GEOLOGIC MAP OF THE LITTLE HARQUAHALA MOUNTAINS, WEST-CENTRAL ARIZONA

by

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INTRODUCTION

The Little Harquahala Mountains of west-central Arizona contain major Mesozoic thrust faults that juxtapose a complex assemblage of Mesozoic sedimentary and volcanic rocks, Paleozoic cratonic strata, and Jurassic and Precambrian crystalline rocks. The structurally lowest rocks, referred to as the Harquar plate, consist of a Jurassic volcanic and volcaniclastic sequence depositionally overlain by primarily sedimentary rocks of the Jurassic and/or Cretaceous McCoy Mountains Formation. The Hercules thrust separates these rocks from the structurally overlying Hercules plate, which is composed of a variety of crystalline rocks of Precambrian(?) and Jurassic(?) age. The structurally higher Centennial thrust places Precambrian, Paleozoic, and Mesozoic sedimentary rocks of the Centennial plate over the Hercules plate. Crystalline rocks in the southern part of the range, referred to as the Sore Fingers assemblage, are structurally below the Centennial plate, but their structural relationship to the Hercules and Harquar plates is uncertain. Lithologic similarity of the Sore Fingers assemblage to rocks of the Hercules plate suggests that the two packages of rocks are related and probably continuous at depth beneath the Centennial plate.

Pre-late Cretaceous rocks of the area locally contain well-developed cleavage and large- and small-scale folds. Large-scale folds are best displayed in the Centennial plate, where the Paleozoic section is commonly steeply dipping or overturned because it occupies the core of a large northeast-trending fold that is overturned to the southeast. Spaced cleavage is present in most parts of the range, but is most intensely developed in Mesozoic rocks of the Harquar plate and along the major thrusts. The sense of transport on the Hercules thrust is not well constrained in the Little Harquahala Mountains, but is probably south to southwest based on asymmetric petrofabrics along a continuation of the thrust in the Granite Wash Mountains to the north.

Post-thrusting rocks include the Upper Cretaceous Granite Wash Granodiorite, which intrudes the Hercules thrust, and a variety of of middle Tertiary volcanic rocks that dip gently off the southwest flank of the range.

Previous studies of the geology and mineral resources of the range are mostly restricted to descriptions of mines (Keith, 1978) and reconnaissance geological mapping (Rehrig and Reynolds, 1980). The Hercules thrust was first recognized in reconnaissance studies by Reynolds and others (1980), Keith and others (1981), and Reynolds (1982). The Golden Eagle thrust, a fault discussed by Reynolds and others (1980) and Keith and others (1981), is interpreted by Richard (1982, 1983, this report) as a discontinuous Tertiary(?) fault of minor displacement that places

steeply dipping Paleozoic rocks over Precambrian monzogranite of the Centennial plate. The Centennial thrust, a generally intracrystalline structure, was not recognized in earlier reconnaissance studies. The rocks and structures of most of the Centennial plate and Sore Fingers Assemblage are described in detail by Richard (1982, 1983), and the information presented here on this area is taken entirely from Richard (1983) with very little modification. The remainder of the range was mapped by the authors in 1982 and 1983, *including Lone Mountain (pgs. 19, 20)*

Plutonic rock nomenclature used in this report is in accordance with that adopted by the IUGS (Streckeisen, 1976). Stratigraphic thicknesses, where given, are estimated from the outcrop width in areas of only minor structural complication.

DESCRIPTION OF MAP UNITS

POST-THRUSTING UNITS

Qs SURFICIAL DEPOSITS (QUATERNARY)--Variably consolidated sand, gravel, and conglomerate deposits, and talus, generally poorly sorted and poorly bedded.

Tvmi MAFIC TO INTERMEDIATE VOLCANICS (MIDDLE TERTIARY)--Vesicular to non-vesicular, dark gray to black flows and flow breccias. One to two mm olivine(?), pyroxene(?) and plagioclase phenocrysts are locally recognizable. Red, highly vesicular scoria and flow breccias are locally present. Quartz, hornblende(?), and biotite(?) phenocrysts are present in less mafic units such as those forming the hills south of Martin Peak. This unit is resistant to weathering and typically forms steep slopes or cliffs.

Tvi INTERMEDIATE-COMPOSITION TUFF BRECCIA (MIDDLE TERTIARY)--Orange-weathering, pumiceous, tuff breccia with 1-5 cm diameter, light gray to light brown, volcanic clasts containing 1-5 mm hornblende and 1-2 mm biotite phenocrysts. Present only in unsurveyed SW1/4 sec. 31, T. 4 N., R. 13 W.

Tvr RHYOLITE (MIDDLE TERTIARY)--Light-tan to dark-brown weathering, generally homogeneous, welded, rhyolite tuff with phenocrysts of quartz, sanidine, biotite, and hornblende. Includes associated dikes that are similar in composition and color, and commonly have a spheriolitic groundmass.

Tc CONGLOMERATE (MIDDLE TERTIARY)--Fining-upward sequence of conglomerate containing clasts up to 1 m diameter of Paleozoic and Precambrian rocks of the Centennial plate. Top of sequence consists of pebble conglomerate, sandstone, and mudstone.

Tbr BRECCIA (MIDDLE TERTIARY)--Composed mostly of angular clasts of

Paleozoic carbonates. Clasts range in size from several cm to several m. Breccia is generally polymictic, but locally contains monolithologic zones, and is well cemented by calcite or silica. The breccia is in low-angle fault contact with Precambrian granite and Paleozoic sedimentary rocks. The low-angle fault is interpreted as a normal fault, and the breccia is interpreted as the product of faulting and related tectonism. The breccia is assigned a middle Tertiary age based on these interpretations and on the interpretation that the fault was active in mid-Tertiary time, as is typical for normal faults of the region. Isolated outcrops of breccia in the southeastern part of the study area (secs. 20 and 28, T. 4 N., R. 12 W.) are largely derived from Coconino Sandstone and Mesozoic clastic rocks and could be associated with a concealed low-angle fault.

