Geologic map of the Oro Valley 7½' Quadrangle, northeastern Pima County, Arizona

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INTRODUCTION

The Oro Valley 7 ½' Quadrangle covers the northern part of the Tucson metropolitan area, located approximately 25 km north of downtown Tucson. It covers most of Oro Valley and includes parts of the adjacent Tortolita Mountains and Santa Catalina Mountains. The area was mapped under the STATEMAP program during November 2001 through April 2002 as part of a multiyear mapping program directed at producing complete geologic map coverage for the Phoenix-Tucson metropolitan corridor. Minor updates to the map and geodatabase were done as part of the National Geological and Geophysical Data Preservation Program. A 1:24,000 scale map is the primary product of this study (Plate 1). Previous geologic maps of the area by Banks (1976) and Dickinson (1994), and maps of adjacent areas by Banks et al. (1977), Skotnicki (2000), and Force (2002) were used to focus mapping on areas of interest (primarily bedrock geologic mapping), but all of the mapping depicted on this map was produced by the authors. The accompanying report describes rock units and other geologic features. This mapping was done under the joint State-Federal STATEMAP program, as specified in the National Geologic Mapping Act of 1992. Mapping was jointly funded by the Arizona Geological Survey and the U.S. Geological Survey under STATEMAP Program Contract #01HQAG0098.

The Santa Catalina and Tortolita Mountains are part of the Catalina metamorphic core complex, an area where low- to moderate-angle normal faulting has accommodated uplift and exhumation of rocks that formerly resided in the middle crust, at depths of perhaps 5 to 15 km. The mylonitic rocks on the south side of Pusch Ridge and locally exposed in the southeastern Tortolita Mountains are product of deep-seated shearing during this uplift and exhumation process (e.g., Davis, 1980; Davis and Lister, 1988; Spencer and Reynolds, 1989; Dickinson, 1991; Force, 1997). Most of the rocks exposed, however, are not mylonitic and were apparently not deeply enough buried to be at temperatures sufficient for mylonitization (e.g., Banks, 1980). Approximately 5 km of displacement on the steeply west-dipping Pirate normal fault uplifted the steep west side of the Santa Catalina Mountains and down-dropped the bedrock beneath what is now Oro Valley (Budden, 1975; Dickinson, 1994).

Surficial deposits cover most of the Oro Valley 7 ½' Quadrangle, between the Tortolita Mountains in the west and the Santa Catalina Mountains in the east.The lower margin of the piedmonts are defined by their intersection with stream terraces or channels of Canada del Oro Wash, Sutherland Wash, and Big Wash, large drainages that head outside of the map area. Areas west and north of Canada del Oro and Big washes are called the Tortolita piedmont in this report; areas east and south of Canada del Oro and Sutherland washes are called the Catalina piedmont. The alluvial deposits in the map area were deposited by larger streams in the valley axis – most of the alluvium in the central and northeastern part of the map were deposited by a combination of Canada del Oro, Sutherland Wash, and Big Wash. Smaller tributaries that head in the Santa Catalina and Tortolita Mountains supplied the piedmont deposits. Oro Valley was filled to a high level in the early Quaternary. The highest remnants of eroded fan deposits on the Catalina piedmont (unit QTg) combined with a fairly extensive, well-preserved high alluvial surface between Canada del Oro and Sutherland Wash (unit Qo) provide clues to the valley geometry at the time of maximum filling; these remnants are 40-90 m higher than adjacent modern washes. Most of the Quaternary has been dominated by stream incision and erosion of the basin deposits on the piedmont, with periods of aggradation superimposed on the long-term downcutting trend recorded by units Qi1, Qi2, and Qi3. Young deposits (units Qy, Qyr, Qyrc) record fluvial erosion and deposition over the past 10,000 years or so. The most laterally extensive young deposits are found along the major washes; along Big

Wash, young deposits are as much as 1.5 km wide. Threads of young piedmont deposits are generally quite thin and are confined by topographically higher older deposits. A few areas with extensive young piedmont deposits are probably subject to sheetflooding during large flow events.

