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TECTONICS AND METAMORPHISM OF THE EL ORO GNEISS DOME NEAR MORA, NORTH-CENTRAL NEW MEXICO

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INTRODUCTION

The area under consideration is a part of the Sangre de Cristo Mountains between Mora on the north and Rociada on the south. The rocks dealt with in this article are of Precambrian age; the overlying Paleozoic rocks and extensive cover of Quaternary alluvium will not be discussed in detail.

Precambrian rocks are exposed widely in the Sangre de Cristo Mountains of New Mexico. Between the latitudes of Santa Fe and Mora, and west of the Picuris-Pecos fault (Miller and others, 1963), the exposed rocks are nearly all Precambrian in age, but east of the fault, an extensive cover of Phanerozoic rocks obscures the Precambrian rocks to a great extent. The Precambrian outcrops near Mora, that form the basis of this study, are part of a discontinuous belt of Precambrian rocks that includes the Rincon Range and the El Oro Mountains, and continues to south of El Porvenir. The present study is restricted to the Precambrian of the El Oro Mountains and adjacent Precambrian terrain between Mora and Rociada.

The general elevation of this area is between 2,150 and 2,600 m (7,100 and 8,500 ft). The area of Precambrian exposures is characterized by sharp peaks, ridges and narrow canyons. Vegetation, which can be quite dense on north-facing slopes, includes pinyon and ponderosa pine, Douglas fir, aspen, and scrub oak. The higher parts of the mountains have a dip-slope topography, cut, on the gently dipping upper Paleozoic rocks, which unconformably overlie the Precambrian. The major valleys are flat or gently sloping, and are underlain by Quaternary and possibly older valley fill.

PRECAMBRIAN ROCKS

The most widespread Precambrian rock type in the area is a light brown to gray mica gneiss, with variable mineral composition. Major constituents, in order of decreasing abundance, are quartz, microcline, oligoclase, muscovite and biotite. Garnet is relatively rare. The constituent minerals vary in amount, giving rise to micaceous, feldspar-rich and quartzitic bands within the gneiss complex.

The variation in composition suggests a sedimentary origin for the gneiss, where arkosic, arenaceous and argillaceous beds alternated in the original sedimentary sequence. An origin from felsic volcanic rocks can not be ruled out; metamorphism has obliterated any original sedimentary or volcanic structures. Magnetite is abundant in quartzite layers, where it may form as much as 25 percent of the rock, indicating that ferruginous sandstones also were present in the original sedimentary sequence.

Biotite and muscovite impart to the gneiss a well defined foliation, which is enhanced locally by concordant quartz-feldspathic veins.

The metamorphic mantle rocks of the gneiss core are mica schist, impure marble, amphibolite and quartzite. Where exposed, these rock types form a ring around the gneiss complex (fig. 1). The mica schist ranges from dark gray to silver gray, depending on the relative amounts of biotite and muscovite; other mineral constituents include quartz, oligoclase and magnetite. Garnet is locally abundant adjacent to pegmatites. The contact with the gneiss is gradational, and lenses and bands of mica schist occur within the gneiss in areas far from the schist-gneiss contact.

Sillimanite and cordierite are encountered sporadically in the mica schist. Near Cebolla Pass, two km southwest of Mora (fig. 1), the mica schist is rich in muscovite and also contains fibrous aggregates of needle-shaped sillimanite in quartz. Northeast of Rociada (fig. 1), several occurrences of cordierite are present in biotite schist and in schistose layers within the gneiss. The mineral occurs as dark blue, six-sided multiple twins, up to 25 mm across, altered to muscovite around the edges. Crystals are flattened parallel to the schistosity, but are undeformed, suggesting a posttectonic origin for the cordierite.

Quartzite layers within the gneiss are usually discontinuous and grade into other rock types. Two distinct bands of quartzite, each about 200 m wide, crop out northwest of the junction of state roads 94 and 105. The rocks are ferruginous quartzite, mainly consisting of granoblastic quartz and containing about 20 percent magnetite and hematite.