Kg GRANITE WASH GRANODIORITE (UPPER CRETACEOUS)--Light-gray, medium-grained, equigranular, biotite granodiorite that generally contains 5 to 10 percent mafics, of which less than 3 to 5 percent is hornblende. Also contains accessory sphene and opaque oxides.

Kgd BORDER PHASE OF GRANITE WASH GRANODIORITE (UPPER CRETACEOUS) --Dioritic, quartz dioritic, or granodioritic rocks with highly variable texture and mineralogic composition. Common varieties include the following: (1) medium-grained, equigranular to slightly porphyritic quartz diorite and granodiorite with more mafic minerals than main-phase granodiorite; commonly contains several percent hornblende phenocrysts that are 1 to 2 cm in length; (2) medium-grained, equigranular diorite to quartz diorite with 50 to 60 percent hornblende and biotite, locally slightly porphyritic with up to 5 percent phenocrysts of hornblende and plagioclase; (3) fine- to medium-grained, porphyritic quartz diorite to diorite with 5 to 10 percent hornblende phenocrysts as long as 1 cm; (4) coarse-grained diorite with abundant crystals of hornblende as long as 2 cm, and varying amounts of medium-grained plagioclase; and (5) hornblendite containing less than 10 percent plagioclase.

ROCKS OF THE HARQUAR PLATE

Rocks of the Harquar plate consist of a sequence of Mesozoic sedimentary and volcanic rocks that rest depositionally on volcanic rocks of probable Jurassic age. The sedimentary and volcanic rocks overlying the basal volcanics are correlated with the McCoy Mountains Formation of Harding (1982) and Harding and Coney (1985), and are divided into two informal members on the basis of sandstone and conglomerate clast composition: the lower, quartz-rich Ranegras member and the upper, volcanic-lithic to feldspathic Harquar member. These informal members may be only locally applicable, but we tentatively correlate the Ranegras

member with basal sandstone members one and two and the mudstone member of Harding and Coney (1985), and the Harquar member with the conglomerate, sandstone, and siltstone members of Harding and Coney (1985).

JKgr GRANITE OF THE HARQUAR PLATE (JURASSIC, CRETACEOUS, OR PRECAMBRIAN)--Gray to orange-brown weathering, medium-grained, moderately porphyritic granite. The nature of the contact between this granite and the surrounding Hovatter volcanics is obscured by alteration. If the contact between the granite and volcanics is a fault, the granite could be Precambrian. Located in one area approximately one and one-half km (1 mi.) east of Harquar Peak.

McCoy Mountains Formation of the Harquar plate

Harquar member (informal name) of the McCoy Mountains Formation

JKhs SEDIMENTARY ROCKS OF THE HARQUAR MEMBER, UNDIVIDED (JURASSIC AND/OR CRETACEOUS)--Sandstone and conglomerate similar to that in the lower and upper sandstone units and conglomerate unit of the Harquar member (described below). Light grey, feldspathic and lithic sandstones with magnetite-rich laminations are characteristic features of this member.

JKhu UPPER SANDSTONE UNIT OF THE HARQUAR MEMBER (JURASSIC AND/OR CRETACEOUS)--Interbedded sandstone, conglomeratic sandstone, and sparse conglomerate, with local maroon siltstone partings. Sandstone is light to medium gray, fine- to coarse-grained, feldspathic-lithic to lithofeldspathic. Mudcracks occur locally on maroon siltstone partings. Mudstone rip-ups and soft-sediment-deformation features are locally present. Conglomerate clasts of quartzite, sparse volcanic rocks, and carbonate are up to 30 cm in diameter but typically are less than 10 cm diameter. Contact with underlying conglomerate unit is marked by the upward appearance of siltstone partings.

JKhc CONGLOMERATE UNIT OF THE HARQUAR MEMBER (JURASSIC AND/OR CRETACEOUS)--Very poorly sorted, light to medium gray, massive conglomerate to poorly bedded conglomeratic sandstone. Clasts are typically 2-20 cm in diameter but range up to 2 m. Clast lithologies include a variety of volcanic rock types with lesser amounts of variably laminated pink quartzite (Coconino sandstone?), and Paleozoic carbonates. Conglomerate is generally sand-matrix dominated, matrix supported, and variably tuffaceous. Interbedded volcanic flows are locally present. Basal contact is gradational with interbedded volcanic and conglomeratic rocks, and is placed at top of highest major volcanic flow.

JKhv HOVATTER VOLCANIC UNIT OF THE HARQUAR MEMBER (JURASSIC AND/OR CRETACEOUS)--Gray-green intermediate-composition volcanic flows, tuffs, volcaniclastic sediments, and feldspathic and volcanic-lithic sandstones, with minor interbedded quartz-rich sandstone of possible eolian origin at lower stratigraphic levels. Volcanic rocks consist primarily of greenish andesite(?) with local plagioclase phenocrysts, and locally occurring gray-lavender, biotite-hornblende flow-banded rhyodacite(?), light-gray biotite rhyolite(?), and gray dacite(?) with quartz and plagioclase phenocrysts. Interbedded volcaniclastic sedimentary rocks are common, but are difficult to distinguish from flows in areas of intense deformation or contact metamorphism near the Granite Wash Granodiorite. Basal contact is marked by spaced cleavage and is probably faulted. Stratigraphic position of this unit above lower sandstone and conglomerate unit (map unit JKhl) is based on structural position and interpretation that fault movement on the basal contact has been minor. Also included in this unit are hypabyssal andesite(?) and rhyodacite(?) intrusives within other units of the Harquar member. The Hovatter volcanic unit is divided into silicic (s) and intermediate (i) map subunits in the area 2-2.5 km (1.5 mi.) east of Harquar Peak.

