GEOLOGIC MAP, GEOLOGIC EVOLUTION, AND MINERAL DEPOSITS OF THE GRANITE WASH MOUNTAINS, WEST-CENTRAL ARIZONA

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INTRODUCTION

The Granite Wash Mountains are located in west-central Arizona and are contiguous with the Harcuvar Mountains to the northeast and the Little Harquahala Mountains to the south. They are part of the *Maria fold and thrust belt*, a belt of large folds and major thrust faults that trends east-west through west-central Arizona and southeastern California (Reynolds and others, 1986). In the Granite Wash Mountains, late Mesozoic deformation related to the Maria belt affected a diverse suite of rock units, including Proterozoic crystalline rocks, Paleozoic carbonate and quartzose clastic rocks, and Mesozoic sedimentary, volcanic, plutonic, and hypabyssal rocks. This deformation was mostly deep seated and produced an assortment of folds, cleavages, and both ductile and brittle shear zones. Several discrete episodes of deformation occurred, resulting in refolded folds, folded and refolded thrust faults, and complex repetition, attenuation, and truncation of stratigraphic sequences. Greenschist-facies metamorphism accompanied deformation and was most intense along the major thrusts. Deformation and metamorphism were followed by emplacement of two Late Cretaceous intrusions and numerous dikes.

The geology of the Granite Wash Mountains was mapped between 1982 and 1988 as part of the U.S. Geological Survey - Arizona Geological Survey Cooperative Geologic Mapping (COGEOMAP) Program, whose goal is to map the geology of the Phoenix 1° X 2° quadrangle. The entire mountain range was mapped at a scale of 1:24,000 (Reynolds and Spencer), with additional, generally more detailed mapping in the central (Laubach and Reynolds), northern (Cunningham), and northwestern (Richard) parts of the range. In addition to the mapping, we performed detailed structural and petrographic analysis at key localities.

This report accompanies a 1:24,000-scale black-and-white map and presents the results of the mapping and describes major findings about stratigraphy, structure, and metamorphism. Some aspects of the research have been presented elsewhere (Reynolds and others, 1983, 1986b, 1987, 1988, 1989; Cunningham, 1986; Laubach, 1986; Laubach and others, 1987, in press), and some parts of this report derive from these earlier publications. Previous geologic studies in the range consist mostly of regional reconnaissance (Bancroft, 1911; Wilson, 1960; Kam, 1964; Wilson and others, 1969; Rehrig and Reynolds, 1980) and two theses covering limited areas (Ciancanelli, 1965; Marshak, 1979).

REGIONAL GEOLOGIC SETTING

The oldest rocks in the region are Proterozoic gneiss, schist, amphibolite, and dioritic to granitic rocks. These are depositionally overlain by a 1-km-thick sequence of Paleozoic carbonate and clastic rocks. Individual Paleozoic formations maintain their distinctive characteristics, even where metamorphosed and greatly attenuated (Stone et al., 1983), and are therefore extremely useful for unraveling complex structure.

Mesozoic sedimentary and volcanic rocks in the region can be subdivided into the following four units (in ascending stratigraphic order):

(1) Buckskin Formation (Reynolds and Spencer, 1989), a sequence of variably calcareous siliciclastic rocks and phyllite, with local conglomeratic, feldspathic, and evaporitic intervals. This unit rests depositionally on Permian Kaibab Formation and largely correlates with Triassic Moenkopi Formation of the Colorado Plateau (Reynolds and others, 1987);

(2) Jurassic or Late Triassic Vampire Formation (Reynolds and Spencer, 1989), consisting of impure quartzose sandstone and quartzite, with conglomerate at the base and locally higher in the section. Because of a major episode of Late Triassic or Early Jurassic uplift, the basal conglomerate unconformably overlies a variety of older rock units, including Buckskin Formation, Paleozoic rocks, and Proterozoic crystalline rocks (Reynolds and others, 1989). The formation probably correlates with the Jurassic Glen Canyon Group of the Colorado Plateau (Reynolds and others, 1987);

(3) Jurassic intermediate to silicic volcanic and volcaniclastic rocks dated at

about 160 Ma (Reynolds and others, 1987). This unit largely consists of feldspar- and quartz-phyric ash-flow tuffs, hypabyssal intrusions, volcaniclastic rocks, and their schistose, metamorphosed equivalents. The volcanic sequence is locally accompanied by contemporaneous(?) granitoid plutons (Tosdal and others, in press); and

(4) McCoy Mountains Formation, a sequence of dominantly clastic rocks of Jurassic age (Harding and Coney, 1985), Cretaceous (Stone and others, 1987) age, or both (Tosdal and others, in press). In several ranges, the McCoy Mountains Formation is 5 to 7 km thick and has been subdivided into the following six members (from bottom to top): (a) basal sandstone member one; (b) basal sandstone member two; (c) mudstone member; (d) conglomerate member; (e) sandstone member; and (f) siltstone member (Harding and Coney, 1985). These thick sequences define a west-northwest-trending outcrop belt, termed the *McCoy basin* (Harding and Coney, 1985; Reynolds and others, 1986), which includes the Granite Wash, Little Harquahala, Plomosa, and Dome Rock Mountains of Arizona and the McCoy, Palen, and Coxcomb Mountains of southeastern California. Some sections of McCoy Mountains Formation are thinner (less than 2 km) and cannot be unambiguously correlated with these six members (Harding and Coney, 1985). To differentiate the two different sequences of McCoy Mountains Formation, we have used the term *Apache Wash facies* for the thinner sequence (after Harding and Coney, 1985) and *basin facies* for the thicker sequence (Reynolds and others, 1986).

Subsequent to deposition of the McCoy Mountains Formation, late Mesozoic tectonism affected the region. Deformation and metamorphism were apparently concentrated in the east-west-trending *Maria fold and thrust belt*, which extends from the Palen and Coxcomb Mountains of southeastern California to the Harquahala and Eagle Tail Mountains of west-central Arizona (Reynolds and others, 1986b, 1988; Hoisch and others, 1988). The thrust belt is characterized by generally southeast-, south-, and southwest-vergent structures, including large recumbent to upright folds and major ductile and brittle thrust faults. The folds are associated with extreme attenuation of Paleozoic and Mesozoic sections and widely involve the underlying Proterozoic crystalline basement. The larger thrust zones include tectonic slices of Jurassic or Proterozoic crystalline rocks and commonly juxtapose thrust plates with contrasting Mesozoic sequences and histories. The thrust and folds have been locally overprinted by northeast-vergent shearing and a late, southwest-dipping cleavage (Richard, 1988).

Late Cretaceous and early Tertiary granitoid plutons and dikes intruded after thrusting and were accompanied by deformation and amphibolite-facies metamorphism in the Harcuvar and Harquahala Mountains (Rehrig and Reynolds, 1980; DeWitt and others, 1988) but not in the Granite Wash Mountains. A major episode of Late Cretaceous to early Tertiary regional uplift followed plutonism and metamorphism, as indicated by widespread 70 to 45 Ma K-Ar cooling ages on a variety of rock types, by the relatively deep-level character of exposed Late Cretaceous and early Tertiary granitoids, and by the absence of Upper Cretaceous and lower Tertiary supracrustal rocks (Reynolds and others, 1986b, 1988).

Middle Tertiary history of the region included widespread volcanism, dike emplacement, and sedimentation that was commonly synchronous with normal faulting, fault-block rotation, and tens of kilometers of transport on gently dipping, ductile shear zones and detachment faults (Reynolds and Spencer, 1985; Spencer and Reynolds, 1989, in press). The Harcuvar Mountains, adjacent to the Granite Wash Mountains, are a metamorphic core complex that was tectonically denuded during middle Tertiary detachment faulting (Rehrig and Reynolds, 1980). Late Tertiary and Quaternary events in the region included: (1) minor Basin and Range normal faulting that blocked out some present basins, (2) movement on northwest-trending strike-slip, reverse, and normal faults within the ranges, (3) eruption of basaltic lavas, (4) deposition of nonmarine clastic rocks and the Pliocene Bouse Formation, and (5) integration of previously internal drainage systems with

accompanying sediment deposition in alluvial fans and along stream channels.

GEOGRAPHIC FEATURES

The geological discussion below references key geographic features that are shown on figure 1. These features include (1) officially named geographic features (that is, recognized on USGS quadrangle maps of the area), (2) mine names not listed on the USGS base map, but determined by a search of all available literature on the area, and (3) previously unnamed geographic features that are assigned informal names. Official names are capitalized, whereas informal and mine names are not capitalized. For example, the long ridge that extends northward from the main mass of the Granite Wash Mountains is informally referred to as Butler ridge because it marks the southwest end of Butler valley. Other important geographic names include Calcite mine, Cobralla, Desert Mine, Dona Kay mine, Glory Hole mine, Glory Hole peak, klippe hill, Little Butler ridge (the small ridge west of Butler ridge), Mt. green, Salome Peak, Three Musketeers mine, True Blue mine, and Yuma mine (fig. 1).

STRUCTURAL AND STRATIGRAPHIC FRAMEWORK

The geology of the Granite Wash Mountains is dominated by a series of major, gently dipping thrust faults that cut Mesozoic, Paleozoic, and Proterozoic rocks and by two major post-thrusting Late Cretaceous plutons -- the Tank Pass Granite and Granite Wash Granodiorite (Fig. 2). The main thrusts are southwest vergent and are, from top to bottom, the Hercules thrust, Yuma mine thrust, and McVay thrust. The Hercules thrust is the most important thrust because it extends north-northwest along the entire length of the range, is marked by the thickest zone of penetrative deformation, and everywhere carries Proterozoic and Jurassic crystalline rocks in its hangingwall. Below the Hercules thrust, the Yuma mine thrust interleaves Mesozoic, Paleozoic, and Proterozoic rocks. The Yuma mine thrust is subsidiary to the Hercules thrust, but is also a major thrust. The structurally lowest McVay thrust cuts mostly Mesozoic rocks and is exposed only in a small window in the center of the range. It is inferred to underlie the rest of the range. These thrusts subdivide the range into four major structural plates that will be discussed separately below. In addition, the northern Granite Wash Mountains will be discussed separately because rocks and structures in this area are isolated from those further south by the large pluton of Tank Pass Granite.

Central Granite Wash Mountains: Below the McVay thrust

The structurally lowest rocks in the range are exposed within a small structural window along "McVay wash," which is located south of the Yuma mine in the west-central part of the range. This structural plate underlies the McVay thrust and consists of quartzofeldspathic and lithic clastic rocks that correlate with the McCoy Mountains Formation. These rocks are structurally overlain along the McVay thrust by Jurassic volcanic rocks, a distinctive stretched-pebble conglomerate with light-colored volcanic clasts, and Paleozoic and Triassic rocks. The McVay thrust is least obvious where the thrust places stretched-pebble conglomerate over McCoy Mountains Formation (because this could simply be an overturned unconformity), but becomes clear where tectonic slivers of Paleozoic rocks intervene between the two rock types. The distinctive stretched-pebble conglomerate is not recognized elsewhere in the range and either is laterally discontinuous or is within a separate, small structural plate. The position of the conglomerate within the associated Jurassic volcanic section is unknown, but is probably near the base, considering its northerly position within the general south-facing volcanic section.

Central Granite Wash Mountains: Below the Yuma mine and Hercules thrusts, Above the McVay thrust

This structural plate is areally the largest in the Granite Wash Mountains and comprises the southwestern two thirds of the range. It includes rocks above the McVay thrust and below the Yuma mine thrust or Hercules thrust where the Yuma mine thrust is absent. This domain is structurally complex, but consists of a large upturned stratigraphic sequence that includes Paleozoic rocks, Triassic and Jurassic sedimentary rocks, Jurassic volcanic and volcaniclastic rocks, and McCoy

Mountains Formation. Bedding and lithologic units in this section strike east to northeast, face south to southeast, and generally are steeply dipping to vertical, but are significantly overturned to upside down over large areas. Because the entire section is on end, progressively higher stratigraphic levels are exposed from north to south. The mostly gently dipping Yuma mine and Hercules thrusts, therefore, cut discordantly across the upturned section in their footwalls.

The stratigraphically oldest rocks in the continuous, upended section are Paleozoic rocks that form three northeast-striking Paleozoic strike belts in the west-central part of the range. Stratigraphic units within these belts are nearly vertical and face southeast. The strike belts are separated from one another by steeply dipping, bedding-parallel faults and ductile shear zones marked by intensified, steep cleavage. The two northern strike belts are the most complete, and each contain an intact section that includes, from northwest to southeast, Devonian Martin Formation, Mississippian Redwall Limestone, Permian-Pennsylvanian Supai Group, and Permian Coconino Sandstone and Kaibab Formation. Kaibab Formation in both of these strike belts is locally overlain by quartzo-feldspathic clastic rocks, phyllite, and gypsum-anhydrite rocks of the Triassic Buckskin Formation. A small irregularly shaped body of Jurassic(?) granite intrudes the Paleozoic units on the southwest end of the central strike belt.

Near the center of the northern two strike belts, the vertically dipping Paleozoic units and their steep, section-repeating fault are discordantly truncated by an overlying subhorizontal thrust klippe of Mesozoic sedimentary and volcanic rocks. A well-developed subhorizontal cleavage concordant with the thrust is present in both the upper- and lower-plate rocks. The fault that bounds this klippe of Mesozoic rocks is interpreted to be a downfolded segment of the Yuma mine thrust.

The northern limit of the Paleozoic strike belts is a structurally complex zone where the rocks have been shuffled by several generations of shear zones and subsequently folded. At the northwestern corner of the Paleozoic strike belts, the vertically dipping Paleozoic rocks are faulted over Jurassic or Proterozoic porphyritic granite along a gently dipping, brittle-ductile shear zone (the term *brittle-ductile shear zone* is used for shear zones in which movement has taken place by a combination of ductile deformation, as indicated by well-developed cleavage or foliation, and slip on discreet fault surfaces and cleavage planes). The porphyritic granite is itself underlain by steeply dipping slivers of tectonically interleaved Paleozoic rocks, Triassic Buckskin Formation, and amphibolite and mafic schist of Proterozoic or Jurassic age. This zone of interleaving displays both north-northwest- and northeast-trending lineations. Where remnants of intact stratigraphic sections are present in the fault slivers, the units face south. To the east, this shear zone is cut by the eastern extension of the gently dipping, brittle-ductile shear zone that floors the main Paleozoic strike belt. This area also contains small klippen structurally correlative with the main klippe in the center of the strike belts. The thrust zone beneath the klippen is broadly to isoclinally folded about northwest- to west-trending axes and is cut by late-stage, brittle-ductile shear zones. The northernmost klippe of deformed Jurassic igneous rocks overlies south-facing Coconino Sandstone on its southern side and Triassic Buckskin Formation on its northern side. This relationship suggests that the fault has overridden a pre-existing (bedding parallel?) fault that repeats the footwall rocks as a fourth strike belt. The youngest structures in the area are minor northeast-trending, high-angle faults.

Northeast and east of the main klippe, the Paleozoic units are extensively intruded by Jurassic alaskite and are overlain by small klippen of Jurassic volcanic and volcaniclastic rocks; these klippen are probably correlative with the larger klippe. The Paleozoic rocks in this area, especially those in the southern strike belt, are extremely attenuated and locally occur as thin tectonic slivers or rootless folds within Triassic and Jurassic rocks. In several localities, a completely inverted, attenuated sequence of Coconino Sandstone, Kaibab Formation, and Triassic Buckskin Formation is tightly folded by west-

northwest-plunging, upright folds. The tight folds are adjacent to a late-stage, northeast-vergent, brittle-ductile shear zone. Northeast, toward the structurally overlying Yuma mine thrust, the Paleozoic section is dragged to the south as a southward-tapering wedge directly beneath the thrust.

The southern of the three strike belts is thinner and less complete, generally consisting of Coconino Sandstone, Kaibab Formation, and Triassic Buckskin Formation. The Paleozoic-Mesozoic contact is tectonized, but generally no more so than the adjacent units, and is regarded as fundamentally depositional in character. The contact is folded by at least one large southeast-facing fold and is locally cut by a near-vertical, brittle fault with associated gouge and breccia.

The Buckskin Formation in the southern strike belt is stratigraphically overlain by a relatively complete Mesozoic section consisting of Jurassic or Upper Triassic Vampire Formation, Jurassic volcanic and volcaniclastic rocks, and McCoy Mountains Formation. For the most part, these units have the same east to northeast strike and steep dip as the Paleozoic rocks. Exposures of bedding are generally absent in the relatively massive volcanic and volcaniclastic rocks, but at least one important marker unit, a K-feldspar-megacrystic porphyry near the the base of the volcanic section, exhibits a map pattern consistent with an east-northeast strike and near-vertical dip. Near the top of the volcanic and volcaniclastic unit are mica schist, quartzite, and, near the Hercules thrust, quartz-kyanite rocks.

The McCoy Mountains Formation stratigraphically overlies the Jurassic volcanic and volcaniclastic rocks and includes, from north to south, the following mappable units (Laubach, 1986; Laubach and others, 1987): (1) a lower lithic sandstone; (2) heterogeneous clastic rocks of the Yellowbird mine sequence; (3) polymict conglomerate; (4) lithic sandstone; (5) mudstone (now phyllite) with interbedded siltstone, sandstone and calcareous clastic rocks; and (6) sandstone and conglomerate. The overall stratigraphic succession, in conjunction with sandstone petrography, suggests that units 1 through 4 are correlative with basal sandstone member two of the McCoy Mountains Formation, whereas units 5 and 6 are correlative to the mudstone member and lowest part of the conglomerate member, respectively, of the basin facies of the McCoy Mountains Formation (Laubach and others, 1987).

Eastern Granite Wash Mountains: Above the Yuma mine thrust, below the Hercules thrust

The Yuma mine thrust places a diverse assemblage of Mesozoic, Paleozoic, and Proterozoic rocks across the upturned sequence described above. The Yuma mine thrust is best exposed near the Yuma mine, where it carries coarse-grained Proterozoic granite, Paleozoic rocks, and Mesozoic alaskite in its hangingwall. The thrust cuts Paleozoic rocks in its footwall north of the Yuma mine, but cuts Jurassic volcanic and volcaniclastic rocks further south, where the southward-tapering wedge of Paleozoic rocks pinch out. In the latter area, the thrust juxtaposes lithologically similar sequences of Jurassic volcanic and volcaniclastic rocks and is marked by discontinuous fault-bounded slivers of Paleozoic rocks and by a zone of intensely developed cleavage and mylonitic foliation. Kyanite-bearing quartzite and tourmaline-bearing, quartz-mica schist are present beneath the thrust.

Above the Yuma mine thrust are numerous shear-zone-bounded thrust slivers, the lowest of which includes Cambrian Bolsa Quartzite in recumbently folded depositional contact with a Proterozoic porphyritic granite. Successively higher thrust-bounded slivers include (1) mafic schist of unknown age, (2) Permian quartzite and marble, (3) Mesozoic sedimentary rocks, (4) undifferentiated Paleozoic rocks, (5) Mesozoic sedimentary rocks, and (6) a fine-grained plutonic equivalent of the Jurassic volcanic rocks. The thrust slivers of Paleozoic rocks thin to the south toward Mt. green into a thick mass of penetratively cleaved and mylonitized Jurassic volcanic and volcaniclastic rocks and their intrusive equivalents.

An offset continuation of the Yuma mine thrust, originally referred to as the Calcite mine thrust (Reynolds and others, 1986b), is exposed in the southern part of the range.

This southern segment of the Yuma mine thrust occupies the same structural position as the Yuma mine thrust further north (e.g., above the upturned section of the McVay plate and below the Hercules thrust). The thrust places a sheet of hydrothermally altered and metamorphosed Jurassic metavolcanic and volcaniclastic rocks, quartzite, and andalusite-rich schist over McCoy Mountains Formation. The thrust is discordant to the underlying south-facing McCoy Mountains Formation; it cuts the lithic sandstone at Calcite mine and the phyllite and upper sandstone and conglomerate further south. North of the Calcite mine, the thrust is itself cut by an east-west-striking, gently north-dipping, late-stage, brittle-ductile shear zone (referred to as the Calcite Wash shear zone). Near this late-stage shear zone, the Yuma mine thrust and foliation related to the thrust are folded into east-plunging folds as large as several hundred meters in amplitude. South of the Calcite mine, the upper plate of the Yuma mine thrust includes a thrust-bounded wedge of Mesozoic metasedimentary rocks of uncertain regional correlation.

Another stack of imbricate thrust sheets that lie above the Yuma mine thrust and below the Hercules thrust is exposed on the west flank of Salome Peak in the north-central Granite Wash Mountains. The lowest thrust sheet in this stack contains a coarse-grained Proterozoic porphyritic granite (dated by a Rb-Sr whole-rock model age) that is identical to the granite above the Yuma mine thrust at Yuma mine. The porphyritic granite structurally overlies Jurassic volcanic and volcaniclastic rocks along a shear zone correlated with the Yuma mine thrust. The granite, like that at the Yuma mine, is depositionally overlain by Cambrian Bolsa Quartzite. Above the Bolsa Quartzite in this area, however, is a low-angle unconformity overlain by conglomerate, sandstone, and fine-grained rocks correlated with the Jurassic or Upper Triassic Vampire Formation (Laubach and others, 1987; Reynolds and others, 1987). The Vampire Formation passes upward into Jurassic volcaniclastic and volcanic rocks that are in turn overlain by a thrust sheet of interleaved Paleozoic rocks and Triassic Buckskin Formation. These rocks are successively overlain by higher thrust sheets of McCoy Mountains Formation, Jurassic volcanic and volcaniclastic rocks, and finally Proterozoic crystalline rocks above the Hercules thrust. The thrust sheet of Jurassic volcanic and volcaniclastic rocks locally contains lenses of massive quartz-kyanite rocks and associated hydrothermal quartz rocks (now quartzite).

