

Location Symbol Type Material %K Comments Volcanic rocks of Black Mesa, Tin Mtn. NW 7

1. F78-59 SE1/4, Sec33, T21N, R13W Tbpd 6.17 4.33x10-11 20.5 + 1.0 Unit was mapped as overlying Peach Springs Tuff, but, tuff may only fill a swale on NW side of dacite 2. F78-64 SE1/4, Sec17, T21N, R13W Tba 13.8 + 0.7 Andesite flow overlies Peach Andesite W/R 2.28 2.83x10-11 Springs Tuff. Hbl Latite Bio 3.57 3.08x10-11 24.3 + 0.8 Latite dome overlies hornblende-N1/2, Sec11, T21N,R12W bearing alkali-olivine basalt. 4. F78-85 Bull Springs 7 1/2 Quad Lat.35°12',Long.113°25' 22.0 + 0.7 Basalt dike cuts Fort Rock Creek 1.98 4.43x10-11 Tuff (of Fuis, 1973). W/R 3.16 5.58x10⁻¹¹ 20.7 + 0.6 Flows were mapped as equivalent to Lat.35°14', Long.113°20' ones that overlie Peach Springs Tuff to north; these flows may interfinger with Peach Springs Tuff. W/R 0.63 5.19x10⁻¹² 9.0 + 1.2 Youngest flow in stack erupted Lat.35°12',Long.113°6' outcrop to east and are cut by numerous normal faults. Volcanic rocks of East Juniper Mtns., Turkey Canyon NE 7 1/2 Quad 7. BA78-82 Center, Sec21,T21N,R5W Tjpb Olivine W/R 5.5 + 0.2 Eroded dike and cone complex at mouth of Big Chino Wash as it enters Big Chino Valley; appears older than Mt. Floyd lavas to NE. 8. BA78-90 Center, Sec1, T20N, R6W 6.2 + 0.3 Basalt flow overlies Redwall Limestone; adjacent to BA78-72 mentioned below. 9. F78-113 Crest of Picacho Butte 0.87 9.02x10⁻¹² 9.8 + 0.7 Eroded rhyodacite dome surrounded by basalt flows of Mt. Floyd volcanic field. 6.61 5.26x10-11 22.4 + 0.8 Andesite dome and flow ovelain and surrounded by younger basalt flows. 11. BA78-72 Turkey Can. NE 7 1/2 Quad Ttc Bio 7.16 8.23x10⁻¹¹ 36.1 + 1.2 Andesite flow and cone (Juniper SE1/4, Sec12, T20N, R6W Andesite Cone); appears to be relatively 6.62×10-11 2.72×10-11 24.4 + 1.2 what younger than F78-88 above. Estimated age from K-Ar dates is <30 m.y. 1K-Ar age dates by Daniel Krummenacher, San Diego State University, San Diego, CA.

Potassium-Argon dates obtained from volcanic rocks mapped between Kingman and Bill Williams Mountain, Arizona

Description of Map Units

Note: Descriptions of Tertiary volcanic units are grouped by geographic area from west to east. Units within the groups are described in approximate order of increasing age. Unreferenced K-Ar ages are by D. Krummenacher, San Diego State University, 1979.

ALLUVIUM Stream and basin deposits of gravel, sand, silt, and clay. COLLUVIUM Slope wash and talus from local sources; mapped only where extensive or where covering critical contacts.

> ALLUVIAL FANS Fan-shaped deposits of gravel and sand at the mouths of valleys. LANDSLIDES Unsorted debris that has moved down steep slopes chaotically or as a

TERRACE GRAVEL Older alluvium that lies along the margins of present streams and basins; now undergoing erosion. OLDER ALLUVIAL FANS Old alluvial fans now undergoing erosion; includes pediment

gravels at the base of mountain fronts. GRAVELS Extensive older deposits of gravel, sand, silt, and clay now undergoing ero-

sion; contains interbedded lake deposits (QgI), e.g., near Big Sandy River, Tin Mountain TERTIARY GRAVELS Deposits of gravel, sand, silt, and clay that are distinguished

from older Tertiary gravels (Tog) by clasts of volcanic flows or as small erosional remnants; may be difficult to distinguish from older Quaternary gravels (Qg); one large deposit occurs north of monocline in north central Bull Springs quadrangle. TERTIARY VOLCANIC UNITS

PEACH SPRINGS TUFF (Miocene) Pink to grey silicic ash-flow tuff containing nocrysts of sanidine, plagioclase, quartz, rare sphene, and minor mafic minerals; nidine in densely welded zones displays a blue iridescence; consists of two thick flow units near Kingman; locally includes white non-welded basal airfall ash and pumice; flow bottom contains abundant rock fragments derived from local and non-local sources; Tps forms conspicuous pink ledges and is the primary stratigraphic marker throughout western side of map area (Young and Brennan, 1974); flows thin to east; vent area probably west of Kingman; K-Ar age about 17.6 Myr (Young and Brennan,