JKhl LOWER SANDSTONE UNIT OF THE HARQUAR MEMBER (JURASSIC AND/OR CRETACEOUS)--Massive to poorly-bedded, light- to medium-gray to locally greenish-gray conglomerate and sandstone. Sandstone is medium- to coarse-grained. Clasts are dominantly subrounded quartzite cobbles with less-abundant subrounded clasts of Paleozoic(?) carbonates and sparse, subangular clasts of medium- to dark-gray volcanic rock. Also contains very sparse volcanic flows. Lower contact is faulted except in SW1/4 SE1/4 sec. 7, T. 4 N., R. 13 W. where rocks similar to the lower sandstone unit of the Harquar member depositionally overlie rocks correlative with the upper unit of the Ranegras member.

Ranegras member (informal name) of the McCoy Mountains Formation

JKr ROCKS OF THE RANEGRAS MEMBER, UNDIVIDED (JURASSIC AND/OR CRETACEOUS)--Sandstone, siltstone, and conglomerate, undivided, of the Ranegras member. Quartz-rich sandstones, including orthoquartzites, are characteristic of this member, and magnetite-rich laminations are almost entirely absent.

JKru UPPER SANDSTONE UNIT OF THE RANEGRAS MEMBER (JURASSIC AND/OR CRETACEOUS)--Gray-, brown-, or orange-weathering, medium- to thin-bedded sandstone with less abundant siltstone and conglomerate beds. Sandstone is quartzose to feldspathic, but is locally greenish and volcanic-lithic. Sequence commonly includes tan-brown to greenish calcareous sandstone and siltstone, thin beds of silty limestone, and calcareous

concretions. Thin brown carbonate lenses and calcareous oncolites (?) are also locally present. Conglomerates occur as lenses less than 2 meters thick, are matrix-supported to clast-supported, and contain well-rounded clasts of quartzite in a sandy matrix. The basal contact of the upper sandstone unit is placed at top of massive conglomerate beds of underlying conglomerate unit.

JKrc CONGLOMERATE UNIT OF THE RANEGRAS MEMBER (JURASSIC AND/OR CRETACEOUS)--Clast-supported, quartzite-cobble conglomerate. Most clasts are subrounded to rounded, but some are subangular. Clasts are mostly 1-10 cm diameter, but range up to 30 cm diameter. Sandstone matrix is quartzo-feldspathic. Base of unit placed at base of lowest major conglomerate bed.

JKrl LOWER SANDSTONE UNIT OF THE RANEGRAS MEMBER (JURASSIC AND/OR CRETACEOUS)--Sandstone with conglomerate, conglomeratic sandstone, siltstone, and calcareous sandstone and siltstone. Sandstone varies from orthoquartzitic to quartzofeldspathic, and is more quartz rich toward base. Metamorphosed orthoquartzites are white and highly resistant to weathering. Less quartz-rich sandstones weather tan-brown or gray and are locally calcareous. Locally interbedded calcareous clastic rocks and silty limestones are brown to dark-gray weathering. Conglomerate clasts are generally subrounded to rounded and are composed almost entirely of quartzite, but locally include cobbles of intermediate-composition volcanic rock, light-colored rhyolite(?), and red chert. Conglomerate beds are most abundant near base of unit. Maroon siltstones associated with conglomerate beds are a distinctive lithology in this unit.

Basal volcanic and volcaniclastic rocks of the Harquar plate

Jbvs SEDIMENTS DERIVED FROM THE BLACK ROCK VOLCANICS (JURASSIC?)--Light-colored to greenish, poorly sorted conglomerate, conglomeratic sandstone, and sandstone composed of disaggregated quartz porphyry of the underlying Black Rock Volcanics. Conglomerate-filled channels are locally associated with light-gray calcareous lenses.

Jbv BLACK ROCK VOLCANICS (JURASSIC)--Silicic to intermediate-composition ash-flow tuffs, flows, and hypabyssal intrusions, and volcaniclastic sedimentary rocks. Sequence includes the following: (1) light-colored porphyry with 5 to 15 percent plagioclase phenocrysts and 5 to 10 percent quartz eyes 1 to 4 mm in diameter; commonly contains several percent hexagonal biotite books and possible hornblende; probably includes both hypabyssal bodies and welded ash-flow tuff; (2) greenish to dark-gray, aphanitic andesite with approximately 10 percent altered hornblende and

mafic clots that are 0.5 to 2mm in diameter; (3) dark-gray volcaniclastic sandstone with plagioclase and quartz grains as large as 4 mm in diameter; (4) tan-, pink-, or cream-colored, rhyodacite(?) tuff and flow-banded rhyodacite(?); and (5) volcanic breccia.

ROCKS OF THE HERCULES PLATE

Ja ALASKITE (JURASSIC?)--Dikes and irregular bodies of medium- to fine-grained alaskite, locally with aplitic texture; some areas contain unmapped pods of diorite or gabbro and pendants of mafic metamorphic rocks with a steep, northeast-trending gneissic foliation.

Jg PORPHYRITIC QUARTZ MONZODIORITE(?) (JURASSIC?)--Dark-gray granitic rock with about 10-15%, 5-30 mm, K-feldspar phenocrysts in intergrown groundmass of 1-15 mm albitic plagioclase, 1-2 mm quartz, and highly intergrown 1-2 mm anhedral biotite, hornblende(?), and magnetite(?). Albitization of plagioclase and apparently also of K-feldspar prevents accurate classification of this granitoid. Classification here as quartz monzodiorite(?) is based on hand-lens examination of stained and unstained slabs. Grades southward into a medium-grained, equigranular to slightly porphyritic, biotite monzogranite(?). A sample of this unit yielded a $^{87}Sr/^{86}Sr$ value of 0.70766±0.00004 with a Rb/Sr value of 0.4166 (P. Damon and M. Shaffiqullah, written communication, 1984), indicating that the unit is not of the same age as Precambrian granitic rocks elsewhere in Arizona, and is probably of Mesozoic age.

