BEDROCK GEOLOGY OF THE SANTAN MOUNTAINS, PINAL AND MARICOPA COUNTIES, ARIZONA

by

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INTRODUCTION

The Santan Mountains are a 25 km long, west-northwest trending uplift composed chiefly of Proterozoic and Cretaceous crystalline rocks overlain in the central and eastern part of the range by Mid-Tertiary sedimentary and volcanic rocks. Santan Mountain at an elevation of 3010 feet is the range's highest point, rising nearly 1700 feet above the basin floor. Elevations decrease rapidly to the southeast towards the Gila River. The eastern two thirds of the range are composed of low hills connected by extensive areas of pedimented bedrock where relief is rarely greater than 400 feet. The range is bounded to the north by the Higley basin, and no extensive, pedimented bedrock surfaces exist here. Instead, abrupt thickening of the basin fill is suggested by the numerous earth fissures along the range's north edge (Harris, 1994; Sauk, 1975). To the south, like the east, an extensive dissected granitic pediment extends all the way to the Gila river. Extensive pediments in the Sacaton Mountains to the southwest also probably extend northward to the Gila River, suggesting that the low area between the two ranges was created more by erosional processes than by tectonic processes. At Poston Butte, near the eastern terminus of the Santan Mountains, crystalline bedrock occurs less than 150 meters below the Gila River (Hoag, 1996).

The name Santan is a corruption of the spanish "Santa Ana". Several well-graded dirt roads traverse the central part of the range between Goldmine Mountain and Mineral Butte. Several other good dirt roads provide access to the eastern and western parts of the range, but because much of the range lies within the Gila River Indian Community a permit is required to enter. Because of the limited access on the Indian Community, roadless areas are surprisingly wild and undisturbed, despite the proximity to the Phoenix metropolitan area.

GEOLOGIC OVERVIEW

Because geology of the Santan Mountains is dominated by Proterozoic and Laramide granitoids that intrude older polydeformed metamorphic rocks (Pinal Schist), little is known about the Laramide (Late Cretaceous to early Tertiary) and Tertiary structural evolution of the area. Regionally, the Santan Mountains lie within a northwest-trending belt of high extension in the Basin and Range physiographic province just to the southwest of transition zone physiographic province. This belt includes northeast-southwest trending, core-complex uplifts (Spencer and Reynolds, 1989) that expose low-angle, strongly NE-SW lineated fault zones. The hanging walls of these faults invariably contain Mid-Tertiary volcanic and sedimentary sequences (c.f. Dickinson, 1991), and these sequences commonly record fanning dips. The Santan Mountains are enigmatic in that the basement-Mid Tertiary contact is depositional, and no evidence of core-complex development has been found.

THE ROCKS

Pinal Schist

The Pinal Schist in the Santan Mountains is a heterogeneous metasedimentary unit ranging in textural grade from phyllite to coarse-grained and compositionally banded schist. A wide variety of porphyroblasts are present, and their occurrence appears to be largely compositionally dependent. The strong development of the post-kinematic muscovite in the coarser-grained schists is typically indicative of contact metamorphic aureoles near intrusive contacts.

The Pinal Schist can be easily divided into three lithologies (more subdivisions are possible). Comprising about half of the Pinal Schist are silvery, greenish gray phyllites and fine- to medium-grained pelitic and semipelitic schists that were probably derived from a relatively thick and monotonous argillaceous sedimentary sequence. These schists locally display thin compositional banding that may represent bedding. The other half consists of evenly thin-banded, light gray, psammitic schists that probably represent argillaceous sandstone intervals. These first two lithologies comprise over 95% of the unit but were not differentiated during our mapping. Comprising less than 5% of the Pinal Schist, and recognized as a separate map unit, are thin zones (commonly less than 20 meters thick) of epidote-rich, calc-schists that are almost everywhere associated with dark bluish-gray, banded quartzites. Amphibolite-rich lenses, although rare in the Santan Mountains, are locally associated with the calc-schists and quartzites.

The calc-schists and quartzites (map unit Xpq) occur in swarms and as single bands within thick successions of pelitic schists. The areas dominated by psammitic schists include lighter gray quartz-rich schists and tan-colored quartzite bands, particularly on the north side of Goldmine Mountain and northwest of Mineral Mountain.

The prominent foliation in the Pinal Schist is a pervasive schistosity defined by parallel alignment of phyllosilicate minerals. Compositional banding is common. The bands range in thickness from a few mm to less than 1 cm. The banding appears to be the product of either metamorphic segregation and/or tightly folded quartz vein arrays in the pelitic schists, or evenly spaced solution cleavage in the psammitic schists. In some pelitic and semi-pelitic schists, the schistosity cuts compositional banding that appears to represent bedding. In the schists where this banding is oriented at high angles to the prominent schistosity, an older cleavage oriented at low angles to the banding is commonly preserved. Only rarely was the compositional banding oriented consistently enough to be measured as an older, pre-prominent schistosity foliation. These older foliations are indicated with a special symbol on the map. Because the schistosity cuts what appears to be an older metamorphic fabric it is considered to be, at the least, a second generation cleavage.

Locally, the prominent schistosity is deformed by a consistently oriented, mm- to cm-scale spaced crenulation cleavage. Where this cleavage was recognized, its orientation is very consistent, and the crenulation (also an intersection) lineation it produces is also fairly consistently oriented. The combination of three consistently oriented markers is used to evaluate younger tilting in the Commode Butte area.

Plutonic rocks

Classification

Our mapping, and definition of map units of the plutonic rocks of the Santan Mountains, was based primarily on compositional criteria. Textural criteria played a less significant role. Plutonic rocks in this report where classified using Streckeisen's IUGS (1973) scheme. The quartz/potassium feldspar/plagioclase ratios required to name the rocks were estimated in the field. It is important to note that mafic minerals are excluded in the classification of the felsic plutonic rocks. Important textural and mafic mineralogical aspects are provided as modifiers to the rock name. The field naming of rocks based on quartz-feldspar ratios agree remarkably well to ratios given by others who have studied the same rocks (e.g. Balla, 1972; Nason et al., 1982). Balla (1972) indicates that some of his modes were quantitative. Any difference in names that these workers used is probably more the result of using different classification schemes (particularly Balla, who did his work before the IUGS scheme was formally recommended) than on differences in how we appraised the rocks.

The recognition of quartz in most of the rocks is fairly easy, and on smooth weathered surfaces, the feldspars can often be distinguished by slight differences in their response to weathering. Plagioclase is typically an opaque, chalky white color, and K-feldspar is typically more translucent and pinkish in color, but this is not always the case. For example, in the granodiorite of the northeastern Santan Mountains, plagioclase is typically the fresher appearing of the two feldspars. In some rocks, particularly the finer-grained more mafic varieties, the distinction between the two feldspars was difficult, and in general, the degree of mafic mineral content was used to implicate the feldspar assemblage as being dominantly plagioclase or potassium feldspar (more mafic rocks were presumed to be higher in plagioclase).

Proterozoic granitoids

Although only one Proterozoic date has been reported from the granitoids of the Santan Mountains, two main suites are presumed to exist; an Early Proterozoic equigranular granodiorite, characterized by abundant S-C fabrics and narrow mylonite zones, and an anorogenic, K-feldspar porphyritic granite-quartz monzonite (see STRUCTURE section for definition of S-C/mylonite fabrics). The granodiorite is restricted to the north half of the range and the porphyritic granite is restricted to the south half. The range is divided along its ESE trending drainage divide, which also appears to be an important structural lineament, bounding a zone where Tertiary supracrustal rocks are restricted to the south.

Early Proterozoic granodiorite

The granodiorite is characterized by abundant ENE-striking ductile shear zones that are expressed as narrow epidotized mylonite zones and S-C fabrics. The northeastern-most exposures are the only areas where the tectonic foliation is pervasive, and this is indicated by a special symbol on the map. Balla (1972) interpreted a K-Ar biotite radiometric age of 1341 $\pm$ 61 Ma (recalculated by Reynolds et al.) of this granitoid to be reset by emplacement of the widespread anorogenic, approximately 1.4 Ga suite of plutons in central Arizona. The granodiorite is presumed to be Early Proterozoic, based on the abundance of epidotized mylonites zones which are typical of this age of granitoid in areas just to the southwest (S. J. Reynolds, personal communication).

