RECONNAISSANCE GEOLOGY OF THE CREST OF THE SIERRA ESTRELLA, CENTRAL ARIZONA

By

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ABSTRACT

A reconnaissance study of the crest of the northwest-trending Sierra Estrella in central Arizona indicates that this range is composed primarily of gneiss and schist with a steeply dipping, northwest-striking foliation similar to that in 1.6-1.7 b.y.-old metamorphic rocks elsewhere in Arizona. Granitic rocks with a concordant foliation form sills and large intrusions into the schist and gneiss, and are thought to be approximately the same age as metamorphism and deformation. Younger, weakly foliated to unfoliated granitic rocks are exposed at the south end of the range, and are probably correlative with the widespread 1.4 b.y. old anorogenic granite suite of North America.

INTRODUCTION

The Sierra Estrella is a northwest-trending mountain range located about 24 km (15 mi.) southwest of downtown Phoenix, and is in the southeastern Phoenix 1° x 2° quadrangle (Fig. 1). The range is approximately 40 km (25 mi) long and 5-7 km (3-4 mi) wide. The southern and central parts of the range are 600-1000 m (2000-3000 ft.) above the adjacent valley floors. A few dirt roads extend to the foot of the range, but none provide access to higher areas. Approximately half the range is within the Gila River Indian Reservation, and it is necessary to obtain permission from the Tribal Council in order to gain access to this part of the range.

The Arizona Bureau of Geology and Mineral Technology, which is presently involved in a survey of the bedrock geology of the Phoenix 1° x 2° quadrangle, obtained permission from the Tribal Council of the Gila River Indian Community for one day of helicopter-assisted field reconnaissance of the crest of the Sierra Estrella. The survey was carried out on June 27, 1984 by the authors, each of whom covered a different segment of the range crest (Fig. 2). Cecil Anton of the Gila River Indian Community was also present on the survey.

Previous work

Early reconnaissance surveys of the Sierra Estrella revealed two primary rock types and three other rock types of lesser significance (Wilson et al., 1957; Wilson and Moore, 1959; Wilson, 1969; Wilson et al., 1969). Wilson (1969) depicted most of the range as Precambrian gneiss intruded at the south end of the range by a Precambrian granite. Wilson also showed smaller outcrops of
granitic and pegmatitic rocks at the south end of the range, thought to be Mesozoic in age (Wilson, 1969), and Tertiary-Cretaceous (?) granite and Precambrian schist near the north end (Wilson et al., 1969). The granite at the southern end of the range yielded Paleozoic biotite K-Ar and Precambrian Rb-Sr dates (Pushkar and Damon, 1974), which indicates that the granite, thought by Wilson (1969) to be Mesozoic, is instead probably related to an adjacent Precambrian porphyritic granite complex, herein informally named the Montezuma granite after Montezuma Peak, which is located north of the granite. This porphyritic granite is almost certainly a product of the 1.4 b.y. old "anorogenic" plutonic event that affected Arizona and other parts of North America (Anderson, 1983). Muscovite from a pegmatite in this area yielded a K-Ar date of approximately 300 m.y., which is interpreted as indicating partial resetting of Precambrian mica by younger thermal events (Pushkar and Damon, 1974). Wilson (1969) briefly described the local copper-gold mineralization that is associated with quartz veins in the gneiss.

The northwestern end of the Sierra Estrella was mapped by Sommer (1981), who recognized seven different Precambrian map units. These consist of a variety of gneissic rocks with inferred sedimentary, volcanic, and granitic protoliths. Two deformational events affected these rocks. The first event, accompanied by upper-amphibolite- to granulite-grade metamorphism, caused isoclinal folding and formation of a pervasive northeast-striking axial-planar foliation. The second, minor event involved refolding of the foliation. Estimates of peak metamorphic conditions using the biotite-garnet geothermometer and the plagioclase-garnet-Al₂SiO₅-quartz geobarometer indicate 725 ± 50°C and 5.5 ± 0.5 kbars as peak temperature and pressure (Sommer, 1981).