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QUATERNARY AND LATE TERTIARY MAP UNITS

Piedmont Deposits

Qy **Young channel, terrace and alluvial fan deposits (Holocene)—** Poorly sorted pebbles, cobbles, sand, minor silt and clay, locally boulders associated with active and recently active washes, and slightly higher terraces with modest rock varnish, minimal soil development. Deposits vary widely in particle size. Qy deposits on the Catalina piedmont are typically quite coarse, locally including medium to large boulders, cobbles, pebbles, sand, and minor silt and clay. Qy deposits on the Tortolita piedmont are finer, consisting mainly of cobbles, pebbles, sand, silt and minor clay. Channels generally are incised less than 2 m below adjacent terraces and fans, but locally incision may be somewhat greater. Channel morphologies generally consist of a single-thread channel or multi-threaded channels with gravel bars adjacent to low flow channels. Fairly extensive distributary channel systems where channels branch and decrease in size downstream existed on the lower margin of the Tortolita piedmont. Many of these systems have been profoundly altered by channelization associated with development. Local relief on Qy deposits varies from fairly smooth channel bottoms to the undulating bar-and-swale topography that is characteristic of coarser deposits. Terrace surfaces typically have planar surfaces, but small channels are also common on terraces. Soil development associated with Qy deposits is weak. Soil clay accumulation is minimal, and calcic horizon development is typically stage I to II (see Machette [1985] for description of stages of calcium carbonate accumulation in soils). Terrace and fan surfaces are brown, and on aerial photos they generally appear darker than surrounding areas, whereas sandy to gravelly channels appear light-colored on aerial photos. Vegetation density is variable. Channels typically have sparse, small vegetation. The densest vegetation in the map area is found along channel margins and on Qy terraces along channels. Vegetation includes mesquite, palo verde, and acacia trees; smaller bushes and grass may also be quite dense. Many areas mapped as Qy are flood prone, including channels and overbank areas. Much of the area mapped as Qy on the Catalina piedmont has been subject to debris flow activity in the past 10,000 years.

Qyd **Young debris flow deposits (Holocene to latest Pleistocene) —**Unvarnished to moderately varnished boulder to cobble levees, snouts, and complexes deposited by debris flows emanating from the Santa Catalina Mountains. Deposits are found in and on the margins of small valleys, and as small alluvial fans on upper piedmont areas (see Youberg et al., 2008, for more detail).

Qiy **Undivided late Pleistocene to Holocene alluvium (<~130 ka)**

Qi3 **Younger intermediate alluvium (Late Pleistocene)—** Pebbles, cobbles,and sand deposits associated with moderately dissected terraces and small relict alluvial fans. Deposits are found on upper, middle and lower piedmonts. Moderately well developed, slightly to moderately incised tributary drainage networks are typical on Qi3 surfaces, with active channels typically incised less than 5 m. Qi3 fans and terraces are lower than adjacent older Qi surfaces, but elevation differences are minimal in some places. Qi3 deposits are much coarser on the Catalina piedmont. Qi3 surfaces commonly have loose, open lags of pebbles and cobbles; surface clasts exhibit weak rock varnish, and appear orange on color aerial photos, reflecting slight reddening of surface clasts and the surface soil horizon. Qi3 soils are moderately developed, with orange to reddish brown clay loam to light clay argillic horizons (McFadden, 1978) and stage II calcium carbonate accumulation. Vegetation includes grasses, small shrubs, mesquite, and palo verde. QI3 surfaces generally are not flood prone.

Qi2 **Intermediate alluvium (Middle to Late Pleistocene)—** Moderately to highly dissected relict alluvial fans and terraces with strong soil development found throughout the map area. Deposits typically consist of sand, pebbles and cobbles, but on the Catalina piedmont are quite bouldery. Qi2 alluvial surfaces are drained by well-developed, moderately to deeply incised tributary channel networks; channels are typically 2-10 m below adjacent Qi2 surfaces. Qi2 surfaces are characterized by scattered cobble to boulder lags with moderate to strong varnish; well-preserved surfaces are smooth with scattered pebble and cobble lags. Surface color is reddish brown, rock varnish on surface clasts is typically orange or dark brown; surfaces have a distinctive bright red color on color aerial photos, reflecting reddening of the surface soil and surface clasts. More eroded, rounded Qi2 deposits are less clay-rich and have some carbonate litter on the surface. Soils typically have reddened, clay-rich argillic horizons (McFadden, 1978), and soil carbonate development is typically stage II to III, with abundant carbonate through at least 1 m of the soil profile. Qi2 surfaces generally support grasses, bursage, cholla, and small shrubs.