Several of the thinner thrust sheets are absent along strike to the south, near a northeast-trending body of Granite Wash Granodiorite. When the rocks reappear on the south side of the granodiorite, only one major thrust is present below the Hercules thrust. This thrust, interpreted to be the Yuma mine thrust, places one section of McCoy Mountains Formation over another and is marked by thin, discontinuous slivers and remnants of Proterozoic crystalline rocks and Jurassic Vampire Formation. The rocks mapped as McCoy Mountains Formation above this thrust could alternatively correlate with the upper fine-grained part of the Vampire Formation. This alternative requires the abrupt southward termination of three thrust sheets above the fine-grained unit north of the granodiorite body. In both cases, the abrupt change in thrust-sheet stacking across the granodiorite body implies that the body intruded along a tear fault or lateral ramp of the thrust system.

Easternmost Granite Wash Mountains: Rocks above the Hercules thrust

The Hercules thrust is a regional structure that places Jurassic and Proterozoic crystalline rocks over Mesozoic and Paleozoic supracrustal rocks (Reynolds and others, 1980, 1986b). In the eastern Granite Wash Mountains, the upper plate of the Hercules thrust consists of (1) Proterozoic amphibolite-grade, quartz-feldspar-biotite gneiss and biotite-muscovite-quartz-feldspar schist, (2) Jurassic granitoid rocks, including a distinctive monzodiorite that is a common lithology above the Hercules thrust in the Little Harquahala and Harquahala Mountains (Spencer and others, 1985), (3) medium- to fine-grained granodiorite of Jurassic or Proterozoic age, and (4) leucogranite of either Jurassic or Proterozoic age. All these rock units have a penetrative mylonitic fabric and are strongly retrograded along the thrust, but retain older fabrics and mineral assemblages

at higher structural levels away from the thrust.

Northern Granite Wash Mountains

In the northern Granite Wash Mountains, rocks older than the Late Cretaceous Tank Pass Granite are restricted to three areas: (1) a main, north-northwest-trending ridge (Butler ridge); (2) a separate bedrock promontory to the east that includes the Cobralla mine; and (3) Little Butler ridge, a small, isolated ridge west of Butler ridge.

Butler ridge contains an imbricate thrust stack of interleaved Mesozoic, Paleozoic, and Proterozoic rocks. Thrust sheets in this zone strike north-northwest parallel to the ridge and dip gently to moderately to the northeast. In the northern half of Butler ridge, the structurally lowest rocks exposed are a Proterozoic granite (dated by a Rb-Sr whole-rock analysis) and a small body of younger diorite. These rocks are overlain by a southward-thinning lens of strongly attenuated Paleozoic and Mesozoic metasedimentary rocks. The contact between the granite and metasedimentary rocks is tectonic in character, but probably does not represent a major structure because Cambrian Bolsa Quartzite, one component of the metasedimentary sequence, rests depositionally on the granite in one locality. The metasedimentary rocks, Proterozoic granite, and small intrusions of Jurassic alaskite are complexly interleaved via both folding and faulting.

The top of the metasedimentary lens is a major thrust that carries Proterozoic gneiss and Jurassic or Proterozoic leucogranite in its hangingwall -- this thrust is interpreted to be the continuation of the Hercules thrust from the southern part of the range. The Hercules thrust zone in this area is characterized by laterally discontinuous slices of Paleozoic and Mesozoic metasedimentary rocks, Proterozoic granite, and Jurassic alaskite. Thin lenses of Paleozoic metasedimentary rocks are also present above the thrust along ductile shear zones within the gneiss and along subsidiary thrusts between the gneiss and leucogranite. The Hercules and subsidiary thrusts continue to the south where they are discordantly intruded by the Tank Pass Granite. Just north of the intrusive contact, the Hercules thrust is underlain by numerous imbricate thrusts that interleave the Paleozoic metasedimentary rocks and underlying Proterozoic granite. Beneath the Proterozoic granite are several additional thrust faults that are not exposed further north on the ridge. These thrusts place the granite over Paleozoic and Mesozoic sedimentary rocks, including Bolsa Quartzite, and Jurassic Vampire Formation. The Vampire Formation is apparently depositional on an underlying Proterozoic granite in several exposures, a relationship similar to that seen in the section near Salome Peak. We infer that these rocks in the northern Granite Wash Mountains are within that same structural plate as those near Salome Peak and would be underlain by the Yuma mine thrust. The thrusts in this area, like those elsewhere in the range, have been broadly to tightly folded.

Thrusts structurally above the Hercules thrust on the east side of the main Butler ridge diverge from the underlying thrust stack and swing to the east into the Cobralla area. At Cobralla, thrust-bounded slivers of Paleozoic and Mesozoic rocks appear along shear zones that juxtaposed only crystalline rocks further west on the main ridge. The main Cobralla thrust dips to the north and places mylonitic crystalline rocks, including foliated granodiorite, quartz diorite, and gneiss, over Proterozoic gneiss and an overturned, south-southeast-facing section of Paleozoic and Mesozoic rocks. The Paleozoic section is strongly attenuated to a total thickness of approximately 40 m, or four percent of normal, yet all of the typical Paleozoic formations are present. The contacts between the inverted Paleozoic sequence and the underlying Mesozoic(?) rocks to the south are conformable and not tectonized more than any other formational boundary. The Mesozoic(?) rocks include mafic schists, quartz-feldspar-lithic sandstone, slightly feldspathic vitreous quartzite, and strongly foliated, fine- to coarse-grained alaskite that is discordantly cut by undeformed Tank Pass Granite.

Little Butler ridge contains an overturned, southwest-facing Paleozoic section that is overlain by a Proterozoic granite. All of the typical Paleozoic units are preserved

beneath the granite, but they are much thinner than normal. On the northern end of the ridge, the granite overlies a thin remnant of Cambrian Bolsa Quartzite along a contact that is interpreted to be an overturned nonconformity. This contact is not more tectonized than adjacent units and is marked by a sericitic zone in the granite that is interpreted as a metamorphosed clay-rich soil horizon associated with original nonconformity beneath the Bolsa. The inverted Paleozoic sequence below the contact in this area is greatly attenuated -- the combined thickness of Cambrian, Devonian, and Mississippian units is only 6 m. Further south, the base of the granite cuts discordantly across the Paleozoic section and ultimately rests on upside-down Permian Coconino Sandstone, without any intervening lower Paleozoic units. This segment of the contact is marked about 10 cm of ultramylonite and is clearly a shear zone. The granite is more strongly mylonitic upward toward a shear zone that is overlain by a thrust sheet of quartzite, calc-silicate rocks, marble, and structurally higher leucogranite.

PHASES OF DEFORMATION, KINEMATICS, AND TIMING

The geologic relationships summarized above clearly show that rocks in the range were affected by multiple episodes of deformation. We have used these map-scale relationships and more detailed structural mapping and analysis to identify four main episodes of deformation and metamorphism, designated D1, D2, D3, and D4, from oldest to youngest. Each episode of deformation has several different manifestations (for example, thrusting, folding, and cleavage development) that we have grouped together because of similar kinematics or timing. Where relative timing between two manifestations of a single deformational episode can be discerned, we have designated these with the suffix a or b (e.g. D2a and D2b, from oldest to youngest). In all, six phases of deformation are recognized:

D1a -- southeast-vergent thrusting, formation of thrust duplexes, and section attenuation; major structures are marked by zones of strongly developed mylonitic fabric and cleavage;

D1b -- southeast- to south-vergent folding of D1a thrusts and attenuated sections, accompanied by formation of an axial-planar slaty cleavage in rocks of appropriate composition;

D2a -- southwest-directed displacement of the Hercules, Yuma mine, and McVay thrusts, with associated folding and development of cleavage and foliation;

D2b -- formation of large, north-northwest-trending folds;

D3 -- large- and small-scale folding about west- to west-northwest-trending axes, locally associated with reverse movement on south- and north-vergent, brittle-ductile shear zones; and

D4 -- development of a southwest-dipping spaced cleavage; the relative timing between this event and D3 is uncertain.

These phases of deformation will be discussed below, from oldest to youngest.

D1a and D1b

The first episode of deformation (D1) was characterized by tectonic transport to the southeast or south and consisted of two phases, D1a and D1b. D1a is most clearly recorded by the north-dipping Cobralla thrust, which places crystalline rocks over a south- to southeast-facing, overturned and attenuated Paleozoic section. Mineral and stretching lineation in mylonitic rocks along the thrust trends north to northwest, and S-C fabrics indicate that the upper plate moved south or southeast (Cunningham, 1986; Reynolds and others, 1986b). The direction of overturning of the underlying Paleozoic rocks is kinematically consistent with this sense of transport. The Cobralla thrust and related fabrics predate D2 because they (1) are overprinted by fabrics related to the Hercules thrust on Butler ridge and (2) bend into parallelism with the Hercules thrust, which continues undeflected across their projection.

Evidence for D1a is also preserved in the southern part of Butler ridge, just north of the Tank Pass Granite. In this area,

mylonitic zones with southeast-trending stretching lineation and southeast-directed S-C fabrics and asymmetric feldspars are associated with a thrust that places Proterozoic granite over Mesozoic and Cambrian rocks. This northwest-trending thrust is apparently truncated to the southeast by more northerly trending thrusts of the Hercules thrust zone. Such fabrics are progressively more strongly overprinted upwards by D2 mylonitic fabric associated with the Hercules thrust.

The main manifestation of D1a in the central Granite Wash Mountains is recorded by the attenuation and repetition of Paleozoic units in the three strike belts. The faults and shear zones repeating the section are parallel to the steeply dipping bedding in the Paleozoic units and are marked by a steep, layer-parallel D1a cleavage that is especially well developed in Mesozoic units along the faults and shear zones. The faults are discordantly cut by a gently dipping D2 thrust that underlies a klippe of Mesozoic rocks. The simplest interpretation is that the section-repeating faults are early (D1a) thrust slices or duplexes that imbricated the section before it was upended by folding. D1a thrusting was accompanied by formation of the layer-parallel cleavage (which is presently steeply dipping) and by attenuation of the Paleozoic-Mesozoic sections, especially in the southern strike belt. Based on where the section-repeating faults cut the section, the floor (sole thrust) of the duplexes is within Cambrian shales and siltstones, and the roof thrust is within mechanically weak evaporitic and phyllitic zones of the Triassic Buckskin Formation. These two stratigraphic horizons are also zones of thrust localization in the Buckskin Mountains, northwest of the Granite Wash Mountains (Reynolds and Spencer, 1989).

D1b deformation, consisting of southeast- to south-vergent folding, widely affected rocks in the central part of the range and was responsible for upturning the entire Paleozoic-Mesozoic section beneath the Yuma mine and Hercules thrusts. The northeast to east strike and steep dip of this section reflect a single, large southeast- to south-facing, recumbent fold. The fold is best defined by the basal units of the McCoy Mountains Formation, which are near vertical in structurally low exposures but at higher levels bend over to the south into a completely inverted limb. The lower, upright limb of the fold is generally below the level of exposure. Associated with the fold is a fine-grained, slaty cleavage (S1) that is quite variable in orientation because of cleavage refraction and subsequent folding. Where unaffected by later folding, the slaty cleavage commonly dips gently to the north and northwest, concordant with the axial surface of the main D1b fold.

D2a

D2a was a major, southwest-vergent deformation that formed the Hercules, Yuma mine, and McVay thrusts and associated widespread cleavage, mylonitic foliation, and small- and large-scale folds. D2a thrusts, folds, and fabric clearly crosscut and are unrelated to D1 structures, as illustrated by thrusts that cut discordantly across the upturned section in the hinge of the large D1b fold. An excellent example of this is the gently dipping klippe of Mesozoic rocks that overlies vertically dipping units in the center of the Paleozoic strike belts. On a smaller scale, S1 slaty cleavage (related to D1b folding) is discordantly cut by D2a cleavage and is folded around the hinges of D2a folds.

A southwest sense of transport during D2a is indicated by (1) southwest-directed S-C fabrics and asymmetrical feldspar porphyroclasts along the Hercules, Yuma mine, and McVay thrusts in the main part of the range and along the Hercules thrust on Butler ridge, (2) observed offsets on small-scale D2a shear zones; (3) southwest-vergent minor folds with their associated northeast-dipping cleavage, and (4) the map-scale drag of Paleozoic and Mesozoic units to the south and southwest beneath the Yuma mine and Hercules thrusts.

The effects of D2 deformation vary markedly with increasing distance both below and above the Hercules thrust. At the deepest structural levels, Mesozoic sedimentary rocks largely retain their primary sedimentary structures and are cut by spaced, disjunctive cleavage or crenulation, reflecting

pressure-solution effects. At higher levels, the rocks are progressively converted into phyllite, semischist, and finally fine- to medium-grained schist directly beneath the Hercules thrust. Upper-plate crystalline rocks are mylonitic near the thrust, but largely retain their original, pre-thrust fabrics within 100m above the thrust.

Three different types of D2-related cleavage are differentiated on the map. These cleavages are all interpreted to be related to D2a and are designated D2a, D2b, and D2m (following Laubach, 1986; Laubach and others, in press). S2a consists of spaced, disjunctive, pressure-solution or crenulation cleavage that is best preserved at deeper structural levels, away from the Hercules and Yuma mine thrusts. It commonly dips northeast and is penetrative in finer grained rocks, but is subvertical and almost fracturelike in the mafic bodies within the McCoy Mountains Formation. It is interpreted to be related to northeast-southwest-directed flattening of the rocks during thrusting.

S2b cleavage forms thin zones of intensified fabric that represent small-scale shear zones, typically with several centimeters to several meters of offset. This fabric and S2a cleavage are commonly both present within a single outcrop and interact in a manner very reminiscent of S-C fabrics in mylonites. They are interpreted as lower grade kinematic equivalents of S-C fabrics and yield a top-to-the-southwest sense of shear.

S2m cleavage represents the most extreme intensification of S2 fabric within the Hercules thrust zone. It varies from a mylonitic foliation with associated stretching lineation to a poorly lineated schistosity or phyllonitic fabric. It is interpreted to represent surfaces of high shear strain (including discrete shear zones) and the resulting asymptotic approach of S2a and S2b fabric to mutual parallelism.

D2b

D2b consists of large (approximately 100m amplitude), northwest-trending folds that fold the Hercules and related D2a thrusts and fabrics. These folds are generally upright antiforms and synforms or southwest-facing monocline. The genetic relation of these folds to D2a thrusting is unknown, but the folds have axes perpendicular to the direction of D2a thrusting and, where asymmetrical, have the same southwest sense of vergence.

D3

The D2 thrusts and thrust-related fabrics are also folded by west- to northwest-trending, small- and large-scale folds. The largest of these is near the Calcite mine, where the Yuma mine thrust, overlying Hercules thrust, and associated mylonitic fabrics are folded by a vertically plunging, westward-opening antiform that causes a sharp bend in the trace of both thrusts. This peculiar folded geometry of the thrusts is interpreted to be an interference pattern resulting from successive folding of the thrusts by a large, northwest-trending D2b fold and an even larger, east-trending D3 fold with an amplitude of approximately 1km. The large D3 fold is accompanied by a series of east-trending folds with amplitudes of tens to hundreds of meters. These folds are spatially associated with the east-trending, north-dipping brittle-ductile Calcite Wash shear zone north of Calcite mine. This shear zone discordantly cuts D2a-thrust-related fabrics and contains south-vergent folds that fold D2a cleavage. The D3 shear zone cuts across the trace of a major D2b fold with no apparent change in orientation, which implies that D3 postdates D2b. Associated with this shear zone is a very locally developed spaced cleavage or fault-zone fabric (S3).

Similar D3 folds and brittle-ductile shear zones are also present northward in the range. A major D3 fold limb is present along the northern boundary of the McVay window, where the McVay thrust rolls over from its typical subhorizontal attitude into a steep northward dip. Along strike to the west, a completely inverted sequence of Permian and Triassic rocks beneath a D2a thrust is folded by tight, west-northwest-plunging, upright D3 folds. D3 folding is also interpreted to be responsible for the steep dip of both D2a and D1a shear zones north of the Paleozoic strike belt. The adjacent brittle-ductile shear zone that places the Paleozoic strike belts over the Jurassic(?) granite is regarded as a D3 struc-

ture. Along the eastern extension of this structure, the D2a thrust that places Jurassic volcanic rocks over Coconino Sandstone is tightly to isoclinally folded by west- to northwest-plunging D3 folds. These folds are adjacent to a southwest-dipping, brittle-ductile shear zone with northeast vergence and D3 style of deformation. The D3 shear zones are commonly accompanied by fault-zone fabric and cleavage with mixed, brittle-ductile character.

D4

In weakly metamorphosed rocks in the western part of the range, D4 is expressed as a disjunctive, pressure-solution-type cleavage (S4) that crosscuts D1 and D2 fabrics. This cleavage is best developed in the western part of the range, where it generally dips southwest and is locally associated with northeast-vergent, brittle-ductile shear zones. In rocks with well-developed D2 fabric in the eastern part of the range, D4 fabric is manifest as a west-northwest- to north-northwest-trending crenulation of D2a-thrust-related foliation and cleavage. The relative timing of D3 and D4 is uncertain, and the two deformations may be related.

Timing

All phases of deformation affected, and must be younger than, rocks correlated with basal sandstone member 2 and the mudstone member of the McCoy Mountains Formation. These members are poorly dated, but are either Late Jurassic or Cretaceous in age. D1 and D2 structures are crosscut by undeformed apophyses of Late Cretaceous Tank Pass Granite and Granite Wash Granodiorite. The Granite Wash Granodiorite is at least 79 Ma, based on an Ar-Ar hornblende date (S. Richard, unpublished data). Tank Pass Granite intrudes and is older than the granodiorite and has yielded a preliminary Rb-Sr whole-rock isochron of about 85 Ma (S. Reynolds and Y. Asmerom, unpublished data). D1 and D2 are therefore broadly constrained to have occurred no earlier than the Late Jurassic (the oldest possible age of the McCoy Mountains Formation) and no later than the Late Cretaceous. It is likely that both deformations are mid-Cretaceous to Late Cretaceous in age. D3 also probably occurred before intrusion of the two plutons, but crosscutting relationships are less clear. Near the Tank Pass Granite, D3 brittle-ductile shear zones commonly contain synkinematic scheelite-bearing quartz veins. This association may imply that the granite and shear zones are of similar age, but no shear zones or D3 cleavage have been observed cutting the granite. Some quartz veins along these shear zones contain fragments of phyllite, but are themselves boudined.

A weakly developed foliation of uncertain significance is present in several granitic dikes southwest of the Tank Pass Granite. This fabric does not appear to be present in the adjacent granite and cannot be correlated with other fabrics elsewhere in the range.

METAMORPHISM

Petrologic studies indicate that metamorphism accompanied both D1 and D2. In the northern Granite Wash Mountains, movement on the D1a Cobralla thrust was accompanied by extreme section attenuation and recrystallization of upper-plate crystalline rocks into mica schists. In the central part of the range, D1a repetition of the Paleozoic rocks in the strike belts was accompanied by ductile deformation and greenschist-facies metamorphism that converted limestone units into fine-grained marble and silty units into slate or phyllite. In the McCoy Mountains Formation, formation of the D1b slaty cleavage was accompanied by chlorite-grade, greenschist-facies metamorphism. Mineral assemblages in pelites and metabasites indicate metamorphic temperatures of less than 450°C and pressures of less than 4 kb (Laubach, 1986).

Metamorphism also accompanied D2a, but its intensity varied markedly with increasing distance below the Hercules thrust. Away from the main D2 thrusts, rocks contain a spaced S2a crenulation or pressure-solution cleavage. At higher structural levels closer to the thrusts, the rocks are phyllitic with greenschist-facies mineral assemblages. Directly beneath the Hercules thrust, the Mesozoic rocks have been converted into schists with mineral assemblages transitional from upper greenschist to lowest amphibolite facies (Laubach, 1986). There is, therefore, an apparent inverted metamorphic gradient

that is directly related to emplacement of crystalline rocks above the Hercules thrust.

D2a metamorphism was partly consequent to tectonic burial beneath a crystalline thrust sheet, and the metamorphic effects are most pronounced near the thrusts, where metamorphic reactions were aided by dynamically induced recrystallization and by the availability of fluid derived from prograde, dehydration reactions (Laubach, 1986; Reynolds and others, 1988). The inverted metamorphic gradients may reflect heat introduced by fluids ascending the permeable thrust zones or by emplacement of hot upper-plate rocks over cooler lower-plate rocks. Such thrusting results in a complex pressure-temperature history in footwall rocks that includes (1) initial increase in pressure and, to a lesser degree, temperature during thrust loading, (2) further increases in temperature as isotherms become re-established after thrusting, and (3) a final period of decompression and cooling due to erosional or tectonic denudation of the overthickened crustal welt (England and Thompson, 1984). This thermal history predicts that metamorphic fabrics formed during D2a thrusting should locally have an overprint of static recrystallization, as is observed near the Calcite mine where Mesozoic metasedimentary rocks above the Yuma mine thrust contain post-kinematic andalusite. Some Paleozoic rocks along the Yuma mine thrust may contain anthophyllite, fibrous actinolite, and tremolite.

