
ECONOMIC GEOLOGY OF THE SIERRA ESTRELLA, MARICOPA AND PINAL COUNTIES, ARIZONA

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This is a preliminary report,
subject to technical and
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ABSTRACT

The Sierra Estrella in south-central Arizona was examined in order to determine the distribution and character of potential geologic resources. The management, access, and mineral rights to the Sierra Estrella are controlled by the Gild River Indian Community and the U.S. Bureau of Land Management. No areas with high resource potential were indentified in the Sierra Estrella. There is low potential for flake mica in the central portion of the range; gold, silver, and copper in epithermal deposits of the south-central portion of the range; dimension stone in the Montezuma Granite; and sand and gravel in the surrounding valleys. The potential exploitation of these resources is highly dependent upon price, local demand, and accessibility.

INTRODUCTION

The purpose of this study was to determine the distribution and character of potential geologic resources of the Sierra Estrella, Arizona. This report makes no attempt to give estimated tonnages of materials and is intended to provide direction and suggestions for further field exploration.

The Sierra Estrella is a northwest-trending mountain range consisting of a single compact ridge that is 38 km in length, and 5 to 7 km wide. The base of the range varies in elevation from 559 m above sea level near the confluence of the Gila and Salt Rivers in the north, to 788 m near the Gila River Indian Reservation boundary in the south. The highest elevations in the Sierra Estrella are an unnamed peak at 1375 m in the north-central part of the range and Montezuma Peak at 1323 m. This study covers approximately 165 km² of the Sierra Estrella. Approximately one-quarter of the study area lies within the boundaries of the Gila River Indian Reservation: It is necessary to obtain a permit from the Gila River Indian Community Council to visit this area. The topography is extremely rugged and irregular, making the area accessible only on foot. Several unimproved dirt roads extend to the base of the range on the east and west sides.

Preparation of this report included research of previous geologic work and geologic mapping. Mapping was done directly on a topographic base map at a scale of 1:24,000. Aerial photos were used as a field mapping aid. Field work was conducted between September 12, 1991 and May 1, 1992.

ACKNOWLEDGMENTS

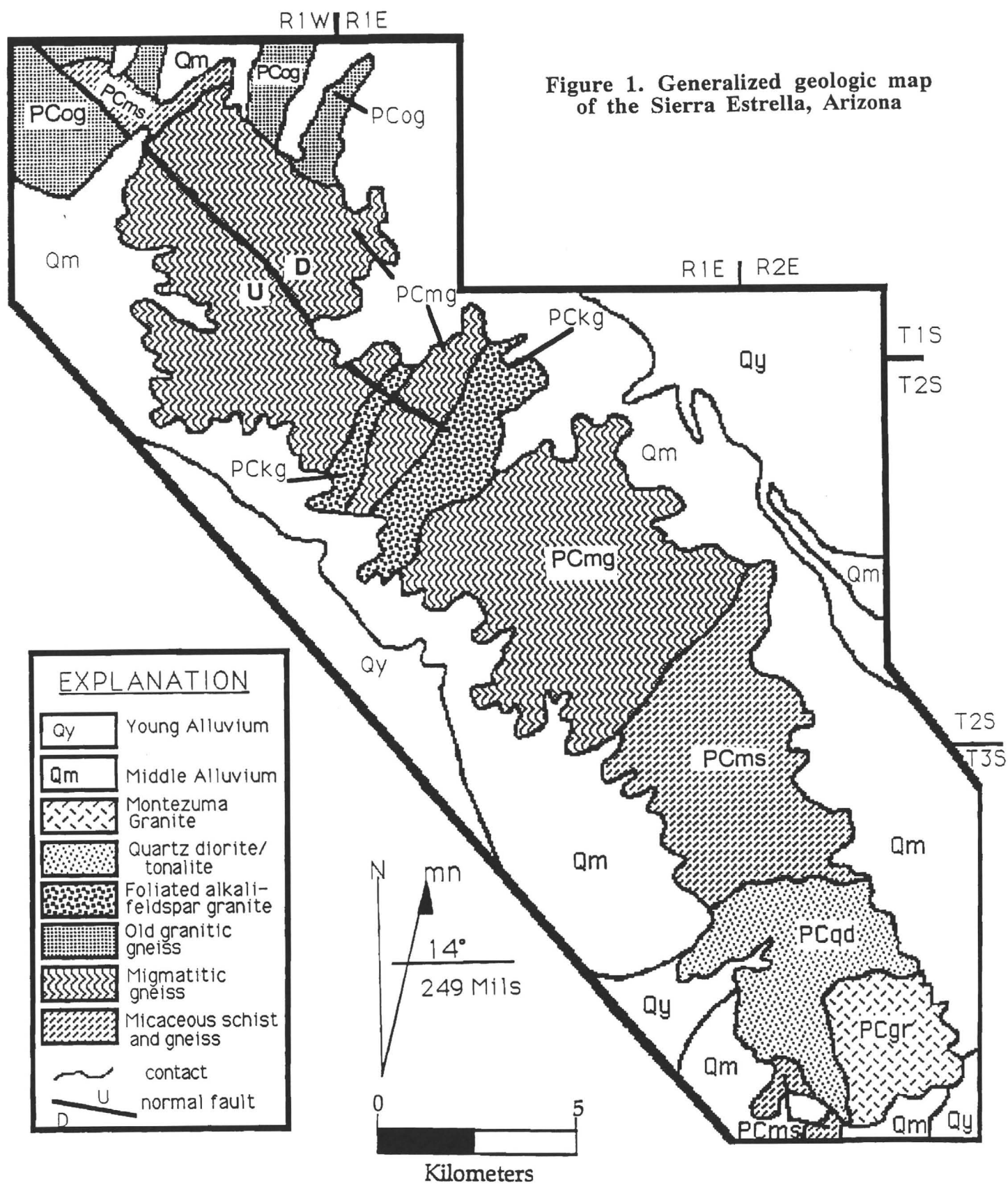
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PREVIOUS WORK

Early investigations of the Sierra Estrella consisted primarily of reconnaissance mapping and basic rock identification (Darton, 1925; Bryan, 1925; Darton, 1933). Bryan (1925) identified a Precambrian gneiss that comprised the bulk of the Sierra Estrella, with later intrusion of Mesozoic (?) granitoid rocks. The next generation of workers (Wilson et al., 1957; Wilson and Moore, 1959; Wilson, 1969; Wilson et al., 1969) expanded upon earlier work and identified the bulk of the range as Precambrian gneiss with minor amounts of Precambrian schist, and several small granitic plutons of Precambrian, Mesozoic, and Tertiary-Cretaceous (?) age. Paleozoic biotite K-Ar and Precambrian Rb-Sr dates were yielded by the southernmost granite (Pushkar and Damon, 1974) that refutes Wilson (1969) who believed the granite to be Mesozoic in age. The most recent mapping of the northern Sierra Estrella (Sommer, 1982) identified 9 map units of various gneissic and granitic rocks. In addition, a helicopter traverse of the range (Spencer et al., 1985) and a wilderness study area report (Keith, 1989) have examined small portions of the study area in detail.