Qi1 **Older intermediate alluvium (Middle Pleistocene)—** Deposits consist primarily of pebbles, cobbles, sand and fines forming moderately to deeply dissected relict alluvial fans. Qi1 surfaces are drained by well-developed, deeply incised tributary channel networks. Surfaces are typically well rounded with a few planar remnants of the original depositional surfaces, and are typically 5 to 20 m above adjacent active channels. Where Qi1 surfaces are fairly well preserved, they are smooth with pebble and cobble lags; rock varnish on surface clasts is typically orange to red. Soil carbonate development is variable, but locally is quite strong. Where well preserved, soils typically contain deep reddish brown, clay argillic horizons, with obvious clay skins and subangular blocky structure (McFadden, 1978). More eroded Qi1 surfaces are more typical; they are characterized by loose cobble lags with moderate to strong varnish, ridge-and-valley topography, and carbonate litter on the side slopes. On aerial photos, ridge crests on Qi1 surfaces typically are reddish brown, reflecting reddening of the surface soil and surface clasts, and eroded slopes are gray to white. These deposits generally support bursage, ocotillo, and creosote.

Qo **Old, very high alluvium (Early Pleistocene)—** Deposits associated with a very old, high, reasonably well-preserved alluvial fan remnant capping high ridges formed on QTg deposits. The Qo surface is 30 m above adjacent active channels. Qo deposits consist of boulders, cobbles, and sand and finer clasts. The surface is dark reddish brown in color, with a reddish brown clay argillic horizons. The surfaces is dominated by grass, small shrubs, and ocotillo. The Qo surface records the highest levels of aggradation in the Canada del Oro valley, and are likely similar in age as the Cordones surface farther north in the valley and other high, remnant early Pleistocene to latest Pleistocene alluvial surfaces found at various locations throughout southern Arizona (Menges and McFadden, 1981).

QTs **Very old alluvial fan and axial valley deposits (Pliocene to Early Pleistocene)—** Unit QTs consists of hillslope deposits formed on fine to moderately coarse, highly eroded alluvial fan and axial valley deposits. QTs surfaces typically are alternating eroded ridges and valleys, with ridgecrests typically 5 to 20 meters above adjacent active channels. QTs deposits are also exposed beneath overlying Quaternary deposits. The thickness of QTs deposits is not known. QTs surfaces are drained by deeply incised tributary channel networks. Even the highest surfaces atop QTs ridges are rounded, and original highest capping fan surfaces are not preserved. QTs deposits are dominated by sand and gravel ranging from pebbles to cobbles. Deposits are moderately indurated and are moderately resistant to erosion because of the clast size and carbonate cementation. Soils typically are dominated by carbonate accumulation, which is typically cemented on ridgecrests, but areas of clay-rich soils are found locally on ridge flanks. Carbonate litter is common on ridgecrests and hillslopes. On aerial photos, QTs surfaces are generally gray to white, but include some dark reddish-brown areas where clay is more abundant. QTs surfaces support creosote, mesquite, palo verde, ocotillo, and cholla. Exposures in stream cutbanks reveal that conglomerate clasts are 1-10 cm diameter, locally to 30 cm, and include abundant sand in matrix (east edge of SE ¼, NE ¼, sec. 13, T. 11 S., R. 13 E.). Unit is crudely to moderately well bedded, with beds typically 5-30 cm thick. Beds are generally planar over 1-3 m lengths, lenticular at larger dimensions. Mostly beds are poorly channelized and many appear planar.

QTg **Very old, coarse alluvial fan deposits (Early Quaternary to Late Miocene)—**Unit QTg consists of massive boulder conglomerate at the foot of the Santa Catalina Mountains. Clasts are typically 10-200 cm, locally to 10 m (one ~20 m clast was observed in Alamo Canyon; some exceptionally large boulders are identified on the map). Clasts are derived from same rock types as are present in nearby bedrock in the Santa Catalina Mountains, and include abundant, highly resistant leucogranite and pegmatite boulders. Deposits also include cobbles, pebbles, and sand, especially in matrix, but matrix is exposed only is stream cutbanks. Deposits are quite resistant to erosion because of the large clast sizes. Carbonate litter is common on ridgecrests and hillslopes.