Northeast of Rociada, the gneiss and amphibolite contain several thin, highly contorted layers of rocks rich in carbonate and calcium silicates. Major mineral constituents are deformed and twinned calcite, diopside, tremolite/actinolite, epidote, spinel, wollastonite and chlorite. Feldspars include oligoclase and microcline.

The mode of occurrence of the marbles (as highly deformed, discontinuous bands) and their mineralogical composition suggest that these rocks are derived from impure dolomitic limestones within the original sedimentary sequence. Several minerals, such as chlorite and actinolite, and possibly epidote, are the products of retrograde metamorphism, whereas calcite, diopside, wollastonite and spine] appear to form the primary metamorphic mineral paragenesis.

Amphibolites of diverse origin are present in zonal arrangement around the central gneiss core of the El Oro Mountains

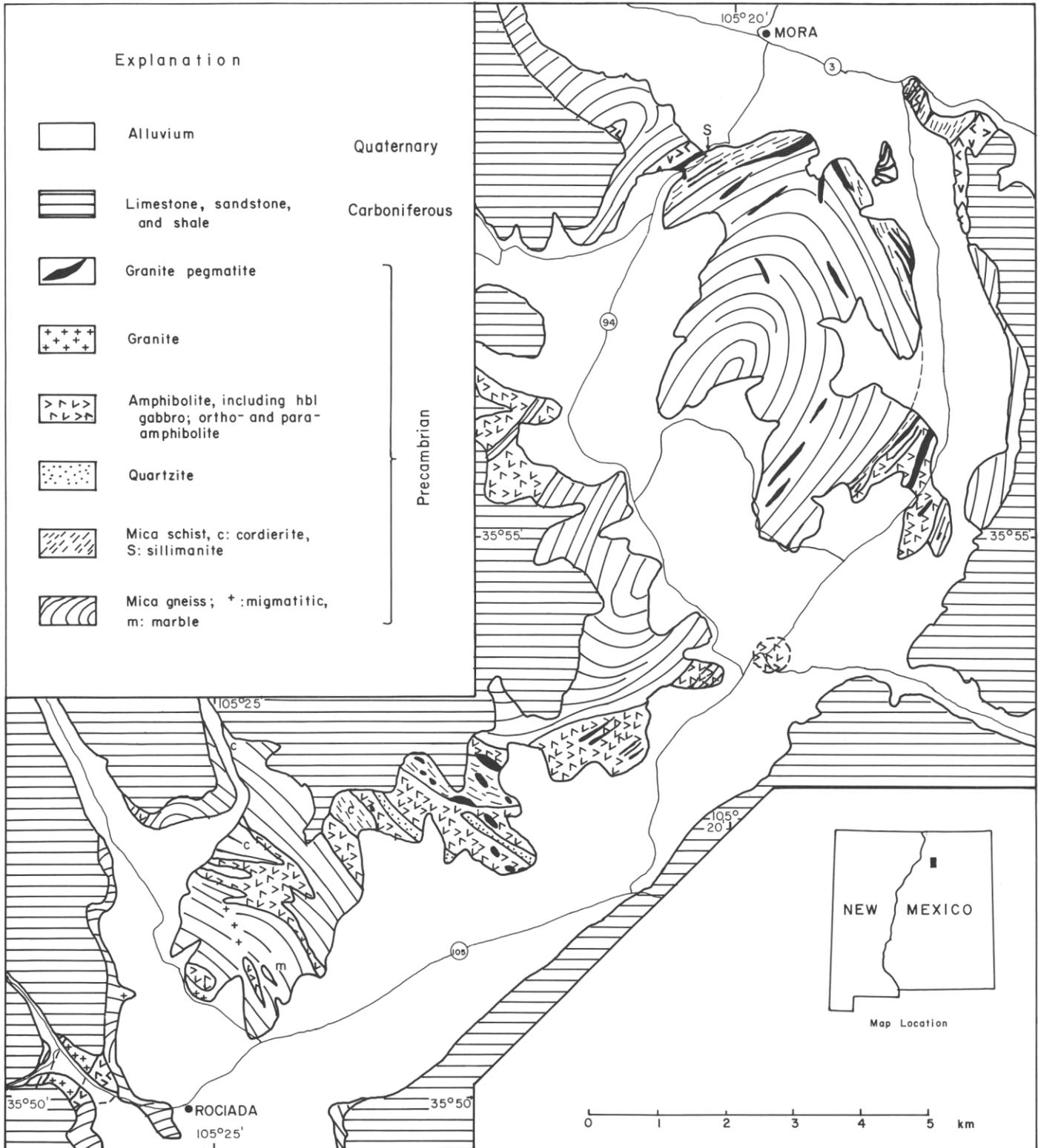


Figure 1. Geology of the country between Mora and Rociada, Mora and San Miguel counties, New Mexico. Topographic base from parts of the U.S.G.S. Mora, Gascon, Rociada and Sapello 7½ minute quadrangles.

