Base from U.S. Geological Survey
Pilot Knob, 1980

Geology mapped by Ward and Nealey, 1985, and by Ward, 1989.

## CORRELATION OF UNITS

| | | |
|---|---|---|
| Qal | QUATERNARY | Holocene |
| Qc | | |
| Qm | | Pleistocene |
| Tbs | TERTIARY | Pliocene |
| Tbo Tboi | | Middle to Late Miocene |
| Tbg | | |
| Tbj | | |
| Tbj Tdj | | Middle Miocene |
| Tdd/Tdi Tdf Tdb Tdbh Tdbb Tdbp Tdfb Tdfp Tdbs Tdbi Tdv | | Early to Middle Miocene |
| Ta | | Early Miocene |
| Tba | | |
| Tb | | Pre-Miocene? |

## DESCRIPTION OF MAP UNITS

### Surficial Units

Qal **Recent alluvium (Holocene)**--Silt, sand, gravel, cobbles, and boulders in active washes. Consists of angular to subrounded, poorly sorted, unconsolidated material of local derivations. Includes late Quaternary terraces and fans in Francis Creek

Qc **Colluvium of Pilot Knob Basin (Holocene and Pleistocene)**--Yellowish-white sand, gravel, and cobbles in Pilot Knob Basin derived from silicic lava flows and breccias; deposited principally by sheetwash and landsliding. Thickness unknown, may be tens of m

Qm **Volcanic mudflow (Quaternary)**--Poorly sorted, subrounded to rounded cobbles and boulders of dacite in a light gray matrix of volcanic sand and gravel. Occurs only in the lower 1/4 of Francis Creek. The upstream portion of the lahar, immediately below Steamboat Tank Canyon, comprises three well-indurated, fan-shaped deposits. Further downstream the unit becomes a massive, highly lithified tongue, in places deeply sculptured by torrential floods into smooth, concave and convex streamlined forms. Thickness 3-4 m

### Bedrock Units

Tbx **Xenolithic basalt (Pliocene)**--Thin, gray-black basalt flows from dikes and cinder cones. Basalt contains sub-millimeter plagioclase laths, olivine, and orthopyroxene; granite, granulite, gabbro, and peridotite xenoliths; and quartz, plagioclase, olivine, clinopyroxene, magnetite, and amphibole megacrysts. Amphibole megacrysts attain maximum lengths of 16 cm. Plagioclase and amphibole xenocrysts contain tubular voids, indicative of volatile loss and perhaps shallow crystallization. Thickness typically is less than 1 m

Tbo **Olivine basalt (Middle to Late Miocene)**--Fine-grained lava flows Tboi interlayered with and overlying Tertiary gravels (Tg). Known sources are dikes (Tboi). As many as a dozen flows are recognized. Most of the flows are interlayered with Tertiary gravels, and two to four capping flows form lava plateaus. Each flow is typically 5-7 m thick. Whole-rock potassium-argon ages range from 8-13 Ma (R.J. Miller, USGS). Basalts are tentatively correlated with the Sunders Basalt of Anderson and others (1955)

Tbg **Olivine basalt and gravels of Francis Creek, undivided (Middle to Late Miocene)**--Consists of interlayered olivine basalts (Tbo) and gravels of Francis Creek (Tg)

Tg **Gravels of Francis Creek (Middle to Late Miocene)**--Tan, white, and gray, thin-bedded deposits of silt, sand, gravel, and cobbles. Derived principally from dacitic and rhyodacitic lava flows and breccias, although lower beds contain Precambrian clasts that may have been derived from the Aquarius Mountains to the west. Well indurated, containing sub-rounded to well-rounded clasts. Thin beds and small, well-rounded clasts suggest that these are alluvial fan and stream deposits. Current bedding indicates stream flow to the southeast. Interlayered with olivine basalts. Thickness greater than 250 m

Tbj **Basalt of Jackass Basin (Middle Miocene?)**--Two superposed fine-grained olivine basalt flows in the northeast corner of the quadrangle. The lower flow is characterized by 1-2 mm clinopyroxene crystals; the upper flow is characterized by 0.5 cm plagioclase phenocrysts. These flows represent the southwesternmost extent of basaltic lavas erupted from vents in the Mount Hope and Sunrise Peak quadrangles. Each flow is about 2 m thick