Axial Stream Deposits

Qyrc **Active river channel and adjacent low terrace deposits (Late Holocene)—** Sand, pebble, cobble, and boulder deposits in river channels and sand, silt, gravel, and minor clay in low terraces and overbank areas. Channels consist of single, relatively large channels and smaller branching channels in areas of channel expansions. Local relief within channels varies from minimal to more than 1 meter between low-flow channels and adjacent gravel bars. Vegetation generally consists of small bushes and grasses, although the channel banks are typically lined with trees including mesquite, acacia, and palo verde. Areas mapped as Qyrc are flood prone unless engineering structures have been built to divert flow away from them.

Qyr **Young deposits of major washes (Holocene)—** Sand, silt, fine gravel, and locally lenses or layers of coarser gravel deposits of terraces of Cañada del Oro, Sutherland, and Big Washes. Surfaces are generally planar; local relief may be up to 1 m where gravel bars are present, but typically is much less. Qyr surfaces typically are about 2 m above adjacent active channels, but may be higher. Deposits typically are composed of Qyr surfaces generally are fine-grained and lightly vegetated, but appear somewhat darker on aerial photos than Qyrc surfaces. Qyr terrace surfaces support creosote and other small bushes, with some mesquite and palo verde trees along drainages. Qyr soils typically are weakly developed, with some soil structure but little clay and carbonate accumulation. Capping surfaces are slightly higher and more vegetated than adjacent channels and low terraces, and generally are not subject to flood inundation.

Qi3r **Younger intermediate terrace deposits (Late Pleistocene)—** Pebble, cobble, sand, and boulder deposits associated with low intermediate terraces. Terrace surfaces typically 3-10 m above adjacent active channels. Qi3r surfaces commonly have loose, open lags of pebbles and cobbles; surface clasts exhibit weak to moderate rock varnish, and appear orange on color aerial photos, reflecting slight reddening of surface clasts and the surface soil horizon. Qi3r soils are moderately developed, with orange to reddish brown clay loam to light clay argillic horizons (McFadden, 1978) and stage II calcium carbonate accumulation.

Qi2r **Intermediate terrace deposits (Middle to late Pleistocene)—** High intermediate terrace deposits with strong soil development. Deposits typically consist of sand, pebbles and cobbles, but locally are bouldery. Qi2r surfaces are typically 10-30 m above adjacent active channels. Surfaces are characterized by scattered cobble lags with moderate to strong varnish; well-preserved surfaces are smooth to broadly rounded. Surface color is reddish brown, rock varnish on surface clasts is typically orange or dark brown; surfaces have a distinctive bright red color on color aerial photos, reflecting reddening of the surface soil and surface clasts. Soils typically have reddened, clay-rich argillic horizons (McFadden, 1978), and soil carbonate development is typically stage II to III, with abundant carbonate through at least 1 m of the soil profile.

Qi1r **Older intermediate terrace deposits (Middle Pleistocene)—** Deposits consist primarily of pebbles, cobbles, sand and fines forming high terrace remnants. Qi1r are typically well rounded with a few planar remnants of the original depositional surfaces, and are typically 15 to 30 m above adjacent active channels of larger washes. Well-preserved, planar surfaces are smooth with pebble and cobble lags; rock varnish on surface clasts is typically orange to red. Soil carbonate development is variable, but locally is quite strong. Where well preserved, soils typically contain deep reddish brown, clay argillic horizons (McFadden, 1978). More eroded Qi1r surfaces are typical; they are characterized by loose cobble lags with moderate to strong varnish, ridge-and-valley topography, and carbonate litter on the side slopes.

Qor **Old terrace deposits (Early Pleistocene)—** Deposits associated with a very old, high, reasonably well-preserved axial valley floor remnant capping QTg deposits. The one preserved Qor deposit is found between the Canada del Oro and Sutherland Washes, where it is 75-90 m above the active channels. Qor deposits consist of boulders, cobbles, and sand and finer clasts. Surfaces are dark reddish brown in color, with reddish brown, clay argillic horizons. Qor surfaces record the highest levels of aggradation in the Canada del Oro valley, and are likely correlative with the Cordones surface farther north in the valley and other high, remnant early Pleistocene to latest Pleistocene alluvial surfaces found at various locations throughout southern Arizona (Menges and McFadden, 1981).

Other Deposits

d **Disturbed ground (modern) —** Areas where human activity has obscured the geologic nature of underlying material.