ROCK UNIT DESCRIPTIONS

Eight major map units were identified within the Sierra Estrella (Fig. 1), as well as three rock units that are too areally restricted to show on the map (dikes and pegmatites). Each major rock unit is described separately, and where appropriate broken down into sub-units. Organization and relative ages of units are based on lithology and field relationships. A more detailed geologic map of the Sierra Estrella is presented in Arizona Geological Survey Open-File Report 92-15.



Young Quaternary Alluvium

These deposits are of inferred latest Quaternary age (Holocene), and include channels and low terraces of small drainages, young alluvial fans, and broad terraces of major drainages. Surfaces are usually underlain by well-sorted sand and silt with local gravel. Minimal soil development is characteristic. Surface clasts generally lack a dark coat of desert varnish. These units are shallowly dissected (<3 m) by active channels.

Middle Quaternary Alluvium

These deposits are of inferred early to middle Pleistocene age. Deposits are composed of well-sorted sand, silt, and gravel. Cobbles and boulders up to a meter in diameter are also present. These surfaces are moderately dissected (3 to 6 m) by active channels. Surface clasts are moderately to darkly varnished. Some soils are locally developed. This unit is most commonly well cemented by caliche.

Pegmatites

Numerous pegmatitic dikes crop out in the Sierra Estrella. The pegmatites are abundant in all units except the Montezuma Granite, where they occur only in the margins of the pluton. Intrusion of the pegmatites is both discordant along major fractures and concordant along foliation planes. The pegmatites range in thickness from 5 cm to 4 m, and are generally 90 m to 110 m long. Several exceptionally thick pegmatites are up to 2 km long. Orientation of pegmatite dikes is roughly northwest-southeast and steeply dipping.

The pegmatites consist of massive milky white quartz (65% to 90%), large K-feldspar crystals up to 10 cm in diameter (10% to 30%), and sericitized plagioclase (0% to 25%). Locally the pegmatites can contain several distinctive accessory minerals. Pegmatites in the pelitic schist

and gneiss unit contain many rounded red garnets up to 4 cm in diameter and books of muscovite and biotite up to 20 cm in diameter and 10 cm thick. Sparse crystals of light green beryl and black tourmaline have also been noted in the pegmatites of the pelitic schist and gneiss unit. Pegmatites of the granitic and granitic gneiss units often contain chrysocolla staining and magnetite grains up to 4 cm in diameter.

Each pegmatite dike has altered the surrounding country rock in a zone extending 1 to 10 m from the edge of the dike. In the pelitic schist and gneiss unit the alteration is usually to a biotite, chlorite, or muscovite schist. In the granitic rocks the alteration is to a granitic gneiss that is enriched in magnetite and occasionally copper oxides.

Aplitic Dikes

Dikes of white, fine- to medium-grained, sugary-textured aplite are present in abundance in all units except the Montezuma Granite, where they occur only in the margins of the pluton. Intrusion of the aplite dikes is both discordant along major fractures and concordant along foliation planes. The aplites range in thickness from 1 to 5 m, and are 100 m to 2 km long. Aplite dike trends are roughly northwest-southeast.

Composition of the aplite dikes is quartz (38%), plagioclase (33%), and alkali feldspar (29%). Accessory minerals include secondary epidote and magnetite. Each aplite dike has altered the surrounding country rock in a zone extending 1 to 10 m from the edge of the dike. In the pelitic schist and gneiss unit the alteration is usually to a biotite, chlorite, or muscovite schist. In the granitic rocks the alteration is to a granitic gneiss that is enriched in magnetite and sparse copper oxides.

Mafic Dikes

A series of northwest-trending dikes of grey-green to black mafic rock that is fine to medium grained are found throughout the range, cross-cutting all units of Precambrian age. Intrusion is discordant with local crystalloblastic foliation and contacts with the surrounding country rock are sharp and well defined. All dikes lack a strong foliation and seem to post-date deformation.

The dikes can be divided into two populations. The small dike group consists of dikes 1 to 3 m in width, 25 m to 1 km in length, and dipping 70° to 90° to the southwest. These dikes are typically fine grained and have compositions ranging from basaltic to amphibolitic. Both types of dikes seem to be passively emplaced due to the unaltered persistent foliation above and below the dikes, and a general lack of drag folds.

The large dike group consists of dikes generally 3 to 6 m in width, 0.5 to 5 km in length, and dipping 40° to 60° to the southwest. The margins of these dikes are aphanitic but the rock quickly grades into a medium to coarse grained amphibole-pyroxene gabbro. Composition is plagioclase (30 to 65%), pyroxene and amphibole (25 to 45%), quartz (0 to 5%), clinopyroxene (0 to 5%), and olivine (0 to 1%) with minor chlorite, muscovite, and magnetite. These large dikes also contain subophitic zones with pyroxene crystals up to 5 cm in length. These diabase dikes are similar in composition, intrusive style, and general appearance to the 1100-Ma diabase intrusions of the Apache Group and Troy Quartzite.

Montezuma Granite

The Montezuma Granite crops out in the southern portion of the Sierra Estrella. This monzogranitic pluton is medium grained and nonporphyritic at its margins, but quickly grades to coarse grained and porphyritic towards the center. This unit is light tan in color on weathered surfaces and a light grey on fresh surfaces. The mode of this compositionally homogeneous

granite, estimated from stained slabs and thin sections, is quartz (32%), alkali feldspar (31%), plagioclase (30%), and biotite (7%). The corresponding ternary plot indicates that this unit is a monzogranite. Accessory minerals include muscovite, sphene, zircon, magnetite, and allanite. Sparse epidote and chlorite were noted as secondary alteration. The distinctive characteristic of this rock is a scattering (5%) of large rectangular alkali feldspar phenocrysts, the largest of which are well zoned and up to 6 cm in length. Plagioclase and quartz grains are equigranular in size, ranging from 2-4 mm.

