GEOLOGIC MAP OF THE SUMMIT AREA OF HOUSE MOUNTAIN, YAVAPAI COUNTY, ARIZONA

by

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INTRODUCTION

House Mountain is in the southwest part of the Sedona, Arizona 7.5 minute quadrangle, approximately 12 km southwest of the city of Sedona (Fig. 1). The summit area is a nearly circular erosional caldera 2.2 km in diameter that is breached on the northwest side by a narrow canyon through which an intermittent creek flows to join Oak Creek. Relief in the caldera is 270 m. The mountain is surrounded on 4 sides by US-89A, AZ-279, I-17, and AZ-179.

In constructing the map, all geologic contacts were traced in the field. Map units were defined on the bases of lithology and stratigraphy; stratigraphic relationships were determined in the field by using traditional geologic principles such as superposition and cross-cutting relationships.

The mapping strategy was to map all lava flows, pyroclastic deposits, and intrusive bodies that could be distinguished in the field as discrete units. The map scale of 1:6000 was adopted in order to show the smallest map units as accurately as possible. Nevertheless, some very thin dikes (< 6 m) are shown on the map with exaggerated thicknesses. Individual lava flows and flow units of the same or similar lithology in sections containing multiple thin flows were not mapped separately because of the field difficulty of tracing the contacts far enough for the subdivision to be worthwhile (for example, hawaiite flows in Tll, and hawaiite, basaltic andesite, and pyroxene mugearite in Tlu).

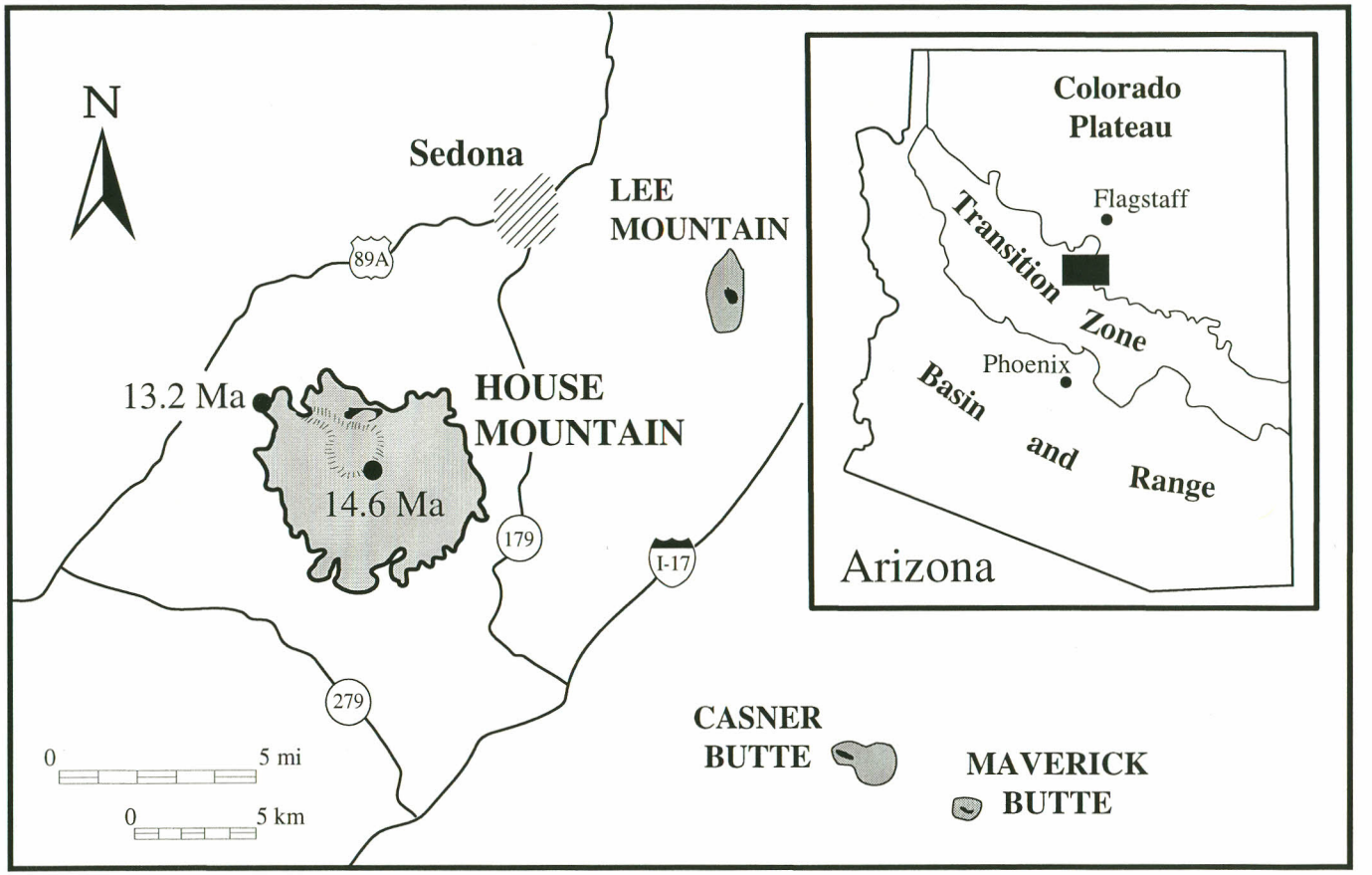


Figure 1. Location of House Mountain. Inset map shows the tectonic provinces of Arizona. K-Ar ages are from Ranney (1988)

GEOLOGY

House Mountain is a Middle Miocene shield volcano that was erupted on faulted and eroded Paleozoic strata in the Verde Valley, a structural basin in the Arizona Transition Zone that lies at the foot of the Mogollon Rim, the physiographic southwestern edge of the Colorado Plateau (Fig. 1). The volcano is between the Middle to Late Miocene Hickey Formation basaltic lavas that cap the Black Hills on the southwest side of the Verde Valley and the Mormon volcanic field, a Middle Miocene to Late Pliocene basaltic province that covers the southwest margin of the Colorado Plateau and eastern side of the Verde Valley. Some volcanic map units at House Mountain are nearly identical in age and composition to older units of the Mormon volcanic field in the Wet Beaver Creek area.