JpCu GNEISSIC METAMORPHIC ROCKS AND ALASKITE, UNDIVIDED (JURASSIC OR PRECAMBRIAN)--Includes thinly-banded, fine-grained granitic gneiss and gneissic granite, altered and sheared mafic dike(?) rocks, a variety of fine-grained, moderately leucocratic granitic rocks, and alaskite. These rocks are suspected of being part of the Hercules Plate, but this correlation is tentative.

ROCKS OF THE CENTENNIAL PLATE

Precambrian granitic rocks of the Centennial plate are overlain by a sequence of Paleozoic and Mesozoic sedimentary and volcanic rocks. Stratigraphic thicknesses of Paleozoic and Mesozoic units are based on average map thickness, and probably only approximate depositional thicknesses due to tectonic disruption.

McCoy Mountains Formation of the Centennial plate

The McCoy Mountains Formation of the Centennial plate consists of a broadly fining-upward sequence of sandstone, siltstone, and silty shale with local conglomerate lenses. As discussed by Richard (1983), it resembles a sequence of Mesozoic sedimentary rocks in the Apache Wash area of the nearby Plomosa Mountains (Miller, 1970; Harding, 1982). These rocks in the southern Plomosa Mountains are thought to be correlative with the McCoy Mountains Formation (Harding and Coney, 1985), but it is uncertain whether they correlate with the upper or lower of the two broadly fining-upward sequences (Ranegras and Harquar members in the Little Harquahala Mountains) that make up the McCoy Mountains Formation (Harding, 1982; Harding and Coney, 1985).

JKs VOLCANIC, INTRUSIVE, AND SEDIMENTARY ROCKS OF THE CENTENNIAL PLATE, UNDIVIDED (JURASSIC AND/OR CRETACEOUS)--Strongly foliated and cleaved, light-colored, quartz-feldspar schists interpreted to have been derived from Mesozoic volcanic, alaskitic, and volcaniclastic rocks. Association with Paleozoic dolomite and less cleaved, quartz-feldspar sandstones is interpreted as suggesting an affinity to rocks of the Centennial plate. Exposed in thrust window near Buckeye-Salome Road in eastern part of map area.

JKmu UPPER SANDSTONE AND SILTSTONE UNIT (JURASSIC AND/OR CRETACEOUS)--Medium- to dark-brown weathering, fine- to coarse-grained, poorly sorted, thin- to thick-bedded, lithofeldspathic sandstone and light-brown- or gray-weathering siltstone and silty shale. Sand grains are mainly monocrystalline and polycrystalline quartz, feldspar, rock fragments, and chert. Beds are normally massive or vaguely plane laminated with only sparse low-angle cross beds. Local conglomerate lenses contain clasts up to 15 cm diameter of primarily vitreous tan quartzite, with less abundant limestone and volcanic rock fragments and rare intrusive rock fragments. In general the unit fines upward, with coarse-grained sandstone and conglomerate predominant near the base, and siltstone and shale progressively more abundant higher in the section. Unit is in gradational contact with underlying lower unit. Distinguished from lower unit by presence of significant feldspar in sandstones and by contrast with distinctive drab gray-green color of lower unit. Thickness is a minimum of 700m.

JKml LOWER SANDSTONE UNIT (JURASSIC AND/OR CRETACEOUS)--Gray-green to olive-drab, medium- to thin-bedded, very-poorly sorted, angular, fine-grained sandstone to gritstone. Grains are mostly volcanic rock fragments and feldspar with minor quartz. Conglomerate beds are sparse in northwestern outcrops, but are more abundant and dominate the section to the southeast. Clast compositions vary greatly and were apparently controlled by local topography. Clasts include quartzite, volcanic rocks, and upper Paleozoic sedimentary

rocks. This unit is absent in northwestern areas where the upper unit rests directly on underlying volcaniclastic sediments. To the east and south the lower unit appears and becomes progressively thicker and more conglomeratic. The contact with the underlying volcaniclastic sandstone is gradational.

Needle formation (informal name) of the Centennial plate

The Needle formation (informal name) overlies a basal, non-volcanogenic, Mesozoic sedimentary unit, and is composed of a sequence of volcanic flows, tuffs, and derivative volcaniclastic sedimentary rocks. Richard (1983) named the basal Mesozoic sedimentary unit the Needle formation, but we revise his usage and apply the name Needle formation to only the overlying volcanogenic rocks.

It is presently unknown if the volcanic rocks in the Needle formation are correlative with the Hovatter volcanic unit of the Harquar member of the McCoy Mountains Formation in the Harquar plate, or are correlative with the Black Rock volcanics of the Harquar plate. Correlation with the Hovatter volcanic unit would indicate that the McCoy Mountains Formation of the Centennial plate is correlative with the upper sedimentary units of the Harquar Member of the McCoy Mountains Formation.

Jnvs VOLCANICLASTIC SEDIMENTARY UNIT (JURASSIC?)--Light- to medium-gray-green, volcanic sandstone and conglomerate. Massive conglomerate or breccia near base grades upward into sandstone. A thin, evaporite and shale zone forms the top of the unit in the area southeast of the Needle. Conglomerate clasts consist primarily of angular volcanic rocks with minor subrounded to rounded vitreous quartzite and rare Paleozoic limestone. Sandstone grains are primarily volcanic rock fragments and sericitized feldspar. Cross-bedding is apparent in some magnetite-rich beds. Base is marked by upward appearance of sedimentary textures. Maximum thickness is 335 meters.

Jnvu UPPER VOLCANIC UNIT (JURASSIC?)--Gray-green, massive, homogeneous volcanic porphyry with a fine-grained groundmass; contains phenocrysts of quartz, albitized plagioclase, potassium feldspar, and biotite(?). Original texture and mineralogy are obscured by pervasive propylitization. Basal contact is locally intrusive but at map scale is parallel to other depositional contacts, suggesting an extrusive origin. Unit is interpreted as a silicic dome with an autobrecciated carapace forming base of overlying volcaniclastic sedimentary unit. Altered and deformed quartz-feldspar porphyry sills in Paleozoic rocks are probably related to this porphyry. Maximum thickness is 335 meters.

