DETAILED GEOLOGIC MAP AND CROSS SECTIONS OF THE RAMSAY MINE AREA, SOUTHEASTERN PLOMOSA MOUNTAINS, WEST-CENTRAL ARIZONA

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MAP UNITS

Late Tertiary and Quaternary deposits

Qs Undivided alluvial sediments. **(Quaternary)** Undivided alluvial sediments; includes non-indurated to poorly indurated sand, silt, and gravel. Generally includes alluvium in active channels, old alluvium underlying adjacent terraces, and some colluvium.

Qtc Talus and colluvium. **(Quaternary)** Includes talus with little or no matrix and colluvium mantling hill slopes.

QTs Boulder and cobble conglomerate. **(Quaternary or Tertiary)** Moderately indurated sandstone and conglomerate, generally buff color; underlies highest geomorphic surfaces preserved. Generally coarser grained and more indurated than Quaternary units. Surfaces on top of this unit typically have thick pedogenic carbonate armor.

Tertiary volcanic rocks

Tb Basalt or basaltic andesite. **(Miocene)** Basalt or basaltic andesite lava flows. Rock is light to dark grey on fresh surfaces, with a very fine-grained groundmass, and 1-5% phenocrysts, in varying proportions, of olivine (variably altered to iddingsite), pyroxene and plagioclase, typically 1 mm or less in diameter. Where flows are clearly delineated by basal breccia and scoria zones, they are 2-10 m thick. This unit includes Tbl and Tbu where they have not been differentiated.

Tbu Olivine-pyroxene basalt. **(Miocene)** Vesicular basalt lavas with a dark grey very fine-grained groundmass and phenocrysts of pyroxene and olivine (mostly altered to iddingsite) in varying amounts. Distinguished from lower unit by absence of plagioclase phenocrysts. These basalts are typically untilted. The thickest section, on Black Mesa, is about ~90 m thick. Seventeen individual lava flows can be counted in the thick section expose at the north tip of Black Mesa.

Ttc Conglomeratic tuffaceous sediments. **(Miocene)** Massive conglomerate with light grey tuffaceous matrix. Contrast with Tts in lack of bedding partings. Rude alignment of clasts indicates bedding. Clasts include phyllitic, strongly cleaved Jurassic(?) volcanic rocks, maroon fine-grained sandstone and white quartzite from Crystal Hill formation. May be debris flow deposit or block tuff.

Tbs Basaltic pyroclastic rocks. **(Miocene)** Red to brown basaltic lapilli to block tuff consisting of scoria, generally poorly indurated and massive. Clasts range from <1 cm to about 1 m in diameter.

Tbl Plagioclase-pyroxene basalt. **(Miocene)** Vesicular basalt lavas with sparse phenocrysts of plagioclase, ranging in size from 1 mm long acicular crystals to 2 mm blocky phenocrysts. Tiny pyroxene and olivine crystals are also present. Apparently tilted 10-15°; dips appear to decrease up section. Overlies unit Tt concordantly. Overlain concordantly by Tbu west of northern part of map area.

Tmi Intrusive basalt or basaltic andesite. **(Miocene)** Basalt or basaltic andesite lithologically identical to unit Tb, but occurs in irregular dikes.

Tt Welded tuff. **(Miocene)** Brown weathering dacite(?) tuff containing 5-7% 1 mm crystals of hornblende and plagioclase, with sparse biotite, and trace amounts of quartz and pyroxene. At base is a dark brown porcelaneous densely welded zone. Fiamme are black and glassy in densely welded zone, and light brown (lighter than matrix) in overlying welded tuff; they are generally small (3-5 cm long, ~1 cm thick). Lithic fragments compose about 5% of rock, and consist of dark to light grey and red-brown felsite.

Tf Felsite lava. **(Miocene)** Light pink grey flow banded felsite containing 2-4% 1 mm crystals of feldspar and biotite. Black vitrophyres are present at the base of the unit and within the felsite in several other places. Locally includes interbedded lapilli tuff. In northeast part of map area may be partly intrusive. Sherrod and others [1990] report a biotite K-Ar date of 19.8 ± .4 Ma (biotite) from this unit, and correlate it with the 'older hornblende-biotite andesite' of Miller [1970], which has yielded K-Ar dates of 19.6±.6 and 20.7 ±.6 Ma (hornblende and biotite respectively) [Miller and McKee, 1971; recalculated to new decay constants].

Tfi Intrusive felsite. **(Miocene)** Lithologically identical to felsite lava, but flow foliation becomes steep, and contacts are clearly intrusive. Contacts with JKs are intrusive. Contact with Tf is approximate; transition from intrusive to extrusive cannot be unambiguously located.