The House Mountain volcano is similar in size, structure, and profile to many small-volume basaltic shield volcanoes. Cross sections indicate the volcanic rocks in the central part of the volcano are about 370 m thick. Although the Verde Formation covers the lower flanks of the volcano, and the distal lavas have not been mapped in detail, the basal diameter is estimated to be at least 13 km. Dip slopes on the flanks are about 4°, and all profiles, except north-south, are symmetrical. The volcano was constructed at the base of an ancestral escarpment edge of the Colorado Plateau, and the topographic barrier prevented northward flow of the lavas. Deep erosion of the summit area of House Mountain produced a large circular valley in which the upper 270 m of the volcanic section are exposed.

The size of the volcano and its broad range of lithologies make House Mountain a major volcanic center. From a distance, the mountain appears to be an ordinary shield volcano typical of late Cenozoic basaltic volcanism in central Arizona. However, the volcano is unusual in this area because the lava flows, which comprise the bulk of the volcano, are differentiated hawaiite, mugearite, and benmoreite that constitute a mildly alkaline igneous-rock series, and basaltic andesite in a subalkaline series; the only basalts analyzed are bombs in pyroclastic deposits. The lavas and pyroclastic deposits are intruded near the summit of the volcano by strongly undersaturated feldspathoidal rocks that include basanitic nephelinite, coarse-grained feldspar ijolite, and nepheline monzosyenite in a strongly alkaline igneous-rock series. The only other localities in Arizona known to have similar strongly undersaturated rocks are Lee Mountain (12 km ENE), Casner Butte (20 km SE), and Maverick Butte (23 km SE) (Fig. 1).

The lowest rocks exposed in the volcano are subhorizontal mildly alkaline hawaiite lava flows. Overlying these lavas is a thick section of basaltic scoriaceous lapilli tuffs and tuff breccias that display radially outward dips up to 35° around 2 centers in the southern part of the central valley where agglomerates crop out. Cross section reconstruction of the volcano indicates the pyroclastic deposits formed a compound cinder cone with 2 vents about 600 m apart. Intersecting at or near the projected feeder conduits of the vents are thick dikes and plugs of mugearite and benmoreite, around which were intruded sheath-like dikes of hawaiite and basaltic andesite. The large dikes, and numerous small dikes of the same compositions, display regular strikes that indicate they were probably guided by west-northwest and northeast striking crustal fractures. The dikes fed an upper section of outward dipping hawaiite, mugearite, benmoreite, and basaltic andesite lava flows that formed the shield and partly buried the pyroclastic cone. The pyroclastic

deposits were extensively eroded to produce the central valley, or erosional caldera. Several of the mugearite dikes can be traced up the inner wall of the caldera to where they either connect with, or come very close to, lava flows in the summit area of the shield volcano.

After construction of the shield, but before dissection, one large and several smaller dikes of fine-grained basanitic nephelinite were intruded into the volcanic section on the north side of the volcano; most of the magma was emplaced in the pyroclastic deposits. One dike of basanitic nephelinite that reached the surface of the shield fed a small lava flow about 110 m long. These mafic dikes host mappable bodies of medium- to coarse-grained feldspar ijolite and nepheline monzosyenite, and small dikes, schlieren, and ocelli of the same compositions. The largest bodies of felsic rocks are a vertical dike that can be traced by discontinuous outcrops through a narrow neck into a subhorizontal sheet. Compositions of the feldspathoidal rocks are consistent with cogenesis, probably by crystal-liquid fractionation of the basanitic nephelinite (Wittke and Holm, 1996).

Although the ijolites and monzosyenites are medium- to coarse-grained, field relationships indicate that the rocks were emplaced near the summit of the volcano, possibly at depths of 30-140 m from the surface, but certainly no deeper than 430 m. These estimates are based on the preserved thicknesses of the upper section lava flows of the shield, and cross section reconstructions of the volcano and the ancestral edge of the Colorado Plateau. Upper section lavas that were intruded by the basanitic nephelinite dike are about 30 m thick, and the thickest preserved section is 140 m. The base of the thickest section, which is on the northeast side of the volcano, is at approximately the same elevation as the highest outcrops of the basanitic nephelinite and felsic phaneritic rocks; the upper section lavas may have served as a cap that prevented most of the alkaline magma from erupting. The 430 m maximum depth is the thickness to which the upper section lavas would have piled up before they spilled over onto the surface of the Colorado Plateau, and there is no evidence that this happened.

CLASSIFICATION OF ROCKS AT HOUSE MOUNTAIN

The rocks are classified in 2 ways, chemically and petrographically. Aphanitic rocks (not including nephelinite) that have chemical analyses (Table 1) are classified with the total alkali-silica (TAS) diagram recommended by the International Union of Geological Sciences (IUGS) Subcommission on the Systematics of Igneous Rocks (Fig. 2; Le Maitre, 1989). The TAS subdivisions for fields S_1, S_2, and S_3, hawaiite, mugearite, and benmoreite respectively, are used for the map, with the principal phenocryst types added as modifiers to mugearite and benmoreite. Analyzed basaltic rocks are further subdivided on the basis of CIPW normative compositions in conformity with the classification used in the Mormon volcanic field (see *Classification of Basalts* below; Holm, 1994). Unanalyzed aphanitic rocks are classified with TAS names on the basis of petrographic criteria established with the analyzed rocks (see *Petrographic Characteristics of Mildly Alkaline and Subalkaline Lithologies* below).

