GEOLOGIC MAP OF THE TWIN BUTTES 7½' QUADRANGLE, PIMA COUNTY, ARIZONA

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Arizona Geological Survey Digital Geologic Map 31

December, 2003

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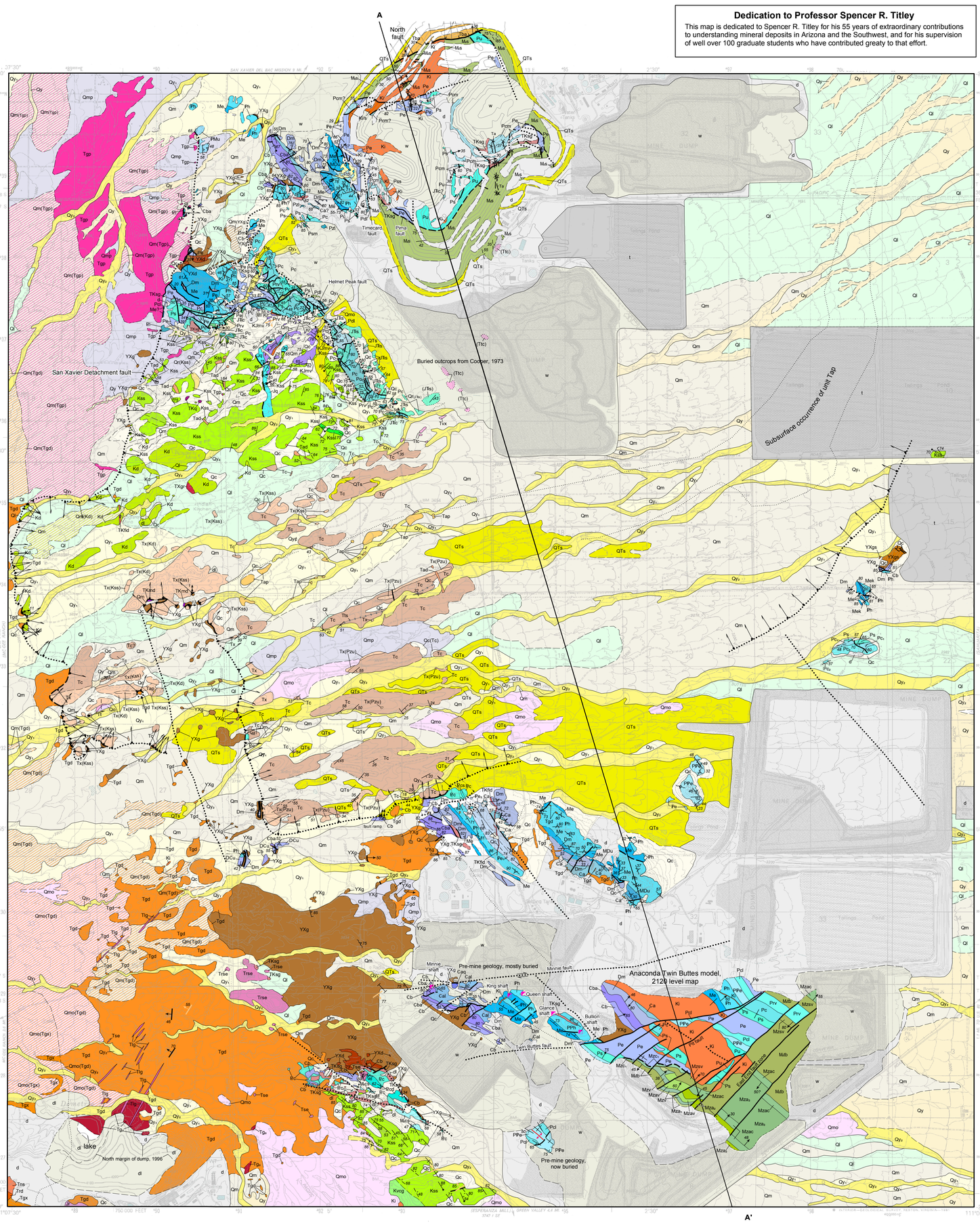
Citiation for this map:
Richard, S.M., et al., 2003, Geologic Map of the Twin Buttes 7½' Quadrangle, Pima County, Arizona: Arizona Geological Survey Digital Geologic Map 31 (DGM-31), version 1.1,1 sheet, scale 1:24,000.

Research supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under USGS award #02HQAG0016. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. government.

Dedication to Professor Spencer R. Titley

This map is dedicated to Spencer R. Titley for his 55 years of extraordinary contributions to understanding mineral deposits in Arizona and the Southwest, and for his supervision of well over 100 graduate students who have contributed greaty to that effort.