Tts Tuff and tuffaceous sediments. **(Miocene)** Buff to white thin to medium bedded massive tuff and laminated reworked or air-fall tuff. Crystal and lithic content is variable. This unit is a catch-all for the thin tuffaceous units interbedded with basalt, felsite and conglomerate in various parts of the Tertiary section. Irregular and generally anomalously steeply dipping attitudes measured in this unit where it is deposited on pre-Tertiary rocks reflect pre-existing topography. In the southeastern part of the map area, two distinct tuffaceous units have been included in Tts. The lower, which overlies Tc when it is present, is characterized by abundant 2-4 mm sanidine and 1-2 mm biotite crystals, and the presence of pre-Tertiary lithic fragments. The upper Tts unit is interbedded in basalt lava flows, and is characterized by its paucity of crystals or lithic fragments. In the canyon on the southeast side of Black Mesa, in the southern part of the map area, the lower part of the Tts section, with a maximum thickness of approximately 65 m, dips 30-50° to the S or SW; dips decrease up section, and on the order of 60 m of untilted tuff underlies the basalt of Black Mesa. In the northern and NE part of the map are the unit includes pumiceous tuff which weathers to a distinctive pitted surface because the pumice clasts are eroded before the ash. The tuffaceous rocks overlying Tc thicken to the east and are about 100 m thick at the SE edge of the map area. The thickness of these tuffaceous rocks is highly variable depending on proximity to sources that apparently lay to the south and southeast. Contacts with felsite (unit Tf) and welded tuff (Tt) are gradational zones of increasing welding. Other contacts are generally abrupt.

Tc Conglomerate. **(Miocene)** Massive cobble to boulder conglomerate. Clasts include all pre-Tertiary units, but clast composition is variable from place to place. Conglomerate on the slopes of Black Mesa in the western part of the map area is mostly pebble to cobble conglomerate, and consists of clasts of Crystal Hill formation (JKh), strongly foliated Jurassic volcanic rocks (quartz porphyry), and Paleozoic sedimentary rocks. In the southeastern part of the map area, the conglomerate coarsens dramatically and is composed almost entirely of clasts of relatively unmetamorphosed, non-cleaved JKh, some up to about 5 m in diameter. The irregular distribution of the conglomerate in the southern part of the map area suggest the conglomerate was deposited on a steep paleotopography. The regional distribution of JKh, along with rare clast imbrication in the conglomerate, strongly suggests that the source was outcrops of JKh at the southern edge of the map area or other outcrops of this unit further to the south. The conglomerate is interpreted as coarse alluvial deposits and possible debris flow deposits. The thickness is highly variable, up to a maximum of about 190 m.

Tbx Monolithologic breccia. **(Miocene or Oligocene)** Bodies of rock derived from a single parent rock unit, which consist of relatively coherent blocks up to 10 m in longest dimension enclosed in a matrix of breccia with comminuted rock matrix. This unit is interpreted rock avalanche deposits. Contact with coherent (but typically shattered) rock is mapped where preexisting internal structure in the parent rock (e.g. bedding, cleavage) becomes strongly rotated and disrupted between blocks.

Rocks related to McCoy Mountains Formation

Interbedded conglomerate, sandstone and mudstone in the Ramsay Mine area probably correlates with some part of the McCoy Mountains Formation [Harding and Coney, 1985; Richard and others, 1987; Stone, 1990; Tosdal and Stone, 1994] but due to uncertainty in the age and correlation of the strata within the map area, units are labeled based on purely lithologic divisions. All of these rocks are considered Jurassic or Cretaceous based on lithologic correlation of underlying volcanic rocks with dated Jurassic volcanic rocks in adjacent ranges [Reynolds et al., 1987; Tosdal et al, 1989] and are the interpretation that tilting of the section to its present steep SE dip is related to pre-latest Cretaceous deformation events.

JKp Porcelaneous sandstone and argillite. **(Cretaceous or Jurassic)** Thin to medium bedded argillite or sandstone. Constituent grains visible only in coarsest grain beds, which locally include grit and pebble to cobble conglomeratic sandstone. Rock is dense and tan to drab grey, with very smooth weathering surfaces, a dull luster, and poor conchoidal fracture. In sparse zones of calcite cementation, intricate ripple cross lamination in commonly visible; otherwise rocks is massive or plane laminated. Conglomeratic beds contain clasts of grey chert, quartzite and Jurassic(?) volcanic rocks. A lense of JKs-lithology sandstone interfingers along strike in upper part. The thickness reported is the maximum exposed thickness, but the top of the section is covered by Tc, so the actual maximum thickness may be greater. Basal contact with JKs interbedded and coincides with a zone of structural disruption. Upper contact with JKs is abrupt as SW end of the strike belt, but the two units interfinger to the NE as JKp thickens. The maximum exposed thickness is 480 m.

JKps Argillitic shale. **(Cretaceous or Jurassic)** Non-resistant pink to yellow-tan laminated siliceous shale, with parting along laminations so that rock weathers to thin plates. Rock has smooth weathering and dull luster characteristic of unit JKp, but appears finer grained and weathers into thin plates. This lithology is mapped in three different locations, with different neighboring units, but always with at least one contact in a zone of structural complexity. Abundant JKd is always associated with this unit. The approximate stratigraphic thickness exposed in the 2 least disrupted sections is 100 m. Depositional contacts with underlying JKh and JKs and overlying JKp are gradational. Other contacts are sheared or disrupted to the point that their original nature is not clear.

JKd Diorite intrusions. **(Cretaceous or Jurassic)** Numerous sills and irregular intrusions of fine to very fine-grained equigranular diorite or gabbro, consisting of altered hornblende(?) and plagioclase. Hornblende typically altered to chlorite and actinolite(?); plagioclase commonly sericitized. Some sills are porphyritic with crystals of hornblende or plagioclase in varying proportions. Occurs as sills within JKs up to about 135 m thick. Lithological similarity to eruptive rocks of unit JKdf suggests that these sills intruded during or very soon after deposition of unit JKs.