Phaneritic rocks and aphanitic nephelinitic rocks for which modal analyses are available are classified with the modal quartz (Q)-alkali feldspar (A)-plagioclase (P)-feldspathoid (F) diagrams for phaneritic and aphanitic rocks recommended by the IUGS (Fig. 3a and b, and Table 2;

Le Maitre, 1989). Phaneritic rocks for which modes are not available are also classified with the QAPF diagram by plotting either normative minerals for analyzed rocks or estimated modes for unanalyzed rocks; these include monzodiorite, monzonite, syenite, nepheline-bearing syenite, and quartz monzonite (See *Petrographic Characteristics of Mildly Alkaline and Subalkaline Lithologies* below).

Classification of Basalts

Basalts are regarded as containing 45-52 weight percent SiO_2 (normalized), and normative An-content (100an/(an+ab)) greater than or equal to 50. The following basalt types are defined on the basis of CIPW normative compositions:

a. quartz subalkali basalt: norm Q > 0
b. subalkali basalt: norm ol, di/hy < 2 (generally hy > 9)
c. transitional basalt: norm ol, di/hy > 2 (generally hy < 9)
d. alkali basalt: norm ne > 0, to 5
e. basanitic alkali basalt: norm ne > 5
f. basanite: modal feldspathoid, norm ab > 5, norm ne < 20, (irregardless of SiO_2)

(prefix "hawaiitic" if An-content < 50 and $Na_2O+K_2O < 5$).

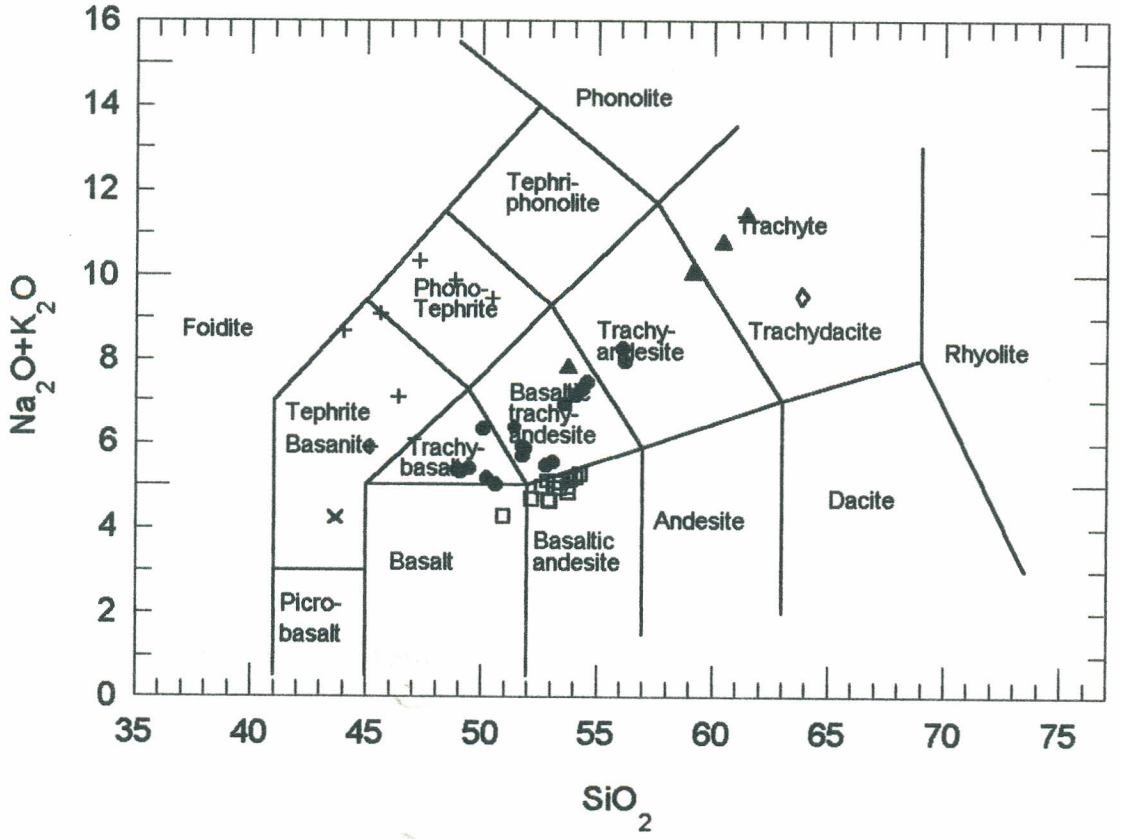


Figure 2. TAS diagram of analyses in Table 1. Strongly alkaline aphanitic rocks shown with X; strongly alkaline phaneritic rocks shown with +; mildly alkaline rocks shown with filled symbols (dots = aphanitic rocks, triangles = phaneritic rocks); subalkaline rocks shown with open symbols (squares = aphanitic rocks; diamond = phaneritic rock). Trachybasalt = hawaiite, basaltic trachyandesite = mugearite, trachyandesite = benmoreite.

