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GEOLOGY OF THE MONTE LARGO HILLS AREA, NEW MEXICO: STRUCTURAL AND METAMORPHIC STUDY OF THE EASTERN AUREOLE OF THE SANDIA PLUTON

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Abstract—The easternmost aureole of the 1.42 Ga Sandia pluton is exposed in the Monte Largo Hills area, east of the Sandia Mountains in central New Mexico. The Sandia pluton and aureole record the dynamic interaction of deformation, magmatism and metamorphism. Heat from emplacement created a 2-km-wide thermal aureole within which syn-emplacement ductile deformation is recorded by shallow lineations and syntectonic contact metamorphic porphyroblasts in country rock and by S-C fabrics and dynamically recrystallized feldspar porphyroclasts in granite. Recent 1:10,000 mapping suggests that the roof of the Sandia pluton is shallowly SE-dipping and truncates vertically foliated supracrustal rocks of interlayered metarhyolite, amphibolite, quartzite and muscovite schist. Metamorphic grade increases toward the pluton from upper greenschist regional metamorphism of the distant country rock to sillimanite grade contact metamorphism. Pluton emplacement postdates the main subvertical fabric, but was synchronous with dextral strike slip. The Monte Largo Hills area thus helps define the eastern edge of the Sandia pluton and contributes to a growing understanding of the thermal and structural setting for 1.4 Ga tectonism.

INTRODUCTION

Recent structural work on the 1.42 Ga Sandia pluton (Kirby et al., 1995) and other 1.4 Ga granitoids of the Southwest (see Nyman et al., 1994, and references therein) have highlighted the importance of understanding the interaction of deformation, metamorphism and plutonism in the middle crust during the regionally extensive but enigmatic (Windley, 1993) 1.4 Ga tectonic event. The purpose of this paper is to report on recent 1:10,000 mapping in the Monte Largo Hills area of the eastern Sandia Mountains and to document the presence of the easternmost exposed part of the aureole of the 1.42 Ga Sandia pluton.

The Monte Largo Hills, included in the Sandia Park and San Pedro 7.5-minute quadrangles, is a belt of Proterozoic rocks bounded by two major splays of the Tijeras fault system (Fig. 1). Proterozoic rocks consist mostly of metavolcanic and metasedimentary rocks, although important outcrops of Sandia granite and related rocks are exposed in the northwest part of the map area (see also Kelley and Northrop, 1975).

PREVIOUS WORK

Previous work in the Monte Largo Hills area provided some lithologic mapping, but only a limited discussion of the regional context for deformation and metamorphism. Herrick (1898) initially described the Proterozoic metamorphic rocks in the Monte Largo Hills area. Darton (1928) briefly discussed the metamorphic structure of the Golden-San Pedro area. Lambert (1961) completed a petrographic analysis of the metamorphic rocks on the west side of the Monte Largo Hills. Huzarski (1971) discussed the petrology and structure of the eastern Monte Largo Hills. Kelley and Northrop (1975) identified Sandia and Cibola granites in the Monte Largo Hills and published a 1:48,000 map of the Sandia Mountains and vicinity.

EARLY PROTEROZOIC COUNTRY ROCK

Metavolcanic and metasedimentary rocks of the Monte Largo Hills include metarhyolite (60% of exposed rock), amphibolite (25%), quartzite (10%) and pelitic schist (5%). The bimodal metavolcanic rocks consist of intimately interlayered metarhyolite and amphibolite with variable thicknesses and lensoidal shapes in map view (Fig. 1). Amphibolites commonly have calc-silicate pods and relict lensoidal clasts, supporting the interpretation that these rocks were originally extrusives. These rocks are similar to rocks dated at 1.66 Ga in the Los Pinos Mountains to the south (Shastri, 1993). Metarhyolite predominates in the northwestern part of the study area, whereas amphibolite predominates in the southeast (Fig. 1).

Metarhyolite is commonly orange-pink in color, fine grained and contains quartz (up to 5 mm) and K-feldspar phenocrysts. Quartz grains are lineated and flattened and, along with aligned muscovite or biotite grains, define the foliation. Average modal composition is quartz, 43%; plagioclase, 34% (An_6 to An_{13}); microcline, 13%; muscovite, 6%; biotite, 2%; and opaques, 2%. Plagioclase exhibits albite twinning (Lambert, 1961). Foliation intensity varies depending on intensity of strain and mica content.