VOLCANIC ROCKS OF KINGMAN AND PEACOCK MOUNTAINS (Miocene)

QUARTZ-BEARING BASALTIC ANDESITE Black flows and red cinder deposits of quartz-bearing lavas containing phenocrysts of hypersthene and/or olivine, minor plagioclase, and resorbed quartz with reaction rims of clinopyroxene. + hornblende microphenocrysts; flows vary in appearance from thin and massive to thick and platy: contains minor maar-type pyroclastic beds south of Kingman; forms extensive volcanic field underlying Peach Springs Tuff (Tps) near Kingman; underlain by and interbedded with olivine basalt (Tkob) on west side of Hualapai Mountains and in southern Peacock

OLIVINE BASALT Black flows and minor red cinder deposits of basalt containing abundant to sparse olivine and minor plagioclase and clinopyroxene phenocrysts: flows are best exposed on west side of Hualapai Mountains, where they underlie quartzbearing lavas (Tkqb) and overlie Precambrian rocks (pE).

ANDESITE INTRUSIVE Grey medium-grained intrusive andesite(?) with phenocrysts of altered olivine, phlogopite, alkali feldspar, plagioclase, and feldspathoid(?); intrudes Precambrian rocks (pE).

VOLCANIC ROCKS OF BLACK MESA (Miocene)

ANDESITE Thick platy flows of grey andesite with sparse microphenocrysts of quartz, plagioclase, and hypersthene(?); overlies Peach Springs Tuff (Tps); K-Ar age 13.8 \pm 0.7

> BIOTITE-OLIVINE ANDESITE Thick platy flows of black to grey andesite with conspicuous phenocrysts of olivine, clinopyroxene, biotite, and minor feldspar; overlies

PORPHYRITIC DACITE Silicic dome of dark grey coarse porphyritic dacite with phenocrysts of hornblende, biotite, sanidine(?), resorbed quartz, and larger plagioclase phenocrysts; apparently overlies Peach Springs Tuff (Tps) but tuff may only fill gully on north side of dacite flow; lies in fault contact with Tertiary conglomerate containing large dacite clasts; K-Ar age 20.5 ± 1.0 Myr (biotite).

OLIVINE BASALT Grey to black flows interbedded with light grey maar-type pyroclastic deposits of basalt with abundant to sparse olivine and minor plagioclase phenocrysts; overlies Precambrian granite (pCg); underlies Peach Springs Tuff (Tps) and biotite-olivine andesite (Tboa)

VOLCANIC ROCKS OF FORT ROCK (Miocene)

QUARTZ-BEARING BASALTIC ANDESITE Dark grey, sheeted basaltic andesite; rare vesicles; sparse microphenocrysts of plagioclase and clinopyroxene and quartz negacrysts with clinopyroxene reaction rims, set in groundmass containing opaques, plagioclase, clinopyroxene, and olivine(?); overlies Precambrian granite (peg); relation to other Fort Rock volcanic rocks unknown.

HORNBLENDE LATITE Two light grey to pink domes of medium-grained latite with aspicuous phenocrysts of hornblende and minor phenocrysts of biotite ± rare apolite and allanite (Goff et al., 1982); overlies olivine basalt (Trob); K-Ar age of east dome 24.3 ± 0.8 Myr (biotite). HORNBLENDE ANDESITE Dark grey thick platy flows and domes of coarse to

medium-grained andesite containing abundant hornblende phenocrysts of variable size in a trachytic groundmass; some flows contain sparse phenocrysts of alkali feldspar, plagioclase, clinopyroxene and quartz; equivalent to the trachyandesites of the Crater Pasture Formation of Fuis (1973); interbedded with (?) and underlain by olivine basalts (Trob); underlie Peach Springs Tuff (Tps).

ANDESITE, UNDIVIDED Grey to dark grey andesitic flows of variable appearance containing abundant to sparse phenocrysts of clinopyroxene, plagioclase, ± biotite; part of the Crater Pasture Formation of Fuis (1973); underlain by and interbedded with olivine

PORPHYRITIC DACITE Poorly exposed domes of light grey coarse-grained extremely porphyritic dacite with phenocrysts of alkali feldspar, plagioclase, biotite, hornblende d minor quartz: probably equivalent to the rhyodacite flows within the Fort Book Creek Rhyodacite of Fuis (1973); underlies Fort Rock Creek Tuff (Tfc) and hornblende andesite (Trha); base of domes not exposed.