The nearby South Mountains, located to the northeast of the Sierra Estrella, are one of a dozen or so metamorphic core complexes in Arizona (the Sierra Estrella is not a metamorphic core complex because it lacks evidence of post Precambrian deformation). The northeast trend of the South Mountains is at right angles to the northwest-trending Sierra Estrella (Fig. 1). The southwestern half of the South Mountains is composed of Precambrian Komatke Granite and Estrella Gneiss (Reynolds, 1985), both of which are lithologically similar to foliated granitic and gneissic rocks in the Sierra Estrella. The gneiss in the South Mountains was thought by Avedisian (1966) to have undergone upper-amphibolite- to granulite-facies metamorphism. The northeastern half of the South Mountains is composed primarily of mid-Tertiary granodiorite and granite that has a strong mylonitic overprint at high structural levels and is bounded above by a mid-Tertiary low-angle normal ( detachment) fault (Reynolds and Rehrig, 1980; Reynolds, 1985).

Gravity data appears to indicate that the basin flanking the Sierra Estrella to the northeast is not a deep sedimentary basin. In fact, the strength of the gravity field steadily increases northeastward from the flank of the Sierra Estrella and reaches a
high of over 40 milligals (residual Bouguer) over the South Mountains (Fig. 3; Lysonski et al., 1981). It thus seems likely that the Sierra Estrella and the South Mountains are not separated by normal faults, and could be structurally continuous, at least with respect to middle or late Cenozoic normal faults. This is consistent with lithologic similarities between the two ranges that are also suggestive of structural continuity. The steep gravity gradient on the southeast flank of the range (Fig. 3), with gravity decreasing away from the range, is probably the result of middle(?) to late Tertiary high-angle normal faulting along the southeast flank of the range.

If the interpretation of structural continuity between the South Mountains and the Sierra Estrella is correct, then both ranges could have undergone middle to late Tertiary isostatic uplift as a result of movement on the South Mountains detachment fault. Although the South Mountains underwent tectonic denudation and associated isostatic uplift, it is uncertain whether the Sierra Estrella has undergone any tectonic denudation. The steep northeast flank of the range could be a geomorphic relict of the listric breakaway zone of the South Mountains detachment fault (see for example Spencer, 1984). In this case, only minor uplift of the Sierra Estrella would have occurred as a result of proximity to denuded and uplifted areas to the northeast. Alternatively, if the South Mountains detachment fault or another unrecognized detachment fault caused unroofing of the Sierra Estrella, then more significant uplift could have occurred as a direct result of tectonic denudation.

A northwest-trending boundary through the Phoenix area separates Precambrian rocks of contrasting metamorphic grade (Sommer, 1982). To the southwest, Precambrian metamorphic rocks in the Sierra Estrella consist of amphibolite to lower granulite grade gneisses that were metamorphosed at depths of about 20 km (5.5 ± 0.5 Kbars) and temperatures of 725° ± 50° C (Sommer, 1982). Lithologically similar rocks are present in the South Mountains (Avedisian, 1966; Reynolds, 1985) and White Tank Mountains. In contrast, greenschist facies metamorphic rocks are present in the McDowell Mountains and at Squaw Peak (Fig. 1). At Squaw Peak, temperatures and pressures during peak regional metamorphism were 350° to 500° C and 2 to 4 kb, respectively, with pressure corresponding to depths of 7.5 to 15 km (Thorpe 1980). Regional metamorphism in the McDowell Mountains occurred at temperatures and pressures of 350 to 450° C and 4 to 6 kb, respectively (Couch, 1981). It is not known to what degree the contrast in metamorphic grade between the Squaw Peak-McDowell Mountains area and the Sierra Estrella-South Mountains-White Tank Mountains area is due to mid-Tertiary low-angle normal faulting that could have caused substantial uplift of the Sierra Estrella, White Tank, and South Mountains, while causing little or no vertical movement in the McDowell Mountains-Squaw Peak area.