Amphibolite layers vary in thickness from 30 cm to tens of meters. Amphibolites are dark gray to black, fine grained, and foliated. Average mineral composition is hornblende, 40%; plagioclase, 37% (An_{37} - An_{45}); quartz, 13%; and magnetite, 8%. Trace amounts of biotite, muscovite, epidote, apatite, sphene and garnet are present. Plagioclase grains are anhedral to subhedral and are generally untwinned although albite and pericline twinning occur locally. Hornblende varies from anhedral equant grains to subhedral prisms. Hornblende crystals are crudely aligned in the foliation plane, but are commonly radiating, suggesting that hornblende grew late during formation of the steeply-dipping regional foliation.

Metasedimentary rocks in the study area include quartzite, muscovite schist and sillimanite schist. Quartzite is typically gray to dark red in outcrop, and locally preserves oxide layering that defines original bedding. Quartz grains are recrystallized and strongly elongate, with length-to-width ratios of up to 9. Pelitic units are gradational with the quartzites and are rich in sillimanite (30%), quartz (>50%) and muscovite (20%). Associated muscovite schists are fine grained and are generally gray to brown.

SANDIA GRANITE AND RELATED ROCKS

Granitic rocks in the Monte Largo Hills include megacrystic granite, medium-grained leucogranite, and pegmatite and aplite dikes. The megacrystic granite has centimeter-scale K-feldspar phenocrysts and elliptical mafic enclaves that are typically aligned in a magmatic flow foliation. The granite generally lacks strongly developed solid state fabric. The medium-grained leucocratic granite is more strongly deformed and crops out in fault-bound slivers in the northern part of the map area. Pegmatite dikes occur as subvertical sheets that were emplaced parallel to the dominant NE-striking country rock foliation. Other dikes crosscut the foliation of the leucocratic granite in the northeast portion of the map area. Pegmatite and aplite dikes generally are undeformed, but locally are sheared parallel to their margins.

Intrusive contacts can be observed between the megacrystic granite and the metavolcanic rocks in the west central part of the map area (Fig. 1). Granite crops out in topographic lows, suggesting that the contact of the roof of the pluton in this area is shallowly dipping and near the present surface (Fig. 2). The inferred low-angle contact truncates the high-angle metavolcanic foliation and, in outcrop scale, undeformed megacrystic granite intrudes into foliation planes. Contacts tend to be sharp and undeformed.