BASALT, UNDIVIDED Black to grey flows, red cinder deposits, and brown to grey maar-type pyroclastic deposits of predominantly olivine basalt; includes scattered basaltic dikes (Trbi); the bulk of this unit is contained within the Crater Pasture Formation of Fuis (1973) but equivalent flows overlie Fort Rock Creek Tuff (Tfc) in center of Bull Springs quadrangle; many flows are coarsely porphyritic; flows contain phenocrysts of olivine and plagioclase + clinopyroxene + hypersthene + microphenocrysts of hornblende or biotite; flows overlie Precambrian granitic rocks (pCq): interbedded with other Fort Bock volcanic rocks and Fort Bock Creek, Tuff (Tfc): overlain by and possibly interbedded with Peach Springs Tuff (Tps); K-Ar age of basalt dike cutting Fort Rock Creek Tuff (Tfc) 22.0 ± 0.7 Myr (whole rock).

FORT ROCK CREEK TUFF (Miocene) White pumice-rich non-welded ash-flow Tuff and air-fall Tuff characterized by abundant lithic fragments of olivine basalt (Trob) and ornblende andesite (Trha); contains less abundant fragments of porphyritic dacite (Trpd) and Precambrian rocks (p6); unit is essentially equivalent to the Fort Rock Creek Rhyodacite of Fuis (1973) but is considerably thinner in map, area, and possesses fewer sub-units and interbedded sedimentary deposits; groundmass contains crystals of quartz, alkali feldspar, plagioclase, biotite and hornblende in a matrix of non-welded glass shards; pumice fragments contain conspicuous phenocrysts of biotite and/or nornblende; source of Tuff is in Aquarius Mountains to south (Fuis, 1973); Tuff fills valleys and swales on a constructional topography of other Fort Rock volcanic rocks and eroded Precambrian rocks (pE); interbedded with olivine basalt (Trob); underlies Peach Springs Tuff (Tps); age delimited by basalt flow (Trob?) underlying Tfc near source dated at 18.2 ± 1.5 Myr (Young and McKee, 1978) and basalt dike (Trbi) cutting

VOLCANIC ROCKS OF THE SLURRY LINE (Miocene)

PYROXENE ANDESITE Grey flows of andesite containing sparse conspicuous phenocrysts of green clinopyroxene; overlies Peach Springs Tuff (Tps). BASALTIC ANDESITE Grey to black flows and red cinder deposits of sparsely porphyritic basaltic andesite with a glassy fine-grained groundmass; contains phenocrysts of olivine, clinopyroxene, and plagioclase; overlies olivine basalts of Fort Rock (Trob); interbedded with Slurry Line basalts (Tsb) and Peach Springs Tuff (Tps);

BASALT, UNDIVIDED Black to grey flows and red cirider deposits of olivine basalt containing olivine, plagioclase, and minor pyroxene phenocrysts; includes unmapped areas of basaltic andesite (Tsba), separated from Fort Rock basalt (Trob) on the basis of geographic and stratigraphic criteria; interbedded with (?) and underlain by Peach

K-Ar age of typical flow 20.7 ± 0.6 Myr (whole rock).

ANDESITE Grey flow of porphyritic andesite with prominent vertical platy jointing; contains phenocrysts of hypersthene, clinopyroxene, and minor feldspar; overlies the

VOLCANIC ROCKS OF CROSS MOUNTAIN (Miocene)

ndivided) of Cross Mountain (Tcob).

OLIVINE BASALT AND OTHER BASALT, UNDIVIDED Black flows, flow breccia, and red cinder deposits of basalt containing abundant to rare phenocrysts of olivine, and minor plagioclase; some flows contain pyroxene; many flows have a very glassy groundmass; includes unmapped flows of quartz-bearing olivine basalt (Tcqb); individual flows may be very difficult to distinguish from basalt flows of the Slurry Line (Tsb) and Squaw Peak (Tpob) groups; occur above, below, and interbedded with other volcanic units of this area; interbedded with Turkey Canyon andesite (Ttc).

ANDESITE Grey flow of andesite containing abundant plagioclase and minor pyroxene

phenocrysts; apparently underlies olivine basalt (Tcob). QUARTZ-BEARING OLIVINE BASALT Black flows of basalt containing sparse phenocrysts of olivine and/or hypersthene and rary microphenocrysts of quartz in a very glassy groundmass; overlies Turkey Canyon andesite (Ttc) and is interbedded with

OLIVINE ANDESITE Grey to pale pink flows of very porphyritic andesite with phenocrysts of iddingsitized olivine in a trachytic groundmass; interbedded with basalts

BIOTITE ANDESITE Grey to pink dome of andesite containing phenocrysts of biotite. clinopyroxene, plagioclase, hypersthene, and quartz; overlies Martin and Redwall