Middle Proterozoic granite

The K-feldspar porphyritic granite of the Santan Mountains is presumed to be Middle Proterozoic in age based on its petrographic similarity to nearby plutonic bodies of the western Sacaton Mountains that have been dated at 1253 $\pm$ 26 Ma, and 870.0 $\pm$ 18.4 Ma by K-Ar biotite (Balla, 1972, recalculated by Reynolds et al., 1986), and because it is cut by NNW-striking diabase dikes which are assumed to be Middle Proterozoic in age. The granitoid consists largely of K-feldspar porphyritic, medium-grained, biotite-bearing, granite, syenogranite, and quartz monzonite. Locally, the granite changes abruptly into two distinct subordinate phases defined principally on textural criteria: (1) equigranular fine- and medium-grained granite, and (2) sparsely K-feldspar porphyritic granite or quartz monzonite. The contacts between these phases and the main body of the pluton are sharp, but not demonstrably intrusive, and the phases are interpreted to be cogenetic. Previous workers (Balla, 1972; Nason et al., 1982) correlated the K-feldspar porphyritic granite of the Santan Mountains with the Oracle Granite of the Tucson area farther south, and they refer to the Santan Mountains version as a quartz monzonite, even though its quartz content averages over 20%.

The K-feldspar porphyritic granite rarely forms high-standing hills because it erodes easily into grus. Consequently the unit makes up most of the extensive pedimented bedrock areas along the south side of the range, and along the north side of the Sacaton Mountains (Skotnicki and Ferguson, 1996a). This tendency earned this unit the dubious, informal field name of "the energizer granite" (because it keeps going, and going!). In fact, almost all pedimented bedrock areas that are farther than a few hundred meters from any outcrop that protrudes above the piedmont are made of this unit. This indicates that the pedimented areas between the Santan and Sacaton Mountains are controlled by lithology (c.f. Kesel, 1977; Huckleberry, 1992; 1994).

At Cholla Butte, at the east end of our study area, the granite locally contains spherical, anhedral quartz phenocrysts up to 1-2 cm, and grades southeastward into a medium-grained, slightly porphyritic granite that we mapped as a separate unit (Ygm). Nason et al. (1982) also noted a gradual east to west change from porphyritic to equigranular textures in the subsurface between Poston Butte and Cholla Butte, and they interpreted the equigranular granite as a phase of the larger porphyritic "Oracle Granite". We tentatively agree with Nason et al. (1982) interpretation, but Balla (1972) interpreted these outcrops at the southeast end of the Santan Mountains as "Laramide" in age, and in support of this, he reports a biotite K-Ar date of 63.90 $\pm$ 2.30 Ma (recalculated by Reynolds et al., 1986). Balla's interpretation is also supported by textural comparisons with the extensive Sacaton Peak pluton of the Sacaton Mountains which is characteristically quartz-porphyritic (Balla, 1972, Skotnicki and Ferguson, 1996a). The biotites Balla dated in the Cholla Butte area may record a thermal event related to emplacement of the Cretaceous stocks and Cretaceous to Mid-Tertiary intermediate dikes in the area.

The Mid-Proterozoic granitoids occur in three distinct forms over a large area: (1) K-feldspar porphyritic granite, (2) sparsely K-feldspar porphyritic, fine- to medium-grained granite to quartz monzonite, and (3) equigranular fine- to medium-grained granite. In the Goldfield Mountains (Skotnicki and Ferguson, 1996b), and in the North Butte area (Richard and Spencer, in preparation), these three phases have been recognized, and interpreted as being possibly cogenetic. In the Goldfield Mountains, all three phases are cut by pervasive S-C foliations. In the Sacaton Mountains, three similar phases were recognized (Skotnicki and Ferguson, 1996a), one of which is both tectonically and magmatically foliated [map unit YXg] and another is magmatically foliated [map unit Yg].

Wilson (1969) mapped a large ENE-trending elliptical area of the K-feldspar porphyritic granite surrounding Mineral Butte as "Laramide" in age. Although this area is extensively altered, we could not recognize any intrusive contact or changes in the granite's primary texture or composition corresponding to Wilson's (1969) contact. Small intrusions of unaltered, fine-grained quartz monzonite occur in the area, and the largest of these has been dated at 72.10 $\pm$ 1.40 Ma (K-Ar biotite, Balla, 1972, recalculated by Reynolds et al., 1986).

"Laramide" granitoids

Late Cretaceous to early Tertiary plutonic rocks in the southeastern Santan Mountains consist of medium- to fine-grained, equigranular quartz monzonite to quartz monzodiorite. The bodies are very homogeneous, but locally have finer grained, monzonite, monzodiorite and rarely diorite phases along intrusive contacts. The rocks tend to be gray colored due to their high mafic mineral content (10-30%). The mafics consist mostly of biotite and minor amounts of hornblende.

Small intrusive bodies of quartz monzonite to monzodiorite and a series of intermediate, porphyritic to holocrystalline dikes occur along an ENE-trending belt within the K-feldspar porphyritic granite in the south-central part of the range, and a larger apparently ENE-trending stock occurs just to the south in between Twin Buttes and Granite Knob. Intense porphyry copper-type alteration and mineralized veins occur around the smaller bodies in the coarse-grained granite (Mineral Butte district), but not around the periphery of the larger (Twin Buttes) stock.

Proterozoic-Cretaceous granitoids

A NNE-trending belt defined by two elongate granitoid stocks of unknown age (Santan Mountain and Goldmine Mountain) occurs in the northern Santan Mountains (map unit KXg). Previously assumed to be Proterozoic (Wilson et al., 1969; Balla, 1972; Reynolds, 1988), these rocks are texturally similar to the southerly adjacent Early Proterozoic granodiorite. However, there are important differences that support a Cretaceous age for the two stocks. The main body of each appears to be slightly more felsic (granite as opposed to granodiorite), they are both associated with mafic border phases, and locally they display moderately east-dipping magmatic layering; all features characteristic of the nearby Cretaceous Sacaton Peak granite (Balla, 1972; Skotnicki and Ferguson, 1996a). These rocks only rarely contain mylonites, which are abundant in the early Proterozoic Granodiorite, and they are not cut by the Late Proterozoic

NNW-striking diabase dikes, although the Goldmine Mountain stock has abundant dioritic border phases that locally display the diabase texture. In addition, the western part of the Santan Mountain stock appears to intrude a major brittle SSE-striking fault.

Dikes

Two main sets of dikes occur in the Santan Mountains. The oldest are a NNW-striking diabases dikes that cut the Middle and Early Proterozoic granitoids and are more common in the northern half of the range. A younger set of ENE-striking dikes of highly variable composition cut all of the area's plutonic rocks. These are classified as felsic, intermediate, and mafic. Some of the intermediate dikes may be closely related to the Laramide plutonic rocks. One of these is erosionally truncated by the unit of Rock Peak just to the west of Commode Butte. No dikes were found that cut any of the Tertiary supracrustal rocks.

In the north, numerous muscovite- and locally pyrope-garnet-bearing pegmatitic dikes cut the Pinal Schist and are typically oriented parallel to its prominent schistosity. On the north side of Goldmine Mountain a pegmatite dike swarm intrudes the axis of a west-plunging antiform in Pinal Schist.

Tertiary Rocks

There are three types of Tertiary supracrustal rocks in the Santan Mountains. The youngest is a crystal-rich ash-flow tuff that is probably an outflow sheet from one of the tuffs of the Superstition Mountains. The two older types are basalt lava and sedimentary rocks (ranging from breccia to minor limestone). The basalt is interbedded with both of the other units.

Welded tuff

A crystal-rich (25-40%), reddish-colored, pumice- and lithic clast-poor, welded ash-flow tuff represents the youngest Tertiary supracrustal rock in the Santan Mountains. An Oligocene K-Ar phlogopite age of 26.00 ± 0.54 (recalculated by Reynolds et al., 1986 from Balla, 1972) was obtained from this unit, but is suspect because the unit is probably Superstition Tuff based on petrographic comparisons (Balla, 1972; this report; and Don Peterson, personal communication) and is, therefore, probably much younger. Paleomagnetic polarity of this unit is normal (Sedgeley, 1976, p. 24).