GEOLOGIC MAP UNITS

Map Units Related to Human Activity

w — **Excavated rock (less than 50 years)** - Heaps of weakly or non-copper-mineralized rock in mone areas. Very poorly sorted, weakly to non-consolidated diamicton with boulders up to about 4 m in diameter of various rock units from adjacent open pit mine. Heaps generally have flat tops, and steep, angle-of-repose slopes along boundaries.

t — **Mine tailings (less than 50 years)** — Very fine-grained pulverized waste rock from copper milling process. Tailings are deposited in a water slurry produced by the mill, captured in tailings ponds bounded by constructed dikes. Pulverized rock is deposited by settling from suspension in slurry, and water is pumped off or evaporates. Tailings deposits have large, flat surfaces on the top, and steep sides formed by banks of earthen impoundment dams. Northeast of the Twin Buttes mines, two large tailings ponds were prepared, but received little or no tailings fill. These are mapped as disturbed areas (unit d).

dl — **Mine dump and leach pads (less than 50 years)** — Heaps of weakly or non-copper-mineralized rock in mine areas. Very poorly sorted, weakly to non-consolidated diamicton with boulders up to about 4 m in diameter of various rock units from adjacent open pit mine. Heaps generally have flat tops, and steep, angle-of-repose slopes along boundaries.

d — **Disturbed ground (less than100 years)** — Areas that have been so profoundly disturbed by human activity as to completely obscure the preexisting natural surface.

Hillslope deposits

Qc — **Colluvium and talus (Holocene and Pleistocene)** — Unit Qc consists of locally-derived deposits on hillslopes. Colluvium is mapped only where sufficiently thick and extensive to obscure underlying bedrock. Deposits are very poorly sorted, ranging from clay to cobbles and boulders. Clasts typically are subangular to angular. Bedding is poorly defined and dips are quite steep, reflecting the steep depositional environment. Deposits are a few meters thick or less; thickest deposits are found at the bases of hillslopes. Probable Pleistocene deposits on more stable hillslopes are reddened and enriched in clay by pedogenic processes. Holocene deposits on more unstable hillslopes have minimal soil development.

Piedmont Alluvium

Quaternary and late Tertiary deposits cover the most of the eastern piedmont of the Sierrita Mountains. This alluvium was deposited primarily by larger streams that head in the mountains; smaller streams that head on the piedmont have eroded and reworked some of these deposits. Deposits range in age from modern to Pliocene. Much of the Sierrita piedmont consists of an exposed or shallowly buried bedrock pediment. The lower margin of the piedmont is defined by the intersection piedmont alluvial fans and terraces with stream terraces of the Santa Cruz River. Approximate age estimates for the various units are given in parentheses after the unit name. Abbreviations are ka, thousands of years before present, and Ma, millions of years before present.

Qy_2 — **Late Holocene alluvium (less than~2 ka)** — Young deposits in low terraces, alluvial fans, and small channels that are part of the modern drainage system. Includes alluvium in active wash channels. In upper piedmont areas, channel sediment is generally poorly to very poorly sorted sand and pebbles, but may include cobbles and boulders; terrace and fan surfaces typically are mantled with sand and finer sediment. On lower piedmont areas, young deposits consist predominantly of moderately sorted sand and silt, with some pebbles and cobbles in channels. Channels generally are incised less than 1 m below adjacent terraces and fans, but locally incision may be as much as 2 m. Channels are flood prone and may be subject to deep, high velocity flows in moderate to large flow events. Potential lateral bank erosion is severe. Channel morphologies generally consist of a single-thread high flow channel or multi-threaded low flow channels with gravel bars adjacent to low flow channels. Flood flows may significantly change channel morphology and flow paths. Downstream-branching distributary channel patterns - small, discontinuous, well-defined channels alternating with broad expansion reaches where channels are very small and poorly defined - are associated with the few young alluvial fans in the area. Local relief varies from fairly smooth channel bottoms to undulating bar-and-swale topography that is characteristic of coarser deposits. Terraces have planar surfaces, but small channels are common. Soil development associated with Qy2 deposits is weak.

Qy_1 — **Holocene alluvium (~2 to 10 ka)** — Older Holocene terrace deposits found at scattered locations along incised drainages throughout the Sierrita piedmont. Qy1 surfaces are higher and less subject to inundation than adjacent Qy2 surfaces, and are generally planar. Local surface relief may be up to 1 m where gravel bars are present, but typically is much less. Qy1 surfaces are 1 to 2 m above adjacent active channels. Surfaces typically are sandy but locally have unvarnished open fine gravel lags. Qy1 soils typically are weakly developed, with some soil structure but little clay and stage I to II calcium carbonate accumulation (see Machette, 1985, for description of stages of calcium carbonate accumulation in soils). Yellow brown (10YR) soil color is similar to original fluvial deposits.

Qy — **Undifferentiated Holocene alluvium (less than 10 ka)** — Includes Qy2, and Qy1 deposits. On upper piedmonts consists of small incised drainages where, at this scale, it was not possible to map surfaces separately. At the lower margin of the piedmont, unit Qy consists of young alluvial fans deposited by piedmont tributary streams interbedded with Santa Cruz River floodplain deposits (unit Qyr).

Ql — **Late Pleistocene alluvium (~10 to 130 ka)** — Deposits associated with slightly to moderately dissected relict alluvial fans and terraces. Extensive slightly to moderately incised tributary drainage networks are typical on Ql surfaces. Active channels are incised up to about 2 m below Ql surfaces, with incision typically increasing toward the mountain front. Ql fans and terraces are commonly lower in elevation than adjacent Qm and older surfaces, but the lower margins of Ql deposits lap out onto more dissected Qm surfaces in some places. Ql deposits consist of pebbles, cobbles, and finer-grained sediment. Ql surfaces commonly have loose, open lags of pebbles and cobbles and are moderately reddened; surface clasts exhibit weak rock varnish. Ql soils are moderately developed, with orange to reddish brown clay loam to light clay argillic horizons and stage II calcium carbonate accumulation.