JKdf Fragmental mafic rocks. **(Cretaceous or Jurassic)** Dark grey green fine to very-fine grained andesite or basalt often with 5-25% vesicles. Fragmental texture common, some zones look like autobreccia associated with lava flows, others may be peperite. Interbedded tuffaceous rocks are present. Typically finer grained and much more texturally variable than JKd sills of similar thickness.

JKc Conglomerate. **(Cretaceous or Jurassic)** Massive pebble to boulder conglomerate. Clasts include Jurassic volcanic rocks (Jv), grey Paleozoic carbonates, grey chert, sparse lithofeldspathic sandstone (recycled Mesozoic?), possible JKd, and vitreous quartzite. Bedding is rarely indicated by thin sandstone lenses. Clasts are rounded to sub-rounded. Contact at base of section is gradational in northern part of strike belt interbedded in middle part of JKs section; to south, on slopes of Black Mesa, the basal contact is clearly a fault. Lateral continuity between the two outcrop areas is subject to interpretation. This conglomerate lense is about 160 m thick.

JKcs Conglomerate and sandstone. **(Cretaceous or Jurassic)** Heterogeneous, interbedded sandstone and conglomerate. Fine-grained volcanic lithic sandstone, quartz-rich lithofeldspathic grit, pebble to cobble sandy conglomerate, and sparse 20-40 cm thick oncolitic limestone beds. Medium to thick bedded; fine-grained sandstone is locally laminated. Low-angle cross bedding is present in coarser-grained sandstone. Clasts in conglomerate include abundant vitreous quartzite; other clast types observed include Jurassic(?) quartz-porphyry, grey crystalline carbonate (Paleozoic?), Proterozoic(?) metavolcanic rocks with a laminated differentiated foliation, and sparse lithofeldspathic sandstone (recycled Mesozoic?). Contacts at base of section is clearly a fault of unknown magnitude. Contact at top of section is in zone of structural disruption within which beds go from overturned in JKcs to upright in stratigraphically(?) overlying JKps; interbedding of the two units near the contact suggests that this is a disrupted depositional contact. The unit is at least 140 m thick.

JKf Fine-grained clastic rocks. **(Cretaceous or Jurassic)** Very thin bedded, locally laminated, mudstone, siltstone and very fine-grained lithofeldspathic sandstone. Thin cobble conglomerate beds are present. Generally light tan grey to grey green weathering. Similar fine-grained sediments are interbedded throughout JKs unit; these are mapped separately where thick enough to show. Based on the presence of tool marks on the soles of beds, graded beds, and partial bouma sequences, it seems likely that this unit was deposited as lacustrine turbidites at least in part. Thick JKf sections are invariably associated with thick JKc lenses, except in stratigraphically highest part of the section near contact with JKh. Contacts are typically gradational where exposed. Up to about 100 of this unit are exposed in one section.

JKs Sandstone. **(Cretaceous or Jurassic)** Mostly fine to coarse grained, brown weathering, thin to medium bedded lithofeldspathic sandstone, with siltstone or mudstone partings. Interbedded coarser-grained intervals, with more abundant conglomeratic sandstone, or finer-grained intervals with more abundant siltstone, mudstone and interbedded oncolitic limestone are present throughout the section. In the lower part of the section just north of Black Mesa (UTM zone 12, 3721900N, 222000E), a series of fining upward sequences, from conglomerate through sandstone to mudstone with sparse interbedded oncolitic limestone is present, capped by a massive conglomerate (unit JKc). Conglomerate beds locally contain clasts up to 20 cm in diameter; clast types include Paleozoic limestone, Jurassic(?) quartz-feldspar porphyry, a distinctive Jurassic(?) hypabyssal porphyry with 1 cm diameter blocky K-feldspar phenocrysts, and rare weakly foliated medium fine-grained biotite granitoid. In finer grained intervals, series of graded beds are occasionally observed. Aligned tool marks are observed on the upward facing base of sandstone beds in many places. Fossil hash (plant material?) is locally present in fine-grained units. Scattered beds of porcelaneous argillite or fine-grained sandstone become more common up section as the contact with unit JKp is approached. The thickness of the section is estimated at 1750 m, including the lenses of units JKc and JKf broken out on the map, and assuming that relatively little section is missing or repeated along the structural discontinuities where the dip changes from upright to overturned. This unit grades into volcanic-clast conglomerate along a poorly exposed contact at its base, and grades into unit JKp at the top.

JKh Crystal Hill formation. **(Cretaceous or Jurassic)** Interbedded quartzite cobble conglomerate, quartzite, calcareous quartz arenite, and fine to very-fine grained purple sandstone. Thin to thick bedded. Equivalent to continental red bed deposits of Miller [1970]. Informal name proposed by Richard et al. [1993] for lithologically distinct quartz-rich sedimentary rocks previously included as the basal units of the McCoy Mountains Formation [Harding and Coney, 1985; Stone, 1990; Tosdal and Stone, 1994]. Tops were not observed within the map area. The section is assumed to be upright. Base of section covered by Tc or late Cenozoic alluvium. Overlain gradationally by JKps, contact placed at the top of the last quartzite bed. A minimum of 530 m of Crystal Hill formation is exposed in the southern part of the map area.