The tuff contains phenocrysts of plagioclase, quartz, sanidine, biotite, and traces of hornblende, sphene, and opaque minerals. The feldspars and quartz are fairly large (1-5 mm) and set in an aphanitic matrix. Dark brown to black vitrophyres occur at and near the base, and locally (section 32, T. 3 S., R.7 E.) basalt is interleaved with these. Lithics are sparse, consisting of basement (granite) and basaltic lithologies and they are seldom larger than 3-4 cm. Although a strong planar fabric and low-angle set of joints resemble eutaxitic foliation, pumice fragments are virtually absent. Near the base, spherulites (radial growth patterns) several centimeters in diameter are locally abundant. In the basal unwelded to poorly welded interval, there are also concentrically ringed spherules up to 10 cm across that may be accretionary lapilli.

Basalt lava

Basalt lava crops out in a number of places in the Santan Mountains. They are all moderately crystal-rich to crystal-poor and they contain standard, olivine-pyroxene-plagioclase phenocryst mineral assemblages. Two areas of relatively steeply dipping scoriaceous agglutinates are present, suggesting that vents are nearby; one along the southeast side of Malpais Hills, and the other at the north end of a low ridge east of Walker Butte. The basalts apparently span an interval of time from early Miocene, and possibly Oligocene to Pliocene. Basalt flows of the easternmost Santan Mountains have no relationship to the regional welded ash-flow tuff, and these are believed to be younger units correlative to latest Miocene and Pliocene flows in the Poston Butte area (Nason et al., 1982).

A series of basalts in the southwestern part of the range are considered older because they underlie and locally interfinger with an extensive outflow sheet of ash-flow tuff that is probably at least early Miocene in age. The basalts in this area form an extensive, greater than 100 meter-thick deposit covering a 40 km^2 area, and therefore representing at least 4 km^3 of material. To the east these basalts thin or pinch out and are replaced by a sedimentary sequence that includes interbedded basalts. Because of the poor exposures in the area, it is not possible to unequivocally correlate any of these thinner basalts with the extensive sheet to the west. Numerous geochronology and geochemistry samples have been collected at key areas from these basalts.

Sedimentary rocks

Tertiary sedimentary rocks crop out in three areas of the Santan Mountains, and in each place they are capped by the crystal-rich, welded ash-flow tuff. To the east, in the vicinity of the Poston Butte porphyry copper deposit, Tertiary sedimentary rocks in the subsurface are interbedded with basalt lavas and a silicic ash-flow tuff (Nason et al., 1982).

There are two main types of sedimentary rocks: (1) bedded sandstone-conglomerate, and (2) coarse-grained breccia.

Bedded rocks

The bedded rocks are apparently more abundant than the breccias. They are chiefly medium- and thick-bedded sandstone, granule sandstone, pebbly sandstone and sandy conglomerate. The conglomerates occur in lenticular, channel shaped bodies, and the sandstones typically occur in tabular bodies. Cross-bedding is rare. In general, the sequence changes upward from non-volcaniclastic to moderately volcaniclastic; the chief volcanic lithic grains being aphyric, pink rhyolite. Mafic lava lithics are also present. The sedimentary rock's tuffaceous nature, reported previously by Sell (1968) could not be corroborated. Non-volcanic detritus dominates, chiefly clasts of nearby basement lithologies; granodiorite and K-feldspar porphyritic granite (Xg and Yg). The clasts are typically rounded to sub-rounded, and locally, subangular and very coarse-grained, particularly near the base in the Yellow Peak area.

Monolithic breccias

The sandstones and conglomerates overlie or are interbedded with poorly sorted, generally monolithic breccias and conglomerates composed of very angular to subangular clasts of basement lithologies (Xg, Yg, and Xp map units). Size of the clasts range from sand to very large boulders (some several meters in diameter) and the deposits are always clast-supported.

The breccias are rarely crudely bedded, and the exposure along the north edge of Malpais Hills (section 30, T. 3 S., R. 7 E.) is interbedded with conglomerate and sandstone. This exposure consists mostly of clasts of the equigranular, medium-grained granodiorite (map unit Xg), and less abundant Pinal Schist, and it lies in the hanging wall of a low-angle fault juxtaposed with the granodiorite.

The extensive exposures of breccia that underlie Yellow Peak are composed mostly of clasts of the K-feldspar porphyritic granite, and lesser amounts of Pinal Schist. The breccias pinch out to the south and west where they overlap basement along a steep, north to northeast-facing scarp. Just to the northeast of the scarp, a sharp, low-angle, basal contact is exposed, but elsewhere no base is exposed.

At Commode Butte, two separate exposures of breccia are present; the southern one containing only Pinal Schist clasts, and the northern one composed mostly of porphyritic granite clasts. These are overlain or interbedded with sandstone and conglomerate.

STRATIGRAPHIC CORRELATIONS, TERTIARY SEQUENCE

The younger age limit of the Tertiary supracrustal rocks of the Santan Mountains is well constrained because they are all capped by a regionally extensive ash-flow tuff that is probably an outflow sheet from the Superstition Mountains area. The Oligocene K-Ar date of this unit reported by Balla (1972) is much older than the Miocene age for the Superstition Tuff from the Superstition Mountains indicated by preliminary, precise $^{40}Ar/^{39}Ar$ sanidine dates from two separate labs (Don Peterson and Bill McIntosh, personal communication).

Rock Peak-Yellow Peak area and the unit of Rock Peak

Rock Peak and Yellow Peak are a pair of teat-shaped hills in the south-central Santan Mountains capped by nipple-like exposures of welded tuff. At Yellow Peak, the beds are nearly horizontal, and the lower conglomerate overlies at least 50 meters of coarse-grained, granite-clast breccia. The sandstone-conglomerate sequence at Rock Peak is much thicker and it forms a fanning dip sequence including two basalt flows, one at the base, and another higher in the section separated by a finer-grained and thinner bedded sequence of sandstone with a thin interval of gray limestone, and limestone-pebble conglomerate.

Sell (1968) differentiated two conglomeratic units at Yellow Peak because they are separated by a thin basalt, and postulated that the sequence, in general, correlates with the Whitetail Conglomerate. This distinction may prove useful in the future, when precise radiometric dates of the basalts in the area are available, and correlations can be made between this area, and the Poston Butte area. At this time, however, since correlation of basalts in even a relatively small area such as Rock Peak-Yellow Peak is uncertain, we suggest defining stratigraphic units broadly.

The unit of Rock Peak is herein defined to include all Tertiary supracrustal rocks of the Santan Mountains preserved below the welded ash-flow tuff unit. This definition distinguishes these rocks from the younger (Pliocene) Big Dome Formation of the Ray area, and it recognizes the chronostratigraphic utility of the unit; because its top is defined by a regionally extensive ash-flow tuff sheet, and it includes many datable basalt flows that interfinger with the sedimentary rocks (including the breccias).

"Commode Butte"

The name "Commode Butte" is a name informally given to the hill in the east-central Santan Mountains capped by welded tuff and underlain by sedimentary rocks. The sedimentary rocks at Commode Butte are assigned to the unit of Rock Peak because they are overlain by the welded tuff, as is a small outlier of sedimentary rocks to the west of here. No basalt flows occur in either of these areas. The sedimentary rocks are similar to those in the Rock Peak-Yellow Peak area.

Poston Butte

Tertiary sedimentary rocks in the subsurface north of Poston Butte were described by Nason et al. (1982). A summary of their findings is provided here for comparison with the rocks exposed farther west in the Santan Mountains. Tertiary supracrustal rocks encountered in drill holes consist of two packages; a lower sequence with a bedded gypsum interval overlain by "blue" basalt, and a younger volcaniclastic sequence above the "blue" basalt. The lower sequence is notably lacking in volcanic material, similar to the lower sequence we describe in the Rock Peak-Yellow Peak area. Nason et al. (1982) attribute steep dips in their lower sequence to local slumping, but we believe the dips are probably tectonic, based on comparison with the locally steep dips we observed at outcrop farther west. Pollen from lower sequence indicate a late Cretaceous to mid-Tertiary age range (Nason et al., 1982), but no specifics are given as to how many samples were analyzed or whether the range they give represents a sequence or a range of possible age for a single sample. If the pollen are from one sample, then it would appear that no time specific Tertiary plants could be identified.