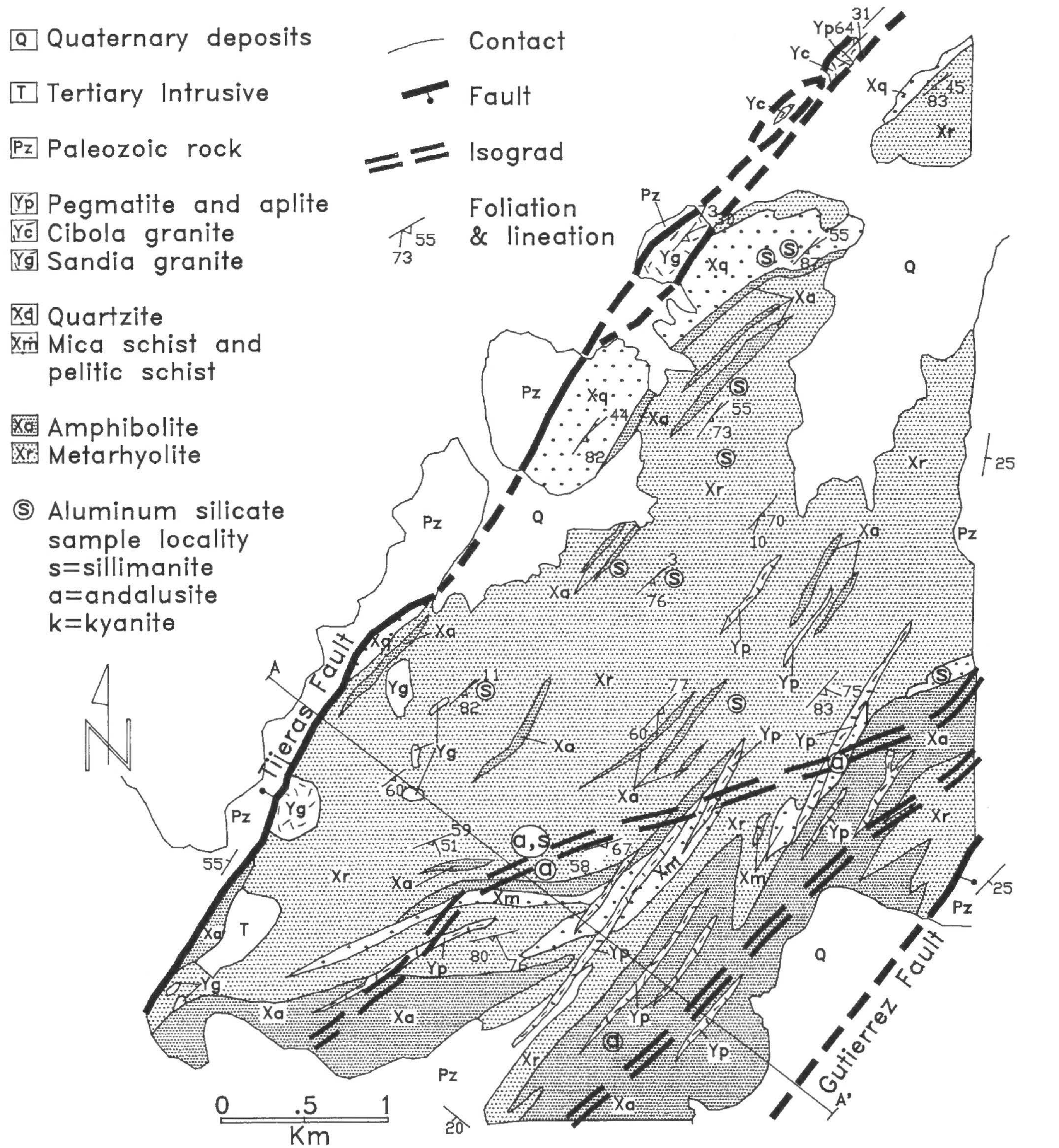

FIGURE 1. Generalized geologic map of the Monte Largo Hills area; see Kirby et al. (this volume) for location map. Sample locations are shown by the circled letters, corresponding to the observed aluminosilicate polymorphs s=sillimanite; a=andalusite; k=kyanite. Isograds are approximate and constructed from thin section petrography on samples shown.

The megacrystic granite and leucocratic granite were correlated by Kelley and Northrop (1975) with the Sandia granite and Cibola gneiss respectively. These correlations seem appropriate in view of the similarities in lithologies and structural fabrics. Here, we refer to the leucocratic granite as the Cibola granite and interpret it to be genetically and temporally related to the the Sandia pluton as discussed below and by Kirby et al. (1995).

DEFORMATIONAL FABRICS

Pre-pluton deformational fabrics

Deformation of the 1.66 Ga country rock involved the development of at least 2 generations of fabrics. The dominant fabric is a penetrative northeast-striking, subvertical foliation (S_1) that is axial planar to isoclinal folds (F_1) of compositional layering. Foliation orientation varies from