Jurassic volcanic rocks

Jvc Volcanic-lithic conglomerate. **(Jurassic)** Massive conglomerate consisting of subangular to rounded cobbles and boulders of various Jurassic volcanic rocks in a matrix of volcanic lithic sandstone similar to Jvs. Grades upsection into lithofeldspathic sandstone of McCoy Mountains formation(?). Exposed thickness of unit increases dramatically to SSW along strike belt, due either to original stratigraphic thickening or to subsequent faulting. The maximum exposed thickness is 130 m. The basal contact is placed as the abrupt transition from massive volcanic rocks (Jxq or Jvp) to conglomerate. A gradational contact with sandstone of the McCoy Mountains formation(?) is poorly exposed for about 150 m along strike in the area NW of hill 2190 (UTM, zone 12, 3723600N, 222600E); otherwise the top of the unit is not exposed.

Jvs Volcanic lithic sandstone. **(Jurassic)** Greenish grey volcanic lithic sandstone derived from Jurassic volcanic rocks. Bedding rarely visible as faint lamination, fine-grained partings or grain-size variations.

Jvu Undivided volcanic rocks. **(Jurassic(?))** Very light grey phyllitic, strongly cleaved quartz-feldspar porphyry, with a sericitic groundmass. Probably derived from Jxt_1 or Jxt_2. Sandstone of Ramsay Mine section is superposed on this unit along a subhorizontal shear zone.

Jvq Quartz porphyry. **(Jurassic)** Light grey green color, massive quartz-feldspar porphyry. About 15 % crystals of quartz, feldspar and sparse biotite; characterized by round quartz phenocrysts up to 6 mm in diameter. Fiamme and lithic fragments very rare. Thins to NNE along strike belt. Thick ranges from 0 to 70 m.

Jvp Plagioclase porphyry. **(Jurassic)** Purple grey very fine grained groundmass with ~20% 2-5 mm diameter plagioclase crystals, ~3% 1-2 mm diameter biotite crystals, and a trace of 1-2 mm diameter quartz crystals. Locally has fragmental texture. Tuff and tuffaceous sandstone locally present at contact with Jva. Maximum thickness is 90 m.

Jva Crystal poor tuff **(Jurassic)** very light grey, porcelaneous, crystal poor rhyolite(?), with 5-10% 1-2 mm diameter crystals of quartz, biotite and feldspar in a very fine grained to aphanitic groundmass.Thickness ranges from 0- to 60 m.

Jxt_2 Quartz-feldspar porphyry. **(Jurassic)** Medium grey quartz-feldspar porphyry. 10-20% crystal; fiamme rare. Equant 2-3 mm quartz, feldspar and biotite phenocrysts. Biotite is more abundant than in Jxt_1. Thickens to NNE along strike belt from 280 to 380 m.

Jmi Mafic intrusive rocks. **(Jurassic)** Very fine-grained dark grey green groundmass of chlorite, plagioclase, epidote and calcite, with 10-15% 1 mm diameter plagioclase crystals. Similar dikes in Jdf unit are not differentiated. Intrudes Jxt_1 and Jdf.

Jdf Intermediate Volcanic Rocks. **(Jurassic)** Dacitic lava flows with associated fragmental rocks, lithic sandstone and hypabyssal intrusive rocks. The dacitic rocks are typically purple to dark grey, with an aphanitic groundmass and sparse quartz and feldspar crystals 1 mm in diameter; fragmental texture is common. Hypabyssal intrusions are typically greenstone lithologically identical to Jmi, locally with altered hornblende and plagioclase crystals 1-2 mm in diameter; some greenstone is vesicular. Chilled margins were also observed at some greenstone contacts. Includes lithologically indistinguishable rocks that both overlie and underlie unit Jxt_1. Thickness is difficult to determine because of apparent non-planar bounding surfaces of unit; the relatively stratiform part of the unit between Jxt_1 and Jxt_2 is between 0 and 140 m thick. Faulted at base against Kaibab Limestone. Contact with younger Jxt_1 is faulted, an abrupt depositional contact, or possibly intruded by Jxt_1 in various places.

Jxt_1 Quartz-feldspar porphyry. **(Jurassic)** Medium grey quartz-feldspar porphyry; 10-20% crystals; fiamme and 1-3 cm diameter angular volcanic rock fragments are common. Equant 2-3 mm quartz, feldspar and biotite phenocrysts. Quartz is more abundant, and lithic fragments and fiamme are more apparent than in Jxt_2. Unit thickens dramatically to NNE along strike belt. Irregular contacts with Jdf in northern part of strike belt suggest that part of this unit may be intrusive. Alternatively, unrecognized faults may be present. Thickness ranges from 400 to 830 m.

JYd Diorite. **(Jurassic or Proterozoic)** Texturally variable diorite, ranges from very fine to medium-fine grained. Dark greenish grey rock consists of hornblende and plagioclase altered to chlorite, calcite, epidote and albite(?). Occurs as sill (now vertical) intruding Yg just below nonconformity with Bolsa Quartzite. On west side of Black Mesa (outside the map area) may intruded Bolsa quartzite.

Paleozoic sedimentary rocks

Pk_2 Kaibab Limestone, unit 2. **(Permian)** Grey cherty limestone, thick bedded to massive. At the base is a recemented breccia, in which angular grey limestone blocks are cemented by silica. The breccia is interpreted to be a solution collapse breccia due to removal of evaporite deposits at the top of unit 1, similar to those observed in the Little Harquahala Mountains.

This breccia is only seen in the section on hill about 1.6 km west of summit 2748 (UTM 3723200N, 777050E). The base of unit 2 is placed at the base of the massive, resistant cherty limestone. Top of Kaibab unit 2 is faulted everywhere in this map area. Minimum thickness is 75 m.