Qtc **Hillslope colluvium and talus, including rockfall (Quaternary)—** Locally-derived colluvial and talus deposits on moderately steep hillslopes in the Santa Catalina Mountains and low-relief, weathered bedrock in the Tortolita Mountains. Colluvium is mapped only where sufficiently thick and extensive as to obscure underlying bedrock. Deposits are very poorly sorted, ranging from clay to cobbles and large boulders derived from rockfalls. Clasts typically are subangular to angular because they have not been transported very far. Bedding is weak and dips are steep, reflecting the steep depositional environment. Deposits are a few meters thick or less; thickest deposits are found at the bases of hillslopes. Some stable hillslopes are covered primarily with Pleistocene deposits, which are typically reddened and enriched in clay. Most colluvial hillslopes are covered with Holocene deposits, which have minimal soil development.

BEDROCK MAP UNITS IN THE SANTA CATALINA MOUNTAINS

Tsu **Clastic sedimentary rocks, undivided (Neogene)—**Concealed strata displaced by the Catalina detachment fault and correlative with with the Swan-Craycroft gravels of Dickenson (1999) and the underlying Pantano Formation. Show in cross-section only.

Tf **Fault rocks (Neogene)**—Fault breccia with abundant hematite-stained fractures and hematite-silica material filling open spaces between breccia fragments. Hematite is earthy and brownish red. Fault breccia is located along the Pirate fault. In some exposures, the fault surface is a planar, polished surface on hematite-silica microbreccia, locally with black manganese oxide coating. Breccia below microbreccia surface is up to 70% hematite-silica microbreccia/hydrothermal silica with as little as 30% of rock consisting of 2-20 mm granitic rock fragments. Brecciation decreases in intensity away from contact into granitic footwall rocks. Fault rocks of this map unit extend over, typically, 1 to 10 m away from fault trace and grade into moderately to slightly brecciated or strongly fractured granitic footwall rocks.

Tx **Breccia (Neogene)**—Well-cemented breccia with no preferred orientation of angular fragments, almost all of which are less than 20 cm diameter. Earthy hematite locally coats fractures but does not discolor the rock as it does with fault rocks of map unit Tf. Breccia is cemented and is moderately resistant to weathering, forming some bold outcrops. Weathers tan with much pale green lichen. Sparse planar fractures and crude variations in color and resistance to weathering define indistinct fabric that dips steeply to northwest, parallel to regional dip of Pirate fault which is buried under younger deposits at some unknown but probably small (<100m) distance to the northwest. Fractures and crude layering that impart a fabric to this rock unit are only weakly and sparsely developed. Most of rock is remarkable massive and directionless, and strongly resembles rock-avalanche breccia in which all clasts are reduced to less than a threshold size.

This rock unit is interpreted as an implosion breccia in which the footwall granite and perhaps coarse hanging-wall conglomerate catastrophically disaggregated, or exploded, into a dilational zone within the Pirate fault. This could have occurred repeatedly during earthquakes that produced dilational voids along the fault. It is not obvious that the area that contains these breccias is a dilational zone along the Pirate fault, but since movement is entirely or almost entirely dip slip, irregularities along the fault that would produce a dilational jog would not likely be visible. A major change in the strike of the fault occurs just to the north of the zone containing the breccia such that the southern sections strikes northwest but the northern section strikes north. The intersection of two planar fault segments with these strikes would be a steeply plunging line. If displacement of the hanging-wall was more northerly than the plunge of this line, dilation would result along the fault surface immediately to the south for the case of a southward-propagating seismic dislocation (a dilational bend, e.g., Sibson, 1989). Finally, the lack of hydrothermal hematite-silica in this breccia or adjacent to it could be the result of downward percolation of groundwater beneath the head of an alluvial fan emanating from the Romero and Montrose canyons area. This could have depressed isotherms. Farther south where hematite-silica breccia is common (map unit Tf), perhaps hot water ascended along the active fault rather than descended.

Tgc **Catalina granite (Oligocene)**—Fine to medium grained, hornblende-biotite granite. Mafic minerals are generally unaltered. Varies from equigranular to porphyritic, with K-feldspar up to 2 cm long. Contains very few pegmatite or aplite dikes and only slightly fractured. Weathering has produced an extensive pediment surface developed on homogeneous granite with few fractures, dikes, or veins.