**OBSERVATIONS FROM THIS RECONNAISSANCE SURVEY**
The objective of this three-kilometer traverse was to investigate the country rock assemblages forming the northern margin of the Montezuma granite, a major 1.4 b.y. old intrusive mass that composes the southernmost portion of the Sierra Estrella (Fig. 4). Pushkar and Damon (1974) have reported a 1.38 b.y. Rb/Sr age for this pluton and recently Anderson (1986) has described its essential mineralogic and compositional features in a regional study of Proterozoic anorogenic granites for this region of the southwestern U.S.

Older Schists and Gneisses (p\textregistered gn)

The oldest rocks observed on the traverse are interlayered granitic gneisses and pelitic schists that have largely been intruded out by emplacement of younger, non-foliated quartz diorite and tonalite. A small but coherent mass makes up the area shown as p\textregistered gn on figure 4, yet inclusions of these rocks are abundant in the younger intrusions. The gneisses are variable in rock type but principally include biotite-hornblende tonalite gneiss, fine-grained laminated to lineated muscovite-bearing leucogranitic gneiss, and fine-grained biotite granitic gneiss. These rocks are probably metaigneous in origin although the leucocratic gneiss could be metasedimentary.

The pelitic schists exhibit a high amphibolite grade (K-feldspar-sillimanite zone) mineralogy largely produced by contact metamorphism. The rocks are well foliated, with foliation principally defined by fibrolitic sillimanite, which is overgrown by post-kinematic garnet, large and randomly oriented books of biotite and muscovite, and a second generation of coarse-grained sillimanite. Two feldspars, oligoclase and perthitic alkali feldspar, are also present. This area is so rich in igneous rocks of various ages that it is uncertain which specific intrusion caused this second, and obviously thermal, metamorphism. The overprint is more strongly developed in inclusions in the tonalite (p\textregistered t), but these also occur close to the contact with the Montezuma granite. The relict foliation in the rocks generally trends N54E to N81E with variably steep dips to the southeast and northwest.

Biotite-Hornblende Quartz Diorite (p\textregistered qd)

A dark-grey, massive quartz diorite forms the southern slopes below Montezuma Peak. Its regional extent to the north (toward the crest of the peak) is unknown. The rock is medium to coarse grained and only rarely has a weak foliation. The pluton is intrusive into the p\textregistered gn unit, forming an injection zone up to 1/2 km wide. Inclusions of amphibolite, calc-silicate rock, and
granitic gneisses contain numerous tight folds and crenulations indicative of a deformation event that predates this intrusive. Biotite is the principal mafic phase although hornblende occurs in minor amounts in darker variations. Stained slabs reveal a general absence of alkali feldspar throughout most of the quartz diorite. The mode, estimated from thin section, is quartz (15%), plagioclase (73%), biotite (10%), and opaques (2%). Accessory phases include allanite, apatite, sphene, zircon, and secondary epidote, all less than 1% in abundance.

Two-Mica Tonalite (p€t)

Along their southern and eastern margins, both the gneiss unit and the quartz diorite are intruded by a massive two-mica tonalite. The pluton is generally nonfoliated but develops a moderate foliation that increases in intensity southward toward, and is concordant to, the outer contact of the Montezuma granite. Light grey in color, the rock is equigranular and medium grained at its contacts with the older units but exhibits a distinctive coarsening of texture inward. Biotite is the sole mafic phase, but muscovite, small and sparse, is evident in most exposures. A distinctive characteristic of the tonalite in thin section is the occurrence of large, pleochroic allanite that is partially mantled by secondary(?) epidote. An estimated mode is quartz (22-24%), alkali feldspar (0-4%), biotite (6-8%), muscovite (1-2%), and accessory magnetite (1%), allanite (less than 1%), apatite, and zircon.

Montezuma granite (p€gr)

This pluton was originally mapped by E. D. Wilson (Wilson and Moore, 1959) and subsequently studied by Pushkar and Damon (1974) and Anderson (1986). The rock is typical of 1.4 b.y. old granites in this region in terms of its intrusive style, texture, and mineralogic and rock composition. The pluton, irregularly circular in map view, measures 3 to 4 km in diameter and represents the youngest form of Precambrian plutonism found in the range. Younger igneous activity in this region of the range include scattered pegmatites, aplites, and quartz-magnetite veins which are abundant along its discordant contact with the two-mica tonalite. Xenoliths are rare to nonexistent.