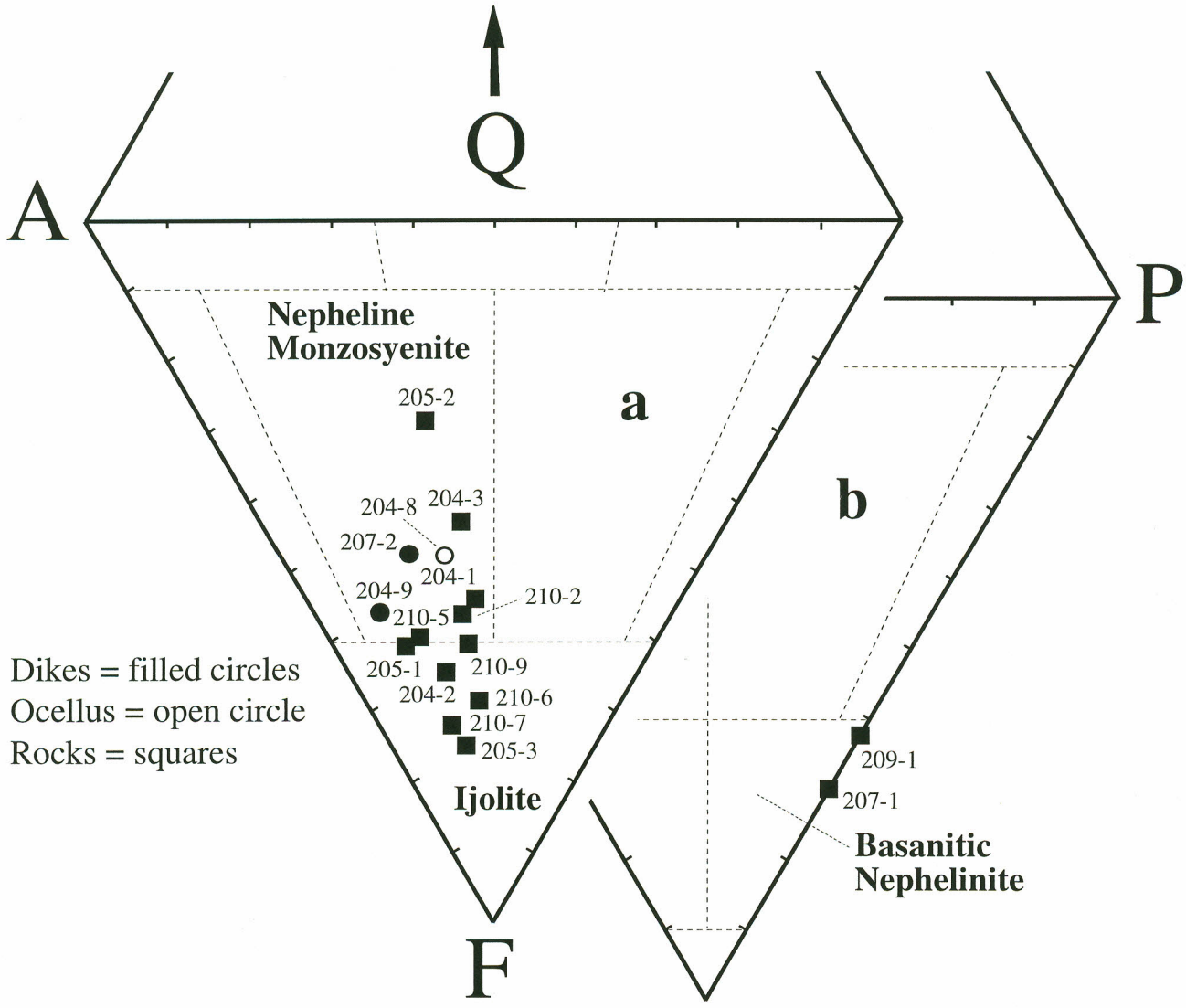


Figure 3. QAPF diagrams for phaneritic (a) and aphanitic (b) rocks in the strongly alkaline series.

Petrographic Characteristics of Mildly Alkaline (MA) and Subalkaline (SA) Lithologies

Aphanitic Rocks*

quartz subalkali basalt (SA)

phenocrysts: olivine.
matrix: olivine.
slender prisms of clinopyroxene.
sublimate tridymite.
intersertal to hyalophitic.
biotite is absent.

hawaiite (MA)

phenocrysts: olivine; rare plagioclase.
matrix: abundant olivine.
slender prisms of clinopyroxene.
biotite in fresh scraps to small poikilitic plates.
alkali feldspar in interstitial patches, and mantles on plagioclase microlites.
local brown amphibole.
microcrystalline in lavas and dikes.

basaltic andesite (SA)

phenocrysts: olivine; may have reaction rims of orthopyroxene in dikes.
clinopyroxene sparse to absent.
plagioclase absent in lavas and local in dikes.
orthopyroxene absent in lavas and rare in dikes.
matrix: olivine moderately abundant to absent.
stubby prisms of "augite" ($2V\gamma = 45°-55°$).
pigeonite is sparse(?) ($2V\gamma = 15°-20°$).
orthopyroxene is rare(?) ($2V\alpha > 60°$) as stout prisms and poikilitic crystals in ophitic texture with plagioclase microlites.
biotite and amphibole absent in lavas, rare in dikes.
biotite reaction rims on opaque oxide in dikes.
alkali feldspar absent in lavas; may be present in dikes.
intersertal to intergranular in lavas and dikes.

pyroxene mugearite (MA)

phenocrysts: clinopyroxene > olivine.
plagioclase present or absent; when present, plag>cpx>>ol.
matrix: olivine abundant to scattered.
stubby and slender prisms of clinopyroxene.
biotite in anhedral scraps to small poikilitic plates.
alkali feldspar is interstitial, and mantles on plagioclase.
sublimate biotite in vesicles.
intergranular in lavas.
intergranular to hypidiomorphic in dikes.

hornblende mugearite (MA)

phenocrysts: brown amphibole, clinopyroxene, plagioclase.
matrix: olivine sparse to absent.
biotite sparse to absent.
stubby to slender prisms of clinopyroxene.
alkali feldspar is interstitial, and mantles on plagioclase.
sublimate biotite in vesicles.
intergranular in lavas; hypidiomorphic in dikes

hornblende benmoreite (MA)

phenocrysts: brown amphibole, clinopyroxene, plagioclase.
matrix: very felsic.
olivine.
stubby to slender prisms of clinopyroxene.
biotite is absent (?).
alkali feldspar is interstitial, and mantles on plagioclase.
sublimate biotite, aegirine(?), and cummingtonite (?) in vesicles.
trachytic in lavas and dikes.