Jnvuu UPPER VOLCANIC UNIT AND VOLCANICLASTIC SEDIMENTARY UNIT, UNDIVIDED (JURASSIC?)--Equivalent to units Jnvs and Jnvl, undivided.

Jnvl LOWER VOLCANIC UNIT (JURASSIC?)--Silicic flows, ash-flow tuffs, agglomerates, massive and laminated tuff, and red volcanic-lithic sandstone and conglomerate. Volcanic rocks are purple-gray, maroon, gray, and gray-green. They are generally flow-banded and contain quartz and plagioclase phenocrysts, with the percentage of phenocrysts being lower than in the upper volcanic unit. Conglomeratic red beds at base of unit contain clasts of limestone, volcanic rocks, quartzite, and rare medium-grained, porphyritic granitoid rocks. Basal contact is probably conformable. Unit is very poorly exposed and is not more than about 210 meters thick.

Basal Mesozoic sedimentary unit of the Centennial plate

Mzs BASAL MESOZOIC SEDIMENTARY UNIT (JURASSIC?)--Basal, red, tan, and dark gray-green siltstone and fine-grained sandstone with a few white limestone beds, overlain by light-gray, fine- to coarse-grained sandstone and pebble to cobble conglomerate with maroon siltstone partings. Sandstone grains include, in order of decreasing abundance: monocrystalline quartz, chert, polycrystalline quartz, limestone, potassium feldspar, magnetite, muscovite, and schist. Conglomerate clasts include tan vitreous quartzite (Coconino?), red-brown and white coarse-grained quartzite (Bolsa?), white-weathering chert, and sparse tan-weathering siltstone and limestone. Unit is between 50 and 70 meters thick. The lower contact is probably an unconformity, as suggested by the abrupt change in lithology and inferred depositional environment at the basal contact. Best exposed in valley just southeast of the Needle (unsurveyed NE1/4 SE1/4 NW1/4 sec. 24, T. 4 N., R. 13 W.).

The tectonic significance of the basal, nonvolcanogenic, Mesozoic sedimentary unit is uncertain because we cannot assess how much time, if any, is missing at the contact between the sandstone and overlying volcanic rocks. If the sandstone is substantially older than the volcanics, it could represent mild tectonism and sedimentation well before the onset of regional mid-Mesozoic magmatism. In this case, the sandstone would probably correlate with the Triassic Moencopi Formation or related units. If, on the other hand, there is little or no time missing at the sandstone-volcanic contact, then the sandstone could represent basin formation and initial sedimentation reflecting the onset of mid-Mesozoic magmatism and associated tectonism.

Paleozoic and Precambrian rocks of the Centennial plate

bc BRECCIA-CONGLOMERATE (PALEOZOIC?)--Massive breccia or conglomerate occurring as intraformational masses in gradational contact

with Kaibab limestone. Consists of buff to red, fine-grained sandstone to boulder conglomerate. Most of the unit is a massive cobble to boulder conglomerate with angular clasts up to 3 m diameter. Conglomerate is monolithologic near enclosing Kaibab limestone, and grades into shattered but untransported rock. Interpreted as a cavern-filling deposit formed after Kaibab deposition and before deposition of overlying Mesozoic clastic rocks.

Pzu SEDIMENTARY ROCKS, UNDIVIDED (PALEOZOIC)--Sedimentary rocks of probable or known Paleozoic age but too deformed or altered to be assigned to a specific formation.

Pk KAIBAB LIMESTONE (PERMIAN)--Composed of 5 units. In ascending order, these are: (1) dolomitic sandstone grading upward into cherty dolomitic limestone which is overlain by fossiliferous gray limestone and dolomitic limestone. This unit is capped by fine-grained tan sandstone with laminated carbonates. (2) Cherty, gray, bioclastic limestone, (3) uniform, medium-bedded, light- to dark-gray limestone, (4) medium- to thick-bedded, light-gray limestone with abundant fossils and chert, (5) a lower tan sandstone with a few conglomerate lenses overlain by cherty and fossiliferous limestone similar in character to unit four. Total thickness is approximately 250 m in the least deformed section. The Kaibab Limestone conformably overlies the Coconino Sandstone.

Pku UPPER MEMBER (INFORMAL) OF KAIBAB LIMESTONE (PERMIAN)--Includes units 3, 4, and 5 described above.

Pkl LOWER MEMBER (INFORMAL) OF KAIBAB LIMESTONE (PERMIAN)--Includes units 1 and 2 described above.

Pc COCONINO SANDSTONE (PERMIAN)--Uniformly white to pinkish-brown, fine-grained vitreous quartzite. Non-resistant due to pervasive internal fracturing. Sandstone is uniformly thin to very-thin bedded and mostly plane-bedded, although medium-scale trough cross beds are locally present. Thickness is 190m. Basal contact is conformable and is placed at top of highest brown- or tan-weathering impure sandstone bed of the Supai formation.

Ps SUPAI FORMATION (PENNSYLVANIAN)--Interbedded shale, sandstone, and limestone. Basal 15 to 20 meters is composed of non-resistant maroon siltstone with interbedded quartzose sandstone and chert-pebble conglomerate. The rest of the Supai formation is composed of a variety of lenticular lithosomes, including gray limestone, tan dolomite or dolomitic limestone, silty brown to tan dolomite, white vitreous quartzite, maroon siltstone, thin-bedded tan siltstone, shaley siltstone, and calcareous siltstone. Beds are typically 1-2 m thick. Total thickness is 150-200 m.