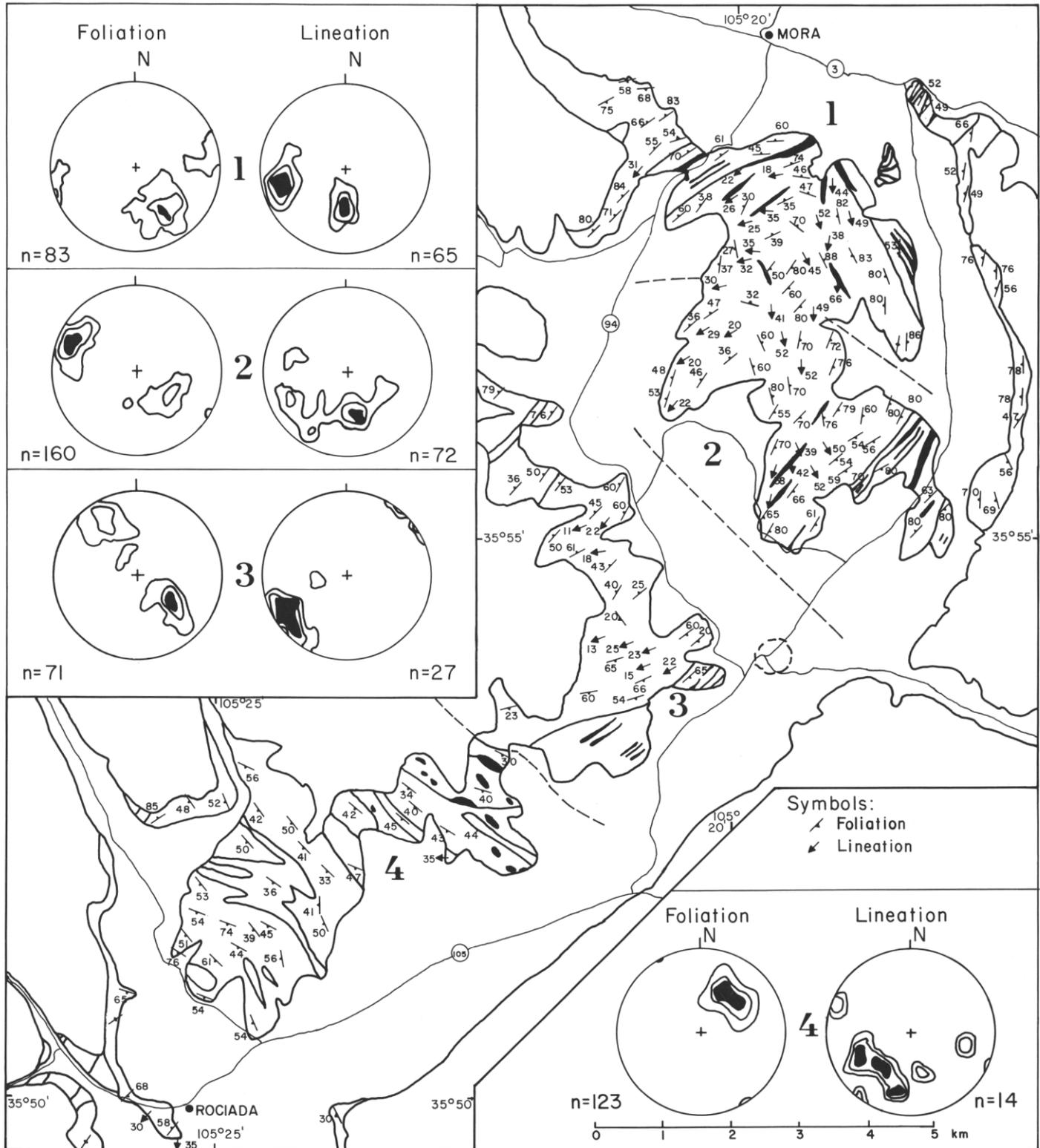


Figure 2. Structural map of Mora-Rociada area. Bold figures refer to structural domains 1 through 4. Stereographic diagrams are Schmidt lower hemisphere projection, with contours at 2%, 6% and larger than 10% per 1% area.

(fig. 1). Amphibolites of sedimentary derivation (associated with calcareous rocks northeast of Rociada) are fine-grained, and have calcite and quartz in addition to hornblende and plagioclase. Homogeneous, granoblastic amphibolites, some with blastophitic texture, are of igneous origin. Many are lensoid and may represent sill-like subvolcanic bodies intruded into the metasediments. Hornblende is blue-green to green in maximum absorption color, although northwest of Cebolla Pass, brown hornblendes also are present in the amphibolites. The plagioclase is from andesine to oligoclase in composition. Minor constituents include quartz, epidote, calcite, magnetite, and sphene or rutile.

Although the gneiss usually is well foliated, in several places the rock is more massive and has a granitic appearance. Several exposures of this type are present north of Rociada and within the central core gneiss. West of Rociada, a 500-m-wide granite occurs between hornblende gabbro and gneiss. The pink, leucocratic, fine-grained granite lens consists of quartz, microcline, albite-oligoclase, and small amounts of muscovite and green biotite.

Lens-shaped bodies of pegmatite are numerous within and surrounding the gneiss dome. With a few exceptions, most pegmatite dikes are concordant to the foliation of the metamorphic rocks. Textural and mineralogical zoning are characteristic of many pegmatites. Grain size increases toward the centers of the dikes. Quartz, plagioclase (albite to oligoclase) and muscovite occur along the borders, while microcline is more abundant in the centers of the dikes. Almandine, black tourmaline, and beryl are locally present. Mica-rich selvages form the contact between pegmatite, and amphibolite and mica schist.