Qm — **Middle Pleistocene alluvium (~130 to 750 ka)** — Deposits associated with moderately to highly dissected relict alluvial fans and terraces with strong soil development found throughout the map area. Qm surfaces are drained by well-developed, moderately to deeply incised tributary channel networks; channels are typically several meters below adjacent Qm surfaces. Well-preserved, planar Qm surfaces are smooth with scattered pebble and cobble lags; surface color is reddish brown; rock varnish on surface clasts is typically orange or dark brown. More eroded, rounded Qm surfaces are characterized by scattered cobble lags with moderate to strong varnish and broad ridge-like topography. Soils typically contain reddened, clay argillic horizons, with obvious clay skins and subangular to angular blocky structure. Underlying soil carbonate development is typically stage III, with abundant carbonate through at least 1 m of the soil profile; indurated petrocalcic horizons are rare.

Qm(Ks) — **Middle Pleistocene alluvium over Demetrie Volcanics pediment**

Qm(Tgs) — **Middle Pleistocene alluvium over Ruby Star granodiorite pediment**

Qm(Tgp) — **Middle Pleistocene alluvium over equigranular biotite phase, Ruby Star granite pediment**

Qm(YXg) — **Middle Pleistocene alluvium over diorite-granitoid pediment**

Qmp — **Middle Pleistocene alluvium veneer on pediment (~130 to 750 ka)** — Qm deposits forming thin veneer on pediment surface underlain by unidentified bedrock. Areas labeled Qm with a bedrock unit label in parenthesis (e.g. Qm(Tgd)) are pedimented surfaces on an identified bedrock unit with a veneer of Qm deposits. The label in parenthesis identifies the bedrock unit.

Qmo — **Middle to Early Pleistocene alluvium (~500 ka to 1 Ma)** — Deposits associated with deeply dissected relict alluvial fans. Qmo surfaces form broadly rounded ridges that are higher than adjacent Qm surfaces but not as high or eroded as adjacent Qo surfaces or the highest QTs deposits. Tributary drainage networks are incised 3 to 6 m, increasing towards the mountains. Eroded QTs deposits are occasionally exposed along some ridgetopes. Where well preserved, Qmo soils are strongly developed with a distinct dark red (5-2.5 YR), heavy clay argillic horizon and subangular blocky to prismatic structure. Carbonate accumulations are 1-2 m thick and range from stage III - V. Areas labeled Qmo with a bedrock unit label in parenthesis (e.g. Qmo(Tgd)) are pedimented surfaces on an identified bedrock unit with a veneer of Qmo deposits. The label in parenthesis identifies the bedrock unit.

Qmo(Tgt) — **Middle to Early Pleistocene alluvium over Ruby Star granodiorite**

Qmo(Tgp) — **Middle to Early Pleistocene alluvium over porphyritic phase, Ruby Star granite**

Qo — **Early Pleistocene alluvium (~500 ka to 1 Ma)** — Deposits associated with very old, high, deeply dissected alluvial fan remnants with moderately well preserved fan surfaces and strong soil development. Qo deposits and fan surface remnants are rare in the Twin Buttes quadrangle. Qo surfaces range from fairly smooth to broadly rounded. Qo deposits vary from cobbles and boulders to sand, silt and pebbles. Stage III to IV calcic horizons are typical, but not always present. Where surfaces are planar and well-preserved, red, heavy clay argillic horizons are typical, but may include pockets of moderately developed, reddish brown (7.5YR), sandy loam with scattered gravel lag. Qo surfaces record the highest levels of aggradation in the Santa Cruz Valley, and are probably correlative with other high, remnant surfaces found at various locations throughout southern Arizona (Menges and McFadden, 1981; Youberg and Helmick, 2001).

QTs — **Early Pleistocene to Pliocene alluvium (~1 to 2 Ma)** — Deeply dissected and highly eroded alluvial fan deposits. QTs surfaces are alternating broadly rounded ridges and deep valleys, with ridgecrests typically 10 to 30 meters above adjacent active channels. The thickness of QTs deposits is not known. QTs surfaces are drained by deeply incised tributary channel networks. QTs deposits include very coarse boulder and cobble hillslope deposits, moderately-indurated pebble to cobble conglomerates, sandy to bouldery alluvial fan deposits, and buried paleosols. QTs deposits are coarser towards the mountains and finer grained near the Santa Cruz River. Soils on ridgecrests are dominated by carbonate accumulation, which is typically stage V (cemented petrocalcic horizons with laminar cap). Carbonate liter is common on ridgecrests and hillslopes. Small pockets of preserved Qo and Qmo may be found along QTs ridges.

Qr — **Regolith deposits (Holocene and Pleistocene)** — Qr deposits form in-situ and vary from disaggregated, angular bedrock clasts to well-developed, reddened, clay-rich residuum, which grades into bedrock and retains original bedrock texture in the C horizon. Regolith is mapped when the underlying bedrock unit is unknown or too variable to map through the regolith.

Qr(JTrs) — **Regolith deposits over unit JTrs**— Qr deposits formed on Rodolfo Formation.