Basal contact is marked by limestone conglomerates formed on a karst surface on top of Redwall Limestone. Correlation with the Supai Group is based on the lithologies and associations of rock types. However, since individual formations of the Supai Group have not been recognized in the Little Harquahala Mountains, the Supai Group has been reduced in rank to a formation (Richard, 1983).

Mr REDWALL LIMESTONE (MISSISSIPPIAN)--Consists of three units. In ascending order, these are: (1) Interbedded, massive, white limestone and massive, tan dolomite overlying a basal bed of sandy varicolored limestone; (2) variably dolomitized cherty limestone; and (3) medium-bedded light-gray limestone. Thin, karst-related conglomerates locally occur along the disconformable basal contact. Total thickness is about 100m.

Dm MARTIN FORMATION (DEVONIAN)--Medium gray, tan, and brown, medium-grained to porcelaneous dolomite and dolomitic limestone. Dolomite is well bedded and medium to thick bedded. Beds are internally laminated, mottled, or massive. Disconformably overlies Abrigo Formation. Thickness is about 100 m.

ϵba BOLSA QUARTZITE AND ABRIGO FORMATION, UNDIVIDED (CAMBRIAN)--Bolsa quartzite as described below, plus conformably and gradationally overlying Abrigo Formation which consists of interbedded thin- to very-thin-bedded, dark-brown to red-brown sandstone, black, maroon, and greenish-gray shale and siltstone, and local medium-bedded tan carbonate beds. Thickness varies from 0 to 27 meters due primarily to tectonic thickness modifications, but the least deformed sections are about 15 meters thick.

ϵb BOLSA QUARTZITE (CAMBRIAN)--Maroon, red-brown, and gray-purple feldspathic quartz grit, sandstone, and siltstone. The lower part of the formation consists of medium-bedded feldspathic grit with abundant planar-tabular cross beds in sets up to 20 cm thick. A thin zone of cobble conglomerate locally overlies the basal nonconformity. Grain size decreases up-section, beds become thinner, and cross beds are less common. The upper part consists of thin- to medium-thin-bedded, brown sandstone with white laminations and gray or light green-gray, silty or shaley partings. Thickness ranges from 50 to 100 meters, probably in part due to original thickness changes.

Jpϵg GRANITOIDS OF THE CENTENNIAL PLATE (PRECAMBRIAN OR MESOZOIC)--Medium-grained biotite monzogranite; groundmass of 2-4 mm, blocky, euhedral plagioclase, with interstitial quartz and biotite, as well as subhedral quartz in rounded grains up to one cm diameter. K-feldspar forms blocky phenocrysts up to 5 cm long. Very similar to porphyritic

monzogranite of Sore Fingers assemblage (unit Jp€mg). Intruded by aplitic leucogranite and pegmatite dikes. Contact with granite of Centennial plate is abrupt, but is obscured by alteration and deformation.

p€a ALASKITE OF THE CENTENNIAL PLATE (PRECAMBRIAN)--Medium-grained, equigranular, white to orangish-weathering alaskite. Poorly resistant to weathering. Locally foliated near thrust faults.

p€g GRANITE OF THE CENTENNIAL PLATE (PRECAMBRIAN)--Orange- to brown-weathering, non-resistant, medium-grained, porphyritic granite with 1-3 cm long K-feldspar phenocrysts. Minor biotite is typically altered to aggregates of muscovite and magnetite. Masses of hematite, chlorite, opaque minerals, and sericite are interpreted as altered mafic minerals. Alteration characterized by light-green, argillitized or epidotized feldspar set in a reddish, argillic groundmass with abundant relict quartz has affected rocks near the depositional contact with overlying Cambrian Bolsa Quartzite. Modal mineral composition of one sample indicates granite plots in the monzogranite subfield of the granite field (Richard 1983). In northeastern outcrops near Centennial Wash, unit grades into medium-grained, equigranular to porphyritic, muscovite-biotite granite, which is continuous across Centennial Wash into the western Harquahala Mountains.

ROCKS OF THE SORE FINGERS ASSEMBLAGE

Intrusive and metamorphic rocks in the southeastern Little Harquahala Mountains are referred to as the Sore Fingers assemblage (Richard, 1983). This assemblage is separated from bedrock in the rest of the Little Harquahala Mountains by faults. A K-Ar biotite age of 140 m.y. suggests a Jurassic age for the assemblage (Rehrig and Reynolds, 1980), but a Precambrian age is also possible. These rocks are similar to crystalline rocks of the Hercules plate, and it is possible that they are correlative and structurally continuous beneath the Centennial plate.

Jp€di DIORITIC INTRUSIVE (JURASSIC OR PRECAMBRIAN)--Fine- to medium-grained plagioclase, chloritized biotite or hornblende, and quartz, with abundant secondary epidote. Mafic content and grain size are variable, but rock is characteristically equigranular. Intrudes metamonzogranite (map unit Jp€mmg) and contains inclusions of metamonzogranite near contact.

Jp€gr GRANITE (JURASSIC OR PRECAMBRIAN)--Equigranular to slightly porphyritic biotite granite (syenogranite). Grain size is variable, and a fine-grained contact phase is locally present. Contacts with monzogranite are gradational, but

local inclusions of monzogranite indicate that granite is slightly younger. Petrologic similarities and the gradational nature of the contact suggest that both are related to the same intrusive event. This rock is commonly foliated, but the orientation of foliation is highly variable.

Jpεmmg METAMORPHOSED MONZOGRANITE (JURASSIC OR PRECAMBRIAN)--Monzogranite (Map Unit Jpεmg) is weakly metamorphosed along its northern boundary. Rock unit is distinguished from map unit Jpεmg by the smaller size and rounded character of K-feldspar phenocrysts, and by its more indurated character and common reddish stain. Rock is locally foliated.

Jpεmg MONZOGRANITE (JURASSIC OR PRECAMBRIAN)--Coarsely-porphyritic biotite granite (monzogranite), with pink K-feldspar phenocrysts up to 8 cm long. Texture varies from coarsely porphyritic to locally almost equigranular.