The Catalina granite is exposed over a large area northeast of the map area. It generally consists of porphyritic biotite ± hornblende granite. Pink orthoclase phenocrysts are as long as 4 cm (Suemnicht, 1977) to perhaps 7 cm (Budden, 1975). Xenoliths are locally abundant (Budden, 1975). Texture is hypidiomorphic granular and plagioclase composition is An 26-32 (Suemnicht, 1977). Three K-Ar dates considered reliable by Reynolds et al. (1986) range from 24.0 Ma to 25.6 Ma (Damon and others, 1963; Creasey and others, 1977), whole rock Rb-Sr isotopic analyses indicate an age of ~26 Ma (Keith et al., 1980), and Shakel et al.

(1977) report “nearly concordant 27 ± 2 m.y. old zircons” but give no uranium-lead analytical data or location information.

Many different names have been used for this granitoid intrusion, but the most common has been Catalina granite (Bromfield, 1952; McCullough, 1963; Shakel et al., 1972, 1977; Budden, 1975; Suemnicht, 1977; Reynolds et al., 1986). Creasey et al. (1977) referred to this intrusion, and much of the rest of the granitoids and gneissic granitoids in the Santa Catalina Mountains, as “quartz monzonite of Samaniego Ridge.” However, 11 of 13 modal mineral determinations indicate that the unit is a granite according to IUGS classification (Streckeisen, 1973). Because of conflicting name usage and because a type area has not been designated, the term “Catalina granite” is here considered informal.

Tgl **Heterogeneous, pegmatitic, muscovite leucogranite (Paleogene)**—Fine to medium grained, equigranular muscovite leucogranite with fine-grained leucogranite dikes and, especially in the Romero and Montrose canyon areas, abundant pegmatite dikes that lack mica but contain abundant K-feldspar up to 15 cm long. Leucogranite generally contains zero to 2% of each of the following, 1-3 mm muscovite, 1-2 mm biotite, and <1 mm garnet. Rocks of this unit are part of the Wilderness Suite granites of Keith et al. (1980) and Force (1997).

Contact between leucogranite and biotite granite of Alamo Canyon is gradational over hundreds of meters. Percentage of pegmatite and leucogranite increases toward area mapped as heterogeneous pegmatitic muscovite leucogranite. Contact marks approximate transition from roughly equal amounts of each rock type, (mapped as biotite granite of Alamo Canyon) to 90-100% heterogeneous pegmatitic muscovite leucogranite.

Tglx **Fractured, heterogeneous, pegmatitic, muscovite leucogranite (Paleogene)**—Areas where heterogeneous, pegmatitic, muscovite leucogranite is significantly fractured, with sparse earthy hematite on some fracture surfaces. Fracturing is associated with the late Cenozoic Pirate fault.

Tgp **Muscovite leucogranite of Pusch Peak (Paleogene)**—Muscovitic, medium grained, slightly porphyritic granite. This granite has a pale orangish tan, iron-stained character, and is more easily weathered, in contrast to white, resistant, heterogeneous, pegmatitic, muscovite leucogranite that makes up a cliff-forming sill below Pusch Peak and that contains less muscovite and is finer grained. Muscovite forms estimated 3-5% of rock in crystals as large as 10 mm, but mostly <5 mm. In weakly mylonitic rocks, muscovite is preferentially aligned with mylonitic fabric.

Muscovite from a leucogranite sill yielded an $^{40}Ar/^{39}Ar$ isochron date of 24.96 ± 0.13 Ma. Biotite from a pegmatite yielded an $^{40}Ar/^{39}Ar$ isochron date of 23.41 ± 0.15 Ma. Both dates are interpreted as cooling dates related to tectonic exhumation, and are younger than the inferred Eocene age of the leucogranites and pegmatites (both dates from Spell et al., 2003).

Kga **Biotite granite of Alamo Canyon (Late Cretaceous)**—Dark, foliated, equigranular, fine to medium grained, biotite (4-8%) granite, intruded by abundant leucogranite and pegmatite dikes and sills. Granite is weakly segregated into layered and/or lineated fabric as defined by color variations that reflect light/dark mineral content. Foliation is somewhat defined by lithologic layering, somewhat by preferred orientation of biotite, generally with little or no evidence of grain-size reduction as is so characteristic of forerange mylonitic fabrics. Foliation attitudes measured here are generally on lithologic layering. Much weakly gneissic biotite granite is too irregularly layered to get meaningful attitudes. Elongation of dark, biotite-rich aggregates defines vague lineation fabric (L fabric). Granite is not consistently foliated and in many areas is an L-tectonite where only lineation could be measured.