Tdj **Dacite of Jackass Basin (Middle Miocene?)**--Dacitic lava flows and flow breccias, perhaps a minor eruptive phase from Dettey Mountain. Breccias are poorly bedded to massive, unsorted, and contain clasts of dacite and pumice. Clasts commonly are 2 cm across. Breccia matrix is predominantly dacite with prominent clinopyroxene and biotite crystals. Breccia clasts typically become smaller upward in the bed and breccia flows grade upward into lava flows. Several such sequences may be present; total thickness of map unit about 7 m

Tdd **Dacite dome (Early to Middle Miocene)**--Small, steep-sided domes of dacite lava. Domes probably developed by addition of material inside a solidified carapace

Tdi **Dacite dikes (Early to Middle Miocene)**--Dikes of medium-grained dacite with hornblende and feldspar phenocrysts 1 clinopyroxene; up to 2 m wide

Tdf/Tdb **Dacitic lavas of Mohon Mountain (Early to Middle**
Tdbh **Miocene)**--Dacitic lava flows and flow breccias erupted from
Tdfp/Tdbp Mohon Mountain (Mohon Mountain quadrangle) and Red Canyon
Tdfb/Tdbb vent. Typical lavas and breccias are grayish to pinkish,
Tdv and contain quartz, plagioclase, and alkali feldspar. Units may be distinguished on the basis of primary and accessory minerals. Tdf and Tdb are dacite flows and breccias, respectively, with hornblende, clinopyroxene, and biotite; Tdbh is a dacite breccia with high (10-15 percent) modal hornblende. Tdfp and Tdbp are dacite flows and breccias with hornblende and clinopyroxene and rare biotite; Tdfb and Tdbb are dacite flows and breccias with hornblende and biotite and rare clinopyroxene. Breccias are generally monolithologic and are interlayered with lava flows; in some instances, breccias are succeeded by a lava of the same mineralogy. Vitrophyric dacite (Tdv) occurs between Pilot Knob and Mohon Mountains. Individual flows are typically less than 3 m thick

Ta **Andesitic lavas (Early Miocene)**--Thin, biotite- and hornblende- bearing andesite flows and breccias; locally dark, glassy, and porphyritic. Erupted from Red Canyon vent

Tba Basaltic andesite (Early Miocene)--High-silica (54 percent $SiO_2$) basalts with clinopyroxene and olivine. Cropping out in Red Canyon as thin (1 m) flow units. Erupted from Red Canyon vent

Tb **Older Basalt (Pre-Miocene?)**--Olivine basalt, highly weathered to spalling clays, medium to dark green in hand sample. Flows are 2-3 m thick

**Contact**--dashed where inferred

**Fault**--Dashed where inferred, dotted where concealed. Bar and ball on downthrown side

**Volcanic vent**

## GEOLOGIC SETTING

This map is part of a regional study of the Mohon Mountains volcanic field (MMVF) in west-central Arizona. Ward and Nealey began work in the Pilot Knob quadrangle in 1985, and Ward continued mapping in this and adjacent quadrangles from 1986-89.

The Mohon Mountains Volcanic Field is located approximately 70 km east-southeast of Kingman, Ariz.; the field is in the Transition Zone physiographic province between the Basin and Range and the Colorado Plateau and covers approximately 2400 $km^2$. It comprises several large volcanic centers, including Mohon Mountain (elevation 2273 m, relief 900 m), Mount Hope (elevation 2201 m, relief 515 m), and two small unnamed silicic centers near Red Canyon and Orejana Canyon, as well as the surrounding plateau basalts of Goodwin, Bozarth, and Behm Mesas (Fig. 1).

Reconnaissance mapping of the Mohon Mountains Volcanic Field is included in the state geologic map of Wilson and others (1969). The first detailed studies in the MMVF include those of Ward and others (1986), Nealey and others (1986a, b), and Simmons (1986), which were used in the new state geological map of Reynolds (1988). Studies of adjacent volcanic terranes include those of Anderson and others (1955), Fuis (1973), Young and Brennan (1974), Luedke and Smith (1978), Moyer (1982, 1986), and Goff and others (1983). This summary is based on the studies of Simmons (1986, 1989) at Mt. Hope and Mohon Mountain, and those of Ward and Nealey for the remainder of the field.