VOLCANIC ROCKS OF SQUAW PEAK (Miocene) BASALT, UNDIVIDED Grey to black flows and minor red cinder deposits of

predominantly olivine basalt and subordinate amounts of quartz-bearing basaltic andesite; principal vent area at Squaw Peak; often contains conspicuous clusters of olivine phenocrysts; other olivine basalts contain sparse to abundant olivine and minor plagioclase phenocrysts; basaltic andesites contain phenocrysts of olivine, plagioclase, clinopyroxene and/or hypersthene and sparse phenocrysts of quartz; overlies hornblende andesite (Tpha) and Turkey Canyon andesite (Ttc); apparently underlies high-alumina basalt of Henry Brown Mountain (Thb); some flows may be equivalent to basalts (undivided) of Cross Mountain area (Tcob); overlies Martin and Redwall Limestone (DMI) and Supai Formation (PPs); K-Ar age of uppermost flow at Squaw Peak 9.0 ± 1.2 Myr (whole rock).

HORNBLENDE ANDESITE Grey to pink, thick flow of massive to flow-banded andesite with phenocrysts of hornblende, clinopyroxene, plagioclase, and quartz; top of flow contains abundant inclusions of altered Precambrian and Paleozoic(?) rocks; overlies Martin and Redwall Limestone (DMI) and Supai Formation (PPs).

BASALT OF HENRY BROWN MOUNTAIN [late(?) Miocene] Grey to black flows of extremely coarse-grained high-alumina basalt with large phenocrysts of plagioclase and phenocrysts of iddingsitized olivine in a diktytaxitic groundmass; apparently overlies basalts of Squaw Peak (Tpob); overlies Martin and Redwall Limestone (DMI).

ANDESITE OF TURKEY CANYON (Oligocene-Miocene) Grey to pale pink flows. domes, and a single cone; very porphyritic andesite characterized by conspicuous phenocrysts of black to reddish biotite. dark green clinopyroxene and minor phenocrysts of plagioclase; contains sparse xenoliths of Paleozoic units and rare biotite pyroxene inclusions; outcrops commonly flow-banded and vertically sheeted; dome and flows underlie basalts (undivided) of the Slurry Line (Tsb); coarse- and medium-grained flows are interbedded with and underlie Cross Mountain basalts (Tcqb and Tcob); flows and dome(?) underlie Squaw Peak basalts (Tpob); flows and cone underlie volcanic units of east Juniper Mountains; overlies Martin and Redwall Limestone (DMI); widespread distribution and variable degree of preservation suggest that Ttc was emplaced over a substantial time interval and is not a time-stratigraphic unit; K-Ar age of west dome 22.4 ± 0.8 Myr (biotite); K-Ar ages of east cone (Juniper

VOLCANIC ROCKS OF EAST JUNIPER MOUNTAINS (Miocene)

BASALTIC ANDESITE Grey to brown flows of platy basaltic andesite characterized by abundant plagioclase microphenocryst laths aligned parallel to the platy jointing; contains sparse plagioclase and rare quartz phenocrysts, with abundant fine-grained opaques disseminated throughout the groundmass; overlies pyroxene porphyritic basalt (Tipb) and is interbedded with olivine basalt (Tipb).

OLIVINE BASALT Black flows and red cinder deposits of basalt containing olivine and minor plagioclase and/or clinopyroxene phenocrysts; interbedded with basaltic andesite (Tjba) and pyroxene porphyritic basalt (Tjpb); underlies basalts of Mt. Floyd (Tfob); overlies andesite of Turkey Canyon (Ttc); overlies Martin and Redwall Limestone (DMI); K-Ar age of flow east of Juniper Cone 6.2 ± 0.3 Myr (whole rock).

PYROXENE PORPHYRITIC BASALT Grey flows, plugs, and dikes of very porphyritic basalt containing phenocrysts of olivine, clinopyroxene, and plagioclase; some flows contain resorbed, clear to partly altered, grains of quartz with feathery clinopyroxene rims and carbonate alteration; interbedded with olivine basalt (Tiph); underlies basaltic andesite (Tjba) and basalts of Mt. Floyd (Tfob); overlies Martin and Redwall Limestone (DMI) and Precambrian granitic rocks (pEg); K-Ar age of plug at head of Big Chino Valley 5.5 ± 0.2 Myr (whole rock).

VOLCANIC ROCKS OF MT. FLOYD VOLCANIC FIELD [Quaternary(?) - Miocene]

BASALT, UNDIVIDED Grey to black flows and red cinder deposits of olivine basalt of widely variable appearance; most flows have olivine, sparse black clinopyroxene or abundant felty plagioclase microphenocrysts; at least one flow of high-alumina diktytaxitic basalt occurs along Partridge Creek in south Cathedral Caves quadrangle; overlies basalts of east Juniper Mountains (Tjob and Tjpb); probably equivalent to basalts of San Francisco Peak volcanic field with respect to time and composition (D. Nealey and E. Wolfe; personal communication, 1978); older flows contemporaneous with those of the Perkinsville Formation to the southeast (McKee and Anderson, 1971).