This pluton is typical of 1400-Ma granites in the region in terms of intrusive style, texture, gamma radiation levels, and rock composition. Xenoliths and a weak foliation are found in this pluton near the margins. The Montezuma Granite represents the youngest episode of Precambrian plutonism in the Sierra Estrella range. This unit has a Rb-Sr date of 1380-Ma (Pushkar and Damon, 1974).

Quartz Diorite/Tonalite

This dark-grey to light-grey massive quartz diorite/tonalite is located on the slopes south of Montezuma Peak in the Sierra Estrella. This pluton is medium grained on its margins and coarser grained towards the center. This unit has a weak foliation near the contact with other units. Weathered outcrops are a mottled black and brown color. Most outcrops are irregular, deeply weathered, and surrounded by large piles of grus. The mode, estimated from stained slabs and thin sections, is quartz (15 to 24%), plagioclase (70 to 75%), and biotite (6 to 10%). The corresponding ternary plot indicates that this rock ranges from a quartz diorite to a tonalite. Equigranular plagioclase and quartz grains range in size from 2-4 mm, while biotite grains average 1 mm. The principle mafic constituent is biotite, although minor amounts of hornblende have been noted in some samples. Accessory minerals include magnetite, ilmenite, allanite, sphene, zircon, and secondary epidote and muscovite.

The pluton intrudes the micaceous schist and gneiss unit to the north, forming an injection

zone up to 0.5 km wide. Numerous xenoliths of pelitic, calc-silicate, amphibolite, and granitic gneisses are found in this injection zone. However, xenoliths are found with less abundance through the entire unit. Most xenoliths are extensively folded and indicate a deformation event prior to intrusion. Inclusions range in diameter from a few cm to large bodies tens of m across. The larger bodies are less common and may be roof pendants. Average xenolith diameter is 10-35 cm. The abundance of inclusions in the injection zone indicates shallow emplacement (8-17 km or shallower) in a brittle country rock, and that stoping was an important mechanism of magma emplacement.

Foliated Alkali-Feldspar Granite

The Precambrian Foliated Alkali-Feldspar Granite is a suite of variably foliated granitic to granodioritic plutonic rocks that are medium to coarse grained and grey to pinkish grey on fresh surfaces. Exposure is predominantly in the central part of the map area. The rock varies from a highly-deformed, well-foliated augen gneiss to an almost undeformed homogeneous granite-granodiorite. Weathered outcrops form spalling, spheroidally weathered tan-to-brown boulders that are surrounded by grus-covered slopes. This unit produces a lighter color soil than the surrounding migmatitic gneiss. This unit intrudes the older migmatitic gneiss and was probably emplaced during a period of intense deformation.

The compositional mode, estimated from hand samples and thin sections, is quartz (38 to 28%), alkali-feldspar (30 to 20%), plagioclase (35 to 29%), biotite (8 to 15%), and muscovite (<1%). Accessory minerals include allanite, apatite, sphene, hornblende, secondary epidote, and magnetite. A distinctive characteristic of this unit is a scattering (5 to 10%) of alkali-feldspar phenocrysts that are 0.5 to 7 cm in diameter. Small regions at the center of the plutons lack the phenocrysts however. When present, the phenocrysts are rectangular with slightly rounded corners in the less deformed exposures and are rounded to lenticular augen in the highly deformed outcrops. This unit has numerous inclusions of the surrounding Migmatitic Gneiss and Amphibole

Gneiss. These inclusions occur as thin, elongate sheets up to 10 m in length. Small, rounded xenoliths up to 0.5 m in diameter were also noted.

This unit is quite similar to the Komatke Granite (Reynolds, 1985) of the adjacent South Mountains in lithology, weathering style, deformation style, gamma radiation levels, and general appearance. Both rock units are on strike with each other across the Gila River valley.

Old Granitic Gneiss

The Old Granitic Gneiss is a strongly foliated to massive granitic gneiss. Weathered outcrops are low, blocky, and a dark grey to dark brown due to desert varnish. Fresh surfaces are light to dark grey. This Precambrian unit is discordantly cut by numerous small bodies of Amphibolite Gneiss. Composition of the Old Granitic Gneiss is plagioclase (30 to 40%), alkali-feldspar (2 to 35%), quartz (15 to 25%), biotite (5 to 15%), and retrogressive muscovite (0 to 3%). Accessory minerals include chlorite, magnetite, sphene, and secondary epidote. Protolith is uncertain due to the high metamorphic grade and a general lack of relict features, but may be plutonic based on mineral compositions and weak mineral textures observed.

This unit seems to have intruded the migmatitic gneiss in places. The local high level of deformation and structural relationships indicate this unit was emplaced prior to deformation. The contacts between the Migmatitic Gneiss and the Old Granitic Gneiss are difficult to accurately locate, as the two units grade into each other over a distance of 50 to 100 m, and most original contact relations have been obliterated. Bodies of swirled and migmatized Old Granitic Gneiss also exist within the Migmatitic Gneiss unit, which adds to difficulties in separating the two units.

Migmatitic Gneiss

The Precambrian Migmatitic Gneiss is an undifferentiated unit mainly composed of interlayered migmatitic rock with minor quartzofeldspathic gneiss, Old Granitic Gneiss, amphibole gneiss, marble, and Biotite-Muscovite Schist and Gneiss. This unit usually forms serrated ridges of dark-colored jagged rock in the central and northern portion of the map area. The weathered surfaces are thickly coated with desert varnish. Layering within the unit ranges from 1 cm to 10+ m. This unit has a well-defined crystalloblastic foliation imparted by compositional layering and alignment of micas. Small-scale folds and other structures <1 m are locally common.