The spatial association of the pegmatites with the gneiss dome is remarkable and the following is a possible explanation. As discussed below in the section on structural geology, the formation of the gneiss dome is thought to have been aided by upward pressure exerted by a subjacent pluton, probably of felsic composition. Under these conditions, the pegmatites would represent the differentiates of this pluton, intruded into higher levels of the crust.

TECTONICS

The major structural feature of the area is the presence of domal and antiformal structures, of which the El Oro dome is the most conspicuous (figs. 1, 2). The core of the domes is made up of mica gneiss, locally migmatitic, which is surrounded by other metasedimentary and metaigneous rocks. The gneiss dome is the most obvious macroscopic structure of the area, but structures on a mesoscopic scale indicate that deformation prior to doming has occurred.

Structures observable in the field are well developed foliation in gneiss and mica schist, and lineations in gneiss, schist and amphibolite. Lineation is expressed as small-scale folding or as parallel mineral orientation, the latter mainly as strong parallelism of hornblende crystals in some amphibolites. The structural data of the area are summarized in Figure 2, which shows the general trends of foliation and lineation. Only few of the measured attitudes are shown in Figure 2; a much larger number has been used to construct the contoured stereograms.

The last Precambrian deformation has produced an elongated, doubly plunging antiformal structure trending northeast (fig. 2). Mesoscopic folds of different styles, with amplitudes

ranging from 0.1 to 1.0 m, are evidence for earlier deformation.