Table 1

HORNBLENDE RHYODACITE OF PICACHO BUTTE Dome and flows of grey to pale pink flow-banded rhyodacite containing conspicuously aligned hornblende phenocrysts, biotite microphenocrysts, and phenocrysts of plagioclase; locally pumiceous and glassy; erosion has partly exposed vertically sheeted core of vent in valley on west side of dome: lower part of unit consists of massive flow by stratigraphic relation to basalt units surrounding dome unclear due to extensive apron of rhyodacitic colluvium; dome older than well-preserved basalt cinder cones nearby;

VOLCANIC ROCKS OF SAN FRANCISCO PEAK VOLCANIC FIELD (Quaternary-Miocene)

BASALT, UNDIVIDED Grey massive to platy flows and abundant red cinder deposits of olivine basalt; most flows contain olivine and plagioclase phenocrysts but others contain large black clinopyroxene or abundant felty plagioclase microphenocrysts (Hughes, 1978); overlies Toroweap-Kaibab Limestone (Ptk); probably equivalent to basaltic flows of Mt. Floyd volcanic field with respect to time and composition, (D. Nealey and E. Wolfe, personal communication 1978); cinder cones commonly aligned along buried fissures or faults with northeast and northwest trends; contemporaneous with basalt of the Perkinsville Formation to the south (McKee and Anderson, 1971); K-Ar ages within map area range from 4.11-4.82 Myr (Hughes, 1978); other basalts within the San Francisco Peak volcanic field are as young as 910 years (Wolfe et al., 1976).

BASALTIC ANDESITE Grey platy flows and red cinder deposits of basaltic andesite with phenocrysts of plagioclase, clinopyroxene, and hypersthene; some flows contain minor phenocrysts of olivine and hornblende (Hughes, 1978); interbedded with basalt Tsfb) and underlain by Hell Canyon dacite (Tsfd).

HELL CANYON DACITE Dome of white glassy dacite containing sparse phenocrysts of plagioclase and hypersthene; interbedded with basalt (Tsfb); underlies basaltic andesite (Tsfa); K-Ar age 5.15 ± 0.17 Myr (Hughes, 1978). MIDDLE-EARLY TERTIARY UNITS

OLDER TERTIARY GRAVELS Eroded and buried remnants of white to pink gravels, sands, and silts characterized by the absence of Tertiary volcanic clasts; contains inly Precambrian (pc) and Tapeats Sandstone (Ct) fragments in Fort Rock area; on east side of map area, fragments are mostly of Supai Formation (PPs) with subordinate Paleozoic limestone (DMI, €m); locally thick accumulations suggest that an extensive prevolcanic drainage system was once well established (e.g., McKee and McKee, 1972; Young and Brennan, 1974); underlies Tertiary volcanic rocks and overlies Paleozoic

LATITE INTRUSIVE (late Cretaceous? - early Tertiary?) Dark grey dikes of porphyritic atite(?); hypabyssal texture, with phenocrysts of alkali feldspar, plagioclase, biotite, and hornblende in a fine-grained sugary groundmass; only observed intruding Precambrian rocks south of Kingman; possibly related to Laramide intrusives in region surrounding west half of map area.

TOROWEAP FORMATION AND KAIBAB LIMESTONE, UNDIVIDED (Permian) Buff to greyish or whitish porous limestone, undivided; generally thick and massive cliffformer; locally sandy and/or fossiliferous (containing brachiopods(?) and other indistinct fossil remains); some interbedded chert; commonly contains lenses of sandstone composed of rounded detrital quartz and feldspar; overlies Coconino Sandstone (Pc); underlies older Tertiary gravels (Tog) and basalt of San Francisco Peak volcanic field (Tsfb); maximum exposed thickness in map area, northwest of Mesa Butte Fault on the Ash Fork quadrangle, about 110-135 m.

COCONINO SANDSTONE (Permian) White to buff cross-bedded sandstone com-

posed predominantly of grains of quartz and feldspar; beds are thick and massive but outcrops weather along bedding planes; overlies Supai Formation (PPs) along a poorly exposed erosion surface of low relief; underlies Toroweap-Kaibab Limestone (Ptk); maximum exposed thickness, west of Picacho Butte, is 150 m. SUPAI FORMATION (Pennsylvanian-Permian) Orange to red well-bedded sandstone,

siltstone, and minor shale composed predominantly of grains of quartz and microcline; lower part of Supai contains limestone similar to the upper Redwall Formation (DMI) with interbedded red chert; beds generally 0.25-1 m thick; rarely observed upper part of Supai primarily consists of red siltstone and shale (Hermit Shale); Supai overlies Martin and Redwall Limestone (DMI) on a poorly exposed erosion surface of low relief; underlies Coconino Sandstone (Pc); maximum exposed thickness, on northeast flank of Big Chino Valley, is 285 m. MARTIN AND REDWALL LIMESTONES, UNDIVIDED (Devonian-Mississippian) Dark

grey to light grey well-bedded limestone and dolomitic limestone; often weathered to

poorly bedded; breaks along partings filled with very thin layers of green to grey clay;

only at Cross Mountain and northwest of Cross Mountain but may occur in areas to the

contains lenses of sandstone and quartzite-rich edgewise conglomerate; unit mapped