Jpεmu METAMORPHIC ROCKS AND LEUCOGRANITE, UNDIVIDED (JURASSIC? AND/OR PRECAMBRIAN?)--Igneous, metaigneous, and metasedimentary rocks, including quartz-muscovite schist, plagioclase-biotite gneiss, and sparse lenses of biotite schist. Variably foliated porphyritic monzogranite and medium- to fine-grained leucogranite are the dominant rock types in some areas. The foliated monzogranite and leucogranite are probably related to the monzogranite. The metamorphic rocks are the oldest in the Sore Fingers assemblage.

ROCKS OF UNCERTAIN STRATIGRAPHIC OR STRUCTURAL AFFINITY

MzCzbr BRECCIA (CENOZOIC OR MESOZOIC)--Volcanic and granite-clast breccia. Unit consists of two subunits, each containing dominantly or entirely clasts of one rock type. Contact between two is gradational. Granitic clasts resemble nearby underlying granite. Volcanic clasts are non-vesicular, medium-to dark-gray, dark-brown to dark-gray weathering, aphanitic, with plagioclase phenocrysts 3-4 mm diameter. Exposed only at one locality just north of the C.A.P. canal (unsurveyed sec. 18, T. 3 N., R. 13 W.).

Mzvu VOLCANIC AND SEDIMENTARY ROCKS, UNDIVIDED (MESOZOIC)--Gray, green, and maroon volcanic breccia, probably of rhyodacitic, dacitic, and andesitic composition. Exposed as a small klippe overlying granite at one locality is southernmost Little Harquahala Mountains (unsurveyed sec. 20, T. 3 N., R. 13 W.). Rock unit is dissimilar to the nearby Black Rock volcanics, but could correlate with the lower volcanic unit of the Centennial plate.

Mzpεgr GRANITE (MESOZOIC OR PRECAMBRIAN)--Equigranular to moderately

porphyritic, light greenish-gray granite with 0.5-2.0 cm K-feldspar phenocrysts, 3-6%, 1-3 mm biotite crystals, and accessory sphene and apatite. Exposed only in the southernmost Little Harquahala Mountains.

MzpEu METAMORPHIC AND INTRUSIVE ROCKS, UNDIVIDED (MESOZOIC AND/OR PRECAMBRIAN)--Moderately high-grade, metasedimentary and metaigneous rocks exposed as pendants within Granite Wash Granodiorite in sec. 33 in the northwest part of the range. Includes banded quartzofeldspathic gneiss, calc-silicate lithologies, and metasedimentary rocks with textural and compositional banding resembling relict bedding. Rock unit commonly contains a steep, metamorphic foliation.

MAP SYMBOLS

MAFIC DIKE--Typically fine-grained, equigranular, hornblende-plagioclase rock. Dike rock is locally porphyritic, may contain biotite, and is variably altered. Weathers dark gray and is poorly resistant to weathering. Dikes are typically oriented NW-SE and are largely if not entirely middle-Tertiary in age.

SILICIC TO INTERMEDIATE DIKE--Includes (1) slightly porphyritic, fine-grained andesite(?) with variably chloritized hornblende and biotite, (2) very-fine grained, locally porphyritic, medium-gray rhyolite(?) (3) light-gray to pinkish-gray, porphyritic rhyodacite(?), generally highly altered with quartz (up to 5 mm diameter), plagioclase (up to 5 mm diameter), subhedral to anhedral feldspar up to 2 cm long, and biotite up to 2 mm diameter, (4) non-resistant, medium-dark-gray, fine-grained, locally slightly porphyritic dacite(?) containing feldspar, quartz, chloritized hornblende or biotite, and limonite after pyrite cubes, (5) red or brown amorphous silica dikes. Most of these dikes are probably of mid-Tertiary age.

QUARTZ VEIN--Typically milky-white bull-quartz with local copper and iron sulfide and oxide mineralization.

50 STRIKE AND DIP OF BEDDING--Upright

45 STRIKE AND DIP OF BEDDING--Overturned

25 STRIKE AND DIP OF BEDDING--Approximate

35 STRIKE AND DIP OF BEDDING--Stratigraphic top direction indicated by bar and ball

STRIKE OF BEDDING--Vertical


HORIZONTAL BEDDING

STRIKE AND DIP OF CONTORTED BEDDING

STRIKE AND DIP OF SPACED CLEAVAGE--Arrow shows trend and plunge of associated lineation

STRIKE OF SPACED CLEAVAGE--Vertical


HORIZONTAL SPACED CLEAVAGE

STRIKE AND DIP OF BEDDING AND PARALLEL SPACED CLEAVAGE

STRIKE AND DIP OF SCHISTOSITY, COMPOSITIONAL BANDING, OR METAMORPHIC SHAPE FABRIC--Arrow shows trend and plunge of associated lineation

STRIKE AND DIP OF MYLONITIC FOLIATION

STRIKE AND DIP OF JOINT


STRIKE OF VERTICAL JOINT

STRIKE AND DIP OF CLOSELY SPACED JOINTS

STRIKE AND DIP OF FLOW FOLIATION


FLOW BRECCIA


CONGLOMERATE

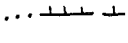
MARKER UNIT OR MAPPABLE CONTACT WITHIN MAP UNIT

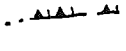
TREND AND PLUNGE OF SMALL FOLD AXES

TREND AND PLUNGE OF SYNCLINE

TREND AND PLUNGE OF ANTICLINE


THRUST FAULT--Showing dip. Dashed where approximately located, dotted where concealed. Teeth on upper plate.


LOW-ANGLE NORMAL FAULT--Dashed where approximately located, dotted where concealed. Hatchures on upper plate.