All minor sub-units of the Migmatitic Gneiss, with the exception of the Amphibole Gneiss and the Marble units, are thin layers of other major units seen elsewhere in the range. The amphibole gneiss and marble units are only found within the Migmatitic Gneiss. The migmatitic sub-unit is light to dark grey on fresh surfaces. Modal composition varies locally, but usually is one-third quartz and two-thirds feldspar. Muscovite, biotite, hornblende, secondary epidote, and magnetite constitute less than 10% of the total rock. This fine- to medium-grained unit has sheet-like intrusions of the Foliated Alkali-Feldspar Granite up to 5 m in diameter. The migmatite has layering that is swirled and intensely deformed, with the most intensely deformed areas being adjacent to intrusions of the Foliated Alkali-Feldspar Granite. Some areas, especially in the northern portion of the map area, have well-developed layering that may represent relict bedding. The protolith of the migmatite sub-unit is uncertain due to the high metamorphic grade and a general lack of relict features, but is partly sedimentary based on the highly variable mineral compositions.

Amphibole Gneiss The Amphibole Gneiss sub-unit of the Migmatitic Gneiss is composed of interlayered amphibolite, quartzite, and minor biotite-muscovite schist and gneiss. This unit is concordant with the foliation of the surrounding Migmatitic Gneiss, but discordant regions do exist. Layering of the sub-units is on the order of 0.5 to 2 meters. The amphibolite is grey to black on both fresh and weathered surfaces, and is fine grained. Composition is

hornblende (45 to 90%), plagioclase (5 to 35%), quartz (0 to 20%), and biotite (0 to 10%). Accessory minerals include minor chlorite, actinolite, apatite, magnetite, and zircon. Hornblende is usually subhedral and 1 to 5mm in length. Parallel alignment of hornblende and biotite define foliation. Layers within the amphibolite are 1-10 cm thick and remarkably homogeneous along the strike of foliation. This sub-unit weathers to produce a black sand and flat, low, grus-covered outcrops.

Quartzite is coarse grained with no visible accessory minerals. White to light grey in color, these layers of quartzite within the amphibolite are massive and homogeneous. Layers of this sub-unit are 0.5 to 2 m thick. The quartzite is more resistant than the surrounding amphibolite and forms ridges up to 2 m high. Composition is quartz (70 to 90%), alkali feldspar (5 to 15%), and plagioclase (5 to 15%). Minor Biotite-Muscovite Schist and Gneiss is also associated with this unit at its contacts with the surrounding Migmatitic Gneiss. The amphibolite and quartzite probably represent metamorphosed mafic sills and quartz veins.

Marble The Marble sub-unit of the Migmatitic Gneiss is a light tan to brown on both weathered and fresh surfaces, and is fine to medium grained. These marbles and associated calcareous rocks exhibit compositional banding on the scale of 1 to 5 cm and form layers up to 30 m thick. Weathered surfaces have a distinctive "elephant-skin texture" that highlights compositional banding. The marble is impure, containing quartz (0 to 20%) and alkali feldspar (0 to 5%) in addition to calcite and dolomite. Accessory minerals within the marble and associated calcareous rocks include minor garnet, epidote, muscovite, subhedral sphene, diopside, and tremolite. Soils surrounding these outcrops tend to be very well cemented with caliche.

Micaceous Schist and Gneiss

The micaceous schist and gneiss unit is broken up into two sub-units. This rock may be part of the Pinal Schist based on lithology, weathering style, and deformation style. Pinal schist is normally a greenschist-grade rock of uniform lithology, but metamorphic grade can be locally

elevated to amphibolite grade near batholiths (e.g., The Table Top and Javelina Mountains near the Maricopa batholith). The lithological uniformity of the micaceous schist and gneiss also links it to the Pinal Schist, which is uniform over large regions due to its origin.

Quartzofeldspathic Schist and Gneiss This massive fine-grained rock is light to dark grey in color and varies locally from a gneiss to a schistose gneiss. Parallel orientation of micas defines schistosity, whereas gneissic layering is defined by both gradational changes in mineralogy and small fine- to coarse-grained veins of quartz and feldspar. The veins are abundant through most of the unit, run parallel to foliation, have sharp contacts with the country rock, and range from 0.5 to 4 cm thick. Ptygmatic structures are present in these pegmatitic to aplitic veins. Modal composition is quartz (30 to 35%), feldspar (40 to 60%), biotite (8 to 20%), and muscovite (0 to 5%) with minor epidote, magnetite, zircon, and ilmenite. This unit rarely has strong layering on the order of 1 to 10 cm, and more commonly is homogeneous and massive with weak to nonexistent layering. Protolith for this rocks is most likely a muddy arkosic sandstone.

Biotite-Muscovite Schist and Gneiss These pelitic schists and gneisses are composed mainly of plagioclase (30 to 40%), quartz (15 to 40%), biotite (5 to 20%), and muscovite (2 to 15%). Almandine garnet is present in the pelitic rocks (1 to 20%) and forms rounded porphyroblastic grains up to 1.7 cm in diameter. Sillimanite is the only aluminum silicate present in the pelites, and it occurs in two varieties. The first variety occurs as fibrous needles up to 0.7 mm long, whereas the second generation of sillimanite occurs as coarse-grained mats of various sizes. A few samples have a high (2 to 10%) carbonate content and exhibit a "pitted" texture on weathered surfaces. Accessory minerals include apatite, zircon, alkali-feldspar, tourmaline, and magnetite. Minor amounts of the secondary minerals epidote, sericite, and chlorite are also present.

Foliation in these pelites is defined by the long axis of quartz and feldspar, and the parallel alignment of the micas and sillimanite needles. In the pelitic gneiss the segregation of mafic minerals and quartz+plagioclase imparts gneissic banding.

Based on the assemblage of minerals present, the protolith of the pelitic schists and gneisses is inferred to be a shale or sandy mudstone with scattered carbonates.

ECONOMIC GEOLOGY

Nonmetallic Resources

Sand and Gravel Young Quaternary sands and gravels (Qy in Figure 1) are by far the most abundant commercial resource. These reserves are present in washes and as surrounding overbank deposits. These deposits have been historically exploited on a very small scale as a construction aggregate and as landscaping material. However, the overall abundance of similar types of deposits within the greater Phoenix area and transportation costs make this resource of limited value for local construction only. The areas of middle alluvium (Qm in Figure 1) are not suitable for sand and gravel extraction as these deposits are well cemented by caliche with depth.

Quartz Many pegmatites in the Sierra Estrella are a source of very pure quartz that may be suitable for use as smelter flux, roofing granules, and landscaping material. However, like most deposits within the Sierra Estrella, the problem of expensive transport from the rugged range to market makes this commodity marginally profitable at best.