Peculiar, highly aluminous rocks, interpreted to be the products of intense metasomatism, are present in at least four localities in the range, and an additional dozen occurrences are present elsewhere in western Arizona and southeastern California (Reynolds and others, 1988 and unpublished data). Three occurrences of aluminous rocks are lenses of massive quartz-kyanite rocks hosted by metavolcanic rocks along the Hercules, Yuma mine, and subsidiary thrusts on the flanks of Mt. green and Salome Peak. The fourth occurrence consists of massive quartz-andalusite rocks, with rare kyanite (observed only in thin section), derived from metavolcanic rocks along the Yuma mine thrust near the Calcite mine. In all four occurrences, the aluminous rocks are associated with either quartzite or massive quartz rocks. The rocks are also associated with quartz rocks, tourmaline-bearing schist, altered metavolcanic rocks, and gypsiferous soil. Accessory minerals include tourmaline, rutile, ilmenite, magnetite, pyrite, and, in one locality, bornite. The Jurassic metavolcanic rocks that host the aluminous rocks are anomalously micaceous and pyritic and are interpreted to have been metasomatized or hydrothermally altered by acidic solutions prior to metamorphism.

The aluminous rocks are interpreted as the metamorphosed products of a shallow-level hydrothermal system (Reynolds and others, 1988). Complete gradations from slightly silicified felsic metavolcanic rocks to foliated quartzite imply that the protolith of some of the quartzite was premetamorphic hydrothermal quartz, intensely silicified metavolcanic rocks, or hot-springs-related quartz sinter. Limonite in the rocks forms streaks parallel to D2 lineation and is presumably derived from oxidation of pyrite introduced by premetamorphic hydrothermal solutions. The protolith of the massive quartz-kyanite rocks is interpreted to have been formed by synvolcanic, near-surface argillic alteration that produced clay-rich rocks and hydrothermal sinter. Subsequent thrust-related metamorphism and tectonic burial of these rocks produced the quartz-kyanite assemblage.

The metamorphic effects of other phases of deformation, specifically D2b, D3, and D4, are more subdued and less thoroughly studied. Metamorphic grades apparently decreased between D2a thrusting and D3; D3 shear zones were (1) more brittle and cataclastic in character, (2) characterized by less fabric development, (3) associated with grain-size reduction rather than new mineral growth, and (4) more open to hydrothermal fluids that deposited quartz-scheelite veins during shearing. Some barren quartz veins, however, were formed during D2.

SUMMARY OF POST-PALEOZOIC STRUCTURAL HISTORY

The oldest recognized Mesozoic structural event was probably faulting and uplift

responsible for removal of Paleozoic rocks prior to deposition of the section of Jurassic or Upper Triassic Vampire Formation that rests on Proterozoic granite near Salome Peak. In contrast, a more complete sequence, consisting of Paleozoic cratonic strata, early Mesozoic sedimentary rocks, Jurassic volcanic rocks, and basin-facies McCoy Mountains Formation, occurs in the main part of the range. These two different stratigraphic sections, which are separated from one another by the Yuma mine thrust, were deposited some distance apart and have been juxtaposed by later thrusting. The first thrusting event, D1, was southeast- to south-directed and was responsible for repetition of the Paleozoic strike belts, the south-facing fold in the McCoy Mountains Formation and underlying rocks, and the Cobralla thrust and associated south-southeast-facing overturned Paleozoic section in the northern part of the range. During D2, the steeply tilted, south- to southeast-facing Paleozoic and Mesozoic section was discordantly cut by the southwest-vergent Hercules, Yuma mine and McVay thrusts. The southwest-vergent thrusting event is not related to the earlier, southeast-vergent event because the transport directions between the two events are at right angles to one another and the southwest-vergent fabrics clearly overprint an already tilted and folded Paleozoic and Mesozoic sequence.

The southwest-vergent D2a thrusts and thrust-related fabrics were folded by large, southwest-facing D2b folds that trend north-northwest, perpendicular to the direction of thrusting, and that may be related to the last stages of thrusting. The latest structures in the range are (1) west- to northwest-trending D3 folds associated with late-stage, brittle-ductile shear zones and (2) D4 southwest-dipping cleavage. In Big Granite Wash, undeformed apophyses of Tank Pass Granite are parallel to and postdate D3 crenulations of D2 cleavage.

QUATERNARY AND TERTIARY ROCKS

Qs - surficial deposits, including alluvium and talus (Quaternary)

Bedrock exposures of the range are surrounded by unconsolidated to weakly consolidated alluvium, probably in large part Holocene to middle Pleistocene in age. Additional small areas of alluvium are present within the range, generally in valleys and in small patches of talus flanking hills.

Holocene alluvium is present in modern channels and in low terraces flanking these channels. It is most widespread along Big Granite Wash, where it forms a wide swath of braided channels with low interfluves. Older alluvium, probably of late and middle Pleistocene age, forms higher terraces that are variably associated with desert pavement, well-developed petrocalcic horizons, and reddish, clay-rich soils (Demsey, 1988).

Tm - mafic intrusive rocks (middle Tertiary)

Mafic intrusive rocks, occurring mostly as dikes, are widespread throughout the range, but are easiest to detect and map where they cut homogeneous, light-colored rocks, such as Tank Pass Granite. Most dikes are finely crystalline rocks of probable dioritic composition and are similar to microdiorite dikes elsewhere in the region (Rehrig and Reynolds, 1980). Most dikes consist of hornblende laths in a plagioclase matrix, and some contain biotite. Some mafic dikes are flanked by, or otherwise associated with, chrysocolla-hematite±pyrite±chalcopyrite mineralization.

Tf - felsic intrusive rocks (middle Tertiary)

Felsic dikes and sills are locally abundant in the southern part of the range and are very widespread on Butler ridge. Dikes and sills in southern part of the range are aphanitic felsite with several percent quartz eyes, which are 1 to 2 mm in diameter. The matrix has a sugary texture and contains limonite-filled cubes, which imply the former presence of pyrite. Some dikes are associated with quartz veins, chrysocolla, and hematite. Dikes on Butler ridge and Little Butler ridge are light to medium gray and silicic to intermediate. They contain poorly developed books of biotite 0.5 to 2 mm in diameter and acicular needles of hornblende 1 to 4 mm long. Moderately dipping, irregular dikes and sills near the Desert Queen mine in the southwestern Granite Wash Mountains are cream colored with sparse plagioclase (2 to 4 mm in diameter) and quartz (1 mm in diameter) in an aphanitic groundmass. Subvertical dikes

in this area and north of Winchester Peak consist of 1 to 4 % quartz (2 to 5 mm in diameter) and 5 to 10 % variably acicular hornblende (1 to 7 mm long) in a microcrystalline groundmass.

CRETACEOUS PLUTONIC ROCKS

Kg - Granite Wash Granodiorite, Main Phase (Late Cretaceous)

The Granite Wash Granodiorite, herein named for the Granite Wash Mountains, forms a number of separate bodies that range in size from thick dikes to larger masses covering several square kilometers. The type locality of the granodiorite is located in Granite Wash Pass at the southern end of the Granite Wash Mountains. The pluton has been informally referred to as the granodiorite of Granite Wash Pass (Rehrig and Reynolds, 1980; Shafiqullah and others, 1980; Reynolds, 1980) and the Granite Wash granodiorite (Spencer and others, 1985; Reynolds and others, 1986b).

Two phases of the pluton are present: a main granodioritic phase and a typically dioritic border phase (unit Kgb). Larger apophyses of the pluton consist mostly of the main granodioritic phases with less abundant dioritic rocks adjacent to the country rocks. Smaller bodies are commonly composed exclusively of the dioritic border phase.

The main phase of the pluton generally consists of medium-grained, equigranular granodiorite with 3 to 10 % biotite, several percent hornblende, and about 30 % quartz. Biotite generally forms discrete books 1 mm in diameter and 0.1 to 0.5 mm thick. Sphene and epidote are also present. Many exposures contain dioritic inclusions that are 2 to 10 cm in diameter. Exposures southeast of Winchester Peak locally display repetitive, 1- to 5-cm-wide bands defined by subtle variations in mineralogy and grain size.

The emplacement age of the pluton is about 80 Ma based on K-Ar biotite cooling ages of 66.5 and 71 Ma, an 79 Ma Ar-Ar hornblende date (S. Richard, unpublished data), and correlations to dated rocks elsewhere in the region (Reynolds and others, 1986b). The pluton intrudes and is younger than the Tank Pass Granite, which is older than 79 Ma.

Kgb - Granite Wash Granodiorite border phase (Late Cretaceous)

This unit is present as a border phase of the main granodioritic phases and also composes most of the smaller apophyses. Whereas the main granodioritic phase is fairly consistent in appearance from area to area, the border phase is characterized by lithologic diversity from outcrop to outcrop. The border phase includes five rock types: (1) medium-grained, equigranular to slightly porphyritic granodiorite with 10 to 20 % hornblende and biotite; (2) medium- to coarse-grained diorite or tonalite with 15 to 40 % hornblende; (3) fine- to medium-grained porphyritic diorite with several percent hornblende phenocrysts that give the rock a spotted appearance; (4) hornblendite with less than 15 % plagioclase; and (5) fine-grained microdiorite mostly composed of plagioclase and hornblende. Most of the lithologic variants of the border phase contain more hornblende than biotite and at least locally contain hornblende phenocrysts 0.5 to 2 cm long. Near the Calcite mine, the rock contains abundant epidote and is locally limonitic and sericitic. Near Winchester Peak, the unit includes coarse-grained granodiorite and monzogranite, alaskite, minor pegmatite, and numerous roof pendants.

Kt - Tank Pass Granite (Late Cretaceous)

The Tank Pass Granite, herein named for its type locality at Tank Pass between the Granite Wash and Harcuvar Mountains, forms a large pluton that underlies most of the northeastern part of the Granite Wash Mountains. The pluton has been informally referred to as the granite of Tank Pass (Rehrig and Reynolds, 1980; Shafiqullah and others, 1980) and Tank Pass granite (Reynolds, 1980; (Reynolds and others, 1986b).

The granite is generally light colored, medium grained, and equigranular to slightly porphyritic. It contains about 1 to 3 % biotite and local sphene crystals as long as 1 mm. Porphyritic outcrops contain scattered K-feldspar phenocrysts 0.5 to 2 cm long.

Aplite and pegmatite dikes within the granite generally contain minor reddish-brown garnet and rare muscovite.

The granite is probably 80 to 85 Ma, because it (1) intrudes the Granite Wash Granodiorite, which is no younger than 79 Ma, (2) yielded an approximately 85 Ma Rb-Sr granite-aplite, whole-rock isochron (S. Reynolds and Y. Asmerom, unpublished data), (3) is no younger than 79 Ma based on U-Pb analyses of a single zircon size fraction (E. DeWitt, oral commun.), and (4) is similar to rocks dated at 73 to 89 Ma in the region.

Kta - Tank Pass Granite; alaskite, aplite, and pegmatite (Late Cretaceous)

Locally associated with the granite are light-colored dikes of alaskite, aplite, and pegmatite. These dikes are generally composed of quartz and predominantly alkali feldspar, with muscovite, biotite, and a trace garnet. Some aplitic dikes have garnetiferous and pegmatitic bands parallel to their margins. Most of the dikes are probably late-stage differentiates of the granite, but some may be younger than and unrelated to the granite.

McCOY MOUNTAINS FORMATION (Cretaceous or Late Jurassic)

In the central part of the range, the McCoy Mountains Formation has been divided into the following seven mappable lithologic units: lower sandstone unit, Yellowbird sedimentary rocks, polymict conglomerate, lithic sandstone unit, mudstone unit, sandstone and conglomerate unit, and mafic igneous rocks that are interlayered with the sedimentary strata. The section generally strikes east-west and faces southward, or else is gently dipping but upside down. We have not mapped these units separately in the structural window below the McVay thrust or in the thrust sheet of McCoy Mountains Formation near Salome Peak where the rocks are intensely deformed and metamorphosed. Units within the McCoy Mountains Formation are described from top to bottom (descriptions are largely from Laubach and others, 1987).

KJmc - Sandstone and Conglomerate Unit (Cretaceous or Late Jurassic)

The uppermost unit in the McCoy Mountains Formation is a sequence of approximately 200 m of sandstone and conglomerate that is only exposed in the southern part of the range. This unit consists of (1) an upper sequence of lithic sandstone and conglomerate and (2) a lower sequence of interbedded orange-weathering sandstone and phyllite. The unit grades downward into the phyllite member and is structurally overlain by the Hercules and Yuma mine thrusts.

The lithic sandstone and conglomerate sequence is dominated by greenish-gray, quartz-feldspar-lithic sandstone. Most sandstone beds are medium to coarse grained, poorly sorted, and thin to medium bedded. Most sandstone and conglomerate beds include (1) a high percentage of volcanic-lithic clasts, (2) abundant magnetite grains, and (3) local rounded, volcanic-derived(?) quartz grains as large as 3 mm in diameter. Clasts in the unit include pebbles of dark volcanic rock, light-colored, fine-grained volcanic or hypabyssal rocks, and dark chert or quartzite. The greenish tint to the rocks is largely due to abundant fine-grained, disseminated epidote.

The underlying sandstone and phyllite sequence consists of orange-weathering, variably calcareous, quartzose to feldspathic sandstone, and tan to dark gray phyllite (derived from mudstone and siltstone). Some sandstone beds are very quartz rich with well-rounded quartz grains. The overall sequence is generally well bedded, with beds 1 to 20 cm thick near the base and beds 0.5 to 1 m thick near the top. This sequence strongly resembles the upper part of the mudstone member and the lower part of the conglomerate member of the McCoy Mountains Formation in the McCoy Mountains of southeastern California (Harding and Coney, 1985). Our observations in the type locality in the McCoy Mountains suggest that there are two lithologically distinct conglomeratic units within the conglomerate member of Harding and Coney (1985). The lower part grades downward into the mudstone member and is mostly resistant, brown-weathering sandstone with lenses of conglomerate. These

rocks are overlain abruptly by less resistant, massive, gray-weathering conglomerate with no brown sandstone. In this context, we note that the conglomerate and sandstone unit in the Granite Wash Mountains resembles the lower, brown-sandstone-dominated part of the conglomerate member, not the main conglomerate-dominated part of the conglomerate member. This distinction may be important because the lithologic break in the McCoy Mountains type locality may also be an important stratigraphic and tectonic break (Tosdal, 1988).

KJmm - Mudstone Unit (Cretaceous or Late Jurassic)

The mudstone unit is exposed over a wide area of the southern Granite Wash Mountains and is a minimum of 500 m thick. The unit is composed predominantly of siliceous gray shale (phyllite and slate), but also includes thin layers of fine-grained calcareous siliciclastic rock, calcareous feldspathic siltstone, lithic-feldspathic sandstone, and rare conglomerate layers (clast size, 2 to 4 cm). Sandstone in the unit petrographically resembles the underlying lithic sandstone and is dominantly composed of lithic grains, plagioclase feldspar, and quartz. Load casts are present at the base of some thin sandstone beds. The gradation upward into the sandstone and conglomerate units is marked by an increase in both the thickness and abundance of sandstone and a decrease in the thickness and abundance of phyllitic mudstone and siltstone.

KJms - Lithic Sandstone Unit (Cretaceous or Late Jurassic)

The lithic sandstone unit consists of approximately 450 to 500 m of sandstone, interbedded mudstone, and polymict conglomerate. The upper part of the unit consists of approximately 150 m of medium- to fine-grained sandstone that forms resistant ridges. The top of the lithic sandstone unit is mapped at the highest continuous sandstone layer beneath the overlying mudstone unit.

The lower part of the unit is coarse-grained sandstone that generally is dark-weathering and develops dark desert varnish. On fresh surfaces, these rocks are gray to dark gray with light-colored spots caused by coarse light-gray, light-brown mudstone or maroon phyllite clasts. Lithic grains include poorly sorted lithic sandstone, siltstone, mudstone, and rare well-rounded quartzite grains. Some clasts are probably volcanic. Some coarse-grained lithic sandstone beds are almost 100 % lithic grains. Sandstone of this unit is generally coarser grained, more poorly sorted, and less calcareous than the lower sandstone unit (KJml).

Sandstone beds range from 5 cm to about 1 m in thickness, and layers are separated by dark gray to brown mudstone interbeds 1 to 10 cm thick. Most sandstone beds are tabular. Beds of comparable thickness occur together. Interbed thickness gradually increases higher in the section as the proportion of phyllite increases. Sedimentary structures include abundant graded bedding, load casts, flame structures, mud-chip rip-up clasts, and rare flute casts. Grading is generally present throughout entire sandstone layers, and granule conglomerate is widespread at the bases of sandstone layers.

Outcrops of McCoy Mountains Formation in the western foothills of the range are structurally complex and cannot be reconstructed into a single coherent stratigraphy but are largely correlative with the lithic sandstone. These outcrops are composed of sandstone, siltstone, and conglomerate. Sandstone is commonly well bedded with beds between 1 and 30 cm thick and varies greatly between quartzofeldspathic and lithic end members. Pure quartzose sandstone is rare and some sandy beds are calcareous. Many sandstone beds are graded, are localized in channels, and have sole marks, including load casts and scour marks, at their bases. Ripple marks are also present. Interbedded with sandstone are thin beds of light-gray siltstone and tannish-gray limestone. The sequence also contains beds 10 cm to several meters thick of clast-supported to sand-dominated, matrix-supported conglomerate. Clasts are mostly pebbles and cobbles of felsic and intermediate volcanic rocks, quartzite, chert, and minor carbonate rocks. In some conglomerate beds, a disparity in rounding exists between well-rounded quartzite clasts and more angular volcanic clasts. Pebbles in conglomerate include

well-rounded vitreous quartzite, locally with bimodal grain size; quartzofeldspathic sandstone; silicic, fine-grained igneous rocks; and intermediate volcanic rocks. Some volcanic-lithic metaconglomerate contains quartz sand in a white altered matrix with white sericitic fragments. Siltstone units beneath some coarser conglomeratic lenses show evidence of soft-sediment disruption.

Adjacent to some bodies of mafic igneous rocks, the sequence is very tuffaceous and includes volcanic-lithic sandstone and conglomerate and greenish-gray, fine-grained siltstone and sandstone, possibly including ash-fall tuff. Some beds have several percent, isolated quartz eyes 1 to 3 mm in diameter and are probably partially reworked tuffs.

KJmp - Polymict Conglomerate (Cretaceous or Late Jurassic)

A polymict conglomerate interval 5 to 10 m thick is present below the lithic sandstone and is the thickest continuous conglomerate unit in the central Granite Wash Mountains. The conglomerate contains distinctive clasts and forms a useful marker horizon in nearly continuous outcrops across the west-central part of the range.

Clasts include several varieties of quartzite, siltstone, sandstone, mudstone, and less abundant pink and white marble (probably originally Paleozoic limestone). Light-weathering porphyritic volcanic clasts with dark-weathering, euhedral, prismatic, zoned plagioclase phenocrysts 1 to 2 cm long are particularly distinctive. In addition to plagioclase phenocrysts, volcanic clasts also contain partially resorbed, subhedral quartz phenocrysts. Some volcanic clasts in the polymict conglomerate are lithologically identical to the Jurassic volcanic and volcaniclastic rocks that stratigraphically underlie the McCoy Mountains Formation in the Granite Wash Mountains. Much of the feldspar and quartz in the matrix of the conglomerate resembles constituents of the volcanic clasts.

Most clasts in the polymict conglomerate are rounded and smooth, but original clast shapes of less competent lithologies are difficult to determine accurately because they are commonly strongly flattened in cleavage. In zones of low strain, where clast shapes reflect sedimentary shapes, some competent quartzite and porphyritic volcanic clasts display high sphericity, but clasts of shale, micaceous and volcaniclastic sandstone, and carbonate are angular. Average clast diameter is approximately 5 cm, but larger clasts up to 40 cm are locally abundant. Sorting is poor to moderate but difficult to specify because of heterogeneous strain.

Some conglomerate beds contain local crude grading, but generally lack other sedimentary structures, except at the base of the unit. The contact between conglomerate and the underlying Yellowbird siltstone and mudstone is locally marked by large, convolute load casts and possible flame structures.

KJmy - Yellowbird Sedimentary Rocks (Cretaceous or Late Jurassic)

The Yellowbird sedimentary rocks consist of approximately 150 to 200 m of mudstone, thin discontinuous beds of marble, siltstone, fine-grained sandstone, and conglomerate. The base of the unit is gradational and is defined as the bottom of the lowest thick mottled mudstone-siltstone interval above the lower sandstone.