Pk_1 Kaibab Limestone, unit 1. **(Permian)** Grey fossiliferous dolomite and dolomitic limestone; sandy at base in gradation into Coconino quartzite. Crinoid columnals 1-2 cm in diameter are common, Productid brachiopods also present. Least disrupted section is located about 1.6 km west of hill 2748 (UTM 3723250 N, 776950 E). Capped by an interval of poorly exposed tan, silty sandstone and laminated algal(?) limestone. The base of the Kaibab Limestone is placed where the white Coconino quartzite abruptly becomes calcareous and develops a dark desert varnish. This basal calcareous quartz arenite typically forms a prominent dark ledge. The top of Kaibab unit one is placed at the slope forming sandy interval beneath the massive cherty limestone of unit 2. Thickness is 67 m.

Pk Undifferentiated Kaibab Limestone. **(Permian)**

Pkc Undifferentiated Kaibab Limestone and Coconino Quartzite. **(Permian)**

Pc Coconino Quartzite. **(Permian)** Very thinly bedded white vitreous quartzite; high-angle eolian cross beds are rarely visible. Typically highly fractured and thus a slope-forming unit. Some greenish mudstone parting are present. Base is placed at abrupt transition from red-brown sandstone of Hermit into white quartzite. Top is placed at abrupt transition up section into calcareous sandstone of basal Kaibab. Thickness between 275 and 310 m; variation may be due to structural thickening or stratigraphic variation.

Ph Hermit(?) Formation. **(Permian)** Red-brown, thin to very thin bedded fine-grained sandstone or argillite. A limestone and chert pebble- to cobble-conglomerate bed about 1 m thick is locally present in the upper part. Contact with Supai formation is placed where non-friable, non-calcareous sandstone or argillite become predominant. Upper contact with Coconino Quartzite placed at abrupt transition to white quartzite. Thickness between 20 and 30 m.

Ps Supai Formation. **(Permian and Pennsylvanian)** Calcareous quartz arenite, interbedded with sandy limestone, vitreous quartzite and purple siltstone; medium to thick bedded. At the base is a 10-15 m thick interval of dark red brown very fine-grained sandstone and mudstone. Contact with Redwall Limestone placed where limestone appears at the base of the basal red-brown clastic unit. The contact with the Hermit formation is placed where non-friable dark red argillite becomes predominant. Thickness is 190 m.

Mr Redwall Limestone. **(Mississippian)** Base of formation is massive light grey limestone about 3 m thick; within which alternations between micrite and bioclastic calcarenite define bedding. Brachiopod and crinoid fragments are present, along with sparse well rounded quartz grains. Upper part is massive limestone with lenticular stratiform chert nodules. Concentric structure within these nodules is locally preserved, and in outcrops just west of the Six Price mine, lamination and small scale cross bedding in the siliceous nodules suggest that the originated as sandy beds. Sparse corals are present in these outcrops as well. At the top the the section a paleo-karst zone is preserved, with carbonate cemented breccias and irregular (cavern-filling?) pods of purple mudstone. Contact with Martin is placed at the base of the first thick limestone bed. Upper contact with Supai Formation is placed at the top of the karst interval where limestone masses disappear. Thickness is 120 m.

Dm Martin Formation. **(Devonian)** Medium bedded dolomite and dolomitic limestone. Basal bed is a resistant, 1 to 1.5 m thick grey crystalline carbonate bed with laminated calcareous sandstone in its upper half. Above this, the lower half of the formation is dark grey, medium-bedded dolomite. This is overlain by a poorly exposed 5~ m interval of light pink grey, calcareous, fine-grained sandstone. Above this is interbedded, massive, medium to dark grey dolomite and finely laminated, light to medium grey dolomite. Total thickness is 93 m.

Ca Abrigo Formation. **(Cambrian)** Thin to very thin bedded quartzite and mudstone. Coarsening upward cycles from mudstone to very thin-bedded fine grained feldspathic sandstone are present in the central part of the unit. Thickness is 57 m.

Cb Bolsa Quartzite. **(Cambrian)** Thin to medium bedded feldspathic and arkosic quartzite. Grades from arkosic grit at basal contact with Yg to thin-bedded fine grained feldspathic sandstone at top. Top of unit is a 10 m thick interval of thinning and fining feldspathic quartzite beds; the contact is placed above the last quartzite bed. Thickness is 272 m.

Proterozoic rocks

Yg Monzogranite. **(Proterozoic)** Coarse grained, slightly porphyritic monzogranite. Consists of 30-35% quartz in 1-5 mm anhedral grains, 30-35% plagioclase in 1-4 mm blocky subhedral grains, 15-25% K-feldspar in anhedral 2-8 mm grains and in elongate blocky, zoned phenocrysts 2-3 cm in diameter, and 3-5% biotite in 1-3 mm very fine-grained recrystallized clots. Equivalent to coarse grained quartz monzonite of Miller [1970]. Lithologically identical to Socorro Granite in western Harquahala and Little Harquahala Mountains.