Dimension Stone The Montezuma Granite in the southern Sierra Estrella is well suited for use as a decorative dimension stone. This hard, unaltered, and attractive stone has an appealing light pink to tan color. This stone may also have use as rip-rap. Since this resource is located adjacent to a well-maintained dirt road it may be profitable as potential quarry sites can be easily reached. The local demand for this product and market price would be the overriding factors determining profitability.

Feldspar The occurrence of large feldspar masses in the pegmatites of the Sierra Estrella may also be of commercial interest. Feldspar is used in mild abrasives, high-temperature ceramic production, and the manufacture of vitrified products. In a finely ground form it may be used as non-reactive filler in paint and plastics. The small tonnages available and the difficult accessibility of the deposits make production of this resource a currently unfavorable venture.

Mica Commercial grade mica is found within the pegmatites and metamorphic rocks of the Sierra Estrella. These deposits have been worked in the past with marginal success (Krasen et al, 1982). The pegmatites contain muscovite books up to 20 cm square and 10 cm thick. This mica splits well but up to 50% is bent, twinned, and contains magnetite grains that make it unsuitable for use as sheet mica. Though this mica is unsuitable for sheet mica, it can be used as a source of flake mica. Flake mica is ground to a mesh size of 80 to 325 and is used in the manufacture of cements, drilling mud, reflective paint, welding rods, and asphalt shingles. Muscovite schist surrounding the pegmatites is also a good source of flake mica. Analysis of the schist (Wilson, 1969) indicated that the rock is composed of up to 21.8 % muscovite. Current mining of flake mica is usually of deposits that are >50 % mica. A similar schist was mined recently in the Buckeye Hills.

Overall, the pegmatitic mica is too sporadic in occurrence and the schist is of too low a grade to warrant mining at the current price range (Table 2). Despite this, there have been efforts to produce mica at two locations within the Sierra Estrella. Several other mica deposits have been prospected (Table 1).

Beryl Beryl crystals up to 10 cm in diameter and 26 cm long have been found within the pegmatites of the Sierra Estrella. Rare light-green beryl crystals are only found within a few of the larger pegmatites. Beryl is a source of beryllium which is used in some ceramics, electronics, metal alloys, and nuclear reactors to moderate neutrons. Because of the scarcity of beryl within the pegmatites and the limited demand for beryllium, these deposits have little prospect for development.

Garnet Red euhedral garnets up to 4 cm in diameter and anhedral garnet masses up to 10 cm in diameter are found within pegmatites of the Sierra Estrella. Garnets are also found scattered through some of the pelitic rocks. Garnet is a popular semi-precious stone, but the garnets of the Sierra Estrella are not of gem quality due to numerous mineral inclusions. Garnet also has industrial uses as an abrasive agent. The garnet however is not found in enough abundance to compete with other larger and more accessible deposits that currently supply the market.

Tourmaline Black tourmaline crystals up to 4 cm in diameter and over 30 cm in length compose up to 2 % of some pegmatites within the Sierra Estrella. This tourmaline does not possess chatoyance or "cats-eye" properties, but may be considered a potential resource if it is found to possess favorable piezo-electric properties. The tourmaline is hard, and cuts and polishes well. There is little current domestic market for tourmaline.

Metallic Resources

Copper All observed copper within the Sierra Estrella occurs as copper oxides within the pegmatites and surrounding country rock. Copper values range up to 8,950 parts per million (ppm) (Keith et al, 1989) but only in small discontinuous lenticular bodies in the pegmatites. As a result, the copper contained within the pegmatites would be costly to exploit. When this consideration is combined with the low tonnages of ore present, the Sierra Estrella presents itself as an unfavorable prospect for copper production.

Gold and Silver Pegmatites of the Sierra Estrella contain an average of 15 to 40 parts per billion (ppb) gold with one pegmatite reportedly containing up to 23 ppm gold and 13.5 ppm silver (Korzeb, 1988). While most of the pegmatites are not presently an economically feasible source of gold or silver, they do provide a possible source for gold placer deposits.

Since 1980 there have been over 75 placer claims located in the alluvium on the western side of the Sierra Estrella. These claims have not been worked beyond a few exploration trenches (as of 1991).

Table 1. Commodity price average for 1991

Commodity	Price
Quartz	\$10-30 per ton
Feldspar	\$50-80 per ton
Mica	\$40-70 per ton
Gold	\$362 per ounce
Silver	\$4.03 per ounce
Copper	\$1.05 per lb.
Beryl	\$60-90 per stu
Garnet	\$195-255 per ton
Dimension Stone	\$20-60 per ton

MINING HISTORY

The proximity of early transcontinental travel routes indicate that the Sierra Estrella was probably explored and prospected prior to 1868. In 1868 the U.S. Land Office noted that several partially developed copper mines were located in T.3S., R.2E. In 1920 there were nine load claims filed for the same township and range (U.S. Mineral Surveys No. 3657 and 3658) that indicated development was restricted to a small stope, discovery cuts, and a few shallow pits. No other records were found that discuss mining activity in the Sierra Estrella prior to 1920. Descriptions of other undated workings and workings postdating 1920 are given in the site descriptions.