The lower part of the Yellowbird sedimentary rocks contains a high proportion of mottled gray-black mudstone (now phyllite) interbedded with thin (5 to 10 cm) layers of fine-grained sandstone. Gray mottling in this rock is a metamorphic effect preferentially developed parallel to a spaced cleavage (Laubach, 1986). The matrix between mottled patches is dark gray, possibly reflecting a high original organic carbon component now converted to graphite. The rocks also contain macroscopic authigenic pyrite. The mudstone is finely laminated, but laminations commonly are obscured by tectonic overprint.

Sandstone, marl (calcareous phyllite and fine-grained, black phyllitic marble), and thin (less than 1 m), discontinuous brown marble layers occur near the middle of the unit. This sandstone resembles the lower sandstone but forms thinner layers and is

somewhat finer grained and richer in lithic clasts.

Thin (1 to 5 m) but persistent conglomerate beds are minor but distinctive components of the upper part of the sequence. These beds are coarser grained and more continuous than the coarse layers in the lower sandstone. Some conglomerate beds may be matrix-supported, but in most cases apparent matrix support is an illusion caused by preferential straining of less competent lithic clasts. Margins of highly deformed lithic clasts are difficult to recognize, and the clasts resemble matrix. Clast types are more diverse than in the underlying lower sandstone unit and include quartzite, light-colored marble, and porphyritic silicic volcanic rocks. The quartzite and marble clasts appear identical to nearby Paleozoic lithologies.

The upper part of the Yellowbird sedimentary rocks also contains thin layers of fine-grained, green-weathering feldspathic siltstone and sandstone and less common brown marble. The siltstone and sandstone resembles, and is spatially associated with, mafic volcanic flows or sills (see below). Because of their compositional similarity to the interbedded volcanic rocks, these siltstones and sandstones may be epiclastic deposits associated with the renewal of volcanism represented by the flows and sills. Load casts are locally preserved at the base of thin sandstone beds within the mudstone units. Possible synsedimentary folds and faults are also present.

KJml - Lower Sandstone Unit (Cretaceous or Late Jurassic)

The basal unit of the McCoy Mountains Formation is a lower sandstone that overlies the volcaniclastic unit or schist-quartzite unit along a sharp contact at the base of the first continuous well-bedded sandstone. The lower sandstone unit is 200 m thick, and is composed of well-bedded sandstone with laterally continuous beds 0.3 to 1.0 m thick. Sandstone is light gray to dark gray on fresh surfaces and develops a light brown to tan desert varnish, except for an interval of green-weathering calcareous sandstone and siltstone near the base of the unit. Sandstone consists of medium-grained, moderately well-sorted, well-rounded grains cemented locally by calcite. Detrital quartz content is greater than or equal to twinned plagioclase; K-feldspar is absent. Lithic clasts, composed of volcanic rock fragments and quartzite, are a substantial but variable proportion of the grains.

Local, thin (0.2 to 0.5 m) discontinuous lenses of granule conglomerate occur at the base of some sandstone layers. Clasts in these conglomerates are rounded, range from 1 to 5 cm in diameter, and are composed of fine-grained, cream-colored siliceous rock. They may have been derived from aphanitic, siliceous volcanic rocks. Unequivocal clasts of Paleozoic rocks and porphyritic or microporphyritic volcanic rocks were not found.

Trough and festoon cross-bedding, planar laminations, and poorly developed graded beds occur locally. Master bedding planes are defined by silty layers and partings. Thin (5 cm) mudstone and shale/siltstone partings separate sandstone beds near the transitional top of the unit. Some groups of sandstone layers fine upward, but this pattern is inconsistent and nonuniform; in many areas there is no pattern of fining. Because of the nature of exposure, the three-dimensional shape of the sandstone bodies is poorly known. The local continuity of individual beds suggests that they may be sheetlike.

KJmb - Basaltic, Andesitic, and Dioritic Rocks (Cretaceous or Late Jurassic)

Mafic sills, dikes, and probable flows are widespread within and above the Yellowbird sedimentary rocks. These rocks include fine-grained rocks of apparent volcanic origin and coarser grained dioritic intrusions.

The thickest and most laterally continuous igneous body in this interval is a green-weathering, cliff-forming mafic sill that is as much as 30 m thick and that occurs near the top of the Yellowbird sedimentary rocks. Large load casts, contorted and peeled-up beds, and a narrow hornfels zone are present in adjacent sedimentary rocks at the basal contact of this body. These

structures suggest that the mafic sill was intruded into semiconsolidated sediments.

The lower mafic sill and related thinner flows or sills are fine-grained, holocrystalline, porphyritic, plagioclase-pyroxene basalt. Despite low-grade metamorphism, some plagioclase feldspar crystals in the western part of the range preserve calcic ($\sim An_{50}$) igneous compositions. Pseudomorphs after olivine and pyroxene are preserved in less strongly deformed rocks. High contents of Cr_2O_3, MgO, and Ni (Laubach and others, 1987) are consistent with the former presence of olivine.

The largest mafic body, located south of the Glory Hole mine, is generally a spotted metadiorite with 15 to 25 % dark spots of chlorite (probably after amphibole) 2 to 3 mm long and 1 to 2 mm wide. This body has several phases: (1) medium- to fine-grained diorite with as much as 40 % hornblende phenocrysts as long as 7 mm and minor altered biotite that is equigranular and about 2 mm in diameter; (2) coarse-grained, porphyritic diorite with 15 to 40 % hornblende phenocrysts as long as 2 cm; (3) medium-grained, equigranular biotite quartz diorite or granodiorite with minor hornblende; (4) porphyritic andesite with 20 to 30 % hornblende as long as 1 cm in an aphanitic green matrix; and (5) aphanitic andesite with less than 5 % phenocrysts.

Some dioritic bodies contain compositional bands defined by varying proportions of mafic minerals or by grain size. Some mafic-rich layers and seams contain 30 to 50 % biotite and hornblende in a feldspathic matrix. Where metamorphosed near the major thrusts, these rocks can be difficult to distinguish from Proterozoic crystalline rocks.

In the western foothills, near the Dona Kay mine, medium-grained diorite grades upward through fine-grained diorite and microdiorite into aphanitic basalt or andesite. The basalt and andesite are interlayered with or overlain by andesitic tuffs and epiclastic sedimentary rocks. In all, these relationships imply that at least some of the basaltic and andesitic rocks are extrusive and that the dioritic bodies may represent the subvolcanic equivalents of the basalt and andesite.

Geochemical analyses reveal that the mafic igneous rocks are slightly alkalic and have immobile-element concentrations consistent with this alkalic character (Laubach and others, 1987). The rocks have low Y/Nb values, which indicate that the slightly alkalic basalts have trace-element affinities to "within-plate" basalts of Pearce and Cann (1973).

KJm - Undifferentiated McCoy Mountains Formation (Cretaceous or Late Jurassic)

Individual units in the McCoy Mountains Formation have not been mapped in the structural window below the McVay thrust and in a thrust sheet near Salome Peak. McCoy Mountains Formation within the structural window beneath the McVay thrust includes interlayered tannish-cream- to brown-colored, lithic and feldspathic sandstone (quartzofeldspathic schist where strongly metamorphosed), dark-gray to silvery-gray phyllite, and thin metasiltstone or mudstone partings. Sandstone beds are typically 30 to 40 cm thick, medium grained, and locally graded. The unit also contains thin-bedded, tan to brown carbonate and calcareous siliciclastic rocks and fine-grained greenish phyllite, probably derived from a metavolcanic rock.

A thrust sheet on the flanks of Salome Peak contains rocks correlative to either McCoy Mountains Formation or the upper, fine-grained part of the Vampire Formation. This section contains a stretched-pebble conglomerate with clasts up to 30 cm in diameter of quartzite with less abundant porphyritic granite. The conglomerate matrix consists of quartzofeldspathic sandstone that includes quartz grains up to 8 mm diameter and feldspar crystals up to 2 cm long. The conglomerate grades up into dark-brown-weathering feldspathic sandstone at the top of the unit. The conglomerate unit is overlain by dark- to medium-gray phyllite with interbedded siltstone and fine-grained quartz-feldspar-lithic sandstone in beds 1 to 2 cm thick, and greenish-brown calc-silicate layers 0.2 to 2 cm thick. Sandstone is more abundant near the top of the unit.

JURASSIC AND TRIASSIC ROCKS

Jk - Quartzite, quartz-kyanite rocks, and mica schist (Jurassic protoliths)

This unit consists of an assemblage of quartzite, unusual quartz rocks of non-sedimentary origin, massive quartz-kyanite rocks, quartz-muscovite schist, and quartz-muscovite-tourmaline schist. The unit is exposed in a discontinuous band of outcrops within the sequence of Jurassic volcanic and volcaniclastic rocks below the McCoy Mountains Formation. In these exposures, the unit consists of approximately 30 m of white-weathering, mica-quartz-pyrite schist interbedded with thin (1 to 2 m) lenses of massive quartzite. This schist and quartzite interval also includes rare schistose metavolcanic rocks, as well as pyritiferous, green, aphanitic metavolcanic rocks and local massive gypsum. All lithologies in this unit form discontinuous lenticular outcrops. Gypsum may be part of the stratigraphic sequence or a product of alteration; some gypsum is in veins.

The largest exposures of the unit are at the eastern end of this outcrop belt, in the valley southwest of Mt. green, within a sequence of hydrothermally altered and metamorphosed Jurassic volcanic and volcaniclastic rocks. These exposures include white- to tannish-brown mylonitic quartzite, vuggy quartz rocks that locally contain kyanite and pyrophyllite, quartz-feldspar-muscovite schist, and some interlayered feldspar-quartz-lithic schists derived from felsic volcanic and volcaniclastic rocks or locally from alaskite. The quartzite and quartz rocks are white- to cream-colored with a pinkish and orangish tint caused by limonite, hematite, and jarosite. Associated with the most limonitic, altered rocks is gypsiferous soil. Some altered zones are adjacent to greenish sheets of deformed and metamorphosed, intermediate-composition igneous rocks.

Two types of kyanite are present. One type, hosted by quartz-muscovite schist and well-foliated quartzite, consists of almost colorless to very pale greenish blue kyanite in crystals as long as 10 cm. Most kyanite crystal are interpreted to be synkinematic with respect to D2 thrusting because they are aligned parallel to lineation. The second type consists of medium blue kyanite in more equant, undeformed crystals 1 to 3 cm in diameter. These are present as clots within unstrained pods, segregations, and veins of coarse-grained quartz. Pyrophyllite is associated with and locally replaces both types of kyanite. Tourmaline is locally abundant and composes 5 to 10 % of some quartz-mica schists. It also occurs as pods within coarse-grained quartz segregations.

Similar rocks exposed in Big Granite Wash include (1) silvery, staurolite(?)-bearing phyllitic rocks, probably derived from altered volcaniclastic rocks, (2) banded, white to dark gray orthoquartzite, and (3) massive quartz-kyanite rocks. The quartzite is massive or laminated with gray to dark-gray mottling and a local pinkish tint and locally contains bornite and covellite that coat specular hematite. Both styles of kyanite described above are present: pale blue to colorless, prismatic kyanite aligned parallel to lineation and medium blue kyanite in coarse-grained clots associated with large, unstrained quartz segregations. Below the kyanite-quartz rocks is siliceous, muscovite schist with gypsiferous soil.

As discussed in the section on metamorphism, these unusual rocks are interpreted to have been formed by metamorphism of previously altered volcanic rocks. The quartzite and vuggy quartz rocks are regarded as the metamorphosed equivalents of hydrothermal sinter, quartz veins, silicified metavolcanic rocks, and jasperoid. The quartz-kyanite rocks, quartz-muscovite schist, and other aluminous rocks are interpreted to be metamorphosed equivalents of clay-rich, hydrothermally altered rocks.

Js - Quartz-mica schist, hydrothermal and sedimentary quartzite, and quartz-andalusite rocks (Jurassic protoliths)

This unit, which is very similar to unit Jk, consists primarily of strongly altered quartz-feldspar-muscovite schist that is white, tan, yellowish, or orangish due to abundant limonite. The rock originally contained sulfides, and pyrite is present at depth in some shafts cut into the unit. The

limonitic streaks are aligned parallel to D2 lineation in the rock, so either the limonite or pre-existing sulfides predated D2 deformation. Parts of the section are covered by punky, gypsiferous soil, and gypsum is present in unoxidized rock samples from several shafts. The unit also contains vitreous gray quartzite with a distinctive bumpy appearance and variable amounts of mica and feldspar. The quartzite is similar in appearance to the quartzite associated with kyanite in unit Jk on the southwest flanks of Mt. green.

Some light-cream-colored quartzite and sandstone near Calcite mine are composed of very well sorted, very well rounded quartz grains with a siliceous cement. Less commonly, the rock has a calcareous cement and is friable. This rock is sedimentary in origin and may be an eolian deposit.

The unit contains massive, cream-colored rocks composed mostly of andalusite and quartz, with minor muscovite and oxidized pyrite. Associated with these rocks is medium- to dark-gray, andalusite-rich phyllite, presumably representing metamorphosed siltstone and shale, possibly with a volcaniclastic component. The quartz-andalusite rocks probably formed in a similar manner as the quartz-kyanite rocks described above (unit Jk).

Jc - Conglomerate, volcanic breccia, and siltstone (Jurassic)

This unit is only exposed directly above the McVay thrust, where it has been juxtaposed over McCoy Mountains Formation. It is in apparent depositional contact with structurally higher Jurassic volcanic and volcaniclastic rocks and locally forms a lens totally intercalated within these rocks. The unit consists of white to slightly pinkish clasts of aphanitic to quartz-phenocrystic volcanic rock (probably a rhyolitic tuff) in a matrix of coarse-grained, lithic sandstone. The clasts are strongly deformed and most are 1 mm to 1 cm thick and about 30 cm long. The unit may represent a tuffaceous fragmental rock or reworked tuff. Associated with the conglomerate is fine-grained quartzose sandstone and light-cream-colored, fine-grained quartz-mica schist probably derived from siliceous siltstone.

Jv - Volcanic and volcaniclastic rocks, locally includes plutonic rocks (Jurassic)

Silicic volcanic and volcaniclastic rocks, probably of Middle Jurassic age, are widely exposed throughout the central part of the range. South of the main Paleozoic strike belts, the unit is in both depositional and fault contact with the underlying lower Mesozoic rocks. In addition, the volcanic and volcaniclastic unit is present in thrust slices above the Yuma mine thrust.

South of the Paleozoic strike belts, the volcanic and volcaniclastic unit roughly consists of a lower volcanic part and a stratigraphically higher volcaniclastic part to the south. The lower volcanic sequence is probably 300 m to 1 km thick and has a northeast strike and steep dip based on map patterns of a distinctive volcanic porphyry marker unit (Jvp). It is composed of poorly stratified, internally massive volcanic rocks that are resistant and form ledges and ridges. Individual flows, intrusions, and layers 1 to 10 m thick are locally evident within the volcanic sequence. The base of the volcanic sequence contains thin (less than 5 m) layers of orthoquartzite identical to those of stratigraphically underlying lower Mesozoic rocks (unit Jq).

The volcanic rocks are typically light to medium gray, dark-green-gray weathering, and fairly homogeneous in composition. Some are aphanitic, but most contain 5 to 30 % phenocrysts (1 to 3 mm in diameter) of plagioclase and quartz in a fine-grained, commonly sericitic matrix. Intervals with large (up to 5 cm) euhedral zoned plagioclase megacrysts are widespread. Subhedral quartz microphenocrysts preserve evidence of partial resorption in the form of embayments.

Relict igneous textures are locally preserved, but other rocks have undergone sedimentary reworking; both aphanitic and porphyritic volcanic rocks locally contain rounded quartzite or fine-grained volcanic clasts that were probably entrained during emplacement of the volcanic rocks. Poorly stratified, internally massive, plagioclase-rich

sandstone, shale, and fine-grained conglomerate with well-rounded clasts are locally interbedded with the volcanic rocks.

The least deformed volcanic rocks plot as trachyandesites on a total alkali versus silica diagram (Laubach and others, 1987). The volcanic rocks are compositionally similar to alaskite and medium-grained plagioclase granite that intrude Paleozoic rocks north of, and stratigraphically beneath, the volcanic sequence.

The volcanic unit passes gradationally upward and interdigitates into a sequence of volcaniclastic and epiclastic rocks. The total thickness of the volcaniclastic interval is about 250 m, but the unit possesses strong cleavage and poorly expressed bedding, so the accuracy of this estimate is uncertain. The volcaniclastic sequence is compositionally similar to the underlying volcanic unit but consists of metasedimentary rocks with less abundant volcanic rocks. Volcaniclastic rocks are a lighter greenish-gray than the volcanic rocks and form broad valleys and low, rounded hills with poor outcrop.

The volcanic and volcaniclastic unit is also extensively exposed above the Yuma mine thrust and underlies most of Mt. green. This section includes volcanic and volcaniclastic rocks and their intrusive equivalents. Most of the volcanic and volcaniclastic rocks are similar to those described above, but there is more lateral variability. In general, the volcanic rocks tend to be more massive cliff formers, whereas volcaniclastic rocks are more platy and less massive and tend to from ledges and slopes. Also, the volcaniclastic rocks generally lack or contain less than 1 % of the large K-feldspar crystals that typify some parts of the volcanic sequence (unit Jvp).

On Mt. green, the unit includes seven main lithologies: (1) light-colored, quartz-eye phyllite probably derived from crystal tuff; these rocks locally contain prolate muscovite-rich clots that probably represent deformed and metamorphosed inclusions or pumice fragments; (2) weakly deformed biotite-hornblende granodiorite with dark inclusions, hypabyssal biotite-feldspar porphyry, and all gradations in between; (3) greenish, homogeneous-composition feldspar-quartz-biotite-chlorite schist exposed in the thrust sliver above the Bolsa Quartzite near the Yuma mine; this schist was probably derived from an intermediate-composition igneous rock; (4) quartz-pebble conglomerate and phyllite that are one component of the thrust sliver above alaskite near the Yuma mine; (5) schistose metavolcaniclastic rocks with white micaceous clasts and conspicuous magnetite grains; (6) metaconglomerate with deformed pebbles of quartzite and light-colored felsic volcanic rocks that occurs on the south side of Mt. green; and (7) fine-grained, greenish andesitic flows or sills.

Rocks mapped as Jv in the highest thrust sheet east of the Yuma mine include large masses of medium-grained, biotite-bearing, foliated granodiorite containing several percent feldspar phenocrysts 1 to 3 mm in diameter and scattered dark, mafic-rich clots that probably represent metamorphosed inclusions. Associated with this granodiorite are quartzofeldspathic rocks that are slightly banded, but much less so than typical Proterozoic crystalline rocks.

Near Big Granite Wash, the unit includes quartz-feldspar-muscovite schist with 30 to 50 % rounded quartz porphyroclasts less than 2 mm in diameter and scattered feldspar as long as 3mm. This rock is a metamorphosed and deformed coarse sandstone derived from the Jurassic volcanic rocks. Associated rocks include (1) heterogeneous cream-colored quartz-feldspar-muscovite schist, locally with white quartz-muscovite fragments or clasts that are flattened and typically 1 to 3 cm, and (2) greenish biotite-muscovite-quartz-feldspar schist probably derived from dacitic volcanic rocks.

Jvp - Volcanic porphyry (Jurassic)

This unit consists of a well-foliated but compositionally homogeneous quartzo-feldspathic rock with 5 to 15 % large feldspar phenocrysts, several percent large quartz eyes, and local sphene (1 to 2 mm in diameter). The matrix is very fine grained or aphanitic but has a granular texture where the rock is strongly deformed. The rock is interpreted to

be an extrusive or hypabyssal volcanic porphyry.

Ja - Alaskite and granite (Jurassic)

In many parts of the range, alaskite and leucocratic granite have intruded Paleozoic and Proterozoic rocks. The intrusive rocks are inferred to be Jurassic in age and were nowhere observed to be in intrusive contact with the volcanic and volcaniclastic rocks or McCoy Mountains Formation. The alaskite and leucocratic granite are typically fine- to medium-grained and equigranular and commonly have an aplitic texture. They locally contain minor biotite and are widely deformed, altered, and limonitic.

Jg - Granite (Jurassic)

This map unit generally consists of medium- to coarse-grained biotite granite but includes several texturally discrete granitic bodies. The small, irregularly shaped body that intrudes the west end of the central Paleozoic strike belt is a medium-grained, light-gray granite with rounded feldspar and quartz phenocrysts as large as 4 cm and 5 mm, respectively. The feldspar phenocrysts locally compose 15 % of the rock. The granite also contains about 3 % altered biotite and hornblende(?).

The granitic body within the steep shear zone north of the Paleozoic strike belt is medium to coarse grained and contains K-feldspar phenocrysts 1 to 4 cm long. It grades laterally into a fine- to medium-grained hypabyssal(?) quartzofeldspathic rock that resembles some components of the Jurassic volcanic unit.

Jgv - Granitoid and volcanic rocks, undifferentiated (Jurassic)

This unit forms the highest thrust sheet on Mt. green and includes strongly mylonitic quartzofeldspathic rocks derived from granitic, volcanic, or hypabyssal protoliths equivalent to units Jg, Jv, or Jvp. These rocks are homogeneous in composition with 10 to 30 % quartz eyes and scattered 0.5- to 5-cm-long K-feldspar porphyroclasts in a matrix of fine-grained sericite, feldspar, and quartz. Coarser-grained parts of the unit have porphyroclasts of plagioclase, K-feldspar, and quartz that are as long as 1.5 cm, 3 cm, and 1.5 cm, respectively. Granitic textures are locally preserved in the least deformed outcrops. Associated with this unit is a medium-grained, equigranular feldspar-quartz-biotite schist that is a metaplutonic rock. All phases of this map unit contain dark inclusions.