*Compiled from specimens that have chemical analyses plotted on the TAS diagram. All aphanitic specimens have matrix plagioclase and opaque oxide.

Phaneritic Rocks

monzodiorite (MA)

plagioclase (An_{45}-An_{40} cores to An_{12} rims).
alkali feldspar; interstitial, and mantles on plagioclase.
sanidine; euhedral crystals associated with interstitial zeolite.
light green clinopyroxene.
olivine.
brown amphibole; discrete crystals, and reaction on clinopyroxene.
biotite; discrete crystals, and reaction on olivine and opaque oxide.
opaque oxide, apatite.
hypidiomorphic, granular.

monzonite (MA)

plagioclase (An_{40}-An_{35} cores to An_{12-10} rims)
anorthoclase; fine tartan twins, mantles on plagioclase.
clinopyroxene; light green and yellow to yellowish brown.
olivine.
brown amphibole; discrete crystals and reaction on clinopyroxene.
biotite.
opaque oxide, apatite.
hypidiomorphic, granular

syenite (MA)

plagioclase (An_{40-34} cores to An_{16-9} rims).
anorthoclase; fine tartan twins, discrete crystals, and mantles on plagioclase.
sanidine; discrete crystals, and mantles on plagioclase and anorthoclase.
clinopyroxene; light green to medium greenish yellow to yellow to yellowish brown.
biotite.
brown amphibole.
opaque oxide, apatite.
hypidiomorphic to idiomorphic, diktytaxitic, granular.

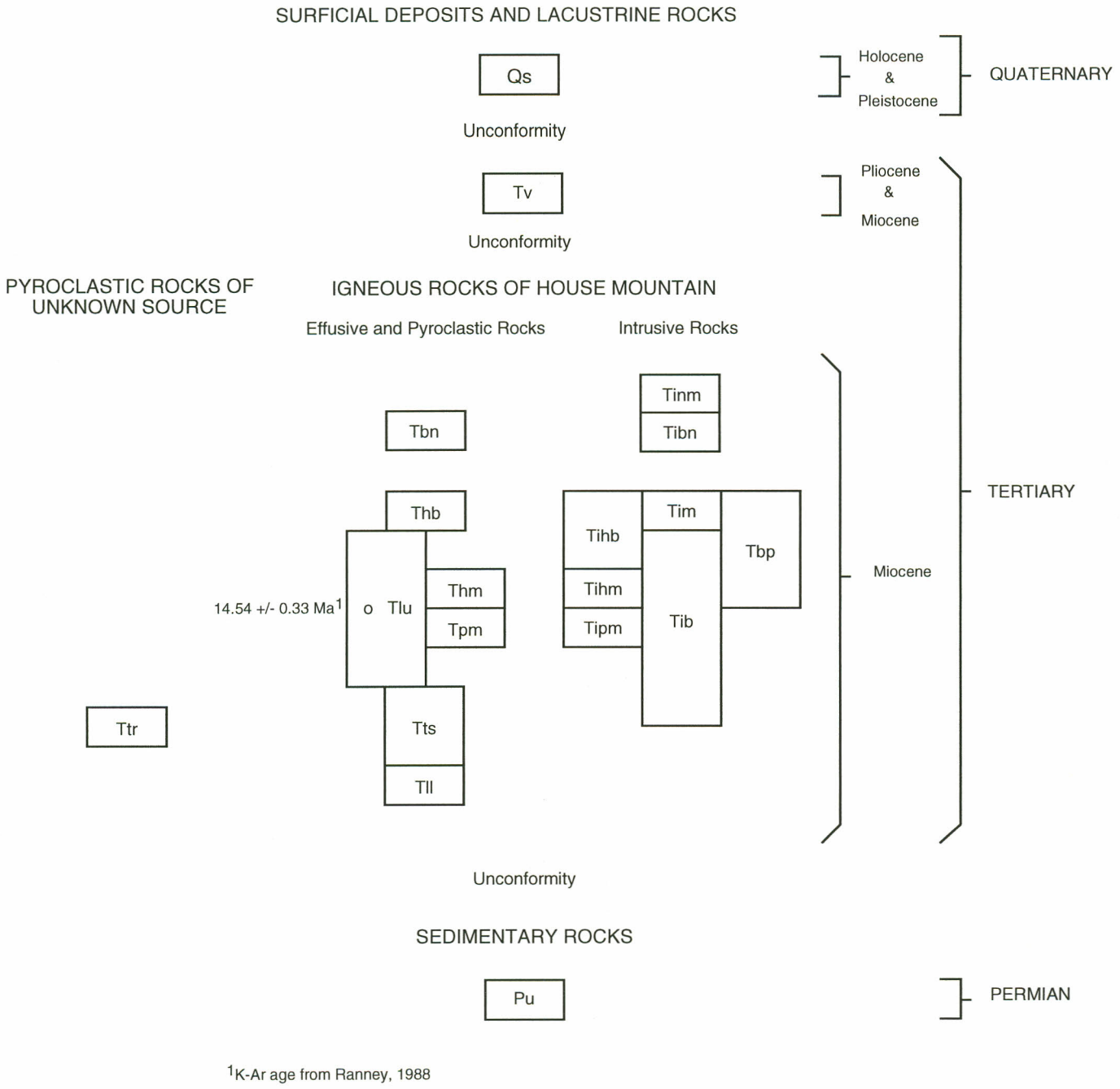
nepheline-bearing syenite (MA)

plagioclase (An_{20}).
anorthoclase; discrete crystals, and mantles on plagioclase.
sanidine; mantles on anorthoclase, and discrete euhedral to interstitial crystals.
nepheline; euhedral to interstitial crystals (5%).
brown amphibole.
biotite.
clinopyroxene; pale tan, zoned to pale to medium green and yellow.
opaque oxide, apatite, sphene.
zeolite; interstitial.
hypidiomorphic, granular.