Qr(Kss) — **Regolith deposits over unit Kss** — Qr deposits formed on Cretaceous sandstone.

Sedimentary and volcanic rocks (Miocene or Oligocene)

Ta — **Andesitic dikes (Miocene or Oligocene)** — Dikes mapped in the Mission Mine are dark gray and aphyric. They occur in groups of 2-5 sub parallel dikes 0.5-3 m thick. Considered middle Tertiary because of the lack of mineralization in the rock and because they cut most of the structures in the pit.

Tad — **Intrusive andesite (Miocene or Oligocene)** — Andesite dike containing 1-3% fresh black hornblende, <4 mm diameter, < 1% fresh biotite, approximately 1 mm diameter, and 5-10%, 2-4 mm feldspar (probably plagioclase). Dikes are not as fractured as host rocks and could be younger than much or all tilting of host strata. Intrudes Helmet Fanglomerate (Tc).

Tba — **Mafic lava flows in the Mission Mine (Miocene or Oligocene)** — Generally massive, medium to dark gray mafic lava flows. Fine to very fine-grained groundmass consists of 40-50% plagioclase, with microlitic fabric in some flows, and 50-60% indiscernible mafic minerals. Some flows contain up to about 5% olivine phenocrysts up to about 1 mm in diameter. Fragmental, vesicular and massive textures are observed in the flows. Individual lava flows appear to be 5-20 m thick. A 15-20 m thick interval of laminated, red mudstone with interbedded lithic sandstone and sparse gypsum is present just above the North fault in the central part of its exposure in the pit (UTM 493130N 3540500E). Bedding it this unit is highly disrupted; no bedding was observed in the lava flows.

Ttc — **Crystal-rich tuff (Oligocene)** – Bedded tuff or reworked tuff, with ~1% biotite up to 1 mm, ~1% hornblende less than 1 mm, 30-40% quartz, up to 2 mm, ~30% feldspar, up to 2 mm, some of which is probably sanidine, and 3-5% reddish brown lithic fragments that are less than 5 mm and possible derived from aphytic volcanic rocks. Exposed only in a few small outcrops south of Helmet Peak. Sample SMR 03-456 from this unit yielded a 40Ar/39Ar isochron date of 58.2 ± 0.4 Ma (Terry Spell, UNLV, written communication, 2004).

TKmd — **Mafic dikes (Tertiary or Cretaceous)** — Very dark gray to black, finely crystalline to aphanitic mafic dike rock with chilled margins.

Tvx — **Volcanogenic breccia (Middle Tertiary or Cretaceous)** — Breccia derived from mixed rock types or where protolith is not clearly determined because of alteration. Includes areas where breccia protolith is either quartzose sandstone or granitic but can't tell because of pervasive hematite staining, and probable epidote and clay alteration products after mafic minerals(?) and feldspar. Includes highly cemented and indurated breccia cemented by silica-iron oxide matrix, now forms some resistant 5 meter blocks in rubble derived from breccia.

Helmet Fanglomerate

The Helmet Fanglomerate was defined by Cooper [1960]. reference exposures along a south-trending line between about UTM 493000E 3535700N and UTM 493000E 3531000N. The width of the Helmet Fanglomerate normal to the average strike of bedding is about 4275 m. Using an average dip of 42° (based on 32 measurements), the thickness of the Helmet Fanglomerate is 2860 m (9385 ft.). The unit consists mostly of conglomerate, with some sandstone. A porphyritic andesite lava flow and a thin tuffaceous sandstone form marker horizons within the unit. In the southwestern part of the outcrop area massive monolithologic breccia lenses are present within the unit. These appear to be associated with the trace of the San Xavier Detachment fault, and the map distribution of the andesite and tuffaceous markers suggests that they pinch out into the breccia zone.

Tc — **Conglomerate and minor sandstone (Miocene or Oligocene)** — Generally massive to poorly bedded (10-100 cm beds), poorly consolidated conglomerate, pale gray, tan, reddish brown, and brown. Clasts are generally matrix supported with sandy and silty matrix. Clasts are generally subangular, 1-50 cm, locally to 1 m and rarely to 5 m, and consist primarily of underlying Mesozoic quartz-rich sandstone and Demetrie mafic volcanic rock, with locally abundant quartzite, quartz-rich felsite, gray limestone marble, tan dolostone marble, and medium to fine grained felsic granitoids, and rare rounded quartzite pebbles and cobbles that are likely reworked clasts. Clasts look as if they could have been derived from local rock types. Some conglomerate contains a high proportion of red, silt-rich matrix and could represent debris flows. Forms low, debris-covered hills, with sparse outcrop.

Tap — **Andesite porphyry lava flows (Miocene or Oligocene)** — Porphyritic andesite with 30-45% plagioclase phenocrysts that are 5-25 mm diameter. Rock is stained with iron oxides and crumbly. Known regionally as "Turkey Track andesite" [e.g., Mieike, 1964].

Tt — **Tuff, reworked tuff, and tuffaceous sandstone** — Ten-meter-thick zone of friable sandstone, pale white to locally tan or light reddish tan, poorly consolidated medium-grained sandstone with 1-3% reflective biotite that looks fresh enough to date. Beds are 1-5 cm thick. This unit crops out in the area Damon and Mauger [1964] collected a K-Ar sample of "tuff" (biotite K-Ar date of 28.6±2.6 Ma from sample RM-01-64, [same as date #836 of Reynolds et al., 1986]), but tuff could be reworked and possibly contaminated by detrital biotite.