Discussion of Mesozoic stratigraphy

Several lines of evidence suggest correlation of the Ramsay Mine clastic section with the section in the Granite Wash Mountains to the northeast. Both sections are intruded by abundant mafic sills [Laubach et al., 1987]. The sandstones in the two sections are lithologically similar, but also resemble sandstone in the type section of the Apache Wash facies in the southern Plomosa Mountains [Richard et al, 1993] and the Apache Wash facies rocks of the southern Little Harquahala Mountains [Richard, 1982; Spencer et al, 1985]. In contrast to the Apache Wash sections in the southern Plomosa Mountains and southern Little Harquahala Mountains, which are large-scale fining upward sequences, the Ramsay Mine and Granite Wash sections show no consistent pattern of fining or coarsening up section. Fine grained intervals that are probably lacustrine turbidites are present in both sections. Reconstruction of Tertiary extension in the region [Spencer and Reynolds, 1991; Richard, 1994] places the Ramsay Mine section on strike with and much closer to the Granite Wash section. In the Granite Wash Mountains, metamorphic grade and the degree of deformation increases rapidly to the southwest. A continuation of this trend to the southwest would be consistent with the unmetamorphosed and relatively non-cleaved condition of clastic rocks in the Ramsay Mine section.

The relationship of the Ramsay Mine section to the Crystal Hill formation at the southeastern edge of the map area is unclear. The contact between the porcelaneous shale (JKps) and Crystal Hill formation is interpreted to be depositional because the contact is concordant to bedding, and very fine-grained sandstone interbedded with quartzite at the top of the Crystal Hill section resembles the overlying shale. Disrupted bedding and abundant irregular diorite bodies obscure relations between the shale units (JKps and JKf) and the typical Apache Wash-type lithofeldspathic sandstone (JKs) to the NW, adjacent to the Tertiary normal fault. The contact between the shale (JKf) and sandstone (JKs) is interpreted as a fault because bedding in the sandstone can locally be seen to be discordant with the contact, and disruption in bedding on both sides of the contact seems to increase towards the contact. No faults rocks were observed in the immediate vicinity of the contact. Its trace suggests that the contact is steep or south-dipping.

Structure

Pre-Tertiary rocks in the Ramsay Mine area form a southeast-facing homocline with Proterozoic granitoid at the base, overlain sequentially by a cratonic Paleozoic section, Jurassic volcanic rocks and Jurassic or Cretaceous clastic rocks. The strata dip steeply, and are locally overturned through most of the section up to the upper part of the Jurassic or Cretaceous clastic rocks. Two major types of faults are recognized: 1) steeply to moderately dipping faults that cut across section at a low angle; and 2) steeply dipping, northwest-trending faults that are nearly normal the the strike of pre-Tertiary rocks, and sub-parallel to the strike of tilted Tertiary strata. Several low-angle faults are also present.

Several faults that disrupt the stratigraphy in the Paleozoic section appear to be a linked array of both fault types. These faults cut up section to the NNE, alternating between near-bed-parallel and cutting across bedding at a high angle. Since the bedding is nearly vertical in the Paleozoic strata, the faults can be described viewing the map as a cross section. In this perspective (looking to the ESE, with the Proterozoic granitoid at the bottom of the map-viewed-as-cross section), the faults excise section, placing younger rocks (on the SE) stratigraphically down against older rocks. Although the faults curve dramatically as they cut across the section, there is no detectable differential rotation of bedding across the faults, indicating that the slip direction is probably out of the plane of the map. If the faults predate the tilting of the Paleozoic strata to near vertical, they may thus be normal faults with transport to either the WNW or ESE (assuming no subsequent vertical axis rotation). If the faults post date the tilting, they probably represent Tertiary normal faults; the bed-parallel segments would be NNE-trending oblique-slip tear faults in this interpretation.

In the Jurassic or Cretaceous clastic rocks, the faults of type one cut across the section at a low angle, and separate domains with upright and overturned bedding (cross section A-A'), or bound domains with significantly different dip. In the field these faults are typically cryptic, found in zones of poor outcrop that separate areas in which the bedding orientation is relatively consistent, but is strongly discordant across the zone of poor outcrop. Red-brown iron staining of rocks is commonly observed in the fault (bedding orientation discontinuity) zone. Most of these faults are discontinuous along strike, either disappearing into domains of uniform bedding orientation or offset by the younger northwest-trending (type two) faults. The fault zone that bounds the upright, southeast-dipping domain that includes most of the porcellaneous sandstone in the upper part of the Jurassic or Cretaceous clastic section can be traced from where it is covered by the basalts of Black Mesa across the map area to where it is truncated by a northwest-trending Tertiary normal fault (this zone passes close to the wildlife guzzler shown on the topographic map and will be referred to as the guzzler fault). These dip-domain-bounding faults are interpreted to be minor zones of displacement related to the tilting of the section to moderate to steep dip. Displacement is considered minor because in every case, rocks above and below the zones are grossly similar.

One of the major structures in the map area separates the Jurassic or Cretaceous clastic rocks on the NW from rocks of the Crystal Hill formation (equivalent to basal unit one of the McCoy Mountains Formation, see Richard et al., 1993) on the southeast. This fault is located in a poorly exposed interval of fine-grained clastic rocks (shale and porcellaneous shale) intruded by numerous irregular bodies of Jurassic or Cretaceous diorite (JKd). A shear zone has been drawn at the structural base of this interval because this is the location of the most abrupt discontinuity in bedding orientation, highly sheared shale with fault-bounded lenses of diorite are exposed just above the contact on the south side of the wash at the northeast end of the zone's outcrop, and because stratigraphic units in JKs below this zone are apparently truncated along strike. The shear zone is interpreted to dip to the southeast at a low angle based on its outcrop pattern and the orientation of cleavage in the observed highly sheared zone. The shale exposed above the mapped shear zone is lithologically identical to other shale intervals within the Jurassic or Cretaceous clastic section. This shale grades into porcellaneous shale identical to that associated with the porcellaneous sandstone that caps the Jurassic or Cretaceous clastic section. Finally, the porcellaneous shale is in depositional contact with quartz arenite of the Crystal Hill formation. The Crystal Hill strata form a WNW-facing homocline; primary facing indicators could not be found in these strata. They have been assumed upright in view of the lack of evidence that they are overturned.