At its contact with the tonalite, the rock is medium grained and nonporphyritic but grades inward over a short distance into medium- to coarse-grained, porphyritic granite. It is uniformly leucocratic (color index less than 5) and is light tan on weathered surfaces. The pluton is a monzogranite in composition and is distinctive in its scattered abundance (2-5%) of large, rectangular alkali feldspar phenocrysts which measure up to 5 cm in length.

The modal (greater than 1000 counts on both thin section and slab), whole rock, and mineralogic composition of sample ASE-83-1 is given in Table 1. This specimen was retrieved from the
southern edge of the range as part of the regional investigation of Anderson (1986). Comparison to samples collected from the northern portion of the pluton demonstrate a general uniformity in composition with a few minor mineralogic variations. The northern portion, which is probably representative of a marginal phase, contains large, wedge-shaped sphene and no primary muscovite. Inward and toward the south, the distinctive sphene diminishes in abundance and late magmatic muscovite appears, although its modal abundance is far less than that of biotite. As shown in Table 1, plagioclase ranges from An26.9-38.1 in composition, whereas coexisting perthitic alkali feldspar has an integrated composition of Or80.1-84.7. Feldspar thermometry for this pair of compositions indicate minimum crystallization temperatures of 622-647°C (Anderson, 1986). Magnetite is the predominant Fe-Ti oxide and the minor amount of ilmenite is significantly manganiferous (9.0 wt.% MnO). The high magnetite proportion and manganilmenite composition point to a moderately high f0₂ of crystallization, consistent with the intermediate Fe/Fe+Mg (0.530-0.545) of the biotite. The muscovite is relatively iron-rich and contains up to 26.5 mole percent of a titaniferous celadonite component. Such muscovites may be stable to relative low pressure in concert with the epizonal nature of the intrusion but more precise barometric constraints await substantive experimental evaluation of this phase.

Traverse #2 (J. E. Spencer)

Rock Types The most abundant rock type occurring in the area of traverse #2 is fine-grained quartz-feldspar+biotite+muscovite schist and gneiss (Fig. 5). Parallel orientation of micas imparts schistosity to this rock unit. Gneissic layering is defined both by gradational changes in dark-mineral content across layering, and by sparse to numerous medium- to fine-grained, quartz-feldspar veins that have sharp contacts, are everywhere parallel to foliation, and generally range from 1 to 5 cm thick. Most rocks of this unit contain at least several percent biotite and opaque, with little or no muscovite. In thin section, local muscovite-rich varieties contain very fine-grained aggregates of moderately aligned white mica. One outcrop consisted of quartz-feldspar-epidote gneiss with some layers containing numerous 1-2 mm pits possibly formed by preferential weathering of calcite or dolomite. Some of the muscovitic rocks that contain epidote and weathering pits are suspected of being calc-silicates with a sedimentary protolith.

Varieties of the schist-gneiss unit that consist only of fine-grained quartz-feldspar-biotite gneiss are well layered in some areas, with layering on a scale of 1-5 cm, and are suspected to have a quartzofeldspathic sandstone protolith. In other areas layering is weak to almost nonexistent and the unit is remarkably homogeneous for distances of tens to hundreds of meters. A
plutonic protolith is possible for these homogeneous rocks. Except for one area, mappable contacts between weakly layered and strongly layered rocks were not recognized, and the transitions appeared to be gradational. In this one area (NW1/4, NE1/4, Sec. 1, T. 2 S., R. 1 E.) a small (50-100 m diameter) body of foliated, medium-grained biotite granite or granodiorite intrudes more biotite-rich, fine-grained schist and gneiss. Foliation as defined by aligned micas seemed equally strong in both rock types.

In many areas the schist-gneiss unit is intimately intruded by numerous sheets and irregular bodies of medium- to fine-grained leucocratic granitic rock, porphyritic granite (+ hornblende), and pegmatite. These intrusive rocks have a foliation that is defined by preferential mineral orientation (especially biotite but also including flattened(?)) aligned tabular potassium-feldspar megacrysts), but do not have gneissic layering.