In order to present the structural data in a coherent fashion, the region has been subdivided into four structural domains, numbered one through four from north to south. Domains have been chosen to include structures of persistent direction and continuity. The boundaries between domains, which are dictated partly by alluvial cover, together with stereographic plots of poles to foliation and lineation projections, are shown in Figure 2. All projections are on lower hemisphere, Schmidt net, and have been contoured at 2, 6 and 10 percent intervals. A total of 437 attitudes of foliation and 178 lineations forms the basis of the structural analysis.

For each domain, the pole to the foliation circle and the attitude of the great circle through the lineations has been determined, using the method of Ramsay (1967, p. 14-22). On the assumption that the foliation surfaces represent an original, planar S-surface prior to the development of the gneiss dome, the pole to the foliation circle represents the fold-axis in that domain. The orientations of the fold axes F1 through F4 (the subscript referring to the domain number) are listed in Table 1.

In domains 1, 2 and 4, the lineations are distributed in a great-circle manner. The orientations of these great circles also are listed in Table 1. The orientation of the fold axes shows a decrease in northerly plunge from domain 1 to domain 2. In the two southern domains (3 and 4) the plunge is southwesterly and increases from 16° to 40°. Foliations dip away from the center of the dome except in the northeastern part of the structure, where the foliation dips steeply west.

Figure 3 represents a synopsis of the data from the four structural domains. The four fold axes define a great circle, labeled S', the stereographic projection of the axial plane of the dome. This surface strikes N34E and dips 50°NW. The lineation circles from domains 1, 2 and 4 also are shown on this projection; they intersect S' at an average point a, the direction of the tectonic a-axis, which plunges 32° in direction S64W.

This result indicates that the direction of tectonic movement that formed the dome is inclined. The domal structure appears to be the result of a combination of horizontal and vertical movements. Tectonic compressive stress combined with vertical buoyant stress, exerted by the subjacent pluton, to form the dome with its "up to the northeast" movement and its steeply dipping northeast limb.

The El Oro gneiss dome closely resembles the infrastructural upwellings described by Haller (1956, 1971) from the East Greenland Caledonides. Some of the structures are domes, but nappes and mushroom-shaped forms also occur. Tectonic movement was not restricted to a vertical and upward direc-

Table 1. Orientations of foliation and lineation circles in each of the four domains.

Domain number	Pole to Π -circle, foliation	Attitude of lineation circle
1	38°, N18W	Str. N82W, Dip 52°S
2	10°, N26E	Str. N85E, Dip 50°S
3	16°, S52W	---
4	40°, S63W	Str. N79W, Dip 50°S

tion, but might have involved tangential movements as well. The shape of the dome or nappe was controlled by the upward driving force generated in the mobilized infrastructure and the resistance of the overlying rock units. If we assume, along with several investigators, that the difference in density between the less dense mobile core rocks, migmatitic or granitic in character, and the denser mantle rocks is the driving force behind the formation of gneiss domes, then the stress resulting from this force would be superimposed on the tectonic stress field at the time of dome formation. The resulting structure would be a combination of a dome and a nappe, depending on the intensity and effectiveness of each of the dome-forming processes. Several examples of gneiss domes are known from the Precambrian of Finland. Eskola (1949) was first to call attention to the existence of mantled gneiss domes in this area. A particularly good example of the Finnish domes is the Mustio dome (Harne, 1954). The central part of the dome consists of leptonite with limestone intercalations, surrounded by a sequence of metavolcanic rocks and mica schists. Lenses of late-tectonic microcline granite outline the ring-shaped structure. The dome is thought to be the result of vertical uplift of the rocks by a subjacent late-tectonic granite.

Thompson and others (1968) have summarized the characteristics of the nappes and gneiss domes of west-central New England, USA. Some of the features of the New England domes include overturning of margins, mushroom-like overhangs and overturning of isograd surfaces. Density contrasts between core and mantle again are thought to be the dominant factor in dome formation. They also point out the geometric similarities between gneiss domes and salt domes.