Nason et al. (1982) indicate that the lower sequence is overlain by gently tilted to horizontal, coarser-grained, volcaniclastic conglomerates with interbedded latest Miocene basalts (dates of 7.9 $\pm$ 0.3 m.y. on a surface flow, and 5.86 $\pm$ 0.14 m.y. on a drilled dike). They correlate the upper sedimentary sequence with Big Dome Formation of the Ray area, and report Pliocene palynomorphs from an extensive clay layer. In addition, Nason et al. (1982) mention a K-Ar date of 17.6 $\pm$ 0.4 m.y. (specific mineral not given) from a tuff in the upper sequence. This age is younger than the unpublished Miocene dates for Superstition Tuff (mentioned previously), but in the same ballpark, and it may correlate with the welded tuff exposed at the surface throughout the Santan Mountains.

Interpretation

The lower sequence of Nason et al. (1982) correlates easily with our older sequence at Rock Peak. Both sequences are overlain by basalt lava, contain mostly non-volcanic detritus, locally steeply dipping, and include thin limestones or bedded gypsum. The lower sequence is interpreted as a mixed fluvial and playa lake deposit, and the presence of playa lake sediments at its base is consistent with an extensional basin origin. The antiquity (possibly early Tertiary age) of Nason et al. (1982) lower sequence is indicated by a possible Upper Cretaceous biostratigraphic age. The younger sequence of Nason et al. (1982) is not correlated with any of the sedimentary rocks we encountered at outcrop in the Santan Mountains. This is chiefly because the sequence at Rock Peak is overlain by Miocene ash-flow tuff, and the age of that Nason et al. (1982) give for their upper sequence is firmly Pliocene.

The depositional environment of the sedimentary breccias in the Santan Mountains is difficult to interpret because of poor exposure, but a catastrophic origin is almost inescapable. The deposits are too aerially extensive to be simple talus-cone deposits, and an origin as dry rock avalanches (c.f. Yarnold and Lombard, 1989; Shreve, 1968; Melosh, 1987), at least in part, seems likely. The breccias are interbedded with sandstone and conglomerate in some areas, and are locally steeply-dipping. For the most part, the breccias occur in the extensive, gently-dipping block to the south and west of Rock Peak and are bounded to the southwest by steep, arcuate(?) erosional scarps which they overlap, and which appear to be the source for the breccias. Similar, but less extensive scarps are also buried by younger basalt lava and welded tuff, indicating a prolonged history of northeast-side-down failure in the area. The combination of northeast-facing scarps, and the general untilted nature of the area overlain by the breccias, in contrast to the narrow zone of steep dips just to the north, leads us to interpret this area as a tectonically denuded, vertically-uplifted, footwall block. This activity occurred during the onset of Basin and Range style sedimentation as evidenced by the fluvial-playa depositional environments of the interbedded sandstone-conglomerate-limestone succession.

STRUCTURAL EVOLUTION

Structure of the Early Proterozoic Pinal Schist

Throughout the Santan Mountains, the prominent schistosity in the Pinal Schist consistently strikes about 075°, except in two areas where it is north-striking and cut by a post-peak metamorphic, crenulation cleavage. The two areas are: (1) the south face of Santan Mountain, and (2) hills to the northeast of "Commode Butte". The Pinal Schist along contacts with the plutonic rocks of Santan and Goldmine Mountains is also folded, but this deformation may be related to intrusion of the granites (e.g. the west-plunging anticline at Goldmine Mountain).

At Santan Mountain, a 7 km-long axial trace of a major south-vergent anticline is exposed along the base of the mountain's southern face. The regionally steeply dipping, 070°-striking foliation is folded into a moderately to gently west and northwest dipping limb composed chiefly of psammitic schists, and these more resistant rocks form the high parts of Santan Mountain. The axial trace of this structure also corresponds to a general change in lithology of the Pinal Schist, and this may indicate that the fold is cut by a fault, perhaps parallel to the axial plane. The lower areas are composed of pelitic schists which include a relatively narrow, strike-parallel zone of calc-schists and quartzite bands that step northward across the projected trace of a SSE-striking fault which cuts through a prominent valley with the same orientation at the west end of the range. The trace of the axial plane of the large fold also steps northward nearly 2 km along the same fault. Although barely exposed, the fault trace is interpreted as a brittle structure. The fault, although oriented parallel to a prominent set of young faults, appears to be "old". This is because its projected trace (though buried) appears to be intruded by the granitoid to the north, and overlapped by the Tertiary basalts to the south.

The broad fold at Santan Mountain displays a similar geometry to large-scale gentle to open folds that have been recognized in the Pinal Schist in the Whitlow Canyon area just to the northeast (Ferguson and Skotnicki, 1995). It also has a similar axial planar, post-peak metamorphic, crenulation cleavage. The age of this folding is unknown, but it may significantly post-date formation of the Pinal Schist's prominent cleavage. The folds in the Whitlow Canyon area were suggested (Ferguson and Skotnicki, 1995) to have also affected the Middle Proterozoic Apache Group.

At Commode Butte, a pervasive, younger crenulation cleavage is also present, but it is not associated with any marked change in the orientation of the prominent schistosity. A narrow fault block in this area, directly north of Commode Butte is bounded by two approximately located faults. Both faults are drawn through geomorphic saddles and the western saddle contains float of breccia and abundant vein quartz. The fault block itself is defined by significant rotation of all fabrics in the Pinal Schist, precluding an explanation that the young cleavage here is axial planar to a set of angular fold limbs (the young cleavage is also rotated). A young brittle deformation related explanation is favored for this rotation. Approximately 50° of northwest-side-down rotation about a nearly horizontal, northeast trending axis would explain the change in orientation of the fabrics.

Mylonites and S-C fabrics

The oldest granitoid in the map area (Xg) and to a lesser degree, the Pinal Schist, are cut by numerous mylonites and S-C shear zones. The term "S-C fabric", as used on the map, is used to denote mylonitic fabrics within granitic rocks where the S and C surfaces are well-displayed. This is in contrast to the term "mylonite" and the symbol for mylonite used on the map, where the term is used to denote intensely foliated and lineated zones with few or no S surfaces remaining, and displaying only one very prominent C foliation. This convention is useful because mylonites (as defined here) mainly occur in this area in narrow zones several centimeters wide, whereas S-C fabrics occur in zones up to several meters wide and locally are pervasive. The authors understand that this definition deviates from the thorough description of S-C mylonites as defined by Lister and Snoke (1984). Throughout most of the area both the S-C and mylonite zones are relatively narrow and discontinuous except for two small peaks at the northeast corner of the range where all of the rocks are affected, except for a diabase dike. The fact that the diabase dike is unaffected, and that none of the other Middle Proterozoic and younger rock units are affected argues for an Middle Proterozoic age for the fabrics. The mylonites and S-C zones that characterize much of the granodiorite are epidotized and generally narrow; the mylonites less than 30 cm wide, and the S-C zones less than a few meters. Their strikes, dips, and kinematic senses are variable, but they are dominantly ENE-WSW striking, and almost always display reverse sense of motion. To the east of The Gap, the fabrics are dominantly north-dipping, and to the west they dip mostly to the south.

The strong pervasive fabric in the two peaks at the northeast corner of the range appears to be partially annealed (based on the recrystallized appearance of the biotite), and it is parallel to the granodiorite's intrusive contact with Pinal Schist to the south, and the prominent regional schistosity. Mylonites are rare but also present in the Pinal Schist (west end of Goldmine Mountain).

Brittle features in the granodiorite

The early Proterozoic granodiorite body is also characterized by hosting numerous, hematite-siderite coated fracture zones in the area north of Rock Peak. The fracture zones are interpreted as faults, and although a variety of orientations were measured, they are mostly ENE-striking and moderately north-dipping (similar to the numerous mylonite zones and S-C fabrics in the area). To the west of The Gap a prominent, east-striking, south-dipping fault was mapped.