Two steeply-dipping, northwest-trending pegmatites were recognized that cut across foliation and are not foliated. These pegmatites contain muscovite books up to 5 cm diameter and locally occurring biotite books.

Structure Foliation generally dips eastward to southeastward toward the foot of the range. Many slopes on the east flank are dip-slopes, whereas steep to vertical cliffs that cut directly across foliation are present on the west side of the range, especially near the range crest.

Disharmonic, irregular folds are weakly to strongly developed in the schist-gneiss unit. Locally-developed lineation defined by elongate, biotite-rich mineral trains could be coaxial with the folds, but insufficient data are available to verify this possibility. Disharmonic folds are so pervasive in the northern part of the traverse (Sec. 25, T. 2 S., R. 1 E.) that it was not possible to determine meaningful foliation attitudes.

Mineral Occurrences Two chrysocolla-bearing quartz veins, each about 10 cm (4 in.) in thickness, were seen on the ridge crest.

Traverse #3 (P. Anderson)

Precambrian rock types encountered on this traverse are divided into two groups (Fig. 6). The older of the two is an assemblage of strongly-foliated and variably-banded gneiss of inferred metasedimentary protolith. This rock type typically varies from schistose biotite-rich gneiss to muscovite- or sericite-rich gneiss. A metavolcanic or metavolcaniclastic protolith is inferred where the rocks are amphibolitic. Epidote-hornblende-feldspar mineral assemblages are most characteristic of rocks inferred to have a volcanic protolith; rocks with this mineral assemblage were seen primarily on the ridge crest about 1.5 km (1 mi.) south of Montezuma Sleeping. The largest recognized body of amphibolite is shown on the map (Fig. 6). South of this area the gneiss is well banded with
interlayered biotite-feldspar and quartz-feldspar layers. Locally numerous, small quartz-feldspar veins give the rock a migmatitic appearance.

The other assemblage is a suite of foliated granitic rocks. These are typically medium-grained, porphyritic, and locally contain numerous concordant sheets of fine-grained granite, aplite, and pegmatite. Both a medium- and a fine-grained phase are present with the fine-grained phase typically occurring as screens or thin, discontinuous sheets within the medium-grained phase. The granite is locally very feldspathic and contains sparse patches of biotite along foliation planes. This granite contains large potassium-feldspar phenocrysts; the largest recognized was a very-well-zoned 4 x 6 cm tabular crystal.

Two Tertiary or presumed Tertiary rock types are present. Mafic dikes are medium-grained hornblende-pyroxene gabbro with nonacicular plagioclase. These dikes are completely unfoliated, and are thought to be Tertiary based on their similarity to NW-trending Tertiary dikes elsewhere in Arizona (e.g. Reynolds and Rehrig, 1980). About 1.5 km (1 mi) southeast of Montezuma Sleeping are several irregular bodies of unfoliated, spheroidal weathering, hornblende-pyroxene gabbro containing hornblende-pyroxene knots. This rock is suspected of being mid-Tertiary based on its undeformed character and lithologic similarity to Tertiary mafic dikes.

Well-developed foliation in all of the Precambrian rocks is defined by compositional layering and by the aligned orientation of minerals, especially micas. Foliation typically strikes northeastward and dips vary from vertical to about 25 degrees to the southeast. Compositional layering is locally folded, and, in these areas, foliation defined by aligned mineral orientations is axial planar to the folds. Sparse lineations defined primarily by quartz-feldspar rodding trend northeastward to eastward, and plunge gently to moderately in this direction.