Tx — **Rock-avalanche breccia, undivided** — Breccia derived from mixed rock types or where protolith is not clearly determined because of alteration. Includes areas where breccia protolith is either quartzose sandstone or granitic but can't tell because of pervasive hematite staining, and probable epidote and clay alteration products after mafic minerals(?) and feldspar. Includes strongly indurated breccia cemented by silica and iron oxide, which now forms some resistant 5 meter blocks in rubble derived from breccia.

Tx(Kd) — **Rock-avalanche breccia derived from mafic Demetrie volcanic rocks**

Tx(Kss) — **Rock-avalanche breccia derived from sandstone** — Pervasively fractured to brecciated, indurate fine-grained to very fine-grained sandstone with abundant opaque minerals << 1mm diameter. Bedding generally not preserved because of brecciation and alteration, and breccia is clast supported. Breccia was derived from quartz-rich sandstone that is too well sorted and too poor in mafics to be Tertiary sandstone. Protolith identification are difficult because of pervasive acid alteration, bleaching, iron-oxide staining, and secondary jarosite(?) and limonite(?). Some iron-oxide alteration is younger than brecciation. At one location a solid mass of Kss (not brecciated) is exposed over a 5 x 10 m outcrop.

Tx(Pzu) — **Rock-avalanche breccia derived from carbonate rocks** — Breccia contains blocks and clasts of medium to dark gray limestone with numerous white calcite veinlets (Colina?) and medium-grained quartz-rich sandstone (Scherrer?) that is brecciated and silicified. In low relief area brecciia outcrops as string of boulders protruding above rubble of conglomerate cobbles and soil.

Altered Rocks (Late Cretaceous or Paleocene)

TKq — **Massive quartz (Paleocene or Cretaceous)** — Shattered but re-silicified, milky white, resistant hydrothermal quartz.

Tse — **Epidote-quartz altered granitoid (Paleocene)** — Ruby Star granodiorite in which mineral constituents have been replaced by quartz and epidote. Mapped as skarn in areas where replacement is extensive and intense enough to obliterate igneous texture in the rock. The epidote alteration makes the generally non-resistant granitoid more resistant to weathering, so that most of the hills in granite pediment areas exposed moderately to strongly altered rock. In the Senator Morgan Mine area, intense epidote skarn is developed in Ruby Star(?) granite adjacent to calsilicate skarn derived from Paleozoic rocks, suggesting that the alteration is related. Epidote skarn zones tend to be elongate NE-trending zones. Locally these zones grade to quartz veins, and rarely into fine-grained aplitic granite dikes, both trending northeast, suggesting that alteration is coeval with aplitic granite intrusion (unit Tg).

Tg_a — **Silica-iron altered granitoid (Paleocene)** — Medium grained, generally equigranular, biotite granite or granodiorite in which mafic minerals have been strongly altered to iron oxides. Protolith is Ruby Star granitoid. Plagioclase is typically altered to phyllosilicates(?) and alteration was possibly accompanied by silicification.

Tsg — **Garnet skarn (Paleocene)** — Massive garnet, garnet-diopside, and garnet-epidote skarn, with pods of relict marble, sandstone and quartzite. Protolith indeterminant. Generally has dark brown color. Primarily garnet-quartz skarn rock, locally including quartz rich veins with open-space-filling textures. At the Senator Morgan Mine site, skarn is more iron rich than elsewhere in this area, with black magnetite and chlorite or actinolite(?).

Laramide igneous rocks (Paleocene or Late Cretaceous)

Ttg — **Biotite leucogranite (Paleocene)** — Fine-grained granitoid contains 3-4%, 1-4 mm biotite. Forms northeast-trending dikes. Alteration has destroyed biotite in many areas and left orange stain on rock. Dike rock contains pyrite in some of these areas; dikes locally grade into quartz veins or vein-like epidote-silica-hematite alteration zones, suggesting these dikes are related to mineralization in the area.

Trd — **Rhyodacite porphyry (Paleocene)** – Porphyritic dacite, small body separates North Sierrita Porphyry (Tns) from porphyritic Ruby Star granodiorite (Tgx) in southwest corner of quadrangle. More abundant on adjacent Samaniego Peak quadrangle [Johnson et al., 2003].

Tns — **North Sierrita Porphyry (Paleocene) –** Fine- to medium-grained biotite monzogranite with phenocrysts of potassium feldspar up to 2cm long and 5-10% biotite. Intrude the Ruby Star granodiorite in adjacent Samaniego Peak quadrangle [Johnson et al., 2003]. Single small outcrop on this quadrangle in southwest corner. Hermann [2001] reports a U-Pb zircon date of 60.5 ± 0.2 Ma from a stock in the north wall of the Sierrita-Esperanza pit.

Tg — **Ruby Star granodiorite (Paleocene)**
A large composite pluton, consisting of three principal phases, described below. The porphyritic phase forms a central zone with the granodiorite and biotite granite forming concentric zones outward from the porphyritic phase. The phases from NNW trending elongate belts. Outcrops in the Twin Buttes quadrangle include the eastern part of the core zone, and parts of the eastern granodiorite and biotite granite zones. Contacts between the phases were not mapped in detail in the Twin Buttes quadrangle because of discontinuous pediment outcrop and access difficulties.