Martin and Redwall Limestone (EM, DMI); maximum observed thickness, on Cross

rellowish or pinkish color; beds are usually 0.5-2 m thick; massive and crystalline, nedium- to coarse-grained; contains thin chert beds, lenses, and pods; upper part of Redwall commonly fossiliferous (abundant foraminifera and/or pellets; rarely observed coral, crinoid fragments and brachiopods); overlies Muav Limestone (Em) and Bright Angel Shale (Cb) along a paleo-erosion surface of low relief; underlies Supai Formation (PPs); maximum observed thickness on Cross Mountain is 235 m. MUAV LIMESTONE (Cambrian) Dark purple-grey to light grey limestone and dolomitic limestone; often mottled grey to yellow-brown (algal limestone?); generally massive and

east; underlies Martin and Redwall Limestone (DMI); overlies Tapeats Sandstone (€t) and Bright Angel Shale (€b); maximum observed thickness, on Cross Mountain, 35 BRIGHT ANGEL SHALE (Cambrian) Brownish grey to greenish grey muscovite-rich shale; strongly foliated, occasionally resembling phyllite; contains interbedded sandstone at some locations; overlies Tapeats Sandstone (€t); underlies Muav and

TAPEATS SANDSTONE (Cambrian) Red to pink to buff cross-bedded finely banded erbedded brown to purple shale; base of unit generally composed of pebble conglomerate with granitic clasts; overlies Precambrian granitic and metamorphic rocks (p€) along an irregular erosion surface; underlies Bright Angel Shale (€b) and Muav, Martin, and Redwall Limestones (Em, DMI); maximum observed thickness, on Cross

BASEMENT COMPLEX (Precambrian)

GRANITIC ROCKS Mostly granitoid; some show minor gneissic texture; mainly comp€g posed of quartz, alkali feldspar, plagioclase, biotite.

SCHISTS, GNEISSES Includes minor amphibolite and hornblendite; more felsic rocks

mainly composed of quartz, alkali and plagioclase feldspar, biotite; more mafic rocks mainly consist of amphibole, plagioclase, biotite, quartz. METAVOLCANIC ROCKS Essentially amphibolite; main minerals are amphibole and plagioclase, ± biotite.

IGNEOUS AND METAMORPHIC ROCKS, UNDIVIDED Locally complicated Precamp€u brian lithologies. These Precambrian granitic and metamorphic rocks often contain dikes and veins of quartz.

pegmatite, micropegmatite and aplite; dikes and pods of amphibolite (meta-basalt?) are common. Many granitic bodies contain sparse lenticular inclusions rich in biotite and/or amphibole. Cross-cutting relations between dikes, veins, and associated intrusive and metamorphic rocks suggest a complicated history of multiple intrusions, and metamorphism. Precambrian basement underlies all other map units. Precambrian lithologies by geographic sub-area, moving west to east across map area, are discussed as follows

Hualapai and Peacock Mountains: Include at least three granitic bodies that intrude generally steeply dipping and northeast-striking metamorphic rocks; granitic rocks include medium- to coarse-grained granite (some porphyritic) and lesser granodiorite, and local biotite diorite (metavolcanic?); metamorphic rocks of probable metasedimentary origin (some possibly metaigneous) include strongly foliated granitic gneisses, mafic to quartzofeldspathic schists and hornblendite; the metavolcanic rocks are mostly amphibolites, forming indistinct contacts with

Black Mesa: Precambrian rocks in area mainly pink coarse-grained granite, highly jointed with orthogonal joint sets oriented essentially ENE and NNW

Tin Mountain: Composed of complex assemblage of granitic and metasedimentary (some

Fort Rock: Precambrian rocks in area mainly pink coarse-grained granite with subordinate schist and gneiss; granitic rocks cut by prominant joint sets, with similar orientations to those of Black

Big Chino Valley: Precambrian lithologies, going from north to south, include grey biotite granite, pink muscovite leucogranite and red (biotite-)granite gneiss.

Note: Geology shown on Bill Williams Mountain Quadrangle is simplified from Hughes (1978). Geology of Ash Fork, Cathedral Caves, and Pichacho Butte SE Quadrangles is updated from previous reconnaissance map by Krieger (1967a, 1967b). Geology of Picacho Butte, South Butte, Red Mountain, Turkey Canyon, Turkey Canyon NE, and Purcell Canyon Quadrangles is updated from previous reconnaissance map by Krieger (1967b, 1967c).