Transect #4 (S. J. Reynolds)

The rock types exposed on this section (Fig. 7) of the Sierra Estrella are generally similar to those encountered on traverse three. The rocks can be subdivided into two main types: an older series of compositionally variable metamorphic rocks and a younger series of variably foliated granitoid rocks. The older, metamorphic rocks include quartzofeldspathic gneiss, mica schist, and minor amphibolite and quartz-rich metamorphics. The gneissic rocks contain a well-developed crystalloblastic foliation defined by large- to small-scale compositional layering and oriented minerals, especially micas. Compositional layering in the gneiss is defined by variations in grain size and mica content. Layers of pegmatite and aplite are abundant and are generally oriented parallel to crystalloblastic foliation. Most gneiss is medium grained and has a granitic composition of approximately one-third
quartz and two-thirds feldspar. Biotite and muscovite content is generally less than 5 percent, but locally exceeds 30 percent in some thin layers. Most exposures of gneiss are devoid of visible accessory minerals, although small reddish garnets are locally present. Some exposures of gneiss contain gray, oval-shaped clots composed of muscovite that presumably has replaced andalusite or some other aluminosilicate. The granitic composition of most gneiss is suggestive of a derivation from impure sedimentary rocks or felsic igneous rocks. If the protoliths are igneous rocks, the widespread compositional banding probably represents metamorphic segregations, although some relict igneous flow layering could be locally preserved.

Mica schist is closely associated with gneiss in many exposures, but is generally limited to relatively thin layers less than several meters thick. Most schist contains abundant feldspar and quartz in addition to biotite and muscovite. Some schist contains muscovite-rich spots and knots that possibly represent altered aluminosilicate minerals. Schist exhibits a well-developed, crystalloblastic foliation or schistosity, which is parallel to compositional layering and pegmatites. Quartz-rich metamorphic rocks, representing quartzites or metamorphosed quartz veins, are locally associated with schist. Most schist in the area was derived from either impure sedimentary rocks or intermediate to felsic igneous rocks.

Amphibolite was noted in only several outcrops along the traverse. Most amphibolite layers were less than several meters thick, and contain biotite in addition to abundant plagioclase and amphibole. Several amphibolite bodies occur within larger areas of biotite-rich schist. The amphibolite was derived from metamorphism of mafic igneous rocks, either in the form of thin dikes or flows.

The second major suite of rocks encountered on this traverse consist of variably foliated granitic rocks. These rocks are more compositionally homogeneous than the gneissic rocks, and clearly represent granitic plutons that were deformed and metamorphosed during and after their emplacement. The granitic rocks range in composition from granite to granodiorite and contain as much as 10 percent total mafic minerals.

The most common plutonic rock type is a medium- to coarse-grained, porphyritic granite-granodiorite. The granite-granodiorite forms several large plutons that have intruded the older, felsic gneiss. The rock varies from nearly undeformed to a well-foliated, augen gneiss, and, where undeformed, forms spheroidally weathered outcrops that are tan and brown due to desert varnish. The pluton is compositionally homogeneous over large areas, but smaller scale layering defined by slight variations in grain size and mineralogy is common in areas of intense metamorphism. Highly deformed outcrops locally have a somewhat swirled aspect due to intense folding of small-scale compositional layering. The granite-granodiorite contains from 2 to 7 percent K-feldspar phenocrysts that are generally between 0.5 and 3 cm in diameter. Phenocrysts as long
as 10 cm are present, but extremely rare. Parts of the pluton lack K-feldspar phenocrysts, and are composed of a medium- to coarse-grained, equigranular granitoid. Phenocrysts in less deformed outcrops are nearly square with rounded corners, but are lenticular augen in highly deformed exposures. The rock contains 5 to 10 percent mafic minerals, with the percentage of biotite and hornblende being approximately equal. In general, the foliated granite-granodiorite is very similar in overall appearance, lithology, and style of deformation to the Komatke Granite of the adjacent South Mountains (Reynolds, 1985); the two rocks are on strike with one another across the alluvium-covered Gila River valley.

Leucocratic, gneissic to foliated granite and granitic gneiss is very common and forms bold, light-colored outcrops that are spheroidally weathered, especially where deformation is slight. Compositional layering is commonly present and is defined by alternating sheets of pegmatite and medium- to fine-grained granite. Most outcrops are free of visible accessory minerals.