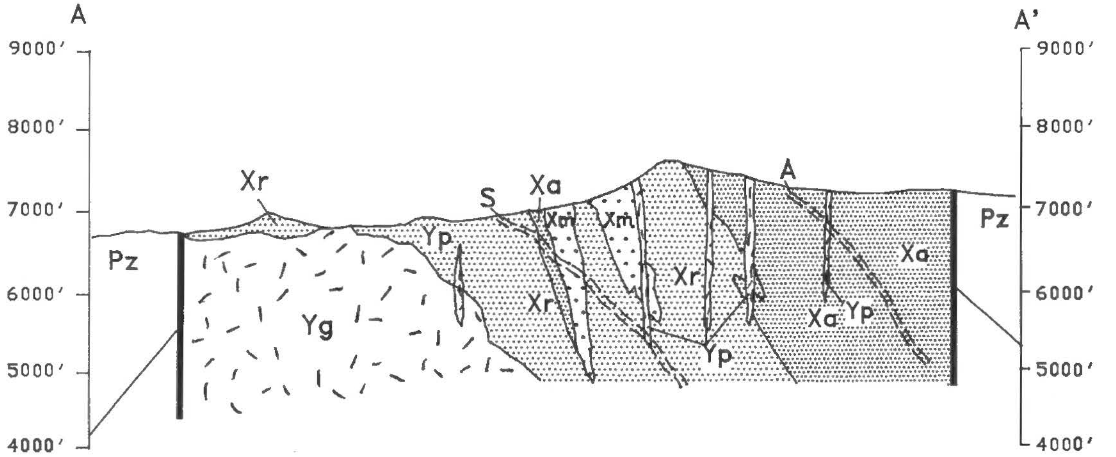

FIGURE 2. Schematic cross section of the Monte Largo Hills from NW to SE. Pluton dips to the SE and truncates 1.66 Ga composite foliation. S and A designate sillimanite and andalusite isograds, respectively.

a strike of 000 to 085, with an average near 040 (Fig. 3). F_1 fold axes trend generally to the south and have a steep plunge (Fig. 4).

L2 stretching lineations plunge steeply south within S_1 (Fig. 5). These lineations are characteristic of the southeastern part of the Monte Largo Hills, the area at greatest distance from the Sandia pluton contact. For this reason and because similar down-dip lineations are found in other areas of the northern Manzano Mountains (see Kirby et al., this volume), they are interpreted to predate the pluton. Kinematic indicators associated with this steep lineation include sigma porphyroclasts and shear bands. The latter show southeast-side-up slip on steeply southeast-dipping shear bands (Fig. 6).

Syn-pluton deformational fabrics

Deformational fabrics associated with the intrusion of the pluton are seen in both granite and country rock. Megacrystic granite is generally unfoliated in outcrops southeast of the Tijeras fault, but is strongly foliated in a sliver preserved between strands of the Tijeras fault in the north-central part of the map area (Fig. 1). In these outcrops, feldspar megacrysts as well as quartz pods are dynamically recrystallized into augen and ribbons (Fig. 7). Solid state ductile deformation of feldspar takes place only above 500°C, indicating that this deformation occurred after the granite crystallized and before it cooled back to regional greenschist facies conditions (see also Kirby et al., this volume), close to the time of emplacement of the granite. Stretching lineations in the deformed granite plunge moderately NE, and feldspars form sigma-type porphyroclasts that indicate dextral oblique shearing during this high temperature deformation (Fig. 7).

The Cibola granite outcrops are also mylonitized and contain dynamically recrystallized feldspar. Here stretching lineations defined by microcline ribbons are subhorizontal and kinematic indicators such as sigma porphyroclasts also indicate dextral strike slip. As mentioned earlier, pegmatite and aplite dikes cross cut the mylonitic layering, which suggests that deformation ended before final crystallization of highly evolved melts from the pluton. These features are similar to the synemplacement deformational features observed in the Seven Springs shear zone that crops out in Tijeras Canyon to the southwest (Kirby et al., 1995), and we interpret the fault-bounded outcrops of deformed Sandia in the Monte Largo Hills (Fig. 1) to represent portions of this same shear zone.

Some of the deformation in aureole rocks adjacent to the pluton is also interpreted to be related to emplacement of the pluton, as foliations and lineations are defined by contact metamorphic sillimanite. In con-

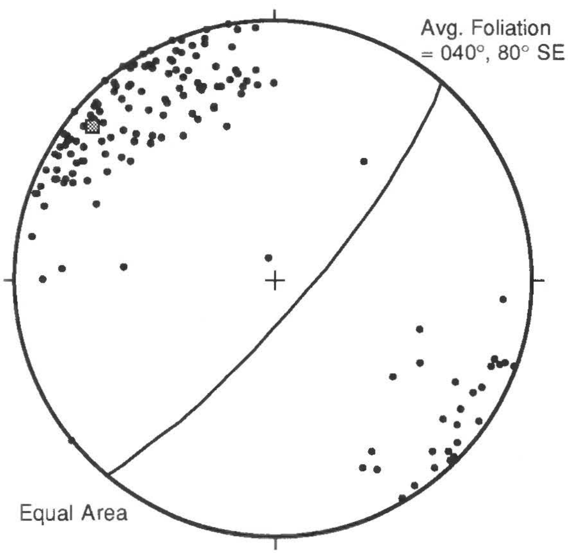

FIGURE 3. Equal-area, lower hemisphere projection of poles to foliations in the Monte Largo Hills. Mean foliation (040°, 80°SE) is shown by great circle.