Tertiary Basin and Range style deformation

The discussion of Basin and Range style tilting in the Santan Mountains concentrates on two separate areas where Tertiary rocks are exposed. The areas in question, Malpais Hills-Yellow Peak-Rock Peak area (herein referred to simply as the Rock Peak area), and the Commode Butte area, suffered markedly different histories of tilting of their Mid-Tertiary supracrustal sequences. The Rock Peak area experienced south-side-down tilting, whereas the Commode Butte area experienced northeast-side-down tilting, apparently at the same time. The problem is that structures to accommodate the great differences in tilting are not obvious.

Rock Peak area structural evolution

The Rock Peak area is bounded on the northeast by a very linear southwest-dipping depositional contact which is mantled by basalt lava in most areas. The contact strikes parallel to the long axis of the range (about 295°), but turns abruptly south at Rock Peak where it is unexposed (probably cut by a young cross fault) for over a km before it is exposed again as monolithic, sedimentary granite-breccia mantling a gently northeast-dipping, scalloped contact.

A fanning-dip sequence of interbedded basalt lava and conglomeratic sandstone occurs along the northeast edge of the Rock Peak area. Dip-directions are chiefly south to southwest and decrease upwards from as much as 47° to less than 7°, but the zone that includes the steepest dips is only exposed along the basal contact. To the south, the conglomeratic sandstones are fairly thin, gently dipping, and they overlap the coarse-grained, granite-clast sedimentary breccia. The contact between the conglomerate and breccia appears to dip gently to the N-NE. The base of the breccia unit is exposed only where it pinches out to the south and west, and here it either dips fairly steeply (up to 37°) to the northeast or is a low-angle sharp contact. No evidence of shearing along the contact was observed. The breccias are interpreted to have come from the local granitic basement, originating mostly by mass-wasting of a north to north-east facing scarp, the youngest part of which is now preserved along the map unit's southwestern contact.

The breccia-mantled contact is interpreted to be the preserved carapace of a tectonically denuded footwall block, that probably experienced little or no tilting during uplift. The steeply-dipping depositional, northeast contact is interpreted as being part of the tilted hanging-wall, and a buried, northeast-dipping, normal fault is inferred to be concealed by younger parts of the unit of Rock Peak in between these areas. The youngest rock is a crystal-rich, welded ash-flow tuff that is presumed to be outflow of one of the major units from the Superstition Mountains. The lowermost basalt and the overlying tuff therefore bracket the duration of this tectonic event. The basin produced along the axis of this structure filled rapidly with basalt, suggesting a relationship between extension and ascent of the mafic magma.

The apparent widening of this basin to the west, may be related to greater amounts of slip along the buried north-dipping normal fault to the west. The eastern extension of this fault is completely unknown at this point, yet if it is as important a structure as we have depicted it on our cross-section (A-A'), then it is hard to believe that it is not expressed at the surface. There are two possible areas where it may be. It may step slightly to the south across a young southwest-side-down, SSE-striking fault zone that cuts off the unit of Rock Peak just to the east of Rock Peak, and run through a low area between hills composed of the Early Proterozoic granodiorite, and Pinal Schist. The E-W striking contact between these rocks is interpreted as intrusive, even though it suspiciously cuts off a Late Proterozoic diabase dike.

The other possible location of the continuation of the fault buried by the unit of Rock Peak is a prominent fault the strikes ENE-WSW through the gap just south of Goldmine Mountain. This fault, whose dip is unknown (although a possibly related fault along the south edge of Goldmine Mountain dips steeply south), cuts off a large diabase dike and is defined elsewhere by an abrupt change in textural grade of the Pinal Schist. Contact-metamorphosed coarse-grained schist on the north is juxtaposed against fine-grained schist/phyllite on the south. The fault's western continuation is cut off, apparently, by the same SSE-striking cross fault that runs through the Rock Peak area. If this northern fault is the continuation of the fault buried in the Rock Peak area, it would require either a significant amount of sinistral strike-slip motion along the young cross-fault, or if the cross fault is purely dip-slip, a fairly shallow northerly dip for the older fault. A strike-slip kinematic history for the cross fault, although not supported by any field data, is compatible with the vertical orientation of some faults that are exposed at Rock Peak.

Commode Butte graben

Commode Butte is an informally named double butte in the eastern Santan Mountains composed of the regional, crystal-rich, ash-flow tuff depositionally overlying sedimentary rocks in a small northwest-striking graben. The sedimentary rocks are tilted in all directions and locally folded, and the strata dip inwards all around the edges of the graben. The geology of Commode Butte as indicated by style of sedimentation (breccias and conglomerates), stratigraphic succession (sedimentary rocks capped by welded "Superstition-Apache Leap Tuff"), its NNW-strike, and its size, are all remarkably similar to the geology of the graben that hosts the Cactus-Carlota porphyry Copper deposit in the Globe-Miami area to the northeast (The Carlota Copper Company, 1996).

Only one of the contacts bounding the Commode Butte graben appears to be purely depositional, and that is at its west end where the steeply dipping (50° to the east) conglomerate directly overlies Pinal Schist and is overlain by a fanning dip sequence. In another area along the southwest edge of the graben, similar, steep-northeasterly dipping strata are apparently erosionally overlain by younger less tilted strata. This northeast-dipping contact at the west end of the graben is interpreted as the oldest Mid-Tertiary depositional surface in the eastern Santan Mountains, and forms the basis for the SSE-striking, schematic, right section depicted in Figure 1. The section depicts how the area is believed to have appeared prior to Mid-Tertiary sedimentation and Basin and Range style tilting, and will be discussed in more detail in the Mineralization section. The depositional contact erosionally truncates a probable Laramide aged dike, oriented parallel to the prominent northeast-striking, steeply southwest dipping regional foliation of the Pinal Schist. The dike changes markedly from a crystal-poor, quartz porphyry westward into an equigranular quartz monzonite. The aphanitic matrix portion of this dike is strongly flow-foliated along its contact with the country rock and an associated lineation is steeply southwest-plunging. The lineation is nearly perpendicular to the overlying erosional unconformity and suggests that the area was untilted between the time of dike emplacement and deposition of the oldest Tertiary sedimentary rocks. Tilting of up to 50° to the northeast plus additional deformation of the graben-fill occurred prior to emplacement of the welded tuff which is only slightly deformed.

The Commode Butte graben is bounded on the southeast by a major southwest-striking fault, which is offset to the left by the fault that bounds the northeast side of the graben. The sedimentary rocks overlap the surrounding Proterozoic rocks to the northeast and southwest along linear contacts that appear to be degraded fault scarps. The contacts are in line with faults recognized in the Pinal Schist that is depositionally overlapped along the northwest end of the graben. The northeast bounding contact is mantled by coarse angular breccias of K-feldspar porphyritic granite, although the basement rock along this strand is Pinal Schist.

A strand of the western fault appears to change from an unexposed surface to a degraded scarp from south to north, suggesting northwesterly tilting after this fault became inactive. There is also evidence of folding about an axis parallel to the long axis of the graben. The zone of folding also affects the compaction foliation in the overlying welded tuff, and it is aligned with a fault zone recognized in the Pinal Schist where the sedimentary rocks overlap basement to the north.