The MMVF comprises two distinct rock suites -- early Miocene (22-20 Ma) rocks of an andesite-dacite series erupted from Mohon Mountain and its satellite centers, and late Miocene-early Pliocene (13-5 Ma) basalts and rhyolites that form a bimodal series. The Mohon Mountains volcanic field developed through six stages (Ward and others, 1986; Nealey and others, 1986a, b; Simmons, 1989). The first stage was characterized by central-vent eruptions from Mohon Mountain and the Red Canyon vent, with the production of pyroclastic andesitic-dacitic breccias and lavas flows at both centers, and trachyandesite lava flows and trachybasalt cinder cones at Mohon Mountain. Most of this activity occurred 20-22 Ma. Dacite domes were emplaced in the western part of the field in the second stage, around 15 Ma. Following a significant period of erosion, olivine tholeiites erupted from vents in the southwest part of the field (stage 3, 13-8 Ma); these are best exposed along Borro Creek and Francis Creek (in the Pilot Knob quadrangle). Volcanism migrated northeast during stage 4, with the emplacement of quartz-bearing alkalic basalts at about 12 Ma. The Mount Hope rhyodacite dome and surrounding basaltic lava flows were emplaced between 9 and 8 Ma (stage 5), and the Orejana Canyon rhyolite dome was emplaced about 8.4 Ma. The last episode of volcanic activity (stage 6) is recorded by the emplacement of widespread xenolith-bearing alkalic basalts flows from dikes and cinder cones.

On the basis of major and trace elements geochemistry (Tables 1, 2) and K-Ar geochronology, we consider the rocks of the entire Mohon Mountain Volcanic Field are of two distinct origins. The (older) rocks erupted from Mohon Mountain and the Red Canyon center represent various mixtures of lower and upper crustal melts, whereas the (younger) basalt-rhyolite series of mesa basalts, The Orejana Canyon rhyolite lava and breccia flows, and the Mt. Hope rhyolite dome and lava flows were derived from the mantle and lower crust. We suggest that the andesites and dacites arose from crustal melting and mixing in early Tertiary time, before regional detachment faulting. Later, mantle-derived basalts erupted through a crust that had been significantly thinned by regional extension, and reached the surface relatively unaltered, although some magma locally stagnated long enough to produce the rhyolites.

## ROCKS IN THE PILOT KNOB QUADRANGLE

The oldest rocks exposed in the quadrangle are highly altered, thin olivine basalt flows found in the bottom of Francis Creek. These lavas have been extensively weathered and are various shades of green and gray owing to the presence of a variety of clays. The flows interfinger with thin gravel units that are alluvial deposits related to thicker deposits to be described later. The next oldest rocks are basaltic andesite flows, and andesite and dacite lava flows and breccias in the Red Canyon vent area. R.J. Miller (U.S. Geological Survey) determined an age of 21.9 ± 1.2 Ma for a feldspar clast in a dacite breccia. These lavas erupted from two principal centers, Mohon Mountain and Red Canyon. We recognize four petrographically distinct dacite lavas and breccias, based on accessory mafic minerals. One flow type contains hornblende, clinopyroxene, and biotite crystals, whereas a second contains hornblende and clinopyroxene, and a third contains hornblende and biotite. The fourth type contains all three mafic minerals, but has very high (15 percent) modal hornblende. Simmons (1988) reports that in the Mohon Mountain quadrangle (immediately north of the Pilot Knob quadrangle), pyroxene-bearing dacites were erupted from Mohon Mountain, whereas biotite-bearing dacites comprise the satellite domes. Thus the lavas and breccias in and around Red Canyon may be from Mohon Mountain as well as the local vent.

Thick deposits of Tertiary gravels, derived in part from intermediate and silicic volcanic rocks in the area, surround Mohon Mountain and its satellite centers. Along Francis Creek, gravels are interbedded with 13-8 Ma olivine basalts. Chemically these basalts are tholeiites, although petrographically they contain both phenocryst and groundmass olivine; they might therefore be classified as transitional basalts. These basalts were erupted from vents in the Aquarius Cliffs to the w; local, small dikes can also be seen in Francis Creek. The youngest volcanic units are alkalic, xenolith-bearing basalts that contain abundant ultramafic, mafic, and crustal xenoliths, and a variety of large mafic and felsic crystals. Several of these flows are found in the Pilot Knob and adjacent quadrangles, and were erupted from dikes and cones. One of the youngest units in the quadrangle is a dacitic mudflow found in the lowest reaches of Francis Creek. This unit is composed mostly of dacitic material derived largely from the Red Canyon silicic center. The mudflow spilled into Francis Creek, which was cut after the last olivine basalt flows were emplaced (<8 Ma), and formed out a few tens of meters upstream, but mostly flowed downstream to the east at least 3 km.