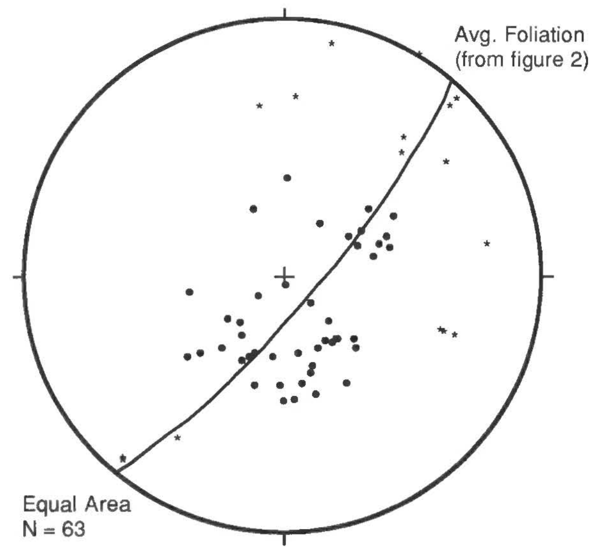

FIGURE 4. Equal-area, lower hemisphere projection of stretching lineations in the Monte Largo Hills. Mean foliation (great circle and pole) from Figure 3. Lineations in and near the pluton (stars) tend to be subhorizontal, while those farther out in the aureole tend to be subvertical. The spread of lineations is interpreted to reflect progressive rotation of lineations during syn-pluton dextral strike-slip.

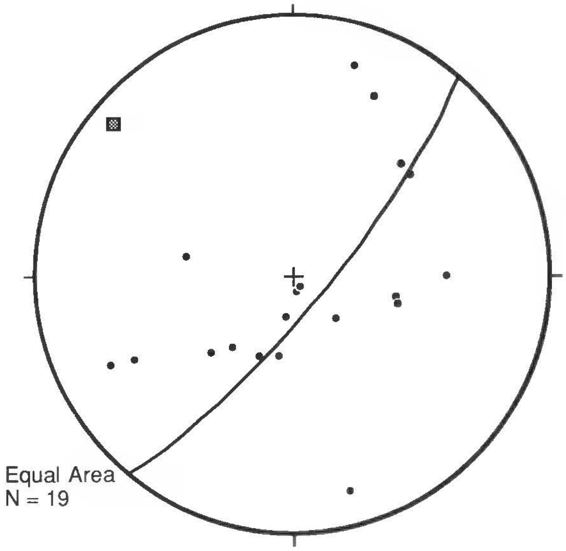

FIGURE 5. Equal-area, lower hemisphere projection of fold hinges in the Monte Largo Hills. Steep and shallow plunges may reflect 1.65 Ga and 1.4 Ga deformations, respectively.

trast to down-dip lineations observed in areas far from the pluton, stretching lineations defined by contact metamorphic sillimanite plunge shallowly NE, parallel to the stretching lineations observed in the deformed granite (Fig. 5). These lineations get steeper away from the intrusion (Fig. 1), suggesting that early steep lineations were rotated to shallower orientations during strike slip associated with pluton emplacement.

Metamorphism

The Monte Largo Hills area preserves an increase in metamorphic grade to the northwest with sillimanite schist found in areas nearest to the granite. Isograds (Fig. 1) are defined by aluminum silicate index minerals. The sillimanite zone in the Monte Largo Hills extends laterally for about 1 to 1.5 km south of the granite contact. This is wider than the ca. 0.5-km-wide sillimanite zone in the other areas of the aureole (Berkley and Callender, 1979), and is compatible with the inferred shallow pluton margin (Fig. 2). Sillimanite occurs as both fibrolite and as prismatic grains and is present with abundant muscovite (no K-feldspar was observed). This suggests temperatures of 500-600°C, below the second sillimanite isograd but above the aluminum silicate triple point. Sillimanite can be seen overgrowing andalusite porphyroblasts, suggesting the polymorphic phase transition of andalusite to sillimanite. This transition, together with the second sillimanite isograd, constrain peak pressures 0.2 to 0.35 GPa (2-3.5 kb). Euhedral garnet is found in the sillimanite-bearing units within the quartzite. Sillimanite grains are strongly aligned in the fabric, are folded and record dextral strike slip (Fig. 8), all indicating that deformation accompanied peak metamorphism during pluton emplacement.