quartz monzonite (SA)

plagioclase (An_{30}-An_{23}).
anorthoclase; fine tartan twins, mantles on plagioclase.
sanidine; discrete crystals; sparse.
tridymite; abundant.
clinopyroxene.
brown amphibole.
biotite.
olivine.
opaque oxide, apatite.
intergranular to intersertal

CORRELATION OF MAP UNITS



[1]K-Ar age from Ranney, 1988

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS AND LACUSTRINE ROCKS

Qs UNCONSOLIDATED SEDIMENTS (HOLOCENE AND PLEISTOCENE)-Coarse alluvium and colluvium

Tv VERDE FORMATION (PLIOCENE AND MIOCENE)-White to light gray limestone and marly limestone in even to irregular beds 0.3 to 1 m thick; fine grained to microcrystalline. At the contact with House Mountain lavas, the limestone fills cracks in fractured lava and cements loose blocks of lava. Thickness in the south part of the map is 0 to 100 m. Interpreted by Ranney (1988) as lacustrine deposits that onlap the House Mountain volcano

PYROCLASTIC ROCKS OF UNKNOWN SOURCE

Ttr RHYOLITIC TUFF (MIOCENE)-Light pink to lavender crystal-vitric tuff in one bed about 80 cm thick. Well sorted crystals, 0.3-1.5 mm, of plagioclase (An_{26-21}), sanidine, quartz, biotite, brown hornblende, yellow clinopyroxene, and opaque oxide, and pumice and felsic lithic pyroclasts are moderately to well cemented with opaline silica. Finely laminated. Occurs in 2 outcrops interbedded in basaltic scoriaceous tuff on the north side of House Mountain. The source of the tuff could be the Hackberry Mountain volcanic center (Lewis, 1983) about 40 km south of House Mountain

IGNEOUS ROCKS OF HOUSE MOUNTAIN

Effusive and Pyroclastic Rocks

Tbn BASANITIC NEPHELINITE (MIOCENE)-Small lava flow of dark gray to black basanitic nephelinite overlying pyroxene mugearite lava flow on northeast side of House Mountain. Abundant olivine microphenocrysts and phenocrysts stand out in relief on surfaces weathered dark brown. The lava flow is blocky, dense, and massive; about 4 m thick. The aphanitic matrix consists of abundant clinopyroxene, olivine, plagioclase, analcite, alkali feldspar, opaque oxide, biotite, and apatite; the texture is trachytoid. The lava extruded from a small dike of basanitic nephelinite that contains small schlieren, pods, and dikes (15 mm thick) of nepheline monzosyenite

Thb HORNBLENDE BENMOREITE (MIOCENE)-Lava dome and lava flow about 420 m long that overlie basaltic andesite lava flows on the southwest and west sides of House Mountain. Phenocrysts of hornblende up to 10 mm long, microphenocrysts of plagioclase (0.5 mm), and scattered

clinopyroxene are set in an aphanitic, medium gray, felsic matrix; weathers grayish tan to gray. Sparce quartz xenocrysts are up to 5 mm in diameter. Thickness of lava flow at terminus is 15 m. Outcrops display prominent platy joints

Tlu UPPER LAVA FLOWS (MIOCENE)-Many lava flows of basaltic andesite, hawaiite, and pyroxene mugearite that overlie basaltic pyroclastic deposits, form the upper flanks of the shield, and cap the east, south, and west walls of the erosional caldera; small outcrops are preserved on the north side. The lava flows range from 2 to 20 m thick; thin scoriaceous lapilli tuffs are interbedded locally. The map unit ranges in thickness from about 4 m where single flows are mapped on the north side of House Mountain to 140 m on the northeast side. Hawaiite and basaltic andesite are distinguished with difficulty in the field. Typically, both lithologies contain olivine phenocrysts in a dark gray aphanitic matrix; both contain local quartz xenocrysts, rare xenoliths of granite, display smooth, round vesicles and platy joints, and weather grayish to reddish tan. Hawaiite tends to have more and larger olivine phenocrysts (up to 5 mm in diameter), whereas basaltic andesite has sparse phenocrysts of clinopyroxene up to 2 mm long in addition to olivine (up to 3 mm in diameter). Felsic segregations of fine grained monzodiorite up to 5 cm in diameter occur in hawaiite lavas on the 4728 ft. knob on the north side of the mountain; felsic segregations appear to be absent in basaltic andesite lava flows. Pyroxene mugearite lava flows in the map unit have conspicuous clinopyroxene phenocrysts up to 3 mm long, and less abundant olivine phenocrysts up to 2 mm in diameter; the matrix is aphanitic, dark gray, weathers tan, and displays smooth vesicles. Most of the lava flows in the map unit are basaltic andesite; hawaiite flows occur on the north side of House Mountain, and 2 or 3 flows of pyroxene mugearite are in the thick section on the northeast side. A sample from the southeast rim of the caldera has a K-Ar age of 14.54 +/- 0.33 Ma (Ranney, 1988)