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Table 1.--Selected Major Element Analyses of MMVF Rocks in the Pilot Knob Vicinity.

| Sample<br>Map Unit<br>Qm Matrix | WPK-1<br>Tbo | WPK-4<br>Ta | WPK-5<br>Tba | WPK-6<br>Tdfb | NPK-27<br>Tdf | NBM-6<br>Tbx | WPKA | WFCF-1<br>Tdb | WFCD<br>Tb | WFCM<br>Qm Clast |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 50.0 | 58.7 | 54.1 | 66.5 | 65.2 | 48.4 | 64.0 | 47.9 | 67.3 | 59.8 |
| $Al_2O_3$ | 16.2 | 15.6 | 14.5 | 15.1 | 16.8 | 16.5 | 15.6 | 17.1 | 12.4 | 15.2 |
| FeO*[1] | 11.4 | 5.64 | 7.69 | 2.98 | 3.51 | 11.6 | 3.65 | 10.8 | 1.03 | 3.71 |
| MgO | 7.04 | 4.04 | 4.53 | 1.63 | 0.81 | 5.89 | 2.33 | 5.56 | 0.99 | 3.62 |
| CaO | 10.4 | 5.51 | 7.77 | 2.96 | 2.52 | 7.77 | 3.92 | 9.74 | 1.96 | 4.16 |
| $Na_2O$ | 2.96 | 3.83 | 3.74 | 3.86 | 4.05 | 4.25 | 3.99 | 3.21 | 1.52 | 2.80 |
| $K_2O$ | 0.69 | 2.98 | 2.84 | 3.51 | 3.01 | 1.06 | 3.37 | 0.90 | 5.51 | 3.07 |
| $TiO_2$ | 1.38 | 0.84 | 1.36 | 0.42 | 0.52 | 2.80 | 0.57 | 2.00 | 0.04 | 0.58 |
| $P_2O_5$ | 0.25 | 0.39 | 0.58 | 0.12 | 0.20 | 0.74 | 0.28 | 0.59 | 0.06 | 0.23 |
| MnO | 0.17 | 0.08 | 0.08 | 0.04 | 0.02 | 0.17 | 0.05 | 0.15 | 0.10 | 0.05 |
| LOI | 0.25 | 1.95 | 2.32 | 2.42 | 1.46 | 0.89 | 1.85 | 2.39 | 9.04 | 6.31 |

X-ray spectroscopy analyses by A.J. Bartel and K. Stewart. All values in weight percent.

*Total iron oxides.

Table 2. Selected Trace Element Analyses of Volcanic Rocks in the Pilot Knob Vicinity.