The boundary between the Crystal Hill formation and the Jurassic or Cretaceous clastic rocks is similar in character to other near-bed-parallel discontinuities in the Ramsay Mine section. The similarity of rocks (JKf, JKps) above the mapped shear zone to rocks within the Jurassic or Cretaceous clastic section suggests that displacement across the zone is not great. The observed relationships suggest that rocks of the Crystal Hill formation are overlain (unconformably?) by fine-grained clastic rocks stratigraphically equivalent to the upper part of the Ramsay Mine section. A similar relationship has been documented in the Apache Wash area on the west side of Black Mesa [Richard, 1992]. The geometry of the unconformity in that area requires that a fault juxtaposing Crystal Hill formation and

Jurassic or Cretaceous clastic rocks of the Apache Wash section is overlapped by the upper part of the Apache Wash section. A similar onlap of the upper part of the Jurassic or Cretacesous clastic rocks onto Crystal Hill formation may exist at the southeast boundary of the Ramsay Mine section, but has been disrupted by subsequent deformation.

Steeply dipping northwest-trending faults cut Tertiary strata in the northern and southeastern part of the map area, and consistently have down-to-the-northeast normal separations. These faults probably continue through the Jurassic or Cretaceous clastic rocks, but are difficult to identify because of the lack of stratigraphic markers. The steeply-dipping guzzler fault shows very little separation across the projection of these faults, indicating that they are probably nearly pure normal faults. In the southeastern part of the map area, older Tertiary strata (Tc and Tts) are moderately to steeply dipping, whereas the youngest basalt (Tbu) is near flat lying. Non-tilted basalt capping the summit located about 3000' (900 m) ESE of summit 2334 (in the SE part of the map area), and basalt forming the SE part of Black Mesa both overlap normal faults that cut strongly tilted Tertiary strata. These relations indicate that the Tertiary section in the map area was deposited while the NW-trending normal faults were active.

Three low angle faults were mapped in the Ramsay Mine area. Two of these are apparently minor faults; one that disrupt the stratigraphy at the contact between the Paleozoic rocks (Kaibab Limestone) and Jurassic volcanic rocks and a second that disrupts the upper part of the Jurassic volcanic section. A potentially significant low-angle fault is exposed as a series of tiny windows on the south side of a Tertiary(?) normal fault just NE of the gap between the NW and SW parts of Black Mesa. A zone of strongly sheared and cleaved Jurassic or Cretaceous clastic rocks is present just above outcrops of strongly sericitized quartz-feldspar porphyry interpreted to be related to the Jurassic volcanic rocks (mapped as Jvu). The style of deformation along this zone is similar to that observed along the Poorman thrust. No primary indication of transport direction was observed. This fault may be a shear related to the Poorman thrust or may be the thrust itself. If the footwall Jvu rocks are related to the Jurassic volcanic rocks in the Ramsay mine section, a minimum of about 2 miles (3.2 km) top to the NW displacement is indicated, which contrasts with the top to the S or SE displacement interpreted for the Poorman thrust [Richard et al., 1993].

Mineralization

Locations of altered or mineralized rocks, mines and prospects are indicated on the geologic map and described below.

1. Black Mesa mine of Keith [1978] (same location as site # 11 of Richard [1992]). Tunnels and shaft in brecciated fault zone between Redwall and Martin formations. Waste heap contains massive

and comb-structured silica-FeO_X vein material, as well as spongy quartz-limonite (after pyrite) stockwork. Sparse malachite and chrysocolla fill open space in refractured silica-FeO_X veins. Brecciated quartz vein material with silica-FeO_X cement also present. In shaft on SE side of canyon mineralized breccia zones in carbonate are irregular and lenticular, with both steep and gentle dip. Adjacent carbonate rocks show little evidence of alteration. Keith [1978] describes "spotty cerrusite, anglesite, galena, chrysocolla, malachite, and brochantite,with siderite, quartz, ankerite, calcite and limonite in lensing replacement deposits in steeply dipping Paleozoic limestone beds. Cellular boxwork and vugs. Some native copper and cerargyrite". Available production data through 1981 indicate that the ore produced contained about 11% lead, 3.5% copper, 7 oz/ton of silver, and .2 oz/ton of gold [Arizona Geologic Survey, unpublished data].

2. Shaft in fault, oriented 134/64 NE, between Redwall and Supai Formations. Massive, dense silica-hematite in irregular clots along fault zone. Also earthy hematite along fractures. A few lenses of sericitized Bolsa quartzite are present in the fault zone, otherwise alteration outside of fault zone is minimal. (Same location as site #16 of Richard [1992])

3. Prospect along fault between Redwall limestone and Bolsa quartzite. Fault is steep, trends ~N070E. Redwall is silicified and iron-stained, with disseminated 1 mm diameter pyrite cubes altered to limonite. Bolsa quartzite is shattered near fault, but bedding is relatively uniform, indicating little rotation between fragments. Along the fault is a 10-30 cm thick zone of silicified Mn and FeO_X, with sparse thin white quartz veins. Some massive, earthy hematite is present along the zone.