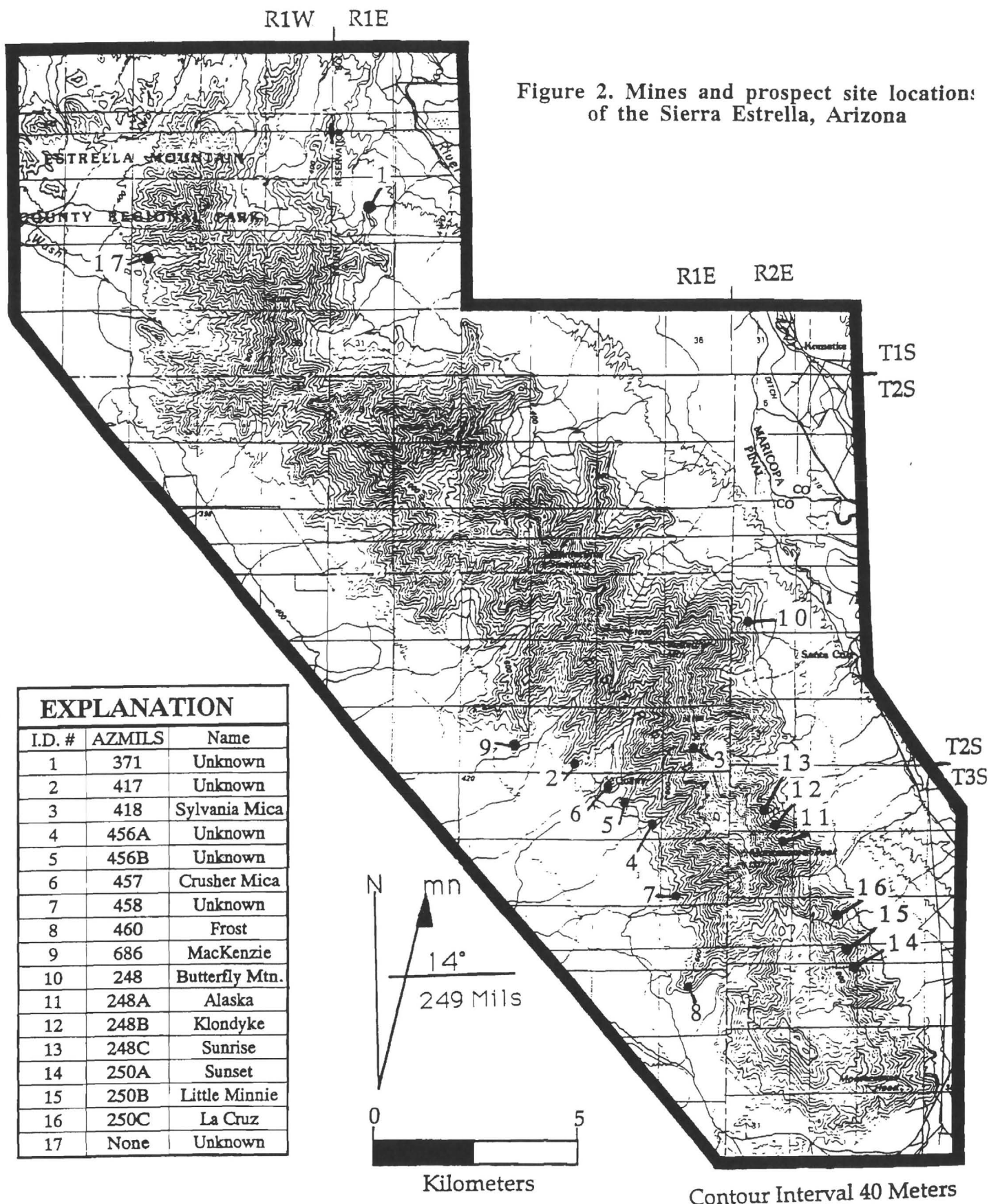
SITE DESCRIPTIONS

The following section describes in detail the workings and geology of the major prospects in Table 2. Location of these sites is denoted on Figure 2 by the corresponding ID number from Table 2. Additional information on some sites is available on file at the Arizona Department of Mines and Mineral Resources under the appropriate AZMILS number or name.

Table 2. Mines and prospects of the Sierra Estrella, Arizona

[AZMILS- Arizona Mineral Industry Location System]

I.D. #	AZMILS	Name	Workings	County	Twn. Shp.	Rng.	Sec.	Qtr.	Minerals or Commodities
1	371	Unknown	Prospect and Adit	Maricopa	1S	1E	19	NE	Cu, Mica
2	417	Unknown	Prospects	Maricopa	2S	1E	34	SE	Cu
3	418	Sylvania Mica	Prospect	Maricopa	2S	1E	36	C	Gold, Cu, Feldspar, Mica
4	456A	Unknown	Prospects	Maricopa	3S	1E	2	SE	Mica
5	456B	Unknown	Prospects	Maricopa	3S	1E	2	NW	Cu
6	457	Crusher Mica	20x10x8ft cut	Maricopa	3S	1E	2	NW	Mica, Qtz, Tourmaline
7	458	Unknown	Prospects	Maricopa	3S	1E	12	SW	Cu
8	460	Frost	Prospects	Maricopa	3S	1E	24	C	Mica, Cu, Qtz, Feldspar, Beryl, Tourmaline
9	686	MacKenzie	Prospects	Maricopa	2S	1E	33	SE	Cu, Mica
10	248	Butterfly Mtn.	Prospect, Adit	Pinal	2S	2E	19	SW	Mica, Qtz
11	248A	Alaska	Prospects	Pinal	3S	2E	7	NE	Cu
12	249B	Klondyke	Prospects	Pinal	3S	2E	6	SE	Cu
13	249C	Sunrise	Adit, Prospect	Pinal	3S	2E	6	SE	Cu, gold, silver
14	250A	Sunset	Prospects	Pinal	3S	2E	20	NE	Cu
15	250B	Little Minnie	Prospects	Pinal	3S	2E	17	SE	Cu
16	250C	La Cruz	Prospects	Pinal	3S	2E	17	NE	Cu
17	None	Unknown	Prospects	Maricopa	1S	1W	27	NE	Cu



#4 Unknown Three Prospects

AZMILS #: 456A

County: Maricopa

Township: 3 S

Range: 1 E

Section: 2

Quarter: SE

Site Description:

Three prospect pits, each 1 by 2 by 3 m deep are located in two 0.5 m wide pegmatitic dikes of approximately 20 m length. The pegmatites discordantly intrude a fine-grained early Proterozoic quartz+feldspar+biotite+muscovite gneiss with locally schistose areas. Crystalloblastic foliation is 030°, 48° SE. The country rock is homogeneous for hundreds of meters surrounding the site, and is believed to have a muddy quartzofeldspathic sandstone protolith. The pegmatites strike north and dip 75° W. No signs of recent activity were seen.

Economic Mineralization:

The pegmatite contains quartz+feldspar+biotite+ muscovite+garnet. Small amounts of chrysocolla and possibly other copper oxides stain the surrounding gneiss to about a 1 m radius of the pegmatite. Highest concentration of copper oxides is within the quartz of the pegmatite. Small irregular shaped bodies (<1 cm diameter) of chrysocolla were also noted within the quartz.

#5 Unknown Two Prospects

AZMILS #: 456B

County: Maricopa

Township: 3 S

Range: 1 E

Section: 2

Quarter: NW

Site Description:

In addition to the 3 pits shown on the Montezuma Peak Quadrangle, 4 other pits were located. The pits are all 1 by 2 meter openings that vary from 0.5 to 2 m depth. Pits are centered on 2 pegmatites (098°, 32° NE and 101°, 19° NE) that discordantly intrude a fine-grained early Proterozoic quartz+feldspar+biotite+ muscovite gneiss with locally schistose areas. Crystalloblastic foliation is 130°, 40° SW. The country rock is homogeneous for hundreds of meters surrounding the site, and is believed to have a muddy quartzofeldspathic sandstone protolith.