______Contact; dashed where approximately located; dotted where concealed; queried where uncertain

Map Symbols

		where the expression and the contest where the entertain
	- 00	Fault showing dip; dashed where approximately located; dotted where concealed; queried where uncertain;
70		bar and ball on downthrown side
APL		Aerial photographic lineament
* ;	→	Anticline or syncline, showing direction of plunge; dashed where approximately located
		Strike and dip of beds
45	5_	Inclined
_	+	Vertical
		Strike and dip of flow banding and flow foliation in volcanic rocks
		Inclined
	-	Vertical Horizontal
		Total Control
		Strike and dip of joints
-	Ш_	Inclined
-	-#-	Vertical
,		Strike and dip of granitic foliation and/or schistosity
	23.0	Inclined
-	-55	Vertical
ہے	75	Sheared or brecciated rock
	*	Vent; queried where uncertain
(7	Landslide
_		Spring should be account to a control of the contro
		Spring, showing measured temperature
0 21	1°C	Well, showing measured temperature
Cu, Mo, Pb,	, Ag	Mineralization: copper, molybdenum, lead, or silver
• 15 Bi I	Mu	Mafic content of Precambrian granitic rock showing combined amounts of biotite and muscovite
	B	Location of proposed magnetotelluric station

Discussion

Scientists of Los Alamos National Laboratory have been evaluating the geology, geophysics and fluid geochemistry of the Aquarius Mountains region of northwest Arizona during the last few years to determine its hot dry rock (HDR) geothermal potential (Goff et al., 1979; West and Laughlin, 1979; Aiken and Ander, 1981; Goff, 1979). As part of this effort, the geology of the Transition Zone between the Colorado Plateau and Basin and Range tectonic provinces was mapped to provide background data on structure and volcanism (Fig. 1). We consider the boundary between the two tectonic provinces to be along the west edge of the Aquarius Mountains and the Transition Zone to extend from the Aquarius Plateau to Big Chino Valley (sheets 2 and 3). Mapping was restricted to an east-west strip roughly 10 km wide and 160 km long that purposely coincides with the line of a magnetotelluric geophysical traverse obtained by Los Alamos. End points and bends in the accompanying cross-sections were originally chosen to correspond with magnetotelluric stations along the traverse but many additional stations have been added since the cross-sections were first drawn. All field work was performed from June to August, 1978 and mapping was

compiled in the fall of 1978. Previous investigations in the region have focused on the evolution of the boundary between the two tectonic provinces and the evolution of the Colorado River drainage (Lucchitta, 1972; Young and McKee, 1978). These references and others included below contain a wealth of information on historical geology, structural geology and relationships between Tertiary gravels and volcanics

The southwestern Colorado Plateau consists of layered Paleozoic sandstone, shale, carbonate, and quartzite resting on a Precambrian basement complex of granitic and metamorphic rocks. The Plateau dips gently eastward so that the Paleozoic section thins westward due to erosion. Early to middle Tertiary gravels overlie the eroded Paleozoic and Precambrian rocks in widely scattered deposits. Many of these deposits are preserved by younger volcanic rocks of predominantly Miocene age. In the Aquarius Mountains region and in the Basin and Range province to the west, volcanic rocks rest directly on Precambrian basement; the Paleozoic section is missing. Young and McKee (1978) believe that much of the uplift and eastward dip of the Plateau were well-established 25 Myr ago

The Aquarius Mountains region occupies a structural transition zone in which Basin and Range tectonics are impinging on the Colorado Plateau. The structure consists of fault blocks seperated by north and northwesttrending normal faults. Displacements, determined from offset volcanic units, are generally down to the west, fault blocks usually dip gently to the east. Faults of this style cut Quaternary basin-fill gravels in Big Chino Valley (sheet 3) east of the Aquarius Mountains (Krieger, 1967b) indicating that extentional tectonics is an active process in the region. The Basin and Range area displays typical north-trending horsts and grabens with major range-

bounding normal faults. Older geologic structures are still preserved throughout the map area. For example, a set of northeast-trending fault systems such as the Bright Angel and Mesa Butte faults (sheet 4) has been intermittently active since Precambrian time (Shoemaker et al., 1975). East-plunging monoclines and the reverse fault in Butcher Knife Canyon, east of Big Chino Valley (sheets 3 and 4) were probably created in Paleozoic rocks during the Laramide orogeny. Latite dikes that cut Precambrian rocks in the Kingman-Hualapai Mountains area (sheet 1) are also interpreted to be of Laramide age. Finally, we mapped a curious set of anticlines, synclines and a monocline preserved in Peach Springs Tuff on the north side of the Fort Rock area (sheet 2). We do not know if these latter structures have developed along reactivated Laramide-age folds buried beneath the volcanic cover. These folds are significant, however, because they indicate compressional tectonic forces were locally active during the earlier phases of Tertiary volcanism in this