Tgp — **Biotite Granite phase** — Generally homogranular, medium-grained granitoid that contains 3-7% biotite in 2-5 mm diameter flakes, and locally abundant aplite and pegmatite dikes. The rock is porphyritic in a few areas, and 2-4 cm K-feldspar phenocrysts are occasionally observed. Poor outcrop on pediment makes mapping of various gradational phases impractical. Distinguished from YXg granitoids by presence of biotite in flakes as opposed to very fine-grain felty masses (characteristic of YXg), and the greater abundance of aplite in the Ruby Star granitoid. In areas where alteration obscures biotite crystal form, the mafic content of the rock was a criteria for distinguishing the two types, with the Ruby Star granodiorite generally having <8% mafic minerals and the Proterozoic granitoids having more. The reliability of this criterion is uncertain.

Tgx — **Porphyritic phase** — Medium-grained, porphyritic biotite granodiorite exposed in the southwest corner of the map area. This rock is known as the as the Esperanza quartz monzonite porphyry in the Sierrita mine area. A sample of this rock unit yielded a U-Pb zircon date of 64.3 ± 0.4 Ma [Hermann, 2001].

Tgd — **Granodiorite phase** — Equigranular biotite-hornblende granodiorite. This unit is relatively homogeneous, with few aplite or pegmatite dikes. Grain size is typically 3-5 mm.

Ki — **Porphyric hypabyssal intrusive rock (Paleocene or Late Cretaceous) –** Undifferentiated intrusive rocks in the Mission-Pima mine complex and the Twin Buttes mine. Rock weakly to intensly altered. Typically has very fine-grained quartz-feldspar groundmass with sparse to abundant quartz or feldspar phenocrysts, generally <5 mm diameter. K-feldspar phenocrysts 1-2 cm long were observed in the unit in the northern part of the Mission Mine complex. Labeled Ki's where rock is strongly altered and mixed with skarn.

TKfid — **Dacite intrusive rock (Paleocene or Late Cretaceous)** — North-trending dike intruding Paleozoic marbles at UTM 494160E 3531000N contains 5-7% crystals of black hornblende and clear plagioclase 1-2 mm long, in a pink-gray fine-grained groundmass of quartz and feldspar. The dike weathers to form tan, rounded boulders. Also includes white felsite dikes, crystal poor, with sparse 0.5-1 mm quartz crystals, and abundant sericite after feldspar(?); a few lenses of medium-grained granitoid are present.

TXgr — **Granitoid (Tertiary, Cretaceous, or Proterozoic)** — Granitoid of uncertain age, rock is too altered to correlate with local granitoid units. The nature of the bounding contacts is uncertain.

Kd — **Demetrie volcanics (Cretaceous)** — Texturally variable intermediate composition volcanic rocks. Includes some clearly volcanic-lithic sedimentary rocks, and probable hypabyssal intrusive phases. Generally consists of medium to dark gray rock with 5-40% 1-4 mm gray to chalky white plagioclase(?) and 2-15%, <2 mm mafic minerals (probably pyroxene). Flattened inclusions, represented by 1-10 cm long, 0.5-5 cm thick pits formed after lithic fragments(?), define fabric that could be related to horizontal flow and vertical flattening. Faint flow(?) banding, defined by differences in resistance to weathering, could be flow banding. Crude layering in autoclastic breccia also defines planar fabric element that could be related to lava flow over the Earth's surface.

Kss — **Angelica Arkose (Cretaceous)** — Consists mostly of fine- to coarse-grained, moderately to poorly sorted sandstone that varies from containing subequal amounts of quartz, feldspar, and lithic fragment to quartz-rich sandstone with up to perhaps 80% quartz. Magnetite laminations are common in less altered sandstone south and southwest of Helmet Peak, and are locally abundant. However, mineral content is generally difficult to discern because of common and pervasive alteration characterized by oxidation of mafic minerals, alteration of feldspar to phyllosilicates(?), iron-oxide staining, local pervasive secondary epidote and quartz veinlets, and moderate to severe fracturing and locally severe crushing. Locally includes pebbly sandstone; clasts are up to 10 cm diameter, subrounded, and consist of quartzite, and rare 10-100 cm thick beds of brown to reddish brown mudstone. Near exposures of underlying mafic volcanic rocks (map unit KJmv), sandstone is dark and lithic rich and is associated with conglomerate or breccia that contains clasts of aphyric mafic volcanic rocks up to 8 cm in diameter. Truncated magnetite laminations reveal channels and clear top direction in the area south and west of Helmet Peak. Top-to-east and top-to-southeast facing is consistent with exposed deposition contact at base where sandstone of this unit rests depositionally on volcanic rocks of map unit KJmv.

Kssl — **Calcareous sandstone marker** — Pale gray limey sandstone to sandy limestone, approximately 10 m thick, located south of Helmet Peak.

Kvcg — **Volcanic-lithic conglomerate (Cretaceous)** — Massive angular to sub-angular volcanic-clast conglomerate. Clasts are generally dacitic in appearance, with light to medium gray very fine-grained groundmass and 1-2 mm feldspar crystals. The contact with sandstone Kss is gradational.