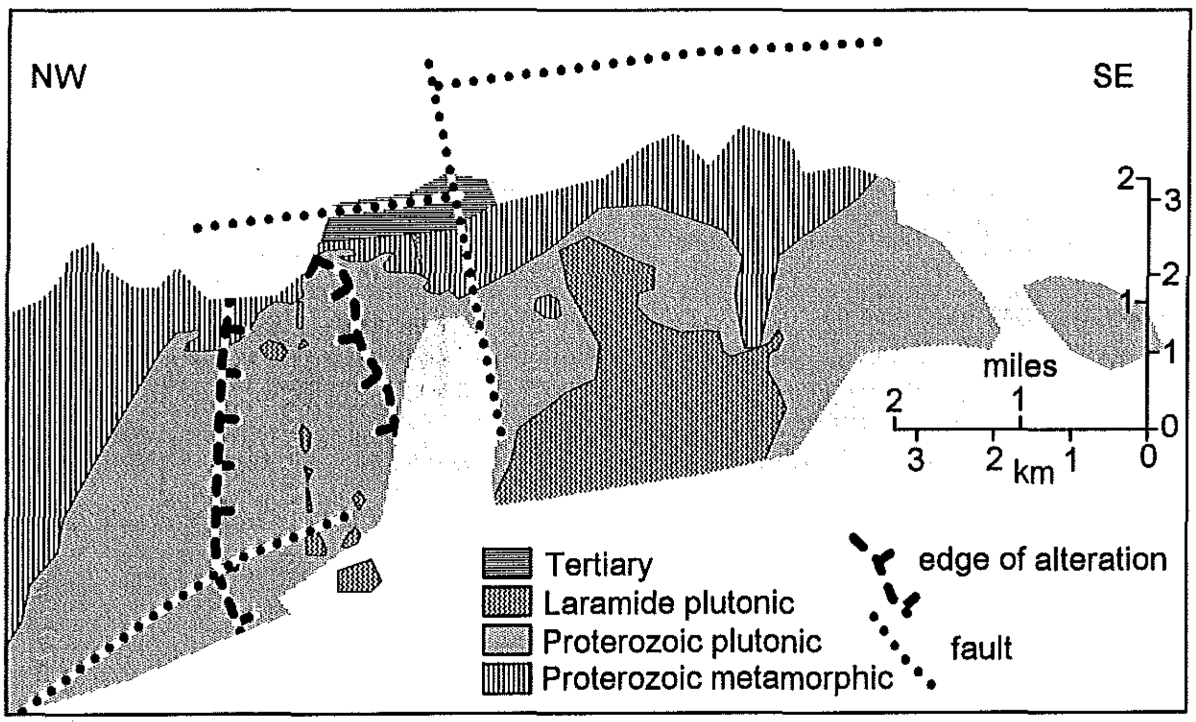

Figure 1 Schematic right section striking 150°, dipping 40° to the southwest drawn through Commode Butte, eastern Santan Mountains. Blank areas depict areas covered by alluvium. Faults bound areas that were treated as undeformed blocks tilted 50° to the northeast. Geology was restored across the fault zones based on surface information. Note the classic porphyry copper alteration halo that occurs around the Mineral Butte area.

Commode Butte obviously suffered a complex history of tilting. The major structure is believed to be a west-side-down SSE-striking normal fault, because: (1) the steepest dips of strata in the graben support this orientation of faulting, (2) many faults of this orientation are present in the Santan Mountains and (3) this is the dominant orientation of normal faulting in nearby areas such as the Poston Butte subsurface (Nason et al., 1982), and bedrock areas to the northeast (e.g. Ferguson and Skotnicki, 1995).

In general, the Commode Butte graben is considered to have initiated as a northwest-tilted block, that later experienced some degree of northwesterly tilting, and the northeast-striking faults associated with this later tilting were later offset by the original northwest-striking set.

Discussion and summary of structural features

The following is a list of important tectonic events, structures that are constrained by cross-cutting igneous relationships, and overlap of supracrustal rocks.

(1) Mylonites, S-C fabrics are found only in the oldest (Early Proterozoic?) granitoid. Mylonites do not cut Middle Proterozoic granite or diabase dikes. Mylonites are also found in the older Pinal Schist-arguing (weakly) that ductile shearing was not related purely to emplacement of granitoid.

(2) A major SSE-striking fault at the west end of the range cuts a major fold axis in the Pinal Schist, but is apparently intruded by the Santan Mountain stock, and overlapped by Tertiary basalts.

(3) A suite of ENE-striking dikes cut through the plutonic rocks of the southeastern Santan Mountains, and one of these is truncated erosionally by the basal Tertiary unconformity at Commode Butte.

(4) Complex overlapping relationships exist for a number of NNW- and ENE-striking normal faults. Major tilting and faulting was complete by the time that a major, regional, probably early Miocene ash-flow tuff outflow sheet was deposited.

(5) The principal Basin and Range fault in the western Santan Mountains is an inferred, shallow, north-dipping normal fault buried by the unit of Rock Peak.

(6) The principal Basin and Range fault in the eastern Santan Mountains is an inferred, moderately southwest-dipping normal fault that is also buried by the unit of Rock Peak.

The map pattern of the Santan Mountains is the result of an interaction between two prominent structural trends; an ENE-striking so-called "Laramide" trend, and a SSE-striking Basin and Range trend. Each of these trends appears to reflect reactivation of much older structures. For example, the Laramide trend is parallel to the prominent cleavage of the Pinal Schist, and mylonites and S-C shear zones in Proterozoic granitoids, whereas the Tertiary trend is parallel to the orientation of the Middle Proterozoic diabase dikes. Both areas that preserve Tertiary supracrustal rocks have been influenced to varying degrees by faults of both trends. There does not appear to be a prevailing orientation through time.

The Rock Peak area is interpreted to be related to an inferred, shallow, north-dipping normal fault. The depositional basin of the Rock Peak area is both cut by and appears to overlap SSE-striking normal faults. The Commode Butte graben was also influenced by both sets of faults; first by NNW-striking faults and later by ENE-striking faults which are in turn offset by the original set.

MINERALIZATION

The principal mineralized region in the Santan Mountains is the Mineral Butte district. It has been described previously by Wilson (1969), Balla (1972), and Chaffee (1976). Additional notes are provided here.

Southwest of Mineral Butte several prominent mineralized joint sets are filled to various degrees by hematite. The surrounding rock is strongly altered and colored red and orange. The feldspars have been altered and are yellow to light gray. Biotite is altered to hematite. Locally, small 1-10 cm quartz-manganese veins striking about E-W cut across mineralized joints. Mineral Butte itself is strongly silicified and the rock is almost entirely quartz. Immediately northwest of Mineral Butte, plagioclase is partially replaced by an unknown, dark gray, low density submetallic-looking mineral. Here quartz-manganese veins, though rare, also cut mineralized joints. North of Mineral Butte chrysocolla and minor malachite are common along the contact between Pinal Schist and granite. This area contains numerous prospect pits. A dacite dike, which intrudes near the contact, has also been extensively mined.

Mineral Butte and a prominent Butte immediately to the southeast are held up by resistant, silicified, mafic-mineral-leached brecciated coarse-grained granite. These buttes are surrounded by a broad zone of hematite-stained, prominently jointed, altered K-feldspar porphyritic granite. The granite is cut by small stocks and ENE-striking intermediate composition dikes that are not altered. The biotite in the altered granite is relatively fresh and abundant. Much of the hematite staining in this area could be from the oxidation of pyrite, and thus may represent a large zone of hemititic alteration associated with a buried porphyry copper deposit. However, we did not recognize sericitic or propyllitic alteration zones that are typical of the classic porphyry copper deposit. The limit of the hematite alteration zone, as well as smaller areas of the silicic-alteration, are shown on our map. Alteration also extends into the Pinal Schist on the north side of Mineral Butte.

Based on structural information from the Commode Butte area just to the east, a right section (Figure 1) striking SSE and dipping 40° to the northeast was constructed through the Commode Butte area. The section depicts intrusive geometries of the Laramide and older plutonic bodies, and the shape of the Mineral Butte alteration halo as it would have appeared prior to Basin and Range tilting. The shape and size of the alteration halo is similar to the classic genetic model (Lowell and Guilbert, 1970) for the porphyry copper deposits. Interestingly, the larger stock at Twin Buttes is not associated with any alteration halo.

Copper mineralization was also noted at a few areas on Goldmine Mountain. On the south side of Goldmine Mountain many deep pits have been dug into a fault with attitude N70°E, 80°E (the pits have been mislocated on the map). A quartz-hematite vein 10-30 cm wide fills the 2 m-wide fault zone, defined by crushed granite. There is chrysocolla staining in the vein. This fault has a similar attitude to another quartz-hematite vein (N70°E, 75°N) 0.5 miles northwest of the fault exposure. In the northeast corner of section 25, T. 3 S., R. 7 E., several shafts have been dug into a band of gray pelitic schist/phyllite 3 m wide within tan-colored, quartz-rich rock (looks like quartzite but could be granite). Chrysocolla and malachite occur with quartz. An inclined shaft was dug into a fracture zone with attitude N70°E, 50°N, within the band.