Jf - Fine-grained sedimentary rocks (correlative with Jurassic or Late Triassic Vampire Formation and overlying Jurassic volcaniclastic and volcanic rocks)

This unit, exposed only in a thrust sheet on the western flank of Salome Peak, is the upper part of a sequence that rests depositionally on Proterozoic granite and Cambrian sedimentary rocks. The unit consists of thinly bedded to laminated, calcareous siliciclastic rocks, schistose phyllite, fine-grained sandstone, and siltstone. Much of the unit contains laminations (1 to 5 mm) of medium-brown to orange-brown calc-silicate rocks and fine-grained, light- to dark-gray, quartz-feldspar-biotite-white mica schist interbedded with fine-grained sandstone in layers 1 to 3 cm thick. The upper part of this unit consists of metasiltstone that grades up into massive, poorly bedded, green-weathering, quartz-muscovite schist, volcaniclastic rocks, and quartz-feldspar porphyritic volcanic rocks. The unit is interpreted to correlate with the Jurassic or Upper Triassic Vampire Formation (Reynolds and others, 1987), except for the upper volcanic and volcaniclastic rocks, which are correlative with the regional Jurassic volcanic suite.

Jq - Vampire Formation quartzite and quartzose clastic rocks (Jurassic or Late Triassic)

Depositionally beneath the fine-grained sequence (unit Jf) on the western flank of Salome Peak is a sequence of sandstone and conglomerate that rest unconformably on Cambrian sedimentary rocks and Proterozoic granite. This unit is composed primarily of tan- to light-gray-weathering quartzose to quartzofeldspathic sandstone with conglomerate, sparse silty sandstone, and calcareous siliciclastic rocks. Bedding varies in thickness from 20 to 30 cm. Conglomerate is brownish-gray weathering and is composed of pebbles and cobbles derived from the

underlying quartzite. The angular unconformity at the base of the unit cuts progressively downward to the south across the underlying Bolsa Quartzite so that quartzose sandstone rests directly on foliated Proterozoic granite in the southernmost exposures. Several meters of quartzite-pebble conglomerate are locally present just above the unconformity.

A distinctive, well-sorted, fine- to medium-grained, friable, calcite-cemented quartz sandstone with well-rounded sand grains is present in the unit and may be eolian in origin. The unit, along with the depositionally overlying fine-grained unit, is correlative with the Jurassic or Upper Triassic Vampire Formation (Reynolds and others, 1987).

Lithologically similar and stratigraphically correlative rocks are present along the southern edge of the southern Paleozoic strike belt. This section, however, is structurally attenuated and is included in map unit JTrs, except for (1) one relatively thick lens of conglomerate near the Black Hawk mine and (2) several 1- to 4-m-thick lenses of quartzite that are present in the basal 50 m of the overlying volcanic and volcaniclastic rocks. These quartzite beds are typically well sorted, medium grained, and pyrite- and muscovite-bearing. They are in sharp, unfaulted contact against metaigneous quartz- and feldspar-bearing volcanic and volcaniclastic rocks.

JTrs - Sedimentary rocks, undifferentiated (includes Jurassic or Late Triassic Vampire Formation, Triassic Buckskin Formation, and local Jurassic volcanic rocks)

This unit is mainly mapped along the south side of the southern Paleozoic strike belt, where Triassic Buckskin Formation and Jurassic or Upper Triassic Vampire Formation are so tectonically attenuated that they cannot be mapped separately at 1:24,000. Buckskin Formation, which composes the lower half of the unit, depositionally overlies Permian Kaibab Formation and consists of 30 to 100 m of orange- and brown-weathering, variably calcareous sandstone and quartzite-pebble conglomerate, calc-silicate rocks, phyllite, siltstone, and gypsum (see descriptions of Buckskin Formation for further information).

Stratigraphically above the Buckskin Formation is 15 to 50 m of interbedded quartzite, quartz-feldspar sandstone, and volcanic-lithic sandstone, which all correlate with the Vampire Formation. Quartzite is fine to coarse grained (generally medium grained), is well to moderately sorted, and weathers brown to tan with shades of orange due to oxidation of pyrite; it commonly contains several percent metamorphic muscovite. Quartzofeldspathic and volcanic-lithic sandstones are medium to coarse grained, poorly to moderately sorted, and locally gritty or conglomeratic. These rocks commonly contain quartz and feldspar grains that are 0.5 to 2 mm in diameter and embedded in a micaceous matrix. Quartzite and quartzofeldspathic sandstone are generally present as discrete interbeds but also grade into one another. Quartzite is the dominant lithology at the bottom of the unit but grades upward into quartzofeldspathic sandstone and volcanic-lithic sandstone.

The map unit is also present at Cobralla, where it consists of somewhat feldspathic, quartzose sandstone, partly calcareous siliceous siltstone, white vitreous quartzite, greenish calc-silicate rocks, and thin layers of marble. The marble is white, grayish, brown, and tan, and may partly represent Paleozoic units, such as Kaibab Limestone, that have been interfolded into the section. Associated with these rocks is mafic schist and quartz-feldspar-muscovite schist derived from Jurassic alaskite.

On Butler ridge, near the northern edge of the map area, the unit consists of dark-gray, sericitic quartzite that is locally feldspathic and is interbedded with mica schist. Associated rocks are greenish quartzite, calcareous siliciclastic rocks, tan quartzite, mica-rich quartzite, quartz-pebble conglomerate, and feldspathic sandstone. Some calcareous sandstone is somewhat feldspathic and is poorly sorted.

Trb - Buckskin Formation (Triassic)

The Buckskin Formation depositionally overlies Permian Kaibab Limestone in several localities and consists of tan-, orange-, and brown-weathering, variably calcareous

sandstone and quartzite-pebble conglomerate, vitreous white quartzite and gritty quartzite, calcareous siliciclastic rocks, phyllite, siltstone, and gypsum. Sandstone is quartzose to locally feldspathic, fine to medium grained, and moderately to well sorted. Degree of sorting decreases with increasing grain size; conglomerate is commonly poorly sorted and feldspathic. The unit contains calc-silicate rocks and small lenses and irregular pods of brown and gray carbonate rock. In addition, some outcrops contain light-colored fine-grained sandstone, siltstone, and phyllite. Gypsiferous zones are associated with greenish, fine-grained, quartz sandstone, greenish phyllite, and cream-colored limestone; such zones are present near the base of the section, either directly above Kaibab Limestone or separated from the limestone by several meters of quartzite, quartz-pebble conglomerate, and calcareous rocks. The gypsiferous rocks are clearly part of the sedimentary section, but, in view of the metamorphic grade of the rocks, probably give way to anhydrite at depth (below the near-surface zone of weathering and rehydration).

The Buckskin Formation is locally difficult to distinguish from rocks of the Permian-Pennsylvanian Supai Group. Compared to the Supai Group, however, the Buckskin Formation is less well sorted, less well bedded, more feldspathic, and more conglomeratic (conglomerate is very rare in all but the basal Supai Group). Another distinguishing characteristic of the Buckskin Formation is its association with either Permian Kaibab Formation or Mesozoic Vampire Formation. This association is not always diagnostic, however, because the Kaibab-Buckskin-Vampire sequence is similar in overall stratigraphic succession to a sequence of Redwall Limestone, Supai Group, and Coconino Sandstone.

Mzs - Mesozoic rocks, undifferentiated (correlative to Cretaceous or Jurassic McCoy Mountains Formation or Triassic Buckskin Formation)

These rocks are present in a thrust slice below the Hercules thrust but above the Yuma mine thrust in the southeastern part of the range, south of Calcite mine. They consist of dark, fine-grained quartzite and siltstone, quartzofeldspathic sandstone, quartzose sandstone with a calcareous cement, and possible metaconglomerate. The section is incomplete and so strongly metamorphosed that it cannot be unambiguously assigned to either the McCoy Mountains Formation or Buckskin Formation, the two units it most closely resembles.

ROCKS OF JURASSIC, CAMBRIAN, OR PROTEROZOIC AGE

J€q - Quartzite (Jurassic or Cambrian)

This unit includes quartzite exposures of uncertain stratigraphic affinity and is mapped in three locations: (1) at Cobralla, (2) on small hills west of Butler ridge, and (3) on the northwestern flank of Mt. green. At Cobralla, the quartzite is somewhat feldspathic, strongly metamorphosed, and interlayered with quartzofeldspathic mica schist, Jurassic(?) alaskite, and biotite-hornblende-bearing quartzofeldspathic schist of metaigneous derivation. Near Butler ridge, the quartzite is more feldspathic than Coconino Sandstone and is associated both with Paleozoic units and with metamorphic rocks of probable Proterozoic age. Near Mt. green, the quartzite is a thin fault-bounded sliver along the Yuma mine thrust and may correlate with Cambrian Bolsa Quartzite, which is present along the thrust to the north, or quartzite and hydrothermal quartz rocks (unit Jk), which are along the thrust directly to the south.

JXc - Crystalline rocks (Jurassic or Proterozoic)

This unit is mapped in three locations: in an isolated klippe 1 km south of Glory Hole Peak, in a thrust sliver along the Yuma mine thrust south-southeast of Salome Peak, and in the southernmost part of the range. The klippe south of Glory Hole Peak is interpreted to represent a down-folded remnant of the Hercules thrust zone and includes (1) blocky weathering, fine-grained porphyritic granodiorite with plagioclase phenocrysts 1 cm in diameter; (2) biotite schist, possibly derived from retrogression of amphibolites; (3) fine-grained granite; (4) muscovite-biotite schist; and (5) dark greenish-gray, fine-

grained, mafic to intermediate igneous rock. This klippe probably includes rocks of both Jurassic and Proterozoic ages.

A small sliver of this unit is present along the inferred continuation of the Yuma mine thrust half of the way between Salome Peak and Calcite mine. This sliver consists of mylonitic and brecciated quartzofeldspathic rocks, probably derived from a granitic protolith.

Rocks mapped as this unit in the southernmost part of the range mostly consist of coarse-grained porphyritic granite with uncertain contact relationships with Mesozoic sedimentary rocks to the north. In addition, the unit includes some compositionally banded quartzofeldspathic gneiss and schist, amphibolite, and pegmatite. The relation between the granite and the metamorphic rocks is uncertain. The porphyritic granite in this area resembles granitoid rocks in the 'S' Mountain area of the western Harquahala Mountains (Richard, 1988).

JXg - Granitoid rocks (Jurassic or Proterozoic)

Granitoid rocks of either Jurassic or Proterozoic age are present above the Hercules thrust in the eastern part of the range. Two thrust slices of this unit are present on Glory Hole Peak. The lower of the two is a strongly mylonitic, porphyritic granite or granodiorite that is medium- to fine-grained. It locally has a very fine grained matrix and may have been a hypabyssal rock. The higher thrust slice consists of a coarser grained, mylonitic granite with local pegmatitic pods.

Above the Hercules thrust in the southern part of the range is a thrust slice of mylonitic, porphyritic monzodiorite, granodiorite, and diorite. This rock is medium grained, except for large K-feldspar phenocrysts 1.5 to 4 cm long. It contains abundant biotite and hornblende, and is very similar to a Jurassic monzodiorite above the Hercules thrust in the Little Harquahala Mountains to the south.

JXl - Leucogranite (Jurassic or Proterozoic)

Leucogranite, probably of either Jurassic or Proterozoic age, is present (1) above the Hercules thrust in the southern part of the range, (2) above the Hercules thrust on Butler ridge and near Cobralla, and (3) near Little Butler ridge. The granite in the southern part of the range intruded Proterozoic metamorphic rocks and is generally medium-grained, muscovite-bearing leucogranite that grades into a homogeneous-composition, muscovite-porphyroclastic, quartz-eye mylonite along thrusts. Rocks mapped as leucogranite on Butler ridge contain some biotite and are light gray, medium grained, and nonporphyritic. The small hill northeast of Little Butler ridge consists of mylonitic, fine-grained, muscovite-bearing leucogranite.

JXm - Mafic rocks, including biotite schist, amphibolite, and metamorphosed quartz diorite (Jurassic or Early Proterozoic)

These rocks are present at Cobralla and north of the Paleozoic strike belt near the Three Musketeers mine. At Cobralla, the unit consists of quartz-feldspar-biotite-hornblende schist interlayered with thin lenses of slightly feldspathic, vitreous quartzite (unit J€q). Near the Three Musketeers mine, it includes amphibolite, foliated quartz diorite, and biotite-rich quartzofeldspathic schist. Some exposures have feldspathic segregations and are probably Proterozoic, but a Jurassic age cannot be ruled out.

MzPzu - Sedimentary and volcanic rocks, undifferentiated (Mesozoic and Paleozoic)

This unit consists of strongly deformed marble, quartzite, calcareous siliciclastic rocks, quartzofeldspathic schist, micaceous quartzofeldspathic schist, and metaigneous rocks that occur in tectonic slices along the western flank of Salome Peak, near Cobralla, and on Butler ridge. These diverse lithologies represent intersliced and interfolded Paleozoic rocks, Buckskin Formation, Vampire Formation, and Jurassic volcanic and volcaniclastic rocks.

The thrust slice near Salome Peak includes of 30 m of Triassic Buckskin Formation or Jurassic Vampire Formation, consisting of (1) medium- to coarse-grained,

locally poorly sorted, variably calcareous, variably feldspathic quartzarenite, (2) calc-silicate rock, (3) thin (less than 10 cm) lenses of white to light-gray carbonate rock, and (4) minor quartz pebble conglomerate with lithic clasts. In addition, this slice contains a 10- to 20-m-thick sliver of foliated, medium-grained biotite granite and smaller, discontinuous slivers of tectonized Paleozoic marble and quartzite derived from Kaibab Formation and Coconino Sandstone.

PALEOZOIC ROCKS

Pk - Kaibab Formation (Permian)

The Kaibab Formation is best preserved in the Paleozoic strike belts, but is also present in slivers along the Yuma mine thrust and near Cobralla. Within the strike belts, the formation is approximately 50 to 100 m thick based on the unit's map width. It consists of white and gray limestone marble and tan to tannish-gray dolomitic marble. Dolomitic parts of the formation are thick bedded, whereas limestone marble units are more thinly layered. The formation is partly cherty and may locally contain some gypsum.

At Cobralla, a complete section of Kaibab Formation is present, but it has been ductilely attenuated to about 10 m. It consists of, from top to bottom, 0.2 m of white marble, 1 m of laminated gray marble, 1 m of nonresistant white and buff marble with possibly small amounts of gypsum, 6 m of white and cream-colored marble with locally abundant chert, and several meters of buff to cream-colored, laminated marble.

Pc - Coconino Sandstone (Permian)

The Coconino Sandstone has been metamorphosed into a white, fine-grained vitreous quartzite that characteristically has a pinkish-tan to gray varnish on weathered surfaces. It is very well sorted and nonfeldspathic. Bedding is rarely preserved, and the unit tends to be a poorly exposed slope former, probably because it is extensively fractured. The thickest Coconino section, which is in the central Paleozoic strike belt, is about 300 m thick on the basis of outcrop width. Thinner remnants are present north and east of the strike belts, along Butler ridge, and near Cobralla.

PPs - Supai Group (Permian and Pennsylvanian)

The Supai Group consists of as much as 150 to 200 m of calcareous and noncalcareous siliciclastic rocks. The unit is resistant to erosion and forms darkly-varnished ledges. Most of the unit consists of thin- to medium-bedded quartzite, calcareous quartz sandstone and siltstone, and thin carbonate beds. Sandstone is mostly fine to medium grained and well sorted. Siltstone is siliceous and thin bedded. The basal part of the unit locally includes calcareous beds, rare carbonate-clast conglomerate, and a greenish schist that probably represents metamorphosed siltstone or a paleosol.

Mr - Redwall Limestone (Mississippian)

The Redwall Limestone consists of white to light-cream-colored limestone marble with locally abundant chert. In the Paleozoic strike belts, it is approximately 100 to 175 m thick. The base of the unit is generally mapped at the boundary between white marble and tan dolomite of the underlying Martin Formation, although this lithologic contact is known to be within the Redwall Limestone elsewhere in the region (Richard, 1982).

Dm - Martin Formation (Devonian)

Massive tan dolomite, inferred to be correlative with the Martin Formation of southeastern Arizona, is present beneath the Redwall Limestone in the northern two Paleozoic strike belts and is also present as thin, fault-bounded slivers along thrust faults near the Yuma mine, Three Musketeers mine, and northern Granite Wash Mountains. The unit is a maximum of 100 to 200 m thick, but its base is generally not exposed, except near the Yuma mine, where the several meters of tan dolomite overlies Cambrian quartzite and schist. It is possible that some of the tan dolomite mapped as Devonian Martin Formation is instead correlative with Cambrian Muav Limestone or its equivalents.

MDs - Sedimentary rocks, undifferentiated (Mississippian Redwall Limestone and Devonian Martin Formation)

Redwall Limestone and Martin Formation are not mapped separately in several

thrust slivers near the Yuma mine and in the northeastern part of the Paleozoic strike belts.

Ꞓs - Sedimentary rocks (Cambrian Bolsa Quartzite and Abrigo Formation)

Metamorphosed Cambrian sedimentary rocks, consisting of a basal arkosic quartzite and an overlying schist, are present (1) near the Yuma mine, (2) at the base of Salome Peak in Big Granite Wash, (3) near Cobralla, (4) on Butler ridge, and (5) on Little Butler ridge. The quartzite and schist are interpreted to be correlative with the Bolsa Quartzite and Abrigo Formation, respectively, of southeastern Arizona. Alternatively, the units could correlate with the Tapeats Sandstone and Bright Angel Shale of the Grand Canyon region. The Cambrian section is largely absent from preserved Paleozoic sections in the range and is nowhere thicker than about 25 to 30 m. In some attenuated sections, it is as thin as 20 cm. The quartzite is in nonconformable contact with Proterozoic granite near Big Granite Wash, the Yuma mine, Cobralla, Little Butler ridge, and where a major stream crosses Butler ridge.

The most complete section is exposed in Big Granite Wash, where the basal quartzite depositionally overlies Proterozoic granite and is a vitreous, light gray, gray- to locally maroon-weathering, cliff-forming unit up to 20 m thick. The base of the quartzite includes a discontinuous, 5-cm-thick zone with isolated pebbles of quartz and granite. The quartzite is feldspathic, fine to medium grained, and medium bedded with bedding parallel to the contact with the underlying granite. Quartzite is well sorted where fine grained, but poorly sorted and arkosic where medium and coarse grained. Locally preserved crossbeds dip to the north and northeast. The quartzite has dark gray, diffuse bands and thin layers of quartz-muscovite schist near its top. It is locally overlain by 5 to 10 m of locally calcareous quartz-mica schist representing Cambrian Abrigo Formation.

A well-preserved depositional contact is also preserved within the core of a recumbent fold within a thrust sliver at the Yuma mine. The quartzite in this area is overlain by a several meters of Cambrian schist and tan dolomite (Martin Formation).

Pzs - Sedimentary rocks, undifferentiated (Paleozoic)

Due to extreme ductile attenuation and other structural complications, individual Paleozoic units locally could not be shown separately on the map, even though they could be identified in the field. Most of these areas are thin thrust slices that contain several Paleozoic units. Such slices are present near the Three Musketeers mine, Yuma mine, McVay window, Mt. green, Glory Hole Peak, and Butler ridge. In addition, Paleozoic units could not be mapped separately where they have been strongly folded, such as on the eastern end of the southern Paleozoic strike belt. Some strongly deformed Paleozoic sections contain all the typical formations but have been attenuated to several percent of their original thicknesses. Such complete Paleozoic sections are 40 m thick (4 % of their regional 1 km thickness) at Cobralla and 8 meters thick (less than 1 % of their original thickness) southwest of the Yuma mine. A highly folded section of Redwall Limestone, Supai Group, and Coconino Sandstone mapped as Pzs on the eastern end of the southern Paleozoic strike belt is only 90 cm thick. This section is about 0.1 to 0.2 % of its normal thickness.

PROTEROZOIC ROCKS

YXg - Granite (Early or Middle Proterozoic)

This unit includes several different types of granitic rocks known or interpreted to be Proterozoic. The most widespread granite forms the western face and northern half of Butler ridge and varies from a coarse- to medium-grained, porphyritic, biotite granite to a medium-grained, nonporphyritic to porphyritic biotite granodiorite. Phenocrysts in the pluton include K-feldspar as long as 2 cm and bluish-gray quartz 3 to 6 mm in diameter. The granite is generally strongly foliated or mylonitic and locally contains multiple generations of fabric: an early steep (Proterozoic?) fabric and superimposed (D2) mylonitic fabric. Where the granite is overlain by Cambrian quartzite, its upper 1 to 2 m is particularly micaceous and has pronounced quartz eyes, possibly due to weathering of feldspar prior to burial. A

single whole-rock Rb-Sr isotope analysis indicates a Proterozoic age for the granite.