Volcanic rocks of the Kingman-Williams region consist primarily of olivine basalt and basaltic andesite with subordinate volumes of intermediate and silicic rocks (Arney et al., 1980; Arney, Goff and Eddy, unpub. data). Contact relations and K-Ar age dates between various volcanic sequences show that volcanism in the Transition Zone decreased in age from ~24 Myr around the Fort Rock area to 6 Myr in the East Juniper Mountains (Table 1). The youngest volcanic rocks studied (~5.2 Myr to present) were vented from the Mt. Floyd and San Francisco Peak volcanic fields on the eastern side of the map area (Ulrich et al., 1979; Hughes, 1978; D. Nealey, U.S. Geol. Survey, oral communication, 1978). An older episode of volcanism is represented by a distinctive group of 22 to 30 Myr old biotite-pyroxene andesites that erupted along a 40 km long west-trending belt across the Transition Zone (Andesite of Turkey Canyon).

Peach Springs Tuff (17.6 Myr; Young and Brennan, 1974), the only ignimbrite in the map area, vented west of Kingman and flowed 100 km eastward providing a convenient stratigraphic marker (sheets 1 and 2). Almost all other volcanic rocks we studied in the Basin and Range province underlie Peach Springs Tuff but their relationship to eastward migrating volcanism in the Transition Zone is not clear. In general, Basin and Range volcanics appear to be slightly younger than the oldest volcanics in the Fort Rock area. The largest volumes of silicic to intermediate volcanics occur in the Aquarius Mountains region (sheet 2). The Fort Rock volcanic field (volume alkali basalt through latite and rhyolite. These rocks underlie Peach Springs Tuff. Recently determined K-Ar age dates are 24.3 Myr for a latite dome on the west and 22.0 Myr for a basalt dike in the center of the field. The Aquarius Mountains volcanic center located south of the map area (volume ≤10 km³) erupted abundant rhyolitic airfall and non-welded ash flow pyroclastics (Fort Rock Creek Tuff of Fuis, 1973). Rhyolitic lavas occupy the vent area. The pyroclastic units underlie Peach Springs Tuff. A basalt flow underlying Fort Rock Creek Tuff is dated at 18.2 Myr (Young and McKee, 1978) but the basalt dike mentioned above dated at 22.0 Myr has cut and hornfelsed the tuff. Obviously, more K-Ar age dates are needed in this area to resolve age problems in this complex volcanic sequence. Picacho Butte dated at 9.8 Myr (sheet 3) is a major rhyodacite volcano

that is surrounded by basalts of the Mt. Floyd volcanic field on the eastern side of the map area. These basalts are apparently equivalent in chemistry and age to those of the San Francisco Peak volcanic field to the east (D. Nealy, U.S. Geol. Survey, personal communication, 1979). Picacho Butte may be the oldest silicic center associated with Mt. Floyd - San Francisco Peak volcanism.

In conclusion, the Aquarius Mountains area and surrounding portions of the Transition Zone possess no Quaternary volcanism that would suggest enhanced geothermal potential due to current magmatism. Additionally, we found no evidence for present large hydrothermal systems (Goff, 1979). The few hot springs existing in the region are chemically unique and occur within the Basin and Range tectonic province or along the boundary between this province and the Transition Zone. Suitable areas for HDR development may occur in the Aquarius Mountain area where depth to Precambrian crystalline rocks are shallow and structure is relatively simple, or in down-dropped basement in valleys of the Basin and Range province where thick Cenozoic sediments provide an insulating thermal blanket. Before HDR development is initiated we recommend additional heat flow holes to better define the thermal regime of the region followed by a comprehensive geologic and hydrologic investigation of a small (50 to 100 km²) target prospect.

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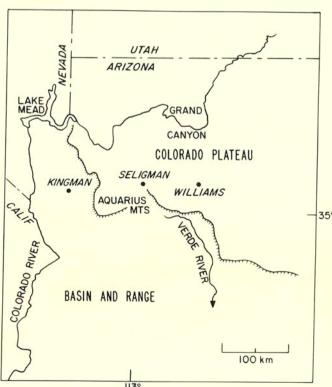
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Figure 1.



boundary between the Colorado Plateau and Basin and Range tectonic provinces (hatched line); the Aquarius Mountains area occupies a structural Transition Zone between the two provinces.

RECONNAISSANCE GEOLOGIC STRIP MAP FROM KINGMAN TO SOUTH OF BILL WILLIAMS MOUNTAIN, ARIZONA

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1983

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Figure 1. Map of northwestern Arizona showing