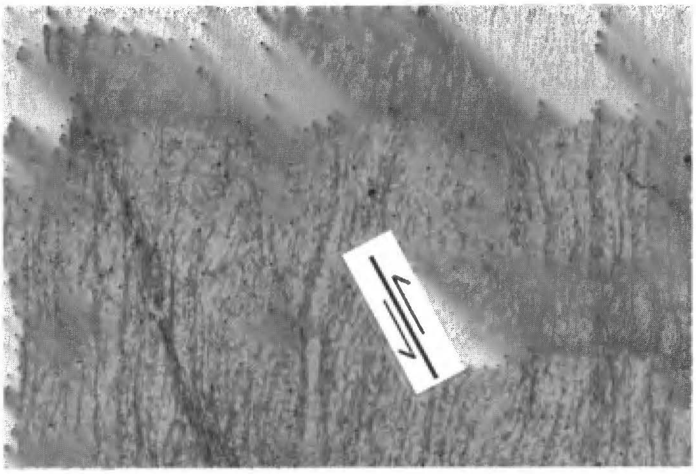

FIGURE 6. Plane light photomicrograph of oriented thin section from quartz-muscovite schist. Section is cut perpendicular to foliation and parallel to down-dip lineation. South is to the right in this cross-sectional view. Asymmetric deflection of fabric into steeply S-dipping shear bands suggests S-side up movement interpreted to predate pluton emplacement. Field of view is about 13 mm.

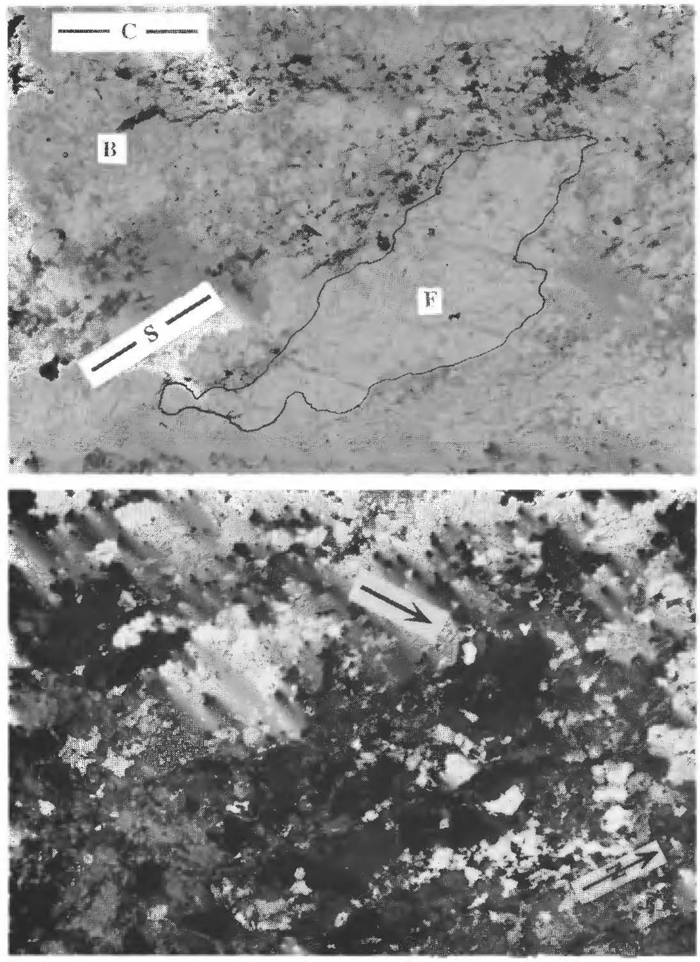

FIGURE 7. Photomicrographs of S-C fabric in deformed megacrystic Sandia granite, in plane-light (A), and crossed-nichols (B). In this nearly plan view section, asymmetric sigma-type feldspar (F) porphyroclast defines S-plane and indicates dextral strike-slip shear on vertical fabrics with horizontal lineations. Dynamic recrystallization (arrow highlights subgrains mantling grain) of feldspar in B suggests that deformation took place at temperatures > 500°C during or shortly after pluton emplacement. Field of view is 10 mm.