LOW-ANGLE FAULT WITH NORMAL SEPARATION--Dashed where approximately located, dotted where concealed. Teeth and hatchures on upper plate.


HIGH-ANGLE NORMAL FAULT--Dashed where approximately located, dotted where concealed. Bar and ball on upper plate.

····———— HIGH-ANGLE FAULT--Dashed where approximately located, dotted where concealed.

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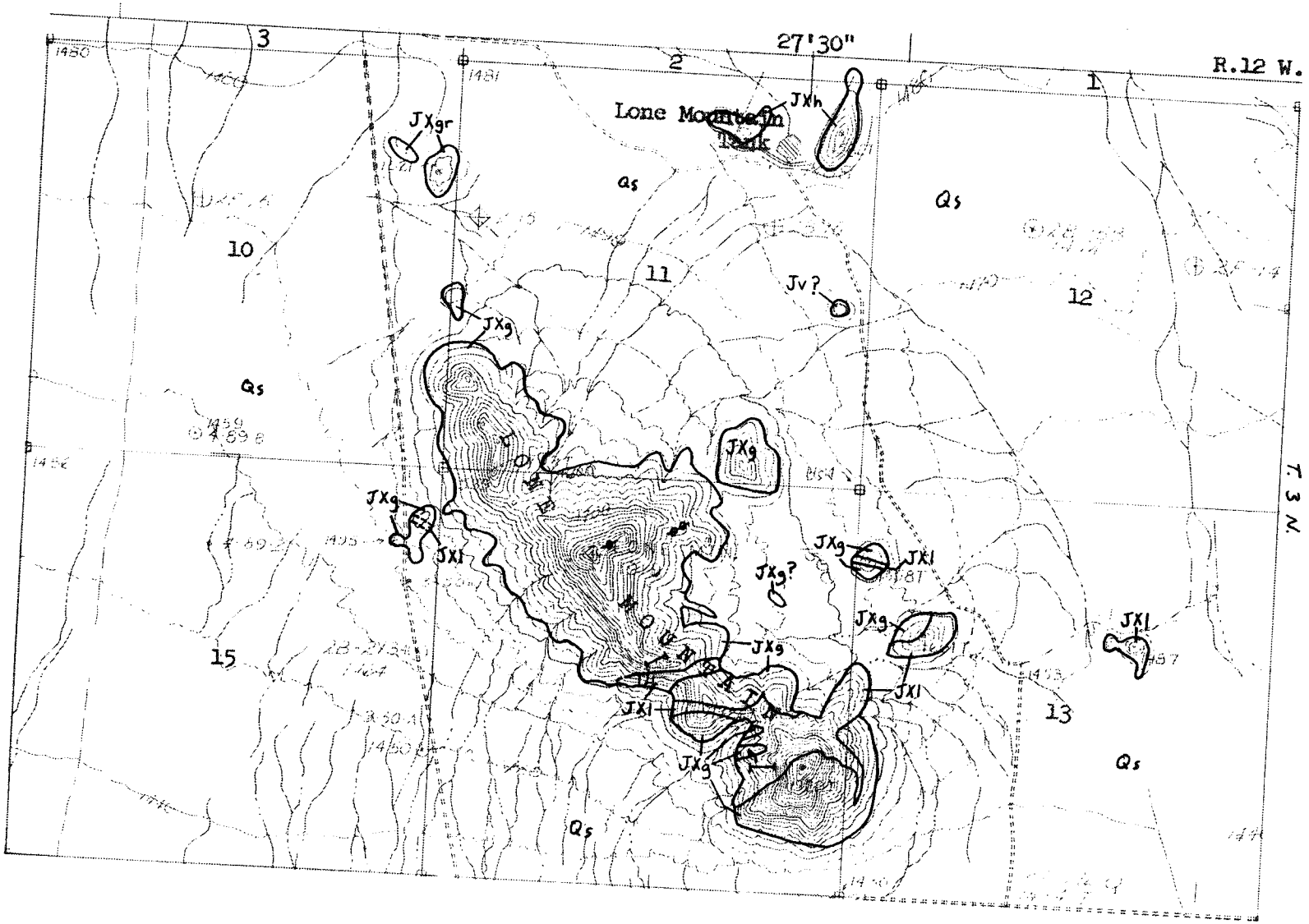

Scale 1:24,000

Lone Mountain

(southeastern Little Harquahala Mountains)

Description of Map Units

Qs **Surficial deposits (Quaternary)**

Jv **Volcanic rocks (Jurassic)**--Light gray, greenish gray, or dark lavender, non-vesicular, intermediate composition volcanic or hypabyssal rocks. Contains abundant opaque mineral grains < 1mm diameter and several percent, variably altered feldspar, hornblende, and quartz(?) phenocrysts up to 4 mm diameter.

JXh **Hypabyssal rocks (Jurassic to Proterozoic X)**--Rock consists of slightly broken appearing, reddish white K-feldspar 1 to 4 mm diameter in dark gray aphanitic groundmass. Rocks of this map unit weather dark gray to black and are unfoliated.

JXl **Leucogranite (Jurassic to Proterozoic X)**--Medium to fine-grained leucocratic granite with 1 to 3 % biotite.

JXg **Granitoid rocks (Jurassic to Proterozoic X)**--Compositionally variable, medium- to fine-grained, nonporphyritic granodiorite, quartz diorite, and diorite(?) with up to 20% hornblende. Locally includes granitic phases with approximately equal parts plagioclase and K-feldspar (especially northwestern end of Lone Mountain) and pegmatite dikes. Anhedral(?) apatite and sphene, 1 to 2 mm in diameter, are common in less leucocratic phases. Intrusive contact relationships suggest that intrusions became progressively more felsic during emplacement.

JXgr **Granite (Jurassic to Proterozoic X)**--Coarse-grained, non-porphyritic granite with red K-feldspar and green plagioclase. Resembles granite of the Centennial Plate in the Little Harquahala Mountains (map unit pCg).