Minor copper mineralization was also noted at Walker Butte on the property of the Walker Butte Granite Company. A small open pit dug into coarse-grained granite (map unit Yg) northeast of Walker Butte, exposes at least two sets of faults or fractures: (1) N45°E, 53-63°E, and (2)N30-40°E, 35°W. There is a 6 m-wide fault zone with attitude N45, 60E that is filled with red clay. Chrysocolla coats fracture surfaces in the granite but is not visible in the faults.

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UNIT DESCRIPTIONS
FOR THE SANTAN MOUNTAINS,
PINAL AND MARICOPA COUNTIES, ARIZONA

ARIZONA GEOLOGICAL SURVEY
OPEN-FILE REPORT 96-9
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RECENT

R **Disturbed areas**, quarries, excavations, and other man-made disturbed zones.

QUATERNARY

Q **Undifferentiated** Quaternary deposits, mostly alluvium.

Qay **Younger alluvium** Unconsolidated alluvium in major washes, differentiated only locally.

Qt **Talus and colluvium** Deposits mantling steep slopes in western part of map area, not always differentiated. Unit consists of locally derived, poorly sorted, angular to sub-rounded clasts. Deposits are locally cemented by laminar caliche, in some places greater than a meter thick.

TERTIARY

Tsy **Younger sedimentary deposits (Late Tertiary)** Poorly sorted, partially to strongly consolidated conglomerate, containing angular to subangular clasts of granite (map unit Xg), diorite (map unit Xd), and Pinal Schist (map unit Xp), ranging in size from silt and sand to boulders 0.5 m across. The deposits (where exposed) are clast-supported, with a matrix of sand and silt with minor carbonate cement. Where exposed, a 0.5 meter-thick layer of caliche marks the base. Unit not everywhere differentiated from Quaternary deposits.

Tbc **Basalt lava (latest Miocene to Pliocene)** Moderately crystal-rich with abundant phenocrysts of fresh, subhedral, needle-like plagioclase up to 6 mm long, pyroxene, and subhedral olivine altered to red opaques (probably iddingsite) up to 4 mm. Plagioclase is locally very coarse-grained (up to 12 mm). A prominent hill at the extreme east edge of the map area is partially composed of crudely bedded, gently to moderately dipping, welded scoria, and this may indicate a vent in this area. This same hill does not appear to be tilted and may be younger than the two tilted hills immediately to the west. K-Ar whole rock radiometric dates on similar lavas and a dike in the Poston Butte area just to the east are 7.9 ± 0.3 Ma, and 5.86 ± 0.14 Ma respectively, and Pliocene palynomorphs have been recovered from a clay layer in associated sediments (Nason et al., 1982).

Ttw **Welded Tuff (Oligocene-Miocene)** Crystal-rich welded to densely welded quartz latite ash-flow tuff, forming ridges and steep cliffs. Phenocryst assemblage consists of plagioclase, quartz, sanidine, biotite, and traces of sphene. The feldspars and quartz are fairly large (1-5 mm) set in a tan-brown aphanitic matrix. Dark brown to black vitrophyres at and near the base are locally interbedded with basalt in section 32, T.3 S., R.7 E. Locally the welded tuff is underlain gradationally by unwelded tuff. Lithics are sparse, consisting of basement (granite) and basaltic lithologies and are seldom larger than 3-4 cm. Although a strong planar fabric and low-angle set of joints resemble eutaxitic foliation, pumice fragments are virtually absent. A prominent joint set is present perpendicular to the planar fabric. An Oligocene K-Ar

phlogopite age of 26.00 $\pm$ 0.54 (recalculated by Reynolds et al., 1986 from Balla, 1972) was obtained from this unit, but is suspect because the unit is probably Superstition Tuff (based on petrographic comparisons, e.g. Balla, 1972; this report, Don Peterson, personal communication) and is therefore probably much younger. Paleomagnetic polarity is normal (Sedgeley, 1976, p. 24).

Tt Unwelded tuff (Oligocene-Pliocene) Generic unwelded, massive ash-flow tuffs that occur at the base of the welded tuff (Ttw) and basalt lava (Tb) map units. Obvious phenocrysts are biotite, hornblende, and quartz. Feldspars are probably also present. The tuff also fills cavities between clasts in the underlying basalt. Another exposure of unwelded tuff occurs below the younger basalt lava unit (Tbc). The two are not considered time equivalent.

Ts Sandstone and conglomerate (Miocene and older?) Medium- and thick-bedded sandstone, granule sandstone, pebbly sandstone and sandy conglomerate. Rare beds of thin gray limestone and limestone-pebble conglomerate occur near the base at Rock Peak. In general, the sequence changes upward from non-volcaniclastic to moderately volcaniclastic; the chief volcanic lithic grains being aphyric, pink rhyolite. Mafic lava lithics are also present. Non-volcanic detritus dominates, chiefly clasts of nearby basement lithologies; granodiorite and K-feldspar porphyritic granite (Xg and Yg). The clasts are typically rounded to sub-rounded, and locally subangular and very coarse-grained, particularly near the base in the Yellow Peak area. The conglomerates occur in lenticular, channel shaped bodies, and the sandstones typically in tabular bodies. Cross-bedding is rare.

Tb Basalt lava (Miocene and older?) Moderately crystal-poor basalt lava flows, containing subhedral olivine phenocrysts up to 6 mm wide (altered to red opaques), dark green pyroxene and clear plagioclase laths up to 2-3 mm. Near the center of section 1, T.4 S., R.6 E., the rock is very coarse-grained. The flows are locally brecciated and commonly vesicular. The unit is over 100 meters thick, consisting of a thick sequence of flows in the southwestern part of the range, and forms cliffs and steep, talus-covered hills. Farther east the flows are thinner and interbedded with sedimentary rocks, and welded tuff.

Tbs Bedded basaltic scoria (Miocene and older?) Weakly to moderately consolidated, bedded, dark red to purple scoria. Scoria clasts range from pebble- to boulder-size, with an average size of between 2-15 cm. Intruded by basalt dikes. Exposed below, and probably genetically associated with, basalt lava (map unit Tb).

Tx Sedimentary breccia (Miocene and older) Poorly sorted, generally monolithic diamictites (sedimentary rock displaying no bedding or sedimentary structures) and conglomerates composed of very angular to subangular clasts of basement lithologies (Xg, Yg, and Xp map units). The unit is generally poorly exposed, and easily confused with colluvium covered granite bedrock areas, but commonly forms rounded hills which are generally moderately dissected. Size of the clasts range from sand to very large boulders (some several meters in diameter) and the deposits are everywhere clast-supported. The unit is overlain by sandstones and conglomerates, basalt lava, and welded tuff. Rarely, the breccia is crudely bedded and the exposure along north edge of Malpais Hills (section 30, T.3 S., R.7 E.) is interbedded with conglomerate and sandstone. This exposure consists mostly of clasts of the equigranular, medium-grained granodiorite (map unit Xg), and less abundant Pinal Schist, and it lies in the hanging wall of a moderate- to low-angle fault juxtaposed with the granodiorite. The extensive exposures of this unit under Yellow Peak are composed mostly of clasts of the K-feldspar porphyritic granite, and lesser amounts of Pinal Schist. At Yellow Peak, where the breccias pinch out to the south and west, they overlie basement along a steep, north to northeast-facing scarp. Elsewhere, the basal contact is sharp and low-angle, but in most areas, no base is exposed. At Yellow Peak, the breccias appear to grade upwards into coarse, bedded conglomerates. At Commode Butte, two separate exposures are present; the southern one composed only of Pinal Schist and the northern one composed mostly of porphyritic granite.

Tri Felsic dikes (Tertiary) Light-colored, aphanitic-matrix, crystal-poor felsic dikes; most common at the east end of the range where they intrude K-feldspar porphyritic to coarse-grained granite (map unit Yg). The dikes contain 5-10%, 1-2 mm phenocrysts of subhedral biotite, quartz, and minor chalky white K-feldspar.