The andalusite zone is about 0.5 km wide and is marked by the presence of andalusite in pelitic rocks. Andalusite is commonly rich in aligned inclusions that are interpreted to be the pre-pluton S_1 foliation. Rotation of matrix relative to andalusite porphyroblasts (Fig. 9) is interpreted to be related to the reactivation of the S_1 fabric during pluton emplacement. Chloritoid, biotite and muscovite assemblages in the pelitic units and hornblende in amphibolites are found at map distances up to about 2 km from the pluton. These minerals are also interpreted to be in the andalusite zone.

The zone farthest from the pluton contains kyanite (Huzarski, 1971). At map distances greater than 2 km from the contact, amphibolites contain actinolite rather than hornblende. Together, these minerals indicate upper greenschist metamorphic facies at distances of greater than 2 km from the pluton contact.

Based on assemblage data, as discussed above, we infer peak conditions of about 600°C and 3 kbar adjacent to the pluton. This is similar to conditions in other parts of the aureole (Berkley and Callender, 1979; Kirby et al., this volume).

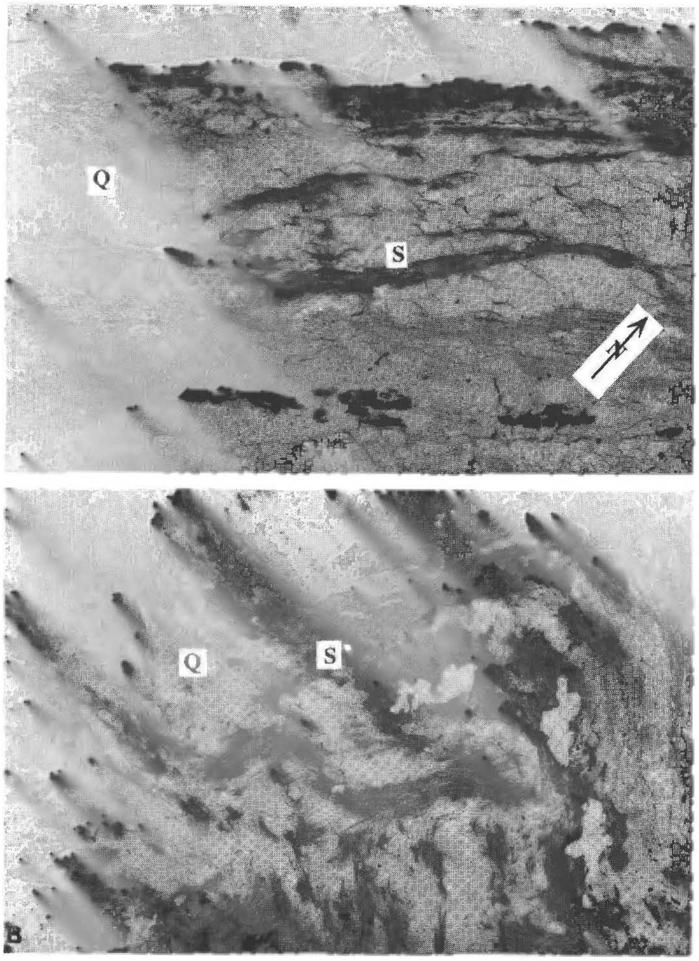

FIGURE 8. Plane light photomicrographs of sillimanite from contact aureole of Sandia pluton in the Monte Largo Hills area. A, Plan view of bladed sillimanite (S) aligned in subhorizontal lineation in quartzite (Q=quartz) at pluton margin. Field of view is approximately 12 mm. B, Folded fibrolite bundles near pluton. Field of view is 10 mm. Both textures suggest that deformation and contact metamorphism were synchronous.