KJmv — **Mafic to intermediate volcanic rocks (Cretaceous or Jurassic)** — Near Mission Mine this unit includes massive mafic volcanic or hypabyssal rocks, massive breccia, bedded breccia and sandstone and conglomerate derived from mafic volcanic rock, and possibly tuffaceous rocks and tuff. Massive mafic to locally intermediate composition volcanic rock and/or hypabyssal intrusions grade through massive breccia to rock that looks crudely layered. Thin volcanic lithic sandstone beds are sparse.

Hydrothermally altered Mesozoic Strata in the Twin Buttes Mine

Descriptions of these rocks are based on Barter and Kelly [1982]

Mzt_b — **Mesozoic strata of Twin Buttes (Mesozoic)** — Undivided Mesozoic metasedimentary and metavolcanic strata mostly east of the East Fault zone.

Mza_3 — **Silty arkose (Mesozoic)** — Biotitized, siliceous silty arkose, local lithic pebbles. Probably correlates with Angelica Arkose.

MzaC — **Arkosic conglomerate (Mesozoic)** — Conglomerate, contains abundant pebbles of tuff. 50-300 ft. thick. Probably correlates with Angelica Arkose (unit Kam of Cooper [1971]?).

Units correlated with Whitcomb Quartzite by Barter and Kelly [1982]

$MzaV$ — **Arkose and volcanic rock (Mesozoic)** — Interbedded arkosic quartzite and volcanic rocks.

Mza_2 — **Arkosic quartzite (Mesozoic)** — Arkosic quartzite with lesser silty arkose.

MzV — **Rhyodacitic volcanic rocks (Mesozoic)** — Porphyritic rhyodacitic tuff, partly welded. Probably correlates with unit Jt.

Mza_1 — **Silty arkosic quartzite (Mesozoic)** — Arkosic quartzite with silty arkose dominant.

Mzsv — **Microcrystalline strata (Mesozoic)** — Siliceous, very fine-grained, often strongly biotitized, clastic rocks. Volcanic detritus present. Lenticular carbonate unit present 20-40 feet above base; this unit is up to 40 feet thick. Correlated with Rodolfo Formation of Cooper [1971].

Mzc_1 — **Carbonate-rich conglomerate (Mesozoic)** — Discontinuous unit composed of altered carbonate rock, siltstone and quartzite. Coarse clastic texture locally preserved. Interpreted as conglomerate composed mainly of carbonate rock with blocks of siltstone and shattered and brecciated quartzite. Field relationships mapped by Anaconda geologists and regional considerations strongly suggest that this unit occupies a fault zone, not an unconformity. Thickness estimated to be 0-250 feet.

Hydrothermally altered Mesozoic Strata in the Mission Mine Complex and Senator Morgan Mine area

Ms — **Strongly altered clastic rocks (Mesozoic)** — A wide variety of clastic rocks are exposed in the Mission-Pima mine; all are moderately to strongly altered. The most common rock type observed in outcrops of this unit is interpreted to have a protolith that was fine-grained sandstone containing a significant percentage of feldspar or lithic fragments. On the south rim of the pit, bedrock outcrop mapped as 'Ka' by Cooper is now an abandoned mill site, and the hill has been removed. Rock in these outcrops is a medium-to coarse-grained feldspathic quartz arenite with magnetite laminations, very similar to sandstone observed along the west base of Helmet Peak mapped as upper member of Angelica Arkose by Cooper [1971]. The protolith for Mesozoic clastic rocks observed along the north side of the pit, in the footwall of the North Fault, includes volcanic-lithic sandstone and conglomerate similar to unit KJmv. These units could not be mapped in sufficient detail to interpret stratigraphic relationships, but appear to correlate with both Amole Arkose and Rodolfo Formation.
In the Senator Morgan Mine area consists of fine to very fine-grained sandstone, with less common medium grained sandstone, siltstone and calc silicate and rare pebble to cobble conglomerate, and limestone. Field examination suggests that sand composition varies from quartz-rich (>95% quartz) to very roughly subequal amounts of quartz, feldspar, and lithic fragments (QFL sandstone). Bedding in calc-silicate rocks could be transposed. Alteration in this area is generally severe, with much secondary epidote, garnet, and possibly quartz. Original composition is difficult to discern in many exposures.

Mesozoic Strata

Jq — **Whitcomb Quartzite (Jurassic)** — Light tannish orange fine-grained quartzite with vague relict bedding laminations that appear to define large-scale cross beds. One bed preserved adjacent to a rhyolitic tuff in andesitic volcanic rocks west of Helmet Peak.

Jt — **Welded Tuff (Jurassic)** — Purplish-red tuff, 20 to 30 m thick, with abundant flattened pumice fragments, 2-5% 1-3 mm feldspar, most of which is probably K-feldspar, and <1% 1 mm biotite. Also contains numerous, <<1 mm opaque grains (probably magnetite). A Jurassic age is inferred because of the association of the tuff with quartz arenite (Unit Jq) that is thought to be regionally correlative with Jurassic eolian quartz arenite [e.g., Bilodeau and Keith, 1986; Busby-Spera, 1988; Tosdal et al., 1989]. Contacts with quartzite and andesitic volcanic rock not exposed.