Thm HORNBLENDE MUGEARITE (MIOCENE)-Two lava flows of hornblende mugearite on the south and west sides of House Mountain. The flow on the south side, 30 m thick, is interlayered in basaltic andesite lava flows of the upper lava flows map unit; the terminus of the flow is covered by the Verde Formation. The flow on the west side, 12 m thick, erupted on scoriaceous tuffs and was covered by the upper lava flows. Phenocrysts of hornblende up to 7 mm long and plagioclase up to 1 mm are in a medium gray aphanitic matrix that contains abundant irregular vesicles; euhedral biotite crystals are attached to vesicle walls. Quartz xenocrysts are rare. The lava weathers medium to light gray. Both flows were fed from dikes exposed in the erosional caldera

Tpm PYROXENE MUGEARITE (MIOCENE)-Two lava flows of pyroxene mugearite on the southeast and northeast sides of House Mountain. The flow on the southeast side, about 7 m thick, erupted on scoriaceous tuffs and was covered by the upper lava flows; the flow on the northeast side, 28 m thick, is interlayered in basaltic andesite flows of the upper lava flows map unit. Phenocrysts of clinopyroxene up to 5 mm long and less abundant olivine up to 3 mm long are in a medium gray aphanitic matrix; sparse glomerocrysts of clinopyroxene and olivine reach 11 mm in diameter. The rock weathers tan; calcite forms amygdules in irregular vesicles. Both flows are connected to thick feeder dikes that are exposed in the erosional caldera for 500 to 800 m along strike; the outcrops lack definitive evidence for the transition from dike to flow, and the extrusion points shown on the map are near the highest elevations of the flows

Tts SCORIACEOUS BASALTIC TUFF (MIOCENE)-Planar bedded to structureless deposit of lapillistone, lapilli tuff, tuff breccia, and minor ash tuff and agglomerate exposed in the erosional caldera at the summit of House Mountain. Pyroclasts are scoriaceous to poorly vesicular basalt that contains olivine phenocrysts up to 3 mm long. Most of the deposit is red, but locally it is pink, gray, or tan to yellow and orange; the beds are poorly to moderately-well cemented with zeolite and carbonate minerals. Thickness ranges from 0 to 180 m. Agglomerate and coarse tuff breccia crop out on and near the hills in the southern part of the caldera where well-formed fusiform bombs of basalt exceed 1 m in diameter. Elsewhere, the deposit is mostly lapilli tuff, and pyroclast sizes decrease toward the margins of the caldera. Radial dips of bedding around the hills, and coarse pyroclasts in the deposit indicate the vent, or possibly 2 vents, of the cinder cone was in the south part of the caldera. South dipping beds of tuff that overlie Paleozoic strata on the north side of House Mountain probably were deposited at the base of the ancestral Mogollon Rim (Ranney, 1988)

Tll LOWER LAVA FLOWS (MIOCENE)-Several subhorizontal lava flows of hawaiite that crop out along the drainage that exits the erosional caldera on the northwest side. Phenocrysts of olivine, up to 3 mm long in most flows, are set in a dark gray aphanitic matrix; the highest flow on the east side of the map unit is distinguished by abundant olivine phenocrysts up to 7 mm long. The lowest flow contains fine- to medium-grained phaneritic segregations of nepheline-bearing hornblende-biotite syenite that range from 0.5 to 7 cm in diameter, and from irregular to spherical in shape. The lavas weather medium gray; most olivine crystals are partly to completely altered, and most vesicles are filled with calcite amygdules. Beds of red scoriaceous lapilli tuff, 0-2 m thick, separate some of the flows. Total thickness of the map unit is about 50 m

Intrusive Rocks

Tinm NEPHELINE MONZOSYENITE AND FELDSPAR IJOLITE (MIOCENE)-Phaneritic intrusions and segregations of medium- to coarse-grained nepheline monzosyenite and feldspar ijolite in a large dike of basanitic nephelinite on the north side of House Mountain. The rocks are heterogeneous on the outcrop scale because of abrupt changes in crystal sizes from around 2mm to 2 cm, color indices that range from 19 to 43, nepheline crystals that are gray, pink, or red, and massive to banded textures. The most abundant and prominent crystals are nepheline and black titanaugite, which typically are euhedral and locally display graphic-like radiate intergrowth textures. Most rocks are reddish brown to reddish gray to medium gray. Miarolitic cavities, 0.5 to 15 mm, are open or filled with sanidine, zeolite, and carbonate minerals; vugs are up to 43 cm wide and 4.5 cm high. The largest bodies are a vertical dike, 15 m thick, and a subhorizontal sheet, about 18 m thick; the sheet has subhorizontal compositional banding on a cm scale and considerable ranges in modal percents of minerals between the lower, middle, and upper parts. Two smaller, circular areas were mapped where many pods and dikes, cm to m in diameter, are concentrated in the basanitic nephelinite dike

Tibn BASANITIC NEPHELINITE (MIOCENE)-One large, complex dike and several smaller dikes of aphanitic, dark gray to black, basanitic nephelinite on the north side of House Mountain. Olivine microphenocrysts and small phenocrysts (0.5-2 mm) commonly stand out in relief on surfaces weathered brown to reddish brown to reddish gray. The largest dike is over 1 km long and ranges from 30 to 230 m in thickness; the smallest dike is 2 m thick. The dikes are massive and nonvesicular, and display prominent joints normal to sharp, vertical to steeply dipping contacts. The dikes host felsic nepheline monzosyenite in m- to cm-scale pods and dikes, and mm-scale schlieren, irregular patches, and ocelli

Tihb HORNBLENDE BENMOREITE INTRUSION (MIOCENE)-Plug and dike apophysis of hornblende benmoreite on the southwest side of House Mountain. Hornblende phenocrysts up to 5 mm long are in a medium brownish gray aphanitic matrix; the rock weathers gray. Silica minerals and red biotite occur in vesicles. Platy joints in the plug display concentric strikes and steep to vertical dips