Biotite granite is extensively intruded by 20-200 cm thick pegmatite and fine-grained leucogranite dikes and sills. Pegmatites, as in heterogeneous pegmatitic muscovite leucogranite (map unit Tgl), are dominated by K-feldspar and contain 0 to 1%, 2 to 20 mm biotite, no muscovite and, commonly, little or no quartz. Lithologic layering in granite is somewhat wavy and non-planar in detail, especially adjacent to some pegmatite and aplite dikes where distortion of layering in host biotite granite apparently accompanied emplacement of dikes. Some dikes follow foliation and lithologic layering in host granite, some are irregular, variably concordant stringers, and some are simply discordant and truncating. Preferred interpretation is that foliation and gneissic layering developed during dike emplacement and associated high temperature deformation and recrystallization, and that some dike emplacement occurred late during or after the period of deformation and development of lithologic layering.

Contact between biotite granite and heterogeneous pegmatitic muscovite leucogranite (map unit Tgl) appears from a distance on the north face of Bighorn Mountain to be gradational over approximately 50 m of structural thickness. Farther southwest this contact zone is marked by a sheet of Pinal Schist that is intruded by pegmatites. Farther northeast, the contact between leucogranite and biotite granite of Alamo Canyon is gradational over hundreds of meters, with numerous dikes of leucogranite and screens of biotite granite.

Foliation and lineation in biotite granite are interpreted as high temperature fabric elements with sufficient recrystallization during deformation that grain-size reduction, characteristic of mylonitic fabrics, is generally not visible. This fabric is therefore considered to be crystalloblastic and to have developed at higher temperature than is characteristic of mylonitization. Some lineations, however, seems to be weakly mylonitic. In the Alamo Canyon area, foliation in biotite granite is associated with weak lithologic layering and does not seem to be at all mylonitic, however lineation developed on foliation surface in some areas, especially near Pusch Peak, does seem to be weakly mylonitic.

The foliation and compositional layering in the biotite granite of Alamo Canyon define a doubly plunging antiform with an axis that trends approximately N 65° E (Pashley, 1963). This feature has been interpreted as a fold (e.g., Pashley, 1963). However, mapping during this study did not locate any axial planar fabric to such a fold, and found that much of the rock that made up the antiform was a high-temperature L-tectonite with lineation trend and plunge parallel to the axis of the antiform. It is suspected that the antiformal form of compositional layering in the biotite granite and intruding pegmatites and aplites is a feature that formed during L and L-S fabric development and vein and dike emplacement. The features that define the antiform may have never been planar and thus the antiform may not be a fold.

The Granite of Alamo Canyon yielded a U-Pb zircon date of 71 ± 1 Ma. This granite is similar to the nearby Pluton of Chirreon Wash in the Tortolita Mountains (Banks et al., 1977; Ferguson et al., 2002), which yielded a U-Pb zircon date of 69.5 ± 0.5 Ma (both dates from Spencer et al., 2003). These two granite rock units are possibly part of the same intrusion.

Kgax **Fractured biotite granite of Alamo Canyon (Late Cretaceous)—**Areas where biotite granite of Alamo Canyon is significantly fractured, with sparse earthy hematite on some fracture surfaces. Fracturing is associated with the late Cenozoic Pirate fault.

Xp **Pinal Schist (Early Proterozoic)—**Pale-gray to medium-gray micaceous schist and psammitic schist, commonly intruded by numerous leucogranite dikes and quartz veinlets.

BEDROCK MAP UNITS IN THE TORTOLITA MOUNTAINS

Ttm **Granite of Tortolita Mountains (Oligocene-Miocene)—** Medium- to fine-grained, equigranular granite with 3-5%, 1-3 mm biotite. This unit locally forms dikes in porphyritic biotite granite of map unit TKgp. Unit is equivalent to Quartz monzonite of the Tortolita Mountains of Banks et al. (1977).

Td **Dikes associated with Granite of Tortolita Mountains (Oligocene-Miocene)**—Fine grained leucogranite dike containing ~1-2% biotite.

Tgd **Granodiorite (Oligocene-Miocene)**—Fine-grained, dark, equigranular, biotite-hornblende granodiorite or granite. Contains up to 20% mafic minerals. In northern exposures along edge of the quadrangle, rocks of this unit contain 5-10% biotite and 5-10% hornblende. This unit is probably correlative with the mafic phase of the pluton of Wild Burro Canyon (Banks, 1980; map unit Tgm of Skotnicki [2000]; C.A. Ferguson, oral communication, 2002). It is not clear that the scattered exposures of this map unit are really all co-magmatic or the same age.