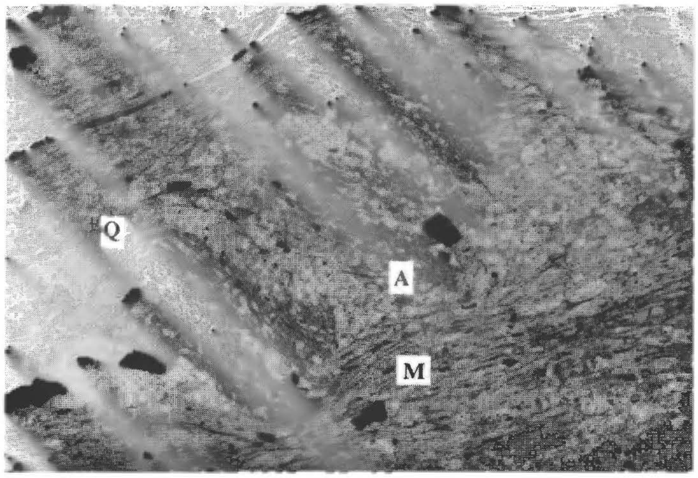

FIGURE 9. Oriented plane light photomicrograph (right side is east and up) of andalusite (A) porphyroblasts from andalusite zone of contact aureole. Internal inclusion trails defined by quartz (Q) and opaques are at a high angle to, but continuous with, matrix foliation defined by muscovite (M) and quartz, suggesting relative rotation of porphyroblast and matrix fabric during and following andalusite growth. Deformation is interpreted to be synchronous with pluton emplacement. Field of view is about 5 mm.

DISCUSSION AND CONCLUSIONS

The Sandia pluton is an important locality for studying the processes of magma intrusion at middle crustal depths far from convergent plate boundaries. Recent studies in the Monte Largo Hills area document the eastern aureole of the 1.4 Ga Sandia pluton and suggest a complex history for Proterozoic tectonism and magmatism in New Mexico.

The Monte Largo Hills preserve part of the southeastern aureole of the Sandia pluton, that is used to infer some aspects of the character of tectonic events before and during pluton emplacement. Exposures of megacrystic granite in the study area are interpreted to be the shallowly southeast-dipping roof of the Sandia pluton. This contact truncates the NE-striking, steeply SE-dipping S_1 foliation. Thus, the regional foliation and associated tight to isoclinal folds predated emplacement of the 1.42 Ga pluton. Stretching lineations in areas far from the pluton are steeply plunging and shear sense indicators suggest reverse slip. These, plus the folds, suggest that the regional country rock fabric formed during NW-SE shortening, probably about 1.65 Ga, based on comparison to nearby areas (Bauer and Williams, 1994). Metamorphic conditions during the early fabric-forming event were probably greenschist grade, as this is the backgroud metamorphism in areas farthest from the pluton.

Tectonic features associated in time and space with the pluton include a contact metamorphic aureole and syn-pluton deformational features. The contact aureole is defined by a 1.5-km-wide sillimanite zone, a 0.5-km-wide andalusite zone, and by a kyanite zone at greatest distance from the pluton. Assemblages suggest peak temperatures of about 550–600°C and peak pressures of 2–3 kb. Textures of sillimanite and andalusite porphyroblasts indicate that deformation accompanied peak metamorphism.

Deformational features around the pluton include variable but locally intense solid state deformation of the granite. Deformation took place at high temperatures (>500°C), as shown by dynamically recrystallized K-feldspar. Lineations are shallowly plunging and kinematic indicators show dextral shear. Pegmatite and aplite dikes locally crosscut mylonitic granite, indicating that this deformation took place during pluton emplacement.

Reactivation of country rock foliation also took place during pluton emplacement. Country rock stretching lineations are defined by contact metamorphic sillimanite and are shallowly plunging in areas near the granite. At greater distances, lineations get progressively steeper. This suggests that older down-dip lineations were progressively rotated to shallower orientations in areas that were thermally softened by the pluton. Overall, the Monte Largo Hills area is similar to other parts of the Sandia pluton in recording the dynamic interaction of pluton emplacement, deformation, and metamorphism at 1.42 Ga.

ACKNOWLEDGMENTS

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