Economic Mineralization:

The pegmatite contains quartz+feldspar+biotite+muscovite+garnet+ tourmaline. No copper mineralization was noted, but abundant 4 by 4 by 1 cm books of muscovite are present. Books are often flawed and contain opaque (magnetite?) inclusions.

#6 Crusher Mica Quarry

AZMILS #: 457

County: Maricopa

Township: 3 S

Range: 1 E

Section: 2

Quarter: NW

Site Description:

Five additional pits and a trench not shown on the Montezuma Peak Quadrangle were located. Pits are all 1 by 2 m openings that vary from 0.5 to 2 m depth. The trench is 4 m long and 0.5 m deep by 1 m wide. Three pits and the trench are centered on 2 pegmatites trending 003°, 85°E and 005°, 88°E. An epidotized fault plane (007°, 42° W) extends through the saddle, 1 pegmatite, and a pit. Pegmatites discordantly intrude a fine-grained early Proterozoic quartz+feldspar+biotite+muscovite gneiss with locally schistose areas. Crystalloblastic foliation ranges from 173°, 42° NW to 138°, 12° SE. The country rock is homogeneous for hundreds of meters surrounding the site, and is believed to have a muddy quartzofeldspathic sandstone protolith. The Crusher Mica Quarry shows no signs of recent activity. A road leads up to the old loading dock where there are the remains of a loading bin, crusher, and screen sieves. A 1 m pile of crushed and sieved mica remains at this location. The quarry consists of three terraces, 3 shallow 1 by 1 by 1 m pits, and 2 large cuts (3 by 4 by 2 meters and 7 by 3 by 2 meters). Last production seems to have been in the late 1950's (Krason et al, 1982).

Economic Mineralization:

The pits and trench on the pegmatite contains quartz+feldspar+biotite+muscovite+garnet+tourmaline. No copper mineralization was noted, but abundant 4 by 4 by 1 cm books of muscovite are present. Books are often flawed and contain opaque (magnetite?) inclusions. The Crusher Mica Quarry production seems to have been centered around zones of

coarse mica schist that are 3+ meters wide. The mica flakes tend to constitute 25%+ of the rock in this zone, and flakes average 1 to 2 cm in diameter. Flakes tend to be irregularly shaped, flawed, and crumpled.

#7 Unknown two prospects

AZMILS #: 458

County: Maricopa

Township: 3 S

Range: 1 E

Section: 12

Quarter: SW

Site Description:

Two prospect pits are present in a stream drainage. The pits are within 2 m of each other and have been partially filled in with sandy stream sediment. Pit dimensions are 1.5 by 2 m, and 1 m deep. The original pit depths are unknown due to stream sediment infilling. The pits are centered on a concordantly intruded quartz+feldspar pegmatite 1.5 m wide, 10+ m in length, and striking 005° and dipping 32° SE. The surrounding country rock is a fine-grained early Proterozoic quartz+feldspar+biotite+ muscovite gneiss with locally schistose areas. Foliation is 008°, 31° SE. The country rock is homogeneous for hundreds of meters surrounding the site, and is believed to have a muddy quartzofeldspathic sandstone protolith.

Economic Mineralization:

Small amounts of chrysocolla and possibly other copper oxides stain the surrounding gneiss to about a 1 meter radius of the pegmatite. Highest concentration of copper oxides is within the quartz of the pegmatite. Small irregularly shaped bodies (1-3 cm diameter) of chrysocolla were also noted within the quartz.

#9 MacKenzie Copper Prospect

AZMILS #: 686

County: Maricopa

Township: 2 S

Range: 1 E

Section: 33

Quarter: E

Site Description:

Numerous prospect pits that have been mostly filled in with sandy sediment are present. The pits are centered on a discordantly intruded quartz+feldspar pegmatites 0.5 to 0.25 m wide, 5+ m in length, and striking 064° and dipping approximately 80° NW. The surrounding country rock is a fine-grained early Proterozoic quartz+feldspar+biotite+muscovite gneiss with locally schistose areas. Crystalloblastic foliation is 042°, 75° NW. The country rock is homogeneous for hundreds of meters surrounding the site, and is believed to have a muddy quartzofeldspathic sandstone protolith. The country rock is altered approximately 2+ meters from either side of the pegmatite. Average pit dimensions are 1.5 by 2 m, and 1 m deep. The exceptions are 2 pits in the saddle that are 1 by 1 by 3 meters deep. Original pit depths are unknown due to sediment infilling. Small piles and scattered samples of chrysocolla stained quartz are located around the pits.

Economic Mineralization:

Most pits contain small amounts of chrysocolla and possibly other copper oxides that stain the surrounding altered country rock to about a 1 m radius of the pegmatite. Highest concentration of copper oxides is within the quartz of the pegmatite. Small irregularly shaped bodies (1 to 3 cm diameter) of chrysocolla were also noted within the quartz. One location has copper oxide mineralization that is 5 to 6% of the rock, and composed of small irregularly shaped bodies (3 to 6 cm diameter) of chrysocolla disseminated throughout a zone for 0.5 meter surrounding the pegmatite.

#10 Butterfly Mtn. Area Mica Deposit

AZMILS #: 248

County: Pinal

Township: 2 S

Range: 2 E

Section: 19 Quarter: SW

Site Description:

A prospect shaft (shown as an adit on the Montezuma Peak quadrangle topographic sheet) extends about 8 to 9 m into a pegmatitic dike. The pegmatite discordantly intrudes a fine-grained early Proterozoic quartz+feldspar+biotite+muscovite gneiss with locally schistose areas. Crystalloblastic foliation is 012°, 29° SE. The country rock is homogeneous for hundreds of meters surrounding the site, and is believed to have a muddy quartzofeldspathic sandstone protolith. The pegmatite strikes 135°, 75° SW and is approximately 2 m wide at the shaft. The pegmatite lenses out 11 m to the southeast and 17 m to the northwest of the shaft.