Tdi Intermediate dikes (Tertiary) Crystal-rich aphanitic-matrix and porphyritic-holocrystalline dikes and lenticular intrusions in the southeastern part of the range. The porphyritic bodies are typically crystal-rich, commonly with abundant coarse-grained quartz, and rarely include crystal-poor varieties. The average composition is probably quartz monzodiorite. These dikes probably correlate with to the "Laramide" dikes and elongate intrusions in the Poston Butte area just to the east (Nason et al., 1982). The unit also contains variable amounts of biotite and hornblende. The rocks weather dark, and the porphyritic varieties have dark gray matrix. The rocks are also locally altered, commonly with epidote-chlorite replacing mafic minerals and plagioclase.

Tbi Mafic dikes (Tertiary) Fine-grained, dark greenish-gray colored mafic dikes. Mineral assemblages are dominated by plagioclase and fine-grained, unidentifiable mafic minerals.

CRETACEOUS

Kv Vein arrays (Cretaceous-Early Tertiary) Hematite-stained clastic dikes, cataclastic zones and/or Cu-mineralized quartz vein arrays.

Kd Diorite/mafic plutonic rocks (Cretaceous-Early Tertiary) Mafic plutonic bodies associated with map unit Kg, typically fine- to medium-grained, equigranular diorite and monzodiorite.

Kg Quartz monzodiorite to quartz monzonite (Cretaceous-Early Tertiary) Medium to fine-grained, equigranular quartz monzonite to quartz monzodiorite, and locally monzodiorite with between 10 to 20% mafic minerals, mostly biotite and lesser hornblende. Biotite K-Ar radiometric dates of 66.00 ± 0.90 and 72.10 ± 1.40 Ma have been reported from the eastern Santan Mountains (recalculated in Reynolds et al. (1986) from Balla, 1972).

EARLY PROTEROZOIC OR CRETACEOUS

KXg Granite (Early Proterozoic-Cretaceous) Medium-grained, equigranular granite with 5-10% biotite. It is similar, texturally, to the Early Proterozoic granodiorite (Xg map unit), but distinguishable due to its higher K-feldspar/plagioclase ratio (making it a true granite), lack of numerous Pinal Schist enclaves, and lack of mylonitic. A middle Proterozoic or Cretaceous age is implied because of its lack of ductile fabrics and because it appears to cut a major northwest-striking fault at the west end of the range. Magmatic layering (a feature associated with the Cretaceous granitoids in the Sacaton Mountains) is common at the northwest corner of the range.

KXgmd Monzodiorite (Early Proterozoic-Cretaceous) Medium-grained, equigranular monzodioritic bodies with abundant (>20%) biotite, probably phases of the KXg granite body.

KXgl Leucogranite (Early Proterozoic-Cretaceous) Medium- to coarse-grained leucocratic, (<1% mafic minerals), pegmatitic (graphic textures) granite and pegmatite dikes or sills, commonly displaying magmatic layering. These rocks, recognized only along the northwest corner of the range probably represent a phase of the KXg granitoid.

MIDDLE PROTEROZOIC

Yd Diabase, diorite (Middle Proterozoic) Diorite dikes and intrusive bodies typically displaying diabase texture. Locally, the bodies contain either pyroxene or hornblende, plagioclase, and opaques. Within the core of thicker dikes the diorite is plagioclase porphyritic, with medium to coarse-grained matrix. Locally, the A biotite K-Ar radiometric date of a similar dike in the nearby Sacaton Mountains is 854 $\pm$ 18.4 Ma (recalculated in Reynolds et al., 1986 from Balla, 1972).

Yg K-feldspar porphyritic granite (Middle Proterozoic) In most areas this is a K-feldspar porphyritic, biotite-bearing, medium-grained granite to syenogranite and locally quartz monzonite. Locally, the granite changes abruptly into two distinct subordinate phases defined principally on textural criteria: (1) equigranular fine- and medium-grained granite, and (2) sparsely K-feldspar porphyritic granite or quartz monzonite. Except for one large body of the equigranular granite (the Cholla Butte area at the east end of the range [Ygm map unit]), these were undifferentiated, but are not extensive. The contacts between these phases and the main body of the pluton are sharp, but not demonstrably intrusive, and the phases are interpreted to be cogenetic. Biotite content ranges from a few percent to 10%, and muscovite was also noted in some of the equigranular bodies. Potassium feldspar phenocrysts are up to 4 cm, and typically perthitic and inclusion rich, particularly near their margins. Rapakivi texture (K-feldspar rimmed by plagioclase) was also observed in some areas. The granite is presumed to be middle Proterozoic in age based on its petrographic similarity to a nearby plutonic body in the western Sacaton Mountains that has been dated at 1253 $\pm$ 26 Ma (K-Ar biotite-recalculated by Reynolds et al., 1986 from Balla, 1972). A biotite K-Ar date of 63.90 $\pm$ 2.30 Ma (recalculated by Reynolds et al., 1986 from Balla, 1972) from the Cholla Butte area appears to have been reset by intrusion of nearby dikes.

Ygm Granite (Middle Proterozoic) Medium- to slightly coarse-grained granite with 5-10% biotite exposed at Cholla Butte. The granite is mostly equigranular but locally slightly quartz and K-feldspar porphyritic. On the west side of Cholla Butte the rock is coarser-grained and quartz-porphyritic, where quartz occurs as 5-12 mm, spherical, anhedral phenocrysts. Similar granite is found across the railroad tracks to the northwest, where it is coarser-grained and appears to grade into the K-feldspar porphyritic granite (map unit Yg). The two granitoids are considered cogenetic phases of a larger pluton.

EARLY PROTEROZOIC

Xg Granodiorite (Early Proterozoic) Medium-grained, equigranular granodiorite, granite, and quartz monzodiorite. Abundant plagioclase is remarkably fresh in most of the granitoid which contains 5-15% biotite and rare hornblende. At Goldmine Mountain the granitoid is slightly finer-grained than exposures farther south. The unit characteristically contains numerous, preferentially oriented, elongate enclaves (from several meters to tens of meters across) of Pinal Schist. The granitoid is also characterized by abundant ENE-striking ductile shear zones expressed as narrow epidotized mylonite zones. The northeastern-most exposures are the only areas where the tectonic foliation is pervasive, and this is indicated by a special symbol on the map. The granite is presumed to be Early Proterozoic based on the abundance of epidotized mylonites, which are typical of this age of granitoid in areas just to the southwest (S. J. Reynolds, personal communication), and a K-Ar biotite radiometric age of 1341 $\pm$ 61 Ma (recalculated by Reynolds et al., 1986 from Balla, 1972), that is interpreted to be reset by emplacement of the widespread anorogenic, approximately 1.4 Ga suite of plutons in central Arizona.

Xgd, Xgmd Diorite, monzodiorite and related mafic plutonic rocks (Early Proterozoic) Mostly fine-grained and locally medium- to coarse-grained equigranular, and plagioclase-porphyritic, dark-colored plutonic rocks. Mafic minerals include both pyroxenes and hornblende, and diabase texture was noted in some areas. These rocks have indeterminate and intrusive contacts with the granodiorite (map unit Xg), of which it is believed to be a phase. The unit crops out as dark, crumbly, rounded hills, commonly on the low flanks of granite knobs.

Xp Pinal Schist (Early Proterozoic) A heterogeneous suite of pelitic and psammitic schist and phyllite. Two general lithologies comprise this map unit; silvery, greenish gray phyllites and fine- to medium-grained pelitic schists (50-60%), and evenly thin-banded, light gray, psammitic schists (40-60%). The two types were not differentiated. The mineral assemblage consists chiefly of quartz, white mica, $\pm$ biotite, $\pm$ chlorite. A variety of porphyroblasts are present, particularly in the contact metamorphic aureoles with the younger granitoids. The most common are 1-2 cm long prismatic, post-kinematic grains replaced by felty masses of chlorite that are interpreted as altered cordierite. Others include garnet (rare), unidentified stubby prismatic to equant dark-colored grains, and needle-like amphiboles. The sedimentary precursor of the Pinal Schist is thought to be monontonous sequences of mudstone and argillaceous sandstone, possibly deposited in a marine turbidite basin. The psammitic rocks locally contain scattered feldspathic granules, as if the precursor was a feldspathic "grit" or granule sandstone.

Xpq Pinal Schist quartzite (Early Proterozoic) Dark bluish-gray banded quartzites and associated epidote-rich calc-schists and rare amphibolite-rich lenses.