The same pluton forms the ridge crest on Little Butler ridge and includes medium- to coarse-grained biotite granite and granodiorite with quartz eyes as large as 6 mm in diameter. The granite is very porphyritic and contains up to 40 % rectangular feldspar phenocrysts 5 to 15 mm wide and 1 to 2 cm long. The granite contains about 10 % biotite and numerous unmapped pods of biotite schist. It is unusually sericitic where adjacent to Cambrian Bolsa Quartzite along a preserved depositional contact.

A similar, but generally coarser grained granite underlies Cambrian quartzite and Mesozoic sandstone and conglomerate in Big Granite Wash. This granite has large K-feldspar phenocrysts and bluish-gray quartz eyes in a coarse- to locally medium-grained matrix. The top of the granite is sericitic and shows evidence of sedimentary reworking beneath the overlying Cambrian quartzite. As at Butler ridge, the granite contains at least two fabrics, one of which has a steep dip. The same granite is present in tectonic slivers along the Yuma thrust near the Yuma mine.

Granite mapped as YXg near Cobralla is porphyritic with K-feldspar megacrysts 4 cm long in a coarse- to medium-grained matrix. Small exposures north of the Cobralla thrust include abundant pegmatite and may be unrelated to the more typical porphyritic phase.

Xgd - Granodiorite, quartz diorite, and their metamorphosed equivalents (Early Proterozoic or possibly Jurassic)

This unit, exposed in the Cobralla area of the northern Granite Wash Mountains, consists of deformed medium-grained, equigranular to slightly porphyritic granodiorite and feldspar-quartz-biotite±hornblende schist interpreted to be a strongly deformed and metamorphosed equivalent of the granodiorite. Rocks are medium gray and homogeneous in composition over entire outcrops. The unit varies in composition between adjacent thrust slices but generally contains about 15 to 20 % biotite, 15 to 25 % quartz, and 60 % feldspar. It is schistose where strongly deformed and locally contains small-scale compositional laminations, but is homogeneous in composition on the scale of an outcrop. Some outcrops of weakly deformed granodiorite are coarse grained.

Xm - Metamorphic rocks (Early Proterozoic)

This unit includes a diverse suite of gneiss, schist, amphibolite, granite, and pegmatite that compose the upper plate of the Hercules thrust. In the southeastern part of the range, the rocks include quartz-feldspar-biotite gneiss with compositional banding, biotite schist, amphibolite, quartz-rich metamorphic rocks (including quartzite), granitic gneiss, and foliated to gneissic granite, granodiorite, and alaskite. Crystalloblastic foliation is parallel to gneissic layering and quartzofeldspathic segregations. Associated with the metamorphic rocks are aplitic alaskite with less than 1 % biotite and coarse-grained, porphyritic granite with several percent large K-feldspar phenocrysts. The porphyritic granite contains 10 to 15 % biotite in shreddy, irregular clots and has a subvertical foliation. Around the margins of the granite are less deformed fine-grained alaskite and pegmatites, some of which are muscovite-bearing.

Two thrust slices of this unit are also exposed on Glory Hole Peak. The lower of the two is mostly amphibolite with local pegmatite, granite, and compositionally banded gneiss. The upper thrust sheet is quartzofeldspathic schist, compositionally banded gneiss, deformed granite, and medium-grained, biotite granodiorite.

On Butler ridge, this unit consists of compositionally banded quartzofeldspathic gneiss, mica schist, and foliated granite and granodiorite. The rocks have steep compositional banding, locally perturbed by ptygmatic folds. Thin, mostly thrust-bounded layers of amphibolite, biotite schist derived from amphibolite, and dioritic rocks are shown as marker units within the metamorphic unit near Cobralla. These mafic rocks are locally compositionally banded and typically do not develop thrust-related mylonitic fabrics as easily as the adjacent quartzofeldspathic lithologies.

GEOLOGY OF MINERAL DEPOSITS IN THE GRANITE WASH MOUNTAINS

compiled by S. J. Reynolds

This list summarizes available information on the mineral deposits of the Granite Wash Mountains. The information was derived from (1) published reports (Keith, 1978, Dale, 1959, and Bancroft, 1911), (2) MRDS, a computerized database on mines from the U.S. Geological Survey, (3) AZMILS, a computerized database on mines that is available from the Arizona Department of Mines and Mineral Resources (ADMMR), (4) unpublished, confidential production data from the U.S. Bureau of Mines, (5) unpublished file data from the Arizona Geological Survey (AZGS) and ADMMR, and (6) geologic mapping and observations made during this study. Although much care was taken in the compilation of this list, the information should be considered preliminary until an ongoing study of specific mineralized sites by the AZGS is completed.

This list generally provides information under the following numbered categories:

1. Location information in township, range, and section
2. Commodities produced or present (a minus sign following a commodity signifies its presence in minor amounts
3. Geologic setting and style of mineralization
4. Sources of information
5. Comments about discrepancies in location information between different sources

ACE (Pacho No. 2)

1. T. 6 N., R. 15 W., W/2 NW/4 Sec 25 and E/2 NE/4 Sec. 26
2. W
3. W mineralization, consisting of sparse, sporadic scheelite, is hosted in carbonate rocks near the contact between the Devonian Martin Formation and the Mississippian Redwall Limestone. The scheelite occurs in the foliated carbonate rocks and in discontinuous quartz veins that are 2 to 60 cm thick, strike N10W to N60W, and dip 40 to 50 ^{o} NE. Minor Production.
4. Dale (1959, p. 17-18), AZMILS
5. Location from Dale (1959). Lat-lon in AZMILS is incorrect.

ARIZONA NORTHERN (see Glory Hole)

B AND B

1. This mine, listed in the Ellsworth district in some reports, is probably equivalent to the Hall (Bunker) mine in the Harcuvar mineral district based on file data

B AND E (see also Silver Eagle)

1. Possibly T. 5 N., R. 14 W., west-center of sec. 4
2. Cu oxide, Au
3. Geology uncertain due to unclear location. If the mine is correctly located, it would be hosted by the mudstone member of the McCoy Mountains Formation or associated basaltic, andesitic, and dioritic rocks.
4. AZMILS
5. Uncertain whether a mine of this name is in the Granite Wash Mountains as shown in AZMILS because references could alternatively apply to the Bonanza and Evelyn mines, which are also referred to as the B. and E., in the Cunningham Pass district.

BALLIF (see True Blue)

BERDIE LEE
1. Possibly T. 6 N., R. 15 W., SE/4 sec. 24
2. W
3. Mineralization is localized in a shear zone, probably in structurally complex Paleozoic and Mesozoic rocks east of the Three Musketeers mine.
4. MRDS, AZMILS
5. Location from MRDS. T-R in AZMILS is incorrect.

BIG DIKE COPPER
1. T. 5 N., R. 14 W., SW/4 NE sec. 17
2. Cu, Au, Ag
3. Mineralization is evidently within lithic sandstone member of McCoy Mountains Formation, probably as veins. Dikes are reported in area.
4. MRDS, AZMILS, file data
5. Location from MRDS. T-R and Lat-Lon in AZMILS is incorrect.

BLACKCAT (Minnezona)
1. T. 5 N., R. 14 W., center N/2, sec. 26
2. Pb, Au, Ag, Cu-, Stone(?)
3. Fissure vein in dioritic border phase of Cretaceous Granite Wash Granodiorite adjacent to contact with upper sandstone and conglomerate member of McCoy Mountains Formation. Mostly oxidized lead mineralization with high-grade gold values in spotty, small pockets.
4. Keith (1978, p. 147), AZMILS

BLACK HAWK GROUP (Iron Dike, King)
1. T. 6 N., R. 14 W., center and NW/4 sec. 30, also secs. 24, 25, and 29
2. Fe, Cu
3. Magnetite partly replaces a bed of yellow marble (Permian Kaibab Formation) within an upside down Paleozoic sequence beneath a D2 klippe of Jurassic volcanic rocks. An irregular mass of Jurassic alaskite intrudes the section beneath the klippe. The magnetite is associated with Cu sulfides and oxides, pyrrotite, pyrite, garnet, actinolite, calcite, and quartz. The magnetite can be traced, as masses and disseminations as much as 15 m thick, along its north strike for hundreds of meters. It dips 10 to 35 ^{o} W. A representative sample contained more than 50 % Fe. It reportedly contains approximately 1 % Cu and 0.0X oz/ton Au. The iron-replaced bed is underlain by gypsiferous rocks of the Triassic Buckskin Formation.
4. Harrer (1964, p. 136-137), this study, AZMILS
5. Location from Harrer (1964) and this study. Lat-Lon in AZMILS is incorrect.

BLUE BIRD (see Dandy)

CALCITE (Oliver Kilroy)
1. T. 5 N., R. 14 W., SW/4 sec. 11 and SE/4 sec. 10
2. Fe, Cu, Gypsum
3. Altered zone is more or less confined to a sequence of quartz-sericite schist, quartz-andalusite rocks, and quartzite (unit Js). These rocks represent metasomatized Jurassic volcanic rocks and quartzose sandstones, possibly with some associated quartz sinter, that were all metamorphosed during D2 thrusting. The schist is overlain to the northeast by Proterozoic crystalline rocks above the Hercules thrust. The mineralized schist and overlying thrust dip northeast and are on the north flank of the large, E-plunging Calcite mine antiform. The mineralized horizon can be traced southward around the nose of the fold where it thins to nothing beneath the thrust. The limonitic streaks in the rock are commonly aligned parallel to D2 lineation, which indicates that the pyrite was introduced into the rocks prior to metamorphism (and thrusting). The mineralization, therefore, is not related to the Late Cretaceous Granite Wash Granodiorite, which

extensively intrudes the rocks but is unmineralized and mostly unaltered. Gypsum is associated with the mineralized zone, as is typical of other occurrences of aluminous metasomatic rocks in the mountain range.

Bancroft reports that the "calcareous rocks have been silicified and subsequently cut by fissures with gypsum. One layer 40 ft wide contains abundant pyrite. ADMMR files report that drill holes in Oliver Kilroy claims contained a few pyrite stringers and green copper silicates.

4. This study, Bancroft (1911, p. 102-103), AZMILS and files

COBRALLA (Cabralla)

1. T. 6 N., R. 14 W., W/2 SE/4 sec. 4
2. Au, Cu, Wollastonite
3. The deposit is localized in an overturned, north-dipping section of metamorphosed Paleozoic and Mesozoic rocks that are in the footwall of the southeast-vergent (D1) Cobralla thrust. The Paleozoic section is attenuated to a thickness of less than 40 m (about 4 % of its original thickness), yet all of the characteristic regional formations are present. Carbonate rocks, described in older published reports, are equivalent to the Kaibab, Redwall, and Martin Formations, all of which are present. The Kaibab Formation is in overturned depositional contact with Mesozoic clastic rocks to the south. Bancroft reports that some marble beds have been completely replaced by wollastonite, which he attributes to contact metamorphism, but which may instead be due to regional metamorphism accompanying D1 thrust burial. He also reports the presence of a granite younger than the Tank Pass Granite, but there is little evidence for any intrusion younger than the Tank Pass Granite, except for local pegmatites and felsic and mafic dikes. The units are widely folded and faulted. The main shaft a Cobralla intersects brecciated schist in a fracture zone that cuts across schistosity in the rocks. Epidote, actinolite, vesuvianite, and garnet were described by Bancroft. The main ore minerals, malachite and chalcocite, are concentrated within the marble beds compared to the schist. Secondary quartz and calcite are abundant and fill small fractures and vugs. Mn oxide is also present.
4. Geology from this study and Bancroft (1911, p. 103-104), Funnell and Wolf (1964, p. 311), Phillips (1987), AZMILS
5. Location from Bancroft (1911, p. 103) and this study. Lat-lon and T-R in AZMILS and Phillips (1987) is incorrect.

CORONET (see Yellowbird)

CUPA DE ORO

1. T. 5 N., R. 14 W., S/2 SW/4 sec. 27
2. Pb, Ag, Au, Stone(?)
3. Located in basaltic, andesitic, and dioritic rocks associated with the McCoy Mountains Formation. File data indicates that vein cuts somewhat altered quartz diorite and dips 8 ^{o}. Ore was high grade with 56 % Pb and 5 to 6 oz/ton Ag. Some production.
4. AZMILS, ADMMR file data

DANDY (Starr, Golden, Blue Bird, see Yellowbird)

DEANNE

1. T. 5 N., R. 14 W., center sec. 9 (?)
2. Unknown, probably similar to True Blue
3. According to inferred location, occurrence would be in the lithic sandstone member of the McCoy Mountains Formation or in associated igneous rocks.
4. File data
5. May be located north of True Blue mine

DESERT (Winchester, Golden Mound?, Gold Eagle?)

1. T. 5 N., R. 14 W., SE/4 NW/4 sec. 21
2. Au, Cu, Ag, Pb, Mo-, Fe-
3. Wide zone of quartz and calcite veins and stringers, and amorphous quartz following schistosity in the fine-grained slates of the mudstone member of McCoy Mountains Formation. Mineralization carries spotty, high-grade Au values and oxidized Cu and minor Pb-Mo with Fe oxides. The small stringers of quartz generally follow schistosity in the Mesozoic rocks. Among the minerals reported include chrysocolla, malachite, and minor cuprite and chalcocite, Veinlets of calcite are abundant in the vicinity and a persistent felsic dike cuts the rocks above the workings. Some production.
4. Bancroft (1911, p. 102), Keith (1978, p. 148)
5. There is some potential for confusion because the Centroid mine in the Cunningham Pass mineral district was also apparently called the Desert mine at a time when the Granite Wash Mountains were referred to as "the southwestern part of the Harcuvar Mountains" and all mines in the area were grouped in the Ellsworth mining district. Some descriptions and production attributed to the Desert mine in the Granite Wash Mountains may instead apply to the Centroid mine. File data indicate that the Golden Mound and Golden Eagle mines (synonyms listed above) are located in the Cunningham Pass district of the Harcuvar Mountains, near the other Desert (Centroid) mine.

DESERT QUEEN

1. T. 5 N., R. 14 W., SW/4 NW/4 sec. 16
2. Cu, Ag, Au
3. Mine is hosted in the mudstone member of the McCoy Mountains Formation or in associated mafic igneous rocks. Large, postdeformational (Tertiary?) felsite dikes and east-dipping sills are present in the vicinity.
4. AZGS clippings file indicates that the Desert Queen mine (listed as being in the Plomosa mining district) produced Cu, Ag, and Au in 1907.

DESERT GLEN (Glen Oro, Rose, Lily)

1. T. 5 N., R. 14 W., SE/4 sec. 23
2. Unknown
3. Workings are in two types of Jurassic(?) granite within the Hercules thrust zone, adjacent to Jurassic volcanic rocks, McCoy Mountains Formation, and Granite Wash Granodiorite.
4. File data.

DONA KAY (Mineral Hill, Oro Fino, Kay Waters, Waters, Noralie)

1. T. 5 N., R. 15 W., NW/4 NE sec. 13 and SE/4 Sec 12
2. Cu, Ag, Au
3. Spotty copper, silver, and Au mineralization, mostly oxidized, with quartz gangue in an irregular deposit in a fissure zone in a thin sequence of lithic sandstone member of the McCoy Mountains Formation and in large, overlying and underlying diorite-andesite bodies. Typical reported assays are 0.1 oz/ton Au, 0.15 oz/ton Ag, and .75 % Cu. Some production.
4. Keith (1978, p. 148), geologic update by this study
5. Location from Keith (1978), file data, and this study. T-R and Lat-Lon in some file data and AZMILS are incorrect.

DREAMS (see Yuma)

1. AZGS clippings file indicates that the Dreams mine was operated by the Yuma Mining Company. Location information and descriptions of the deposit in the clippings file, such as the ore being a replacement of a limestone bed, are consistent with those of the Yuma mine.

DUTCH HENRY CLAIMS (see Granite Wash Mountains placers)

1. T. 6 N., R. 14 W., secs. 32 and 33 or
   T. 5 N., R. 14 W., sec. 9
2. Au placer
3. Quaternary gravels if placer and McCoy Mountains Formation if lode.
4. Bancroft (1911, p. 98), Johnson (1972, p. 74)
5. Both gold and lode workings are variably attributed to this name. Johnson states that workings are placers in secs 32 and 33, but Bancroft indicates that they are lode deposits (quartz veins in schist) and are "in the second wash south of the Yellowbird camp," which could place them further south (sec. 9). According the Bancroft, most veins are parallel to the "lamination planes" (schistosity?) in the southeast-dipping schistose host rocks (McCoy Mountains Formation and associated mafic bodies?), but one prominent vein dips west and cuts across the schists. Some veins are along the contacts between "diabase" and slates.

ELLSWORTH KING (see True Blue)

EWER

1. T. 6 N., R. 14 W. sec. 33(?) or T. 6 N., R. 15 W. sec. 33(?)
2. Au, Ag, Cu
3. Unknown geology because of uncertain location. Some production.
4. AZMILS, file data, mentioned by Bancroft (1911)
5. Location given in AZMILS plots in area of no bedrock, file data implies claims are close to, and perhaps northeast of, Glory Hole mine

FAITH AND HOPE

1. T. 5 N., R. 14 W., W/2 SE/4 sec. 35 (?)
2. Unknown
3. Apparent location is at southern tip of range in area dominated by Granite Wash Granodiorite.
4. AEC (1955, PRR PB 172-491), AZMILS

GLORY HOLE (Arizona Northern, Salome Strike)

1. T. 5 N., R. 14 W., NW/4 NW/4 sec. 4
   T. 6 N., R. 14 W., SE/4 SE/4 sec. 33
2. Au, Ag, Cu, Pb-, Fe-, Mn-
3. Veins and irregular, contorted and discontinuous quartz veins, and large masses of quartz. Hosted by dioritic, andesitic, and basaltic rocks within the McCoy Mountains Formation. Some veins contain high-grade pockets of gold and a gangue of siderite, Fe oxides, and some Mn oxides. The veins also contain pyrite and some galena and chalcopyrite. Discovery of a high-grade pocket triggered a short-lived gold rush. According to Bancroft (1911, p. 101), some ore derived from this pocket was one-half free gold! Bancroft also describes a ledge of free-gold-bearing material above the original high-grade glory hole. This ledge cuts across schistosity in the rocks and is composed of a gangue of siderite and limonite, with a subordinate amount of quartz. According to Bancroft, the rock in which the ledge occurs is very calcareous and resembles a dolomite, but this is uncharacteristic of the rocks exposed in the mine.
4. Bancroft (1911, p. 98-102), Keith (1978, p. 148), MRDS (Arizona Northern)

GOLDEN (see Dandy)

GOLD EAGLE (see Desert)

GOLDEN EAGLE (see Yuma)

1. Reported as a synonym of Yuma mine in ADMMR Yuma mine file

GOLDEN JACKPOT

1. T. 5 N., R. 14 W., sec. 26
2. W
3. Mineralization is present in granodiorite, schist, and gneisses that have been intruded by andesite and narrow aplite dikes. Rocks are cut by northeast, northwest, and east-trending fractures. Some of the fissures are filled with narrow veins of quartz, which carry sparse copper, iron, and manganese oxides and very sparse, sporadic scheelite. One shaft contains a 30-cm-thick zone of disseminated scheelite in gneiss. This zone is estimated to contain 1% WO3 and is along a fault that strikes N20E and dips 70 ^{o} SW.
4. Dale (1959, p. 8-9), AZMILS

GOLDEN MOUND (see Desert)

GOLDEN ORBIT (see True Blue)

GRANITE WASH MOUNTAINS PLACERS (Desert mine placers, Yellowbird mine placers, Dutch Henry, Safe Deposit placer)

1. T. 5 N., R. 14 W., secs. 4, 5, 20, 21
   T. 6 N., R. 14 W., secs. 32, 33
2. Au
3. Au-bearing Quaternary gravels in small gulches. Gold probably derived from lode gold in areas near Glory Hole, Desert, and Yellowbird (Dandy) mines.
4. Johnson (1972, p. 74), Keith (1978, p. 148), AZMILS

GREEN HILL MINE

1. T. 5 N., R. 13 W., SW/4 sec. 7
2. W, Cu-
3. Sparse, sporadic scheelite grains and masses as large as 2 cm in narrow, discontinuous quartz veins in Cretaceous Granite Wash Granodiorite. Nearby are narrow, mafic dikes. Cu oxides also occur in the quartz and along fracture through the granodiorite. Some W production.
4. Dale (1959, p. 10-11), Keith (1978, p. 148)

GRAY (see True Blue)

HALL BARIUM MINE

1. T. 6 N., R. 14 W., sec. 6 or 7 (Harcuvar Mountains)
2. Ba, Cu oxide
3. Vein deposit, but precise geology uncertain because of unclear location
4. Stewart and Pfister (1960, p. 79-81)
5. Lat-Lon and T-R location in AZMILS are in northern Granite Wash Mountains and are mutually inconsistent. Published and file data suggest that deposit is instead in the Harcuvar Mountains, near CottonWood Pass (Hall mine)

HOWARD

1. T. 5 N., R. 14 W., NW/4 sec. 22 (?) or secs. 14 or 15(?)
2. Cu(?), Dimension stone (?)
3. Geology unknown because of location uncertainties. ADMMR file data indicates that mineralization is in a 45-degree-dipping limestone bed that is overlain by quartzite and underlain by schist and various intrusive rocks, including quartz porphyry. Later mafic dikes discordantly cut across the mineral veins and intrusions. The data indicates that the limestone bed is 100 m thick and can be followed for 5 miles along strike, a description that is difficult to reconcile with geology anywhere in the Granite Wash Mountains.
4. AZMILS, ADMMR file data
5. Location very uncertain because of limited file data and because Lat-lon and T-R in AZMILS are mutually inconsistent and inconsistent with geology.