Economic Mineralization:

The pegmatite contains quartz+feldspar+biotite+ muscovite+garnet. The books of biotite are small and sparse, while the muscovite books are up to 10 cm long by 8 cm wide, by 5 cm thick. The books of muscovite are irregular shaped, flawed, and fairly plentiful in a zone 0.5 m wide adjacent to the footwall. Garnets are less than 1 cm in diameter, grossular to spessertine in composition, highly fractured, and retrogressively metamorphosed.

#13 Sunrise

AZMILS #: 249C

County: Pinal

Township: 3 S

Range: 2 E

Section: 6

Quarter: SE

Site Description:

Remnants of a small hand-made aerial tram were still at the site. The rusted cables and rotted poles of the tram extend along the trail from the former loading bin to the mine site. Ore samples were found in abundance at the old loading bin and all along the tram route. At the mine site a prospect pit measuring 2 by 2 by 1 m and an adit 2 m high and 2 m wide extends inward approximately 18 m. The adit was driven into the hanging wall zone of a discordantly intruded

quartz pegmatite that is 3 m wide, 25+ m in length, striking 134°, and dipping 48° SW. At the back of the adit the pegmatite narrows to 30 cm. No recent work on the adit was evident, and the entrance was partially collapsed. The pegmatite is coarsely crystalline, vitreous, colorless to white, brecciated body. The surrounding country rock is a fine-grained early Proterozoic quartz+feldspar+biotite+muscovite gneiss with locally schistose areas. Foliation is 058°, 34° SE. The country rock is homogeneous for hundreds of meters surrounding the site, and is believed to have a muddy quartzofeldspathic sandstone protolith.

Site History and Economic Mineralization

The site was apparently active prior to 1868, based on a U.S. Land Office report of that year that states that, "Several copper mines, as yet but partially developed," were located at the site (See also AZMILS # 249A, 249B, 250B, and 250C). In 1920 a lode claim was surveyed at the site, but not patented. The same claim was resurveyed in 1922. Both surveys were performed by the Sacaton Copper Company. In April of 1963 an investigation of the site revealed no recent improvements to the site. The same study yielded ore samples from the back of the adit that assayed as follows:

3% copper

0.22 ounce per ton gold

0.35 ounce per ton silver

Small amounts of chrysocolla and possibly other copper oxides stain the surrounding gneiss to about a 1 m radius of the pegmatite. Highest concentration of copper oxides is within the hanging wall of the quartz pegmatite. Small irregularly shaped bodies (1 to 5 cm diameter) of chrysocolla, limonite, and hematite were also noted within the quartz.

#14 Sunset

AZMILS #: 250A

County: Pinal

Township: 3 S

Range: 2 E

Section: 20

Quarter: NE

Site Description:

At this site shallow excavations that are centered on several discordantly intruded quartz+feldspar pegmatites 0.5 to 1 m wide, 10+ m in length, and striking N-S and dipping SE. The surrounding 1.6 Ga. quartz diorite country rock is altered approximately 15+ m from either side of the pegmatites. Small pieces of chrysocolla are located in small scattered piles in this area.

Economic Mineralization:

Small amounts of chrysocolla and possibly other copper oxides stain the surrounding altered quartz diorite up to a 1 m radius of the pegmatite. Highest concentration of copper oxides is within the quartz of the pegmatite. Small irregularly shaped bodies (1 to 3 cm diameter) of chrysocolla were also noted within the quartz.

#15 Little Minnie

AZMILS #: 250B

County: Pinal

Township: 3 S

Range: 2 E

Section: 17

Quarter: SE

Site Description:

A prospect pit that been mostly filled in with sandy sediment was present. The pit is centered on a concordantly intruded quartz+feldspar pegmatite 0.5 m wide, 5+ m in length, and striking 007° and dipping approximately 50° SE. The surrounding 1.6 Ga quartz diorite country rock is altered approximately 15+ m from either side of the pegmatite. Pit dimensions are 1.5 by 2 m, and 1 m deep. The original pit depth is unknown due to sediment infilling. A small pile and scattered samples of chrysocolla stained quartz are located around the pit.

Economic Mineralization:

Small amounts of chrysocolla and possibly other copper oxides stain the surrounding altered quartz diorite to about a 1 m radius of the pegmatite. Highest concentration of copper oxides is within the quartz of the pegmatite. Small irregular shaped bodies (1 to 3 cm diameter) of chrysocolla were also noted within the quartz.

#16 La Cruz

AZMILS #: 250C

County: Pinal

Township: 3 S

Range: 2 E Section: 17 Quarter: NE

Site Description:

A prospect pit that has been partially filled in with sandy sediment is centered on a concordantly intruded quartz+feldspar pegmatite 1 m wide, 10+ m in length, and striking 008° and dipping 41° SE. The surrounding 1.6 Ga quartz diorite country rock is altered approximately 15+ m from either side of the pegmatite. Pit dimensions are 1.5 by 2 m, and 1 m deep. The original pit depth is unknown due to sediment infilling.

Economic Mineralization:

Small amounts of chrysocolla and possibly other copper oxides stain the surrounding altered quartz diorite to about a 1 m radius of the pegmatite. Highest concentration of copper oxides is within the quartz of the pegmatite. Small irregularly shaped bodies (1 to 3 cm diameter) of chrysocolla were also noted within the quartz.

#18 Unknown

AZMILS #: None

County: Maricopa

Township: 1 S

Range: 1 W Section: 27 Quarter: NE

Site Description:

Two prospect pits, each 1 by 2 m by 3 m deep are located in a 0.5 meter wide pegmatitic dike of approximately 20 m length. The pegmatite discordantly intrudes a fine-grained early

Proterozoic quartz+feldspar+biotite+muscovite gneiss with locally schistose areas. Crystalloblastic foliation is 061° , 64° SE. The country rock is homogeneous for hundreds of meters surrounding the site, and is believed to have a muddy quartzofeldspathic sandstone protolith. The pegmatite strikes 004° and dips 77° W. No signs of recent activity were seen, but a pile of rotten timbers and a broken ladder into one of the pits remain.

Economic Mineralization:

The pegmatite contains quartz+feldspar+biotite+ muscovite+garnet. Small amounts of chrysocolla and possibly other copper oxides stain the surrounding gneiss to about a 1 m radius of the pegmatite. Highest concentration of copper oxides is within the quartz of the pegmatite. Small irregularly shaped bodies (1 to 3 cm diameter) of chrysocolla were also noted within the quartz.

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