| Sample<br>Map Unit | WPK-1<br>Tbo | WPK-4<br>Ta | WPK-5<br>Tba | WPK-6<br>Tdfb | NPK-27<br>Tdf | NBM-6<br>Tbx | WPKA<br>Tdb | WFCF-1<br>Tb | WFCD<br>Qm Clast | WFCM<br>Qm Matrix |
|---|---|---|---|---|---|---|---|---|---|---|
| *Nb | 17 | 16 | 38 | 10 | 33 | 46 | 14 | 26 | 58 | 10 |
| *Ba | 1.0 | 63 | 70 | 62 | 84 | 14 | 76 | 76 | 350 | 84 |
| *Sr | 414 | 1250 | 1225 | 1050 | 1050 | 710 | 1100 | 690 | 60 | 850 |
| *Zr | 117 | 158 | 24 | 170 | 338 | 266 | 230 | 190 | 90 | 210 |
| *Y | <20 | 23 | 25 | <20 | <20 | 27 | 14 | 28 | 50 | 12 |
| *Cu | 83 | 50 | 65 | 20 | 50 | 79 | 30 | 40 | 18 | 20 |
| *Ni | 92 | 70 | 137 | 20 | <20 | 76 | 20 | 50 | 15 | 40 |
| *Zn | 73 | 74 | 87 | 46 | 59 | 84 | 68 | 80 | 68 | 66 |
| Rb | 101.0 | 76.0 | 128.0 | 30.6 | 26.0 | 83.0 | | | | |
| Sr | 393 | 1420 | 1320 | 1060 | 1260 | 770 | | | | |
| Ba | 573 | 1340 | 1640 | 1470 | 1660 | 398 | | | | |
| Ce | 41.0 | 15.0 | 25.9 | 8.26 | 5.53 | 14.6 | | | | |
| Cr | 249.0 | 118.0 | 332.0 | 42.3 | 28.4 | 69.2 | | | | |
| Cs | 0.18 | 0.85 | 0.88 | 1.09 | 1.02 | 0.33 | | | | |
| Hf | 2.5 | 4.2 | 5.5 | 4.2 | 8.2 | 3.0 | | | | |
| Rb | 13.5 | 47.9 | 66.0 | 60.0 | 84.0 | 20.0 | | | | |
| Sb | nd | 0.55 | 1.33 | 0.33 | 0.33 | 0.05 | | | | |
| Ta | 0.64 | 0.72 | 2.23 | 0.36 | 2.20 | 3.45 | | | | |
| Th | 3.1 | 6.5 | 9.0 | 4.1 | 11.2 | 3.5 | | | | |
| U | 0.5 | 1.0 | 1.9 | 1.0 | 2.1 | 1.7 | | | | |
| Zn | 62 | 102 | 108 | 75 | 73 | 107 | | | | |
| Zr | 113 | 209 | 227 | 160 | 223 | nd | | | | |
| Sc | 31.0 | 10.2 | 18.5 | 5.2 | 3.9 | 17.0 | | | | |
| La | 19.1 | 46.5 | 63.8 | 24.0 | 41.8 | 22.1 | | | | |
| Ce | 37.7 | 92.3 | 119.4 | 48.0 | 61.6 | 48.5 | | | | |
| Nd | 16.9 | 36.8 | 48.2 | 19.4 | 25.4 | 31.9 | | | | |
| Sm | 4.17 | 6.13 | 8.59 | 3.49 | 4.54 | 6.99 | | | | |
| Eu | 1.37 | 1.76 | 2.61 | 0.89 | 1.36 | 2.36 | | | | |
| Gd | 3.99 | 4.72 | 6.77 | 2.45 | 3.39 | 6.92 | | | | |
| Tb | 0.70 | 0.61 | 0.94 | 0.35 | 0.38 | 0.97 | | | | |
| Tm | 0.36 | 0.22 | nd | 0.12 | nd | nd | | | | |
| Yb | 2.21 | 1.37 | 1.89 | 0.88 | 0.98 | 2.22 | | | | |
| Lu | 0.33 | 0.20 | 0.25 | 0.14 | 0.15 | 0.32 | | | | |

All values in parts per million. (*) indicates analyses by x-ray spectroscopy. All other analyses by instrumental neutron-activation analysis. "nd" indicates that the element was not detected. Analyses performed by D.V. Vivit, J.S. Budahn, R.J. Knight, and D.M McKown.

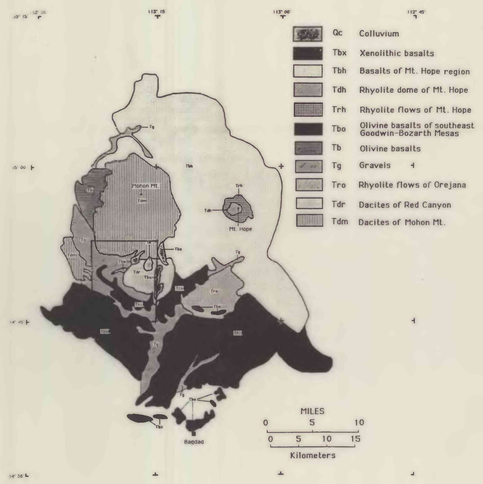


Figure 1. Sketch map of the MMVF; Pilot Knob quadrangle is outlined.

# PRELIMINARY GEOLOGIC MAP OF THE PILOT KNOB QUADRANGLE, MOHAVE AND YAVAPAI COUNTIES, ARIZONA

By

A.W. Ward and L. David Nealey

1990

This map is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.