TKgp **Porphyritic biotite granite (Cretaceous to Paleogene)**—Heterogeneous, coarse-grained, porphyritic, biotite granite with 1-2 cm K-feldspar phenocrysts. This unit is probably correlative with the porphyritic phase of the pluton of Wild Burro Canyon (Banks, 1980; map unit Tgc of Skotnicki [2000]; C.A. Ferguson, oral communication, 2002), but it also resembles middle Proterozoic Oracle granite (Peterson, 1938). Southernmost exposures (sec. 24 and 25, R. 13 E., T. 11 S.) locally have weak mylonitic fabric and very sparse, strongly developed mylonitic shear zones with a very high degree of grain size reduction such that shearing processes appear to be almost entirely brittle with little recrystallization during shearing or plastic deformation of quartz. Foliation measurements are shown on map as protomylonite. No chlorite and/or epidote fracture coatings or hematite fracture coating were seen in southernmost exposures, which suggests that a buried detachment fault is not located to the south near bedrock exposures and does not project over these outcrops closer than perhaps 50 to 100 m.

Pzm **Metasedimentary rocks (Paleozoic to Cretaceous or Paleogene)**— Paleozoic protolith, Mezozoic to Cenozoic metamorphism. Includes several rock types, including the following: (1) Fine-grained to locally medium-grained (crystals up to 3 mm) biotite+chlorite+quartz+feldspar rock. Protolith is inferred to be sandstone or silty sandstone, in some areas calcareous. (2) Tan carbonate. (3) Gray, fine grained metaquartzite. Contact with adjacent granitoids is locally mineralized with at least one prospect pit and minor green or blue copper stain in rubble. (4) Thin bedded quartzite with thin layers of recess-forming carbonate, both in layers 2-20 mm thick.

Yg **Porphyritic granite (Middle Proterozoic)**—Dark, coarse-grained, K-feldspar-porphyritic (up to 4 cm) granite containing up to 10% biotite. Probably correlative with Oracle Granite of Peterson (1938) or with the coarse-grained phase of the pluton of Wild Burro Canyon (quartz monzonite of Wild Burro Canyon of Banks [1980]).

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MAP SYMBOLS

Depositonal or intrusive contact—Dashed where approximately located.

Gradational contact

Fault, showing dip and striation trend—Dashed where approximately located, dotted where concealed.

Ultramylonite shear zone

Quartz vein

Mafic dike

Bedding

Apparent dip of bedding

Primary lithologic layering in igneous rocks—Primarily defined by compositionally distinct layers in pegmatitic granite. Variations in crystal size and relative content of quartz, K-feldspar, and plagioclase are primary defining features. These rocks are generally undeformed.

Gneissic layering—Layering in Pinal Schist with parallel alignment of mica.

High temperature foliation with lineation—Mineralogic preferred orientation and lithologic layering produced at sufficiently high temperatures that recrystallization obscured or prevented significant grain-size reduction associated with shearing and flattening. Fabric is defined by elongation of mafic mineral aggregates, weak lithologic segregation of light and dark minerals into layers or elongate linear forms, and development of preferred orientation of biotite. Identified primarily in granite of Alamo Canyon where stretching to produce an L fabric was commonly dominant.

High temperature lineation without foliation—Lineation that was produced by constrictional strain at sufficiently high temperatures that recrystallization obscured or prevented significant grain-size reduction. Fabric defined by elongation of mafic aggregates and weak lithologic segregation of light and dark minerals into elongate forms. Identified primarily in granite of Alamo Canyon where stretching to produce an L fabric was commonly dominant.

Mylonitic foliation with lineation

Mylonitic lineation without folition

Weak mylonitic foliation (protomylonite) with lineation—Mylonitic foliation that is restricted to discrete shear zones that affect a tiny fraction of the rock in the southeastern Tortolita Mountains.

Sets of joints, and crude layering in breccia—These are possibly relict fault surfaces or large parallel fractures, small faults, or brittle shear zones associated with the Pirate fault.

Joint—Sparse joints, but some joints may be areally extensive.

Joint that could be footwall surface of Pirate fault

Boulder—Seven to twenty meters diameter

Geochronology location