The structure of this area is similar to that exposed further south along the crest of the range, and in the nearby South Mountains (Reynolds, 1985). Crystalloblastic foliation in the metamorphic and deformed plutonic rocks strikes northeast and dips vertically to steeply to the southeast. Steep, northwest-dipping foliation is present along the northern part of the traverse. The foliation is axial planar to isolated folds of the compositional layering. Lineation is absent, except in a few localities.

Postdating all rock types and structures described above are a series of northwest-trending dioritic dikes of probably middle Tertiary age. The dikes are undeformed and range from very fine-grained microdiorite to medium- to coarse-grained diorite. The dikes are similar in trend and lithology to dikes in the South Mountains that are approximately 22 to 25 m.y. in age.

There was no evidence of Tertiary mylonitic fabric or brittle fabrics such as those present in the South Mountains. One isolated exposure contains a moderately southeast-dipping mylonitic foliation and east-northeast lineation, but this fabric is probably not correlative with fabrics in the South Mountains because of differences in character and orientation of foliation.

CONCLUSION

Two groups of rock types were encountered on all four traverses and make up most of the rocks observed in the Sierra Estrella. The older of these are compositionally variable schists and gneisses of inferred metasedimentary and local metavolcanic protolith, with possible granitic protoliths locally. The schists and gneisses have a strong, steeply dipping, northeast-striking foliation that is characteristic of 1.6-1.7 b.y.-old rocks throughout Arizona, and we are confident that the foliated rocks that comprise most of the Sierra Estrella are of this age. The
younger group consists of foliated and unfoliated granitoids. Crystalloblastic foliation in the foliated granitoids is concordant to foliation and compositional layering in older schist and gneiss, and the foliated granitoids are inferred to be part of the 1.6-1.7 b.y. old suite.

Three types of granitic rocks in the southernmost part of the range are late- to post-kinematic, and the youngest of these is thought to be part of the 1.4 b.y. anorogenic granite suite (Anderson, 1986). The other two (quartz diorite and two-mica tonalite) could be associated with either the 1.6-1.7 or 1.4 b.y. old suites.

The youngest rocks are sparse, northwest-trending mafic dikes and local irregular bodies of hornblende diorite and hornblende-pyroxene gabbro of probable middle Tertiary age.

ACKNOWLEDGMENTS

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Spencer, J. E., 1984, Role of tectonic denudation in warping and uplift of low-angle normal faults: Geology, v. 12, p. 95-98.
A density of 2.67 g/cm³ is used for the Bouguer correction and for terrain corrections calculated by computer for a radial zone of 2.6 to 167 km around each station. A trend surface of elevations of Arizona (Inset 1a) was used to define a regional Bouguer anomaly (Inset 2a) and to compute residual anomaly values. For a complete discussion of data sources, availability, and data reduction programs see:

Aiken, C. L. V., 1976, Analysis of Gravity Anomalies in Arizona: Ph.D. dissertation, University of Arizona, Tucson; Ann Arbor, University Microfilms Order No. 77-02313.


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Fig. 3
Montezuma granite. Injection complex (pCqd + pCgn).

Two-mica tonalite.

Biotite-hornblende quartz diorite.

Strikes and dips of crystalloblastic foliation, and trend and plunge of lineation. Exact plunge specified.

Figure 4.
Quartz-feldspar±biotite±muscovite schist and gneiss.

Foliated biotite granite or granodiorite.

Schist and gneiss (pCgn) with numerous granitic sills.

Strike and dip of crystallloblastic foliation, and trend and plunge of lineation. Exact trend specified.

Mafic dike.

Figure 5.
Tertiary mafic dike

medium-grained, equigranular, foliated granite and quartzofeldspathic gneiss

coarse-grained, porphyritic, foliated granite - granodiorite

quartzofeldspathic gneiss, mica schist, and minor amphibolite

strike and dip of foliation showing trend of lineation
### Table 1. Modal, Whole Rock, and Mineral Compositional Data for the Sierra Estrella Granite (A5E-83-1)

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<th>A. Mode</th>
<th>B. Whole Rock</th>
<th>C. Alkali Feldspar (Integrated)</th>
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<th>H. Muscovite</th>
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#### D. Plagioclase

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#### G. Muscovite

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