I. AND A. (see Yuma)

1. Bancroft (1911, p. 95) and Keith (1978, p. 150) indicate that I. and A. (Ironwood and Arizona) was another name for the Yuma Copper Company.

IBEX (Tanaka, Red Bird)

1. Location unknown
2. Cu, Au, Ag
3. Production is listed for a mine of this name in the old Ellsworth mining district, which included at the time the western Harcuvar, Granite Wash, and Little Harquahala Mountains. mine name is also spelled Ibix and Ipex in some reports.
4. file data

IRON DIKE (see Black Hawk)

JEWEL ANNE

1. T. 6 N., R. 15 W., NW/4 sec. 25 and parts of secs. 23, 24, and 26
2. W, Ba, F, Cu-
3. Disseminated blebs and pockets of scheelite with quartz, siderite, barite, Cu-staining in small, narrow stringers in metamorphosed Mississippian Redwall Limestone. Scheelite is present in widths ranging from 30 cm to 5 m and strike lengths of 65 m. The mineralized zone strikes N65W and dips 15 ^{o} north under the hill. Some barite is present. Best scheelite is reportedly associated with margins of brown limestone and is not always associated with quartz. Some W production.
4. Dale (1959, p. 17), Keith (1978, p. 149), AZMILS, ADMMR file data
5. Location from Dale (1959). Lat-lon in AZMILS is incorrect.

KAY WATERS MINE (Waters, Noralie, see Dona Kay)

1. T. 5 N., R. 15 W., secs. 12, and 13, and T. 5 N., R. 14 W., center sec. 7
2. Cu, Ag, Au
3. Localized in sedimentary rocks of the McCoy Mountains Formation adjacent to large dioritic-andesitic bodies.
4. AZMILS, ADMMR Yuma mine file data
5. Location from verbal description of property in ADMMR Kate Waters file, which is consistent property being 2 1/2 miles southwest of Yuma mine, as indicated in the ADMMR Yuma mine file. T-R and Lat-Lon in consultant's report in ADMMR Kate Waters file and in AZMILS are for northern Granite Wash and are incorrect.

KING GROUP (see Black Hawk)

LONE GRANITE HILL

1. T. 5 N., R. 14 W., S/2 sec. 12
2. W
3. Pockets of scheelite have been mined from a quartz veins within a small, isolated hill of Late Cretaceous Granite Wash Granodiorite. A quartz vein on top of the hill strikes N70E and dips 40 ^{o} SE, and is surrounded by altered, light-colored granite. Another pocket of scheelite at the southeast corner of the property was within a quartz vein that strikes N15E, dips 70 ^{o} southeast, and is several cm to 1 m wide. The pocket occurred where an iron-stained cross fracture, striking N40W and dipping 65 ^{o} southwest cuts the quartz. The quartz contains vugs with remnant Fe and Cu oxides. Narrow, discontinuous mafic dikes cut the granodiorite, usually near the quartz veins and lenses. Some production.
4. Dale (1959, p. 10), AZMILS
5. Location from Dale (1959), Lat-lon in AZMILS is incorrect.

LUCKY #1
1. T. 5 N., R. 14 W., SE/4 sec. 11
2. W
3. Scheelite occurs in sparse, sporadic grains and in masses up to 2 cm wide within quartz lenses as thick as 1.5 m occur along a fault striking N15E and dipping 80 ^{o} SE. Minor amounts of Fe oxides are in the quartz, and muscovite and orthoclase are present along the extremities of the vein. The host rock is an altered granitoid with hornblende and biotite.
4. Dale (1959, p. 9-10), AZMILS
5. Location from Dale (1959), but not precisely described. Lat-lon and T-R in AZMILS are mutually inconsistent.

MARCH (Ranger, see March-in-Victory?)
1. location unknown
2. Minor Au, Ag, and Cu Production in 1936-1939

MARCH-IN-VICTORY (Laxton, March?, Ranger?, see True Blue? or Yellowbird?)
1. T. 5 N., R. 14 W., S/2 sec. 9
2. Au
3. Geology uncertain because of unclear location.
4. ADMMR files
5. Location, which is near True Blue mine, is from ADMMR files, which also state that this is the northeast corner of the Yellowbird claims. Possibly also referred to as the March claims.

McVAY (see Ace and Pee Wee)
1. This mine name may refer to either the ACE or PEE WEE, both of which were operated by McVay mining company.
4. Dale (1959, p. 15-17), MRDS

MENDOZA (see Yellowbird)
1. This mine produced very minor Au and Ag in 1911. Mine name, listed as Mendota, given as a synonym for Pandoras Box (=Yellowbird) in AZMILS.

MINERAL HILL (Orofino, see Dona Kay)

MINNEZONA (see Black Cat)

ORO FINO (Mineral Hill, see Dona Kay)
1. same as Dona Kay
2. Cu, Ag, Au
3. Some production.
4. Keith (1978, see entry for Dona Kay), AZMILS
5. Lat-lon in AZMILS is incorrect.

PANDORAS BOX (Mendoza, Coronet, see Yellowbird)
1. same as Yellowbird(?) or possibly a nearby, separate mine to north
2. Au, Ag, Cu, W (scheelite) reported.
3. AZMILS, ADMMR file data

PEE WEE (McVay?, Oliver)
1. T. 6 N., R. 15 W., SW/4 sec. 24 and SE/4 sec. 23
2. W, Zn-, Fe-
3. Mineralization is located north of the Three Musketeers mine, where Paleozoic, Mesozoic, and Proterozoic rocks are structurally interleaved and strongly deformed in a steeply dipping, northwest- to west-striking shear zone. These rocks are intruded by unfoliated Tank Pass granite. Mineralization consists of sparse, sporadic scheelite grains, pods, and

crystals in 1- to 6-cm-wide quartz veinlets that evidently cut Cretaceous Tank Pass Granite. The granite its host rocks are extensively fractured. Small zones of enriched scheelite are present along fractures trending N50E. Mafic dikes are present on the claim. Some Fe oxide, willemite, sphalerite, and traces of other minerals. Some W production.
4. Dale (1959, p. 15-16), Keith (1978, p. 149)
5. Location from Dale (1959). Lat-lon in AZMILS is incorrect.

RANGER (see March)

RYAN PROPERTY
1. Uncertain location. Possibly T. 5 N., R. 14 W., S/2 SE/4 sec. 23
5. Clippings files on Black Cat mine indicate that the two mines are "just over hill" from one another.

SAFFIRE (see Sulfa)

SAGUARO
1. T. 5 N., R. 14 W., NE/4 sec. 14
2. W, Au(?)
3. Discontinuous quartz veins in an altered granitic rock, probably Granite Wash Granodiorite. There are many fractures in the quartz and granitic rocks. The main vein strikes N30E, dips 80 ^{o} SE, is exposed for 150 m along strike, and ranges from several cm to 1 m in width. Sparse, sporadic scheelite occurs throughout the quartz vein and small concentrations occur at intersections of the vein with vertical fractures striking N45W. The quartz also contains local concentrations of limonite and hematite, and possibly some gold.
4. Dale (1959, p. 9)
5. Location from Dale (1959). Location given in AZMILS is SW/4 sec. 14, corresponding to shaft symbols on map, but this latter location is inconsistent with the geologic description given by Dale.

SALOME PEAK WOLLASTONITE
1. T. 6 N., R. 14 W., center sec. 21 (?)
2. Wollastonite
3. Geology unknown. This location plots in Tank Pass Granite, not in metamorphosed carbonate rocks as might be expected.
4. Phillips (1987), AZMILS
5. Locality may refer instead to the Cobralla area to the north, where wollastonite was reported by Bancroft (1911).

SALOME STRIKE (see Glory Hole)

SECURITY (Mendoza, Coronet, see Yellowbird)

SILVER EAGLE (B. and E.)
1. T. 5 N., R. 14 W., W/2 sec. 4
2. Cu oxide, Au
3. Y-shaped adit is in 10- to 30-cm-thick sugary quartz vein with limonite-filled vugs. Vein reportedly increases to 2 m thick and becomes bull quartz in canyon to southwest, where it ends against a fault. Chrysocolla and malachite are also present. Based on the given location, the mineralization would be hosted by the lithic sandstone member of the McCoy Mountains Formation or associated mafic bodies.
4. AZMILS and file data
5. Location from AZMILS, file data indicates mine is 2 miles north of Desert Queen mine, which is consistent with the reported lat-lon.

SKIDO (see True Blue)

SQUAW T MINE

1. T7N, R. 15 W., center of N/2 sec. 27 and sec 26 (located north of map area)
2. W, Cu (Be)
3. Sparse, sporadic scheelite in schist, marble, and granite. Some high-grade pockets and pods near contact of micaceous and calcareous schist and marbleized limestone overlying granite. This mineralized zone is about 6 m wide and can be traced for 100m. Near the crest of the ridge, narrow seams of nearly pure scheelite occur in the granite near the intersection of NE-striking fractures with a fault zone that strikes N25W and dips 25 SW. This scheelite is associated with muscovite and quartz. The average seam is 2 cm thick. Numerous mafic and rhyolitic dikes and some wide, continuous, barren quartz veins cut the schist and limestone and dip gently north. Some production.
4. Dale (1959, p. 18-19), Keith (1978, p. 149)

STARR (see Yellowbird)

SULFA (Sapphire)

1. T. 6 N., R. 14 W., north-center sec. 32
2. Kyanite
3. Massive kyanite and quartz-kyanite rocks and associated hydrothermal quartz rocks (metamorphosed sinter?), gypsiferous soil, and muscovite-tourmaline schist within Jurassic volcanic rocks beneath the Yuma mine thrust. The kyanite rocks are continuous along lithologic strike to the west with kyanite-barren, aluminous metasomatic rocks (see description of map unit Jk). Phillips (1987) also reports sillimanite, but this could not be verified.
4. this study, Phillips (1987), AZMILS

TANK PASS GRANITE QUARRY

1. T. 6 N., R. 14 W., center SE/4 sec. 22
2. Granite dimension stone
3. Large, spheroidally weathered knobs of Cretaceous Tank Pass Granite along the mountain front were evidently used in construction of some of the state capitol in Phoenix. Some granite from this quarry was also probably used for tombstones in the cemetery on the north flank of Eagle Eye Peak, south of Aguila.
4. Phoenix usage from Townsend (1962, p. 31-32), probable location and Aguila-tombstone interpretation from this study.

THREE MUSKETEERS

1. T. 6 N., R. 15 W., SW/4 sec. 24 and NW/4 sec. 25
2. W
3. W mineralization is localized along the Three Musketeers (D3) brittle-ductile shear zone that places an upturned Paleozoic section over Jurassic granite, Jurassic volcanic rocks, Triassic Buckskin Formation, and several types of mafic schists of Jurassic or Proterozoic age. Small grains and pods of scheelite occur in discontinuous quartz lenses and adjacent calcareous rocks and in quartz veins in granitic rocks (probably Jurassic granite in the footwall of the D3 shear zone). Narrow veinlets of scheelite less than 1 cm thick occur both in the quartz and in the calcareous rocks. The quartz is brittle and easily broken, but the scheelite shows little evidence of crushing or distortion. A few quartz lenses have been faulted and most tend to pinch out within short distances. In the granite, the scheelite is confined to the quartz, but much quartz is barren of scheelite. Strong fracturing and associated diabase dikes. Black-light observation of the ore indicates that the scheelite-bearing veins are localized within the D3 shear zone, but are themselves folded and cut by further shear (this study). Some scheelite, therefore, may be syn-D3 in origin. Other scheelite could be related to the Tank Pass Granite, which is located a short distance to the north of the workings. Some production.
4. Dale (1959, p. 11-15), Keith (1978, p. 149), AZMILS
5. Lat-lon in AZMILS is incorrect.

TRIONI
1. T. 6 N., R. 15 W., sec. 25
2. W
3. Narrow stringers of quartz, 4 to 6 cm wide, contain sporadic pockets if scheelite. The stringers strike N47W, are subvertical, and cut gneiss, shale, schist, and limestone. Some production.
4. Dale (1959, p. 18), AZMILS
5. Lat-lon in AZMILS is incorrect

TRUE BLUE (Golden Orbit, Ballif, Gray, Verdugo)
1. T. 5 N., R. 14 W., SE/4 SW/4 sec. 9.
2. Au, Ag, Cu
3. Mineralization is present in calcareous and other slaty rocks of the mudstone member of the McCoy Mountains Formation and in associated basaltic-dioritic rocks. Pockety gold with silver and small lenses of copper carbonates, oxides, and sulfides, associated with quartz seams in a northwest-striking brecciated zone in interbedded limestone, shale, argillites, and quartzites. Quartz veins and stringers reportedly follow the schistosity (cleavage). Pyrite and chalcopyrite are both reported. Mafic dikes, felsite, and apophyses of Late Cretaceous Granite Wash Granodiorite are nearby. Tellurides and sylvanite are both reported. Some production.
4. Keith (1978, p. 149), this study, AZMILS, file data

VERDUGO (see True Blue)

VICTORY
1. File data indicates that a Victory mine, assigned to the Ellsworth mining district in some reports, is located 3 miles southwest of Brenda (in Plomosa Mountains). This name could also conceivably be used to refer to the March-in-Victory, a possible synonym of the True Blue mine.

WATERS (Kate Waters, see Dona Kay)

WINCHESTER (see Desert)

WOOPIE (or Woopee)
1. Ag, Au, Cu
2. Possibly T. 5 N., R. 14 W., sec. 23
3. Geology uncertain because of unclear location. Some production.
4. Reportedly 4 miles west of Salome

YELLOWBIRD MINE (Dandy, Coronet, Mendoza, Mendota, Security, Starr, Golden, Blue Bird)
1. T. 5 N., R. 14 W., center E/2 sec. 6
2. Cu, Ag, Au, Pb-, Zn-
3. Irregular, quartz and quartz-carbonate veins cutting an andesite-diorite body and adjacent sedimentary rocks of the Yellowbird mine sequence of McCoy Mountains Formation. Veins contain spotty copper, gold, silver, lead, and zinc mineralization and may be related to D2 deformation. Some production.
4. Keith (1978, p. 148), this study, AZMILS, and file data

YELLOWBIRD PLACERS (see Granite Wash Mountains placers)

YUMA MINE (Dream, Golden Eagle, I. and A.)

1. T. 6 N., R. 14 W., SE/4 sec. 19 and NE sec. 30
2. Cu, Ag, Au, Fe, Azurite and chrysocolla for jewelry
3. Mineralization consists mostly of Cu carbonates and oxides in Paleozoic marble interleaved with metamorphosed Mesozoic sedimentary rocks. The marble is overlain by Jurassic alaskite, mylonitic (originally porphyritic) Proterozoic granite, and Cambrian Bolsa Quartzite along the Yuma mine thrust. The rocks are intruded to the north by Cretaceous Tank Pass Granite and by mafic and felsic dikes. File data reports strong Fe gossans from primary magnetite and pyrite, with quartz stringers, calcite, and contact-metamorphic minerals. The wall-rocks are reportedly fractured and strongly chloritized and epidotized, but most deformational features preserved in surface exposures are ductile, not brittle, in character. File data also indicate that (1) the lode strikes N78W and dips 30 N, (2) some shipments averaged 1.7 % Cu, (3) the shaft encounters mineralization at 75-140 feet, and (4) oxidized zone extends 90 feet below adit. A mafic dike exposed in the shaft (and represented by abundant pieces on the dump) is reportedly vertical and postmineralization, and does not displace ore body. Garnetized limestone is locally 5 to 6 % Cu as chalcopyrite and bornite. Much ore was reportedly 15 to 18 % Fe, 0.25 oz/ton Ag, and 0.03 oz/ton Au. Bancroft (1911, p. 96) reports (1) thin layers of actinolite in the magnetite and quartz, (2) gypsum in one vertical shaft that was filling open-space fractures within quartz-mica schist, and (3) some Mn oxide stain.
4. Keith (1978, p. 17), Bancroft (1911, p. 95-97), this study, AZMILS and file data

OTHER MINES WITH REPORTED PRODUCTION IN ELLSWORTH DISTRICT, BUT UNKNOWN LOCATION AND GEOLOGIC SETTING

Listed below are mine names that may be in the Granite Wash Mountains based on limited information. This list of mines is derived from note cards compiled by Stanton B. Keith during his research on the mines of Yuma County (Keith, 1978). These names are in turn probably largely derived from production records from the U.S. Bureau of Mines. In some cases, the mine names listed below are the name of the mining company or owner. Some of these mines are probably in what are now referred to as the Cunningham Pass, Harcuvar, and Little Harquahala mineral districts, because all these areas were originally included in the Ellsworth mining district.

1. ABBOTT - Au, Ag
2. AEROPLANE - Au, Ag, Cu
3. ALTO - Au, Ag
4. BETTLE No. 1 - Cu, Ag, Au
5. BETTY NO. 2 - Cu, Ag, Au
6. BLACKWELL - Au, Ag, Cu
7. BLUE STREAK - Cu, Ag
8. BOUSE ARIZONA COPPER - Au, Ag
9. BRIGGS - Au, Ag
10. COPPER BELL - Cu, Ag
11. COPPER CHIEF - Cu, Au, Ag, Pb
12. COPPER GEM - Cu
13. COPPER KING AND COPPER QUEEN - Cu, Au, Ag
14. CRACKER JACK NO. 2 - Cu, Ag, Au
15. CUMBERLAND - Pb, Ag, Cu, Au
16. D. AND D. (Judd) - Cu, Ag, Au
17. DODSON AND WENTWORTH - Cu, Ag, Au (oxide)
18. ELLISON - Au
19. GOLD BELL, GOLDEN BELL - Au, Ag
20. GOLD COPPER - Cu, Au, Ag
21. GOLD DOLLAR - Au, Ag, Cu
22. GOLDEN MAID - Cu, Au, Ag
23. GOLDEN SLIPPER - Cu, Ag, Au, Pb
24. GOLDIE - Cu, Ag, Au
25. HARD - Au, Ag, Cu (oxide)
26. HART - Au, Ag
27. HIGGINS - Pb, Ag
28. HILL - Cu, Ag, Au
29. JACKY AND CINDY JOE - Pb, Cu, Ag, Au
30. HIPSCHEN - Pb, Ag, Au, Cu
31. JOKER - Cu, Ag, Au
32. JUDGE - Cu, Ag, Au
33. KLEINDENST - Au, Cu, Ag
34. KNOB HILL - Cu, Ag, Au
35. LEAD KING - Ag, Au
36. LIZZIE (Clipper) - Au, Ag, Cu
37. LUCAS - Au, Cu, Ag
38. MAUD - Au, Ag
39. MOGER AND RAMSEY - Cu, Au
40. MOORE AND JUDD - Cu, Ag, Au
41. NEALE - Cu, Ag, Au
42. NOBLECHECK - Au, Ag

43. NORD - Au, Ag
44. ODIN - Ag, Au
45. ONE - Cu, Au (ore was 25 % Cu)
46. PARKER - Ag, Cu, Au
47. PABLO - Cu, Au, Ag
48. RANGER AND MARCH - Ag, Au
49. QUICK - Ag, Au
50. RED BIRD (Ibex) - Au, Ag, Cu
51. TRAYNOR AND TAYLOR - Cu, Au, Ag
52. TRI METALS - Cu, Au, Ag
53. URADICOLOR - Cu, Ag, Au
54. VESURINO - Cu, Ag, Au (oxide)
55. WENTZ - Cu, Ag, Au (oxide)
56. WONDER - Pb (oxide)
57. W.J.B. - Au, Ag, Cu

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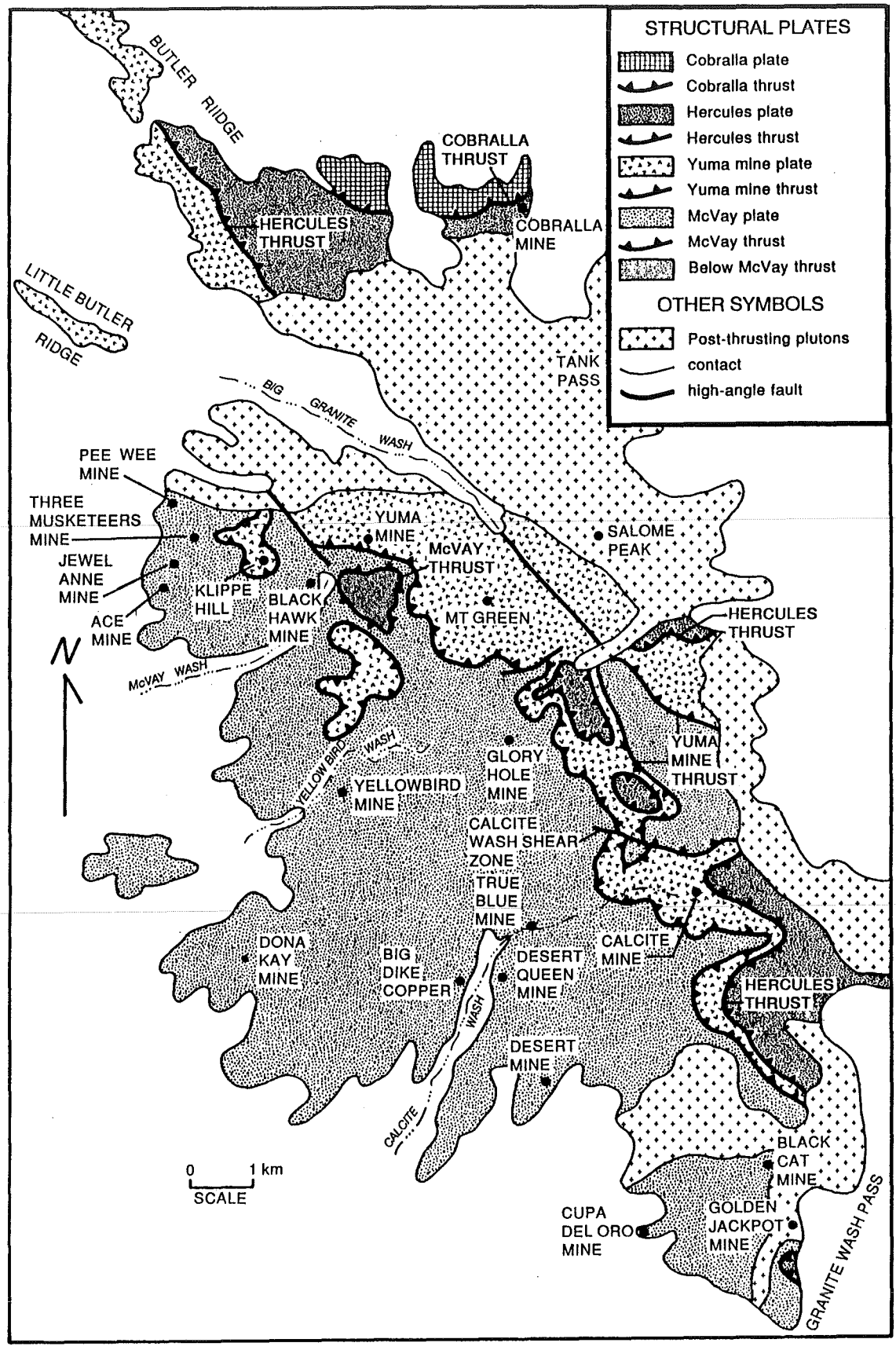


Figure 1. Major thrust plates, geographic features, and mines of the Granite Wash Mountains.