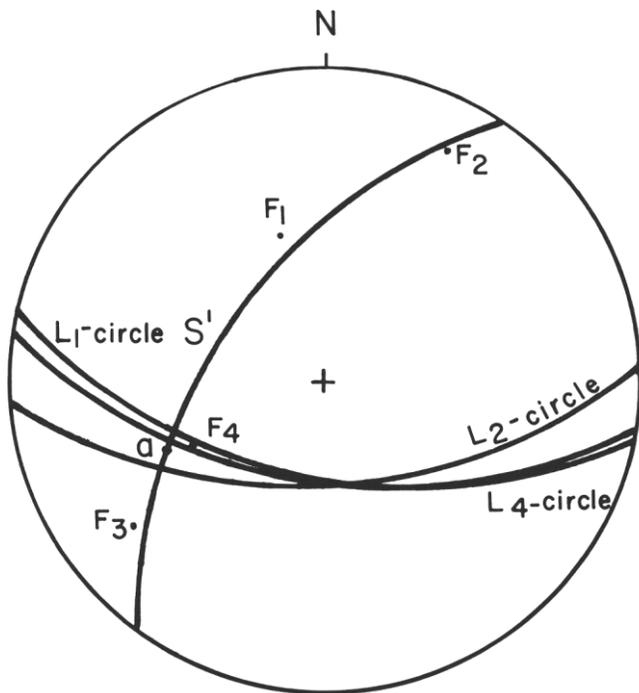


Figure 3. Synoptic diagram of fold axes F_1 , F_2 , F_3 and F_4 , and lineation circles L_1 , L_2 and L_4 . The four fold axes define the axial surface of the domal antiform with an attitude of $N34E$, dip $50^\circ NW$. The intersection of the lineation circles with S' is the tectonic a axis, plunging 32° in direction $S64W$. Wulff net projection on lower hemisphere.

METAMORPHISM

The most widespread indicators of metamorphic grade in the area are amphibolites and related rocks, which contain green or brown hornblende together with plagioclase of oligoclase or andesine composition. This association, the presence of sillimanite in mica schist, and the migmatitic aspect of some of the gneisses indicate that at the peak of metamorphism the upper or sillimanite grade of the amphibolite facies had been reached.

The presence of wollastonite in calcsilicate rocks northeast of Rociada adds another example to the growing list of occurrences of this mineral under conditions of regional metamorphism. Where thin limestone layers are intercalated in noncalcareous sediments, the CO_2 pressure upon metamorphism is sufficiently low due to dilution by water vapor to allow the formation of wollastonite at regional metamorphic temperatures.

Late cordierite, as porphyroblastic crystals cutting across the foliation in mica schists, apparently belongs to a late phase of metamorphic recrystallization, during which the temperature was high, but the deformation was negligible. As pointed out before, the formation of the gneiss dome may have been caused, or at least influenced, by the intrusion of a subjacent body of granitic composition. This intrusive, besides being the source of the granitic pegmatites, also may have provided the heat necessary for the formation of cordierite in rocks of appropriate composition.

CONCLUDING REMARKS

The Precambrian rocks of the Mora-Rociada area have been derived from a series of predominantly clastic sediments (or felsic volcanics) ranging from arkosic and ferruginous sandstones to shales, with calcareous intercalations. Amphibolites of igneous derivation make up less than half of the exposed sequence. In this respect, the sequence of rocks occupies an intermediate position between the Precambrian terrain to the southwest, the Pecos greenstone belt of Robertson and Moench (this guidebook), and the Precambrian quartzite terrain to the north and west.

At least two periods of Precambrian deformation are indicated (Cepeda, 1972, 1973). An earlier deformation phase imparted a penetrative lineation to the rocks. This lineation subsequently was redistributed by the doming process. The El Oro gneiss dome, southeast of Mora, is asymmetrical, with a steep northeastern limb, and more gently dipping western and southern limbs.

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