west normal fault displacement of these flows is near 275 m (O'Neill, 1988). The valley is clearly a half-graben, bounded on the east by normal faults that are closely associated with Laramide reverse and thrust faults. The normal faults probably are reactivated Laramide structures that moved during late Cenozoic extension in this region, coeval with the development of the Rio Grande rift to the west.

ACKNOWLEDGMENTS

I acknowledge the encouragement given me by Elmer Baltz to pursue the study of cratonic rocks in this part of the Sangre de Cristo Mountains. This paper was originally written several years prior to the publication of this guidebook; it was resurrected at the request of Paul Bauer whose review comments, suggestions and assistance in updating the report with respect to geologic studies conducted in this area during the 1980's greatly improved the manuscript. Thoughtful and helpful reviews by George Snyder, William Johnson and Christopher Mawer also are greatly appreciated.

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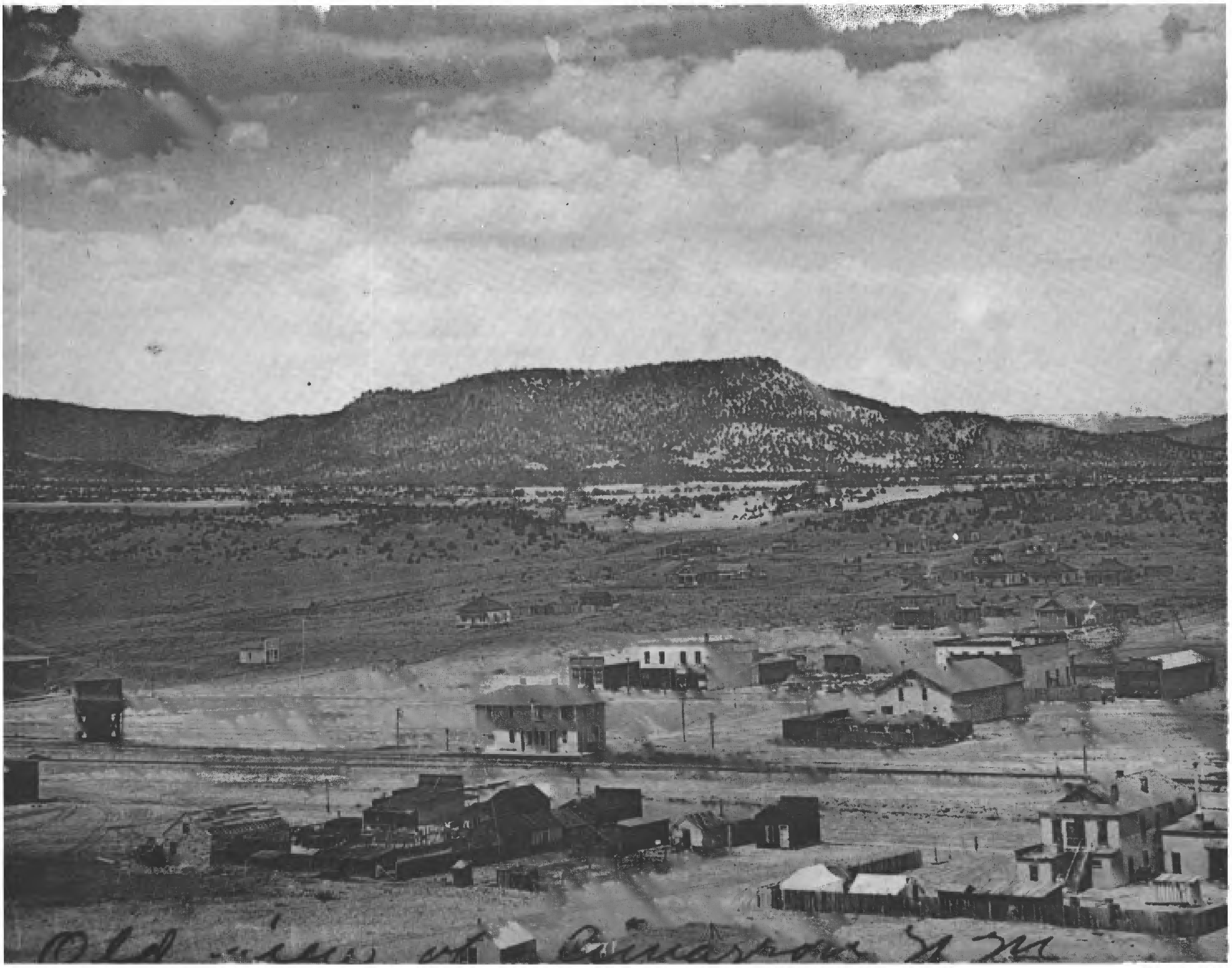
El Paso & Northwestern RR locomotive No. 3460 leaves the Dawson area with an early day "coal drag" destined for parent Phelps Dodge Co.'s Arizona copper smelters. Photo circa 1920, courtesy of Phelps Dodge Co.



Cimarron would bask in the New Mexico sun fully 65 years before the iron horse came to town. But arrive it did during the summer of 1906. Wholly owned by the St. Louis, Rocky Mountain and Pacific Co., with extensive coal reserves at Brilliant, Koehler, Van Houten, Gardner and Sugarite, the railway of the same name officially opened for business 20 February 1907. Known as the "Swastika Route," its logo was the well-known ancient Indian symbol so badly misused during WWII. The railway was well built with state-of-the-art maintenance shops, roundhouse (the Cimarron depot and water tank are shown in this view), and other facilities, and was among the first western roads to dispatch trains completely by telegraph and telephone. Although it connected with three major railroads and one short-line lumber road, it failed to generate enough traffic to pay its indebtedness. A constant drain upon the resources of the parent company, it was sold to the Santa Fe in 1913. As coal was mined out and revenues declined, the once proud railroad was abandoned branch by branch. The end for both Cimarron and Ute Park came on 9 November 1942. Photo circa 1906, courtesy of Philmont Scout Ranch.