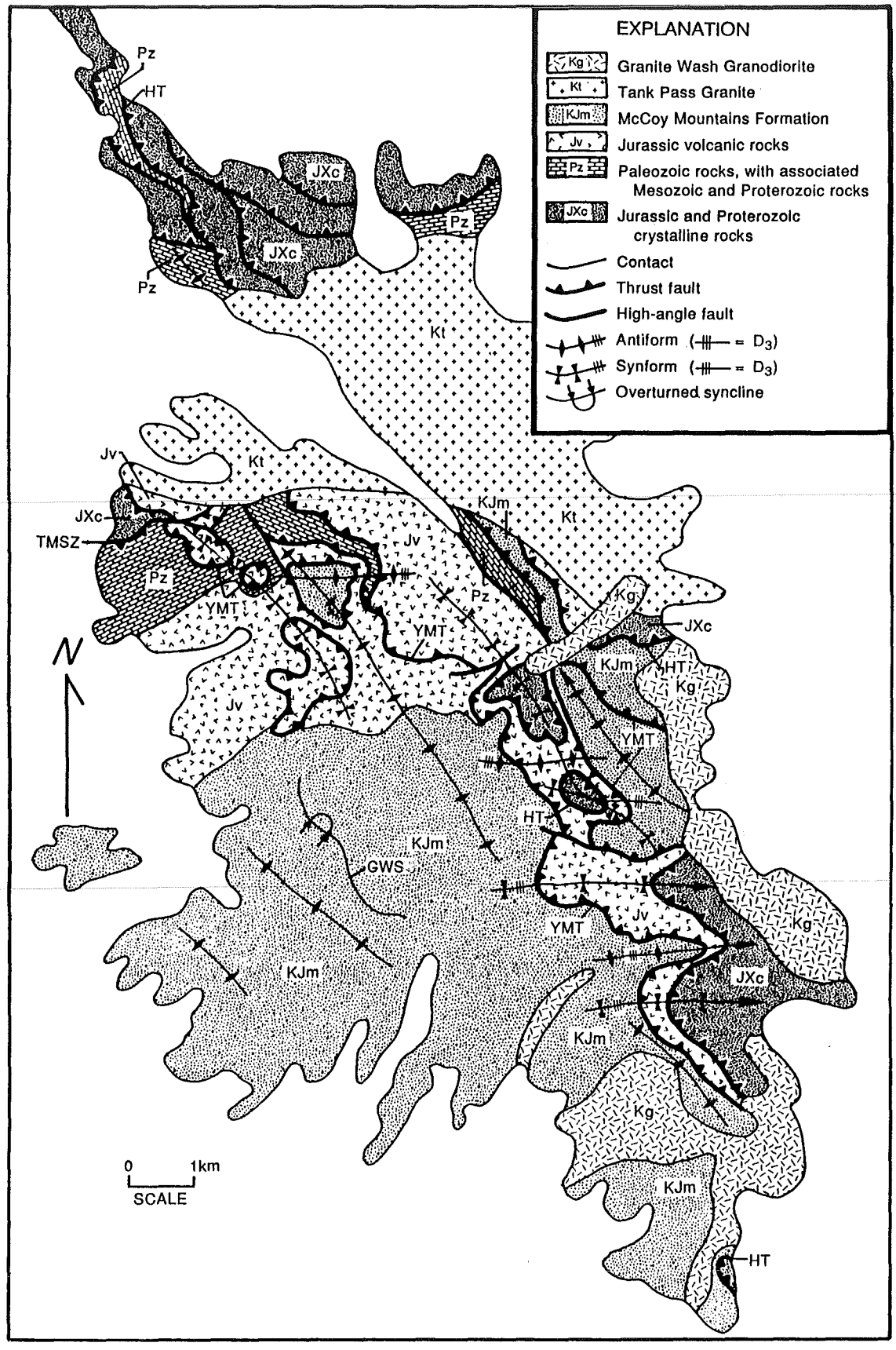


Figure 2. Generalized structural map of the Granite Wash Mountains, showing major folds. Labeled structural features (see also Fig. 1) include GWS - Granite Wash syncline, HT - Hercules thrust, TMSZ - Three Musketeers shear zone, and YMT - Yuma mine thrust.

Geology of the northwesternmost and southwesternmost Granite Wash Mountains

J.E. Spencer, S.M. Richard, and S.J. Reynolds

Addendum to Arizona Geological Survey Open-File Report 89-4
Added to OFR 89-4 in September, 1993

INTRODUCTION

The narrow ridge that extends northwestward from the Granite Wash Mountains toward the Bouse Hills was mapped in the winter of 1984 but was not included in Arizona Geological Survey Open-File Report 89-4 or on Arizona Geological Survey Map 30. Two hills of Tertiary Volcanic rock directly west of the southwestern Granite Wash Mountains were also not included in the OFR or in Map 30. Maps of these areas, at 1:24,000 scale, are included in this addendum.

Most of the northwesternmost Granite Wash Mountains consist of foliated granodiorite of probable Proterozoic X or Jurassic age. The granodiorite is intruded by numerous north to northwest trending, Tertiary dikes. On the accompanying map the dikes appear differently in the northwest than in the southeast. This difference does not reflect differences in the dikes, but reflects the mapping styles of the different mappers (Spencer to the northwest, Reynolds to the southeast). The southeastern end of the map area extends southward into the area covered by Map 30 and by the plate that forms part of this Open-File Report, but is somewhat different because it reflects field interpretations by S.M. Richard that are not identical to interpretations by S.J. Reynolds.

Northwesternmost Granite Wash Mountains

Rock units and structure symbols

Qs **Surficial deposits (Quaternary)**

Tis **Intermediate to silicic dikes (Tertiary)**--Quartz-feldspar porphyry, with fresh 1-2 mm diameter biotite crystals, rounded quartz crystals up to 2 mm in diameter, and subhedral 2-4 mm feldspar crystals. Locally contains hornblende and is gradational with map unit Tim. The groundmass is light gray and very fine grained. Some dikes are aphyric.

Tim **Intermediate to mafic dikes (Tertiary)**--Hornblende-plagioclase dikes with hornblende crystals locally up to 15 mm long. Grades into biotite-hornblende felsite and biotite felsite included in map unit Tis.

q **Massive hydrothermal quartz**--Bull quartz of uncertain age. No evidence of metallic mineralization seen.

Ꞧs **Buckskin Formation(?) (Triassic)**--Complexly interleaved quartzite, marble,

chloritic schist and rare conglomerate. Most of the unit consists of heterogeneous, interleaved calcareous very fine-grained sandstone, tan marble and quartzite. Lithologic layering is generally 1-2 m thick. One outcrop of conglomerate consisted of a very fine-grained chloritic schist matrix cut by abundant quartz veins. Clasts were flattened and recrystallized, and included granitoid, quartzite, and probable silicic volcanic rocks.

Ꞧsq **Quartzite (Triassic?)**--Quartzite with thin lenses of marble. The quartzite is gray weathering and vitreous; sparse biotite is locally present. Biotite-quartz-feldspar schist is locally interleaved in the quartzite. This quartzite could be equivalent to the Permian Coconino Sandstone, Jurassic Vampire quartzite, or local quartzose zones in the Triassic Buckskin formation.

Pk **Kaibab Limestone(?) (Permian)**--Tan to buff marble, locally with tremolite clots probably replacing chert nodules. Some lenses of pure white calcite marble are present.

JXgd **Granodiorite (Jurassic or Proterozoic X)**--Medium grained, equigranular to locally porphyritic, foliated granodiorite consisting of feldspar, quartz, and 5-7% biotite. Locally includes leucogranite and alaskite, and is locally gneissic and contains lenses of schist and gneiss. Relict feldspar phenocrysts are locally up to 1 cm in diameter.

—— — — ··· **Low-angle fault**

—▲—▲—▲··· **High-angle fault**

17 ∟ 35 **Crystalloblastic, weakly mylonitic foliation and lineation**

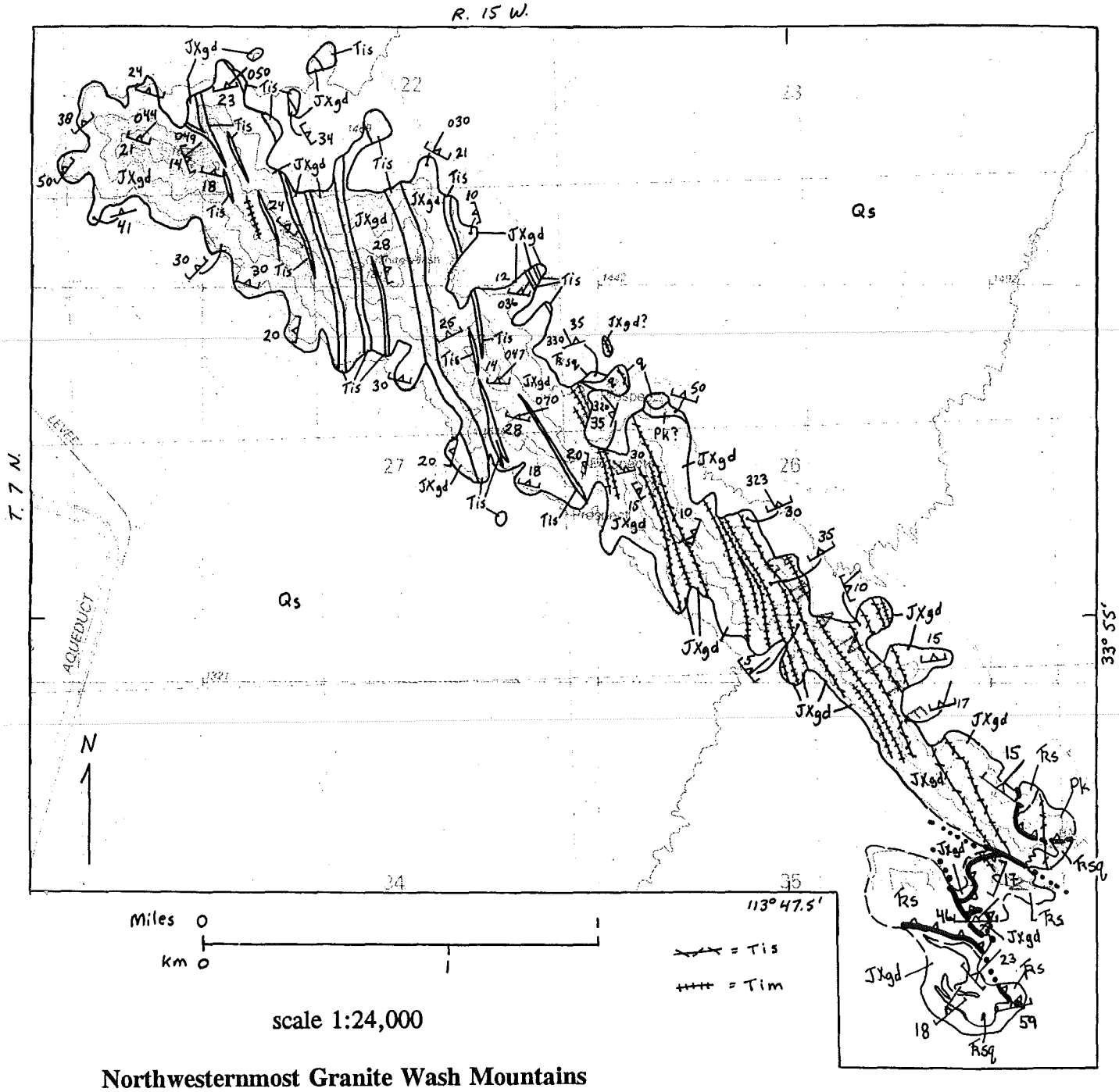
The foliated granodiorite that forms most of the bedrock in the map area is characterized by a weakly to moderately mylonitic, crystalloblastic fabric. Fabric development was generally not associated with significant grain size reduction and is thus unlike typical mid-Tertiary mylonitic fabrics that formed during lithospheric extension and uplift of matamorphic core complexes. This semi-crystalloblastic fabric is locally lineated. Lineation generally trends northeast and is thought to reflect deformation during the second major deformation and thrust emplacement in the Granite Wash Mountain. Locally developed, northwest-trending lineations are associated with cleavage that is distinct from the mylonitic crystalloblastic fabric.

The southeast end of the ridge in this map area is characterized by an assemblage of metasedimentary rocks, complexly interleaved with the foliated granodiorite; these rocks are intruded by a northwest-trending swarm of intermediate to silicic dikes. The metasedimentary rocks are correlated with Buckskin formation and Kaibab limestone based on lithologic similarity to these units to the south in the Granite Wash Mountains. The

quartzite unit somewhat resembles Coconino sandstone, but contains more impurities (mica and feldspar) than typical meta-Coconino. The heterogeneous unit strongly resembles Supai Formation, but conglomerate is unknown in bona fide Supai Formation in this region.

Lithologic layering in the metasedimentary rocks is interpreted to represent transposed bedding. Isoclinal fold hinges in these rocks trend northeast, parallel to lineation. S-C fabrics and fold asymmetry indicate top-to-the-northeast transport. The complex interleaving of the quartzite and granodiorite at their contact, and the fact that foliation is oblique to the contact in many places indicate that the contact pre-dates the development of the prominent foliation. This may be an older fault, an intrusive contact, or possibly an unconformity. Lithologic similarity to Jurassic granodiorite in the Trigo Peaks area, and the possible intrusive contact with Paleozoic or Triassic metasediments suggests that the granodiorite may be Jurassic. A low-angle fault superposes Supai-like Buckskin formation above the quartzite-granodiorite assemblage. This fault is concordant with the prominent foliation in the rocks. Northeast-trending lineation associated with this fault and the prominent foliation suggests correlation with the Hercules thrust system in the adjacent Granite Wash Mountains.

A west-northwest-trending high-angle fault separates the southwest end of the main outcrop ridge from the south-trending outcrops at the southern tip of the map area. This fault cuts the Tertiary dikes. Southwest of this fault, Tertiary dikes are thinner and less abundant.



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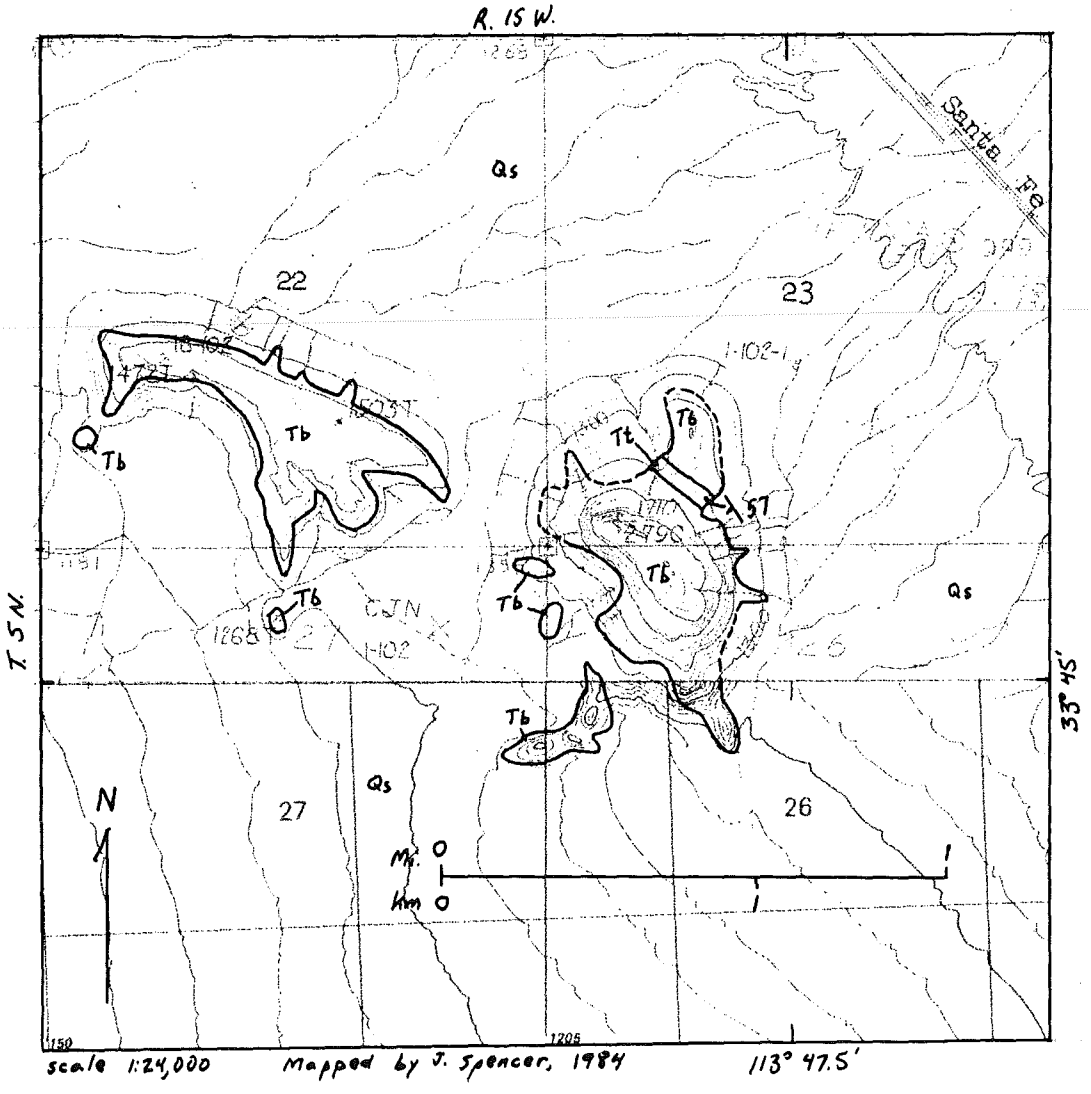
Northwesternmost Granite Wash Mountains

Southwestern Hills of the Granite Wash Mountains

Two hills composed of Tertiary volcanic rocks are located west of the southwestern Granite Wash Mountains and are west of State Highway 72 and two to three miles northwest of the town of Vicksburg.

Rock units

Qs **Surficial deposits (Quaternary)**

Tb **Basalt (Tertiary)**

Tt **Tuff, reworked tuff, and agglomerate (Tertiary)**--Light-gray to tan, volcanic lithic tuff with numerous 1 to 5 cm diameter clasts of tuff that is similar to matrix. Both matrix and clasts are finely vesicular, pummiceous, and have low density. Tuff also contains sparse clasts of indurated, siliceous, biotite tuff. At the base of this unit is a 1 to 2 m thick bedded, light-gray, reworked tuff with quartz grains. Steep dip of bedding is attributed to rotational normal faulting along faults that do not outcrop here.