Jr — **Rhyolite (Jurassic)** — Generally pale gray, massive rhyolite with faint and vaguely defined aphyric silicic lithic fragments visible on weathered surfaces. Small outcrop in southwest corner of map area, where unit is intruded by Ruby Star granodiorite (Tgd).

JTrs — **Rodolfo Formation (Jurassic or Triassic)** — Generally very poorly exposed sandstone with interbedded dark reddish mudrock. Sandstone petrography appears to be quite variable, ranging from mostly volcanic lithic to quartzofeldspathic; quartz content of sandstone estimated to vary from 40 to 95%. Conglomerate clasts are up to 15 cm diameter, subrounded, consist of carbonate, fine grained quartzite, and chert(?). Bedding is variable from outcrop to outcrop, which in combination with poor exposure, makes determination of stratigraphic sequence impossible. Contact with Angelica Arkose placed between sandstones with reddish mudrock interbedded (commonly identified by float), and more massive, generally gray to brown sandstone and mudrock. Angelica Arkose in general appears to be less volcanic-lithic. General character of unit is very similar to lower Mesozoic clastic rocks in Waterman Mountains and Empire Mountains.

JTrc — **Basal sandstone and conglomerate (Mesozoic)** — Basal Mesozoic sandstone and conglomerate. Medium to coarse-grained feldspathic quartz sandstone with rounded chert and quartzite pebbles to cobbles distributed throughout unit. Sandstone occasionally contains detrital muscovite. Poorly exposed and highly disrupted at contact between Concha or Rainvalley formations and Mesozoic strata north and south of Helmet Peak.

Hydrothermally altered Paleozoic rocks of the Senator Morgan Mine area

Pu — **Undifferentiated Paleozoic rocks (Paleozoic)** — Shown in cross-section only.

Pc — **Carbonate rocks (Paleozoic)** — Interlayered tan dolomite marble and white calcite marble, with scattered calc-silicate gneissic layers. Layering is generally 2-20 cm thick. Silty protolith zones now contain calc-silicate minerals (epidote, garnet?) that form 2-20-mm-thick laminations, and siliceous zones that weather to produce ribs. Layering is defined by differential weathering and by color variations that probably reflect different amounts of silica, but color variation is commonly subtle. Unit also includes tan, gray, and orangish brown siltstone and calc-silicate granofels, and tan, gray and white calcite or dolomite marble.

Pcd — **Carbonate rocks, dominantly dolostone (Paleozoic)**

Mcs — **Calcsilicate granofels, siltstone, and sandstone (Mesozoic)** — This unit, exposed only in the Senator Morgan mine area, consists of fine to very fine grained sandstone, with less common medium grained sandstone, siltstone and calcsilicate granofels and rare pebble to cobble conglomerate, and limestone. Field examination suggests that sand composition varies from quartz-rich (>95% quartz) to very roughly subequal amounts of quartz, feldspar, and lithic fragments (QFL sandstone). Bedding in calc-silicate rocks could be transposed. Alteration in this area is generally severe, with much secondary epidote, garnet, and possibly quartz. Original composition is difficult to discern in many exposures.

Metamorphosed Paleozoic rocks of the Mission Mine Complex

Rocks in the pit at the Mission Mine complex were found to be too complexly interleaved to map in the time available. Larger-scale units were defined based on the general character of the rocks interleaved in a given area. ASARCO mine model maps for the 3350, 3150, 2950, 2750 and 2550 levels were used to assist in locating contacts and interpreting structure.

Pu — **Epitaph dolomite marble, Scherrer quartzite, and Concha marble (Permian protolith)** — Structurally mixed, altered dolomite and calcite marbles, quartzite, and garnet and diopside skarn. Interpreted to represent hydrothermally altered, metamorphosed structural zone similar to that mapped on the south side of White Hill.

Pcs — **Concha marble, Scherrer quartzite and skarn (Permian protolith)** — Complexly faulted(?) and metamorphosed/altered Concha Limestone and Scherrer Quartzite with zones of moderate to intense garnet and diopside skarn development obscuring the protolith.

Pcm — **Concha marble (Permian protolith)** — Massive, fine- to medium-grained, light and dark gray mostly calcite marble; color variations define crude layers in some areas, in others they are irregular, and do not define a fabric. Irregular zones of garnet skarn are developed within the marble. Marble included with this unit on the west side of the pit, near Mineral Hill is darker gray and more prominently banded (light and dark gray) on a scale of 10-20 cm than marble on the east side of the pit, and may represent a different unit (upper Abrigo?) or simply a different deformation history.

Pss — **Scherrer quartzite and skarn (Permian protolith)** — Skarn may be derived by metamorphism of dolostone units in Scherrer.

Pes — **Undivided Earp, Epitaph, and Scherrer formations, and skarn (Permian Protolith)** — Structurally mixed quartzite, fine-grained dolomitic marble, calc-silicate granofels, garnet skarn, and diopside skarn. Lacks lenses of calcite marble found in Unit Pu.

Paleozoic Strata outside of hydrothermally altered areas

Prv — **Rainvalley Formation (Permian)** — Thick-bedded light to dark gray dolostone and calcareous dolostone. Chert lenses and stringers are present in many beds, but nowhere as abundant as in the lower Concha. The Concha-Rainvalley contact is