4. Extensive weak to moderate alteration in vicinity of contact between Bolsa quartzite and coarse-grained Proterozoic granitoid. Bolsa quartzite is strongly fractured, locally forming a breccia with a red brown or yellow, iron oxide-rich matrix. Abundant iron staining is present on fractures, and some feldspar (plagioclase?) is partially replaced by sericite. Some tiny limonite after pyrite cubes are present. In the coarse grained granitoid, biotite is chloritized, plagioclase partially replaced by sericite, and tiny silica-filled veinlets are abundant.

5. Prospects in fault between Redwall limestone on the north and Supai Formation on the south. The fault is a crush zone 10 to 20 m wide. The Redwall limestone forms a thin sliver between this fault and another parallel strand to the north. The limestone is shattered and bedding within it is disrupted. Limestone in the eastern prospect pit (shown on the topographic map) is apparently nonmineralized. In a pit along strike to the west, a few thin silica veinlets in Redwall limestone contain some malachite.

6. Sandy dolomite of basal Kaibab formation is strongly bleached near intersection of mafic dike and fault contact between Kaibab and the Jurassic volcanic rocks.

7. Trench in sheared and brecciated mafic dike. Fractures in the dike have abundant iron staining, and feldspar in the dike is moderately sericitized. Jurassic volcanic rocks adjacent to the dike are very little altered. The mineralization and the dike are truncated at the steep fault separating the Jurassic vol-

canic rocks and Kaibab formation. This dike may be an offset equivalent of that observed at site 6 (above).

8. Six Price Mine. 50' long incline along a dark brown, siliceous and hematitic vein in coarsely recrystallized (3-4 mm grain size) Redwall formation dolomite. Fractures near the mouth of the incline have some chrysocolla in them. Some black MnOx or chalcocite is also present in thin veinlets in the marble. The principal vein is oriented 133/46 NE, and is about 20 cm thick, continuous for 2-3 m along strike and visible for ~15 m down dip in the incline. Keith [1978] reports the occurrence of lead, zinc, silver and copper here.

9. A 2-3 m wide zone of weak to moderate sericitic alteration and iron staining in Jurassic crystal tuff (Jxt_1). Disseminated ~1 mm limonite after pyrite cubes are present in the zone. Plagioclase crystals weather out to form a pitted surface. Minor silica microveining is present in the zone. The zone can be followed along strike at least 30 m.

10. Dark purple grey andesitic dike intruding fault zone. Mafic minerals in the dike are strongly chloritized, plagioclase is strongly sericitized and the dike is slightly silicified. Tiny, 1-2 mm diameter cavities in the dike contain sericite. The Jurassic tuff south of the dike is bleached and sericitized for about 10 m from the dike, and biotite in tuff adjacent to the dike is altered to a light tan chlorite(?).

11. Shallow prospect pit in shattered quartz vein about 30 cm thick. The vein is oriented 095/80N, and consists of massive quartz with some open space containing drusy quartz crystals and an earthy hematite filling. Coarse-grained Proterozoic granitoid wall rocks are greenish and moderately sericitized along the margin of the vein for 1-2 m, and contain minor disseminated limonite after pyrite.

12. 'Open-pit mine' marked on topographic map. Gougy fault zone/shear trends 044/82E, subparallel to bedding. Porcelaneous sandstone near the fault is highly fractured with iron staining on the fractures; minor red earthy hematite is present along the fault zone. The iron staining near this fault is typical of that observed along several of the type 1 faults (see structure section).

13. Mine shaft marked on topographic map. Vertical shaft, well timbered, estimated to be 70 to 100' deep, with graded access road. Shaft is in Jurassic or Cretaceous clastic rocks. No mineralized rock could be found on the dump or in adjacent surface outcrops. This is a good place to collect fresh samples of typical JKs sandstone. Keith [1978] reports the occurrence of copper, silver and lead here.

14. Ramsay Mine. Large dump (est. 70 m by 20 m by 10 m), with near vertical, well timbered main shaft (covered) and other subsidiary workings. Mine is in Tertiary extrusive and intrusive(?) felsite near contact with Jurassic or Cretaceous clastic rocks. The felsite may have intruded and erupted along a NW-trending fault zone separating the Mesozoic and Tertiary rocks. Material on the dump consists mostly of black and brown calcite vein fill and felsite, both containing abundant black manganese(?) oxide. Some clear, colorless calcite is also present. Mineralization at the two smaller mines to the east is identical. A vein observed at the closer of these two subsidiary mines trends NNW

and dips steeply east. Keith [1978] describes "spotty, but often locally high-grade, oxidized, lead, silver, zinc and copper mineralization with barite, celestite, vanadinite and manganese and iron oxides, in a relatively wide vein zone of fractures and fissures, strongly brecciated". His description indicates that the mineralization is localized along the contact between the Jurassic or Cretaceous clastic rocks and the Tertiary felsite. Available production data through 1981 indicate that the ore produced contained about 1% lead, 0.1% copper, 35 oz/ton of silver, and <0.01 oz/ton of gold [Arizona Geologic Survey, unpublished data].

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