Tihm HORNBLENDE MUGEARITE INTRUSIONS (MIOCENE)-Plug and several dikes of hornblende mugearite on the southwest side of House Mountain. Hornblende phenocrysts, up to 5 mm long, and scattered phenocrysts of olivine (up to 2 mm), clinopyroxene (up to 2 mm) , and plagioclase (up to 1 mm) are in a medium gray aphanitic matrix that weathers gray to tan. The rock is dense to vesicular; vesicles are open or contain biotite sublimates

and calcite amygdules. Platy joints in the plug display concentric strikes and steep to vertical dips. One of the western-most dikes is connected to a lava flow in the wall of the erosional caldera, and the southern dike can be traced to within 60 m of a long lava flow of hornblende mugearite on the south flank of House Mountain

Tipm COMPOSITE INTRUSIONS OF PYROXENE MUGEARITE, HORNBLENDE MUGEARITE, BASALTIC ANDESITE, MONZODIORITE, MONZONITE, QUARTZ MONZONITE, AND SYENITE (MIOCENE)-Dikes and plugs in the erosional caldera. Most of the rocks are pyroxene mugearite, and this lithology appears to be the only type in the large dikes that fed lava flows on the northeast and southeast sides of House Mountain. The large dike that trends west-northwest across the south side of the caldera consists principally of pyroxene mugearite, but internal dikes of hornblende mugearite and basaltic andesite occur locally. In addition, small dikes of phaneritic monzodiorite, monzonite, and syenite were injected in platy joints in pyroxene mugearite, and quartz monzonite was injected in basaltic andesite. The phaneritic dikes, intruded principally in the margins of the large dike, range in thickess from 1 cm to 40 cm; the longest dike is 20 m. Locally, where the pyroxene mugearite host is massive in the interior of the large dike, the syenite occurs in pods several cm to several m in diameter.

Pyroxene mugearite contains scattered to sparse phenocrysts of clinopyroxene up to 4 mm long, and less abundant olivine up to 1 mm, in a medium gray aphanitic matrix; locally, the rock is aphyric. Hornblende mugearite contains hornblende phenocrysts up to 5 mm long, plagioclase up to 1mm, and sparse clinopyroxene up to 1mm, in a medium gray aphanitic matrix. All mugearites are massive to jointed, dense to vesicular, contain biotite sublimates and calcite amygdules in vesicles, and weather gray to tan. Basaltic andesite has scattered phenocrysts of olivine up to 3 mm long in a medium gray aphanitic matrix; in thin section, orthorhombic pyroxene can be identified. The phaneritic rocks are fine to medium grained, light gray, felsic, and typically display granular, diktytaxitic to dense textures; syenite has the lowest color index, and abundant tridymite is seen in thin sections of quartz monzonite

Tim MONZODIORITE INTRUSION (MIOCENE)-Small plug of monzodiorite intruded into the upper lava flows on the northwest side of House Mountain. The outcrop area is about 15 m by 15 m in size, and surrounded on most sides by colluvium of basaltic blocks. The contact with hawaiite lava is preserved at the top of the outcrop. The rock is light gray, fine to medium grained, granular, and massive; it weathers tan

Tib BASALTIC INTRUSIONS (MIOCENE)-Dikes and plugs of hawaiite and basaltic andesite in the erosional caldera. The dikes range from <1 m thick to about

80 m thick; the plugs range from 9 m in diameter to about 90 m in longest diameter. Most of the dikes occur as sheaths marginal to the large dikes of pyroxene mugearite in the south part of the caldera. Hawaiite and basaltic andesite are distinguished with difficulty. In general, hawaiite has abundant phenocrysts of olivine, up to 4 mm long, whereas basaltic andesite has scattered phenocrysts of olivine, up to 3 mm, and sparse phenocrysts of clinopyroxene up to 1 mm; in thin sections, rare phenocrysts of orthorhombic pyroxene can be identified in basaltic andesite. Both lithologies have an aphanitic matrix that is medium to dark gray to black on fresh surfaces and weathers medium gray to tan to reddish tan. Locally, hawaiite contains schlieren of biotite syenite, 0.5-2 mm thick, that were segregated in platy joints, and irregular spots of monzonitic material 0.2-0.6 mm in diameter. The intrusions were the principal feeders of the upper lava flows

Tbp BRECCIA PIPES (MIOCENE)-Several breccia pipes in the large dike of pyroxene mugearite on the east side of the 4864' hill in the southwest side of the caldera. The pipes are several m in diameter, and contain angular, matrix-supported blocks of aphyric mugearite that range from <1 cm to about 30 cm in diameter and are identical in lithology to the host mugearite

SEDIMENTARY ROCKS

Pu SEDIMENTARY ROCKS UNDIVIDED (LOWER PERMIAN)-Medium to light red sandstone of the Schnebly Hill Formation and light tan sandstone of the Coconino Sandstone

EXPLANATION OF MAP SYMBOLS FOR GEOLOGIC MAPS IN THE MORMON VOLCANIC FIELD:

SUMMIT OF HOUSE MOUNTAIN, SEDONA, ARIZONA QUADRANGLE

Line, Point, and Structure Symbols

——— ———	Boundary of mapped area.
———— —	Geologic contact; long dash where located approximately.
. . . . .	Approximate boundary between intrusive and effusive facies of lava flows and feeder dikes.
▲ 14.54	Locality and age in millions of years of sample dated by K-Ar analysis (Ranney, 1988).
•203	Locality and number of sample with chemical analysis listed in Table 1.
⊢ 35	Strike and dip of bedding.
▼ 80	Strike and dip of platy joints.
—◆—	Strike of vertical platy joints.

TABLE 1. *X-ray fluorescence analyses of rocks from House Mountain, Arizona*

Sample	S-182-1	S-185-1	S-186-1	S-187-1	S-190-1
Map Unit	Thb	Tim	Tll	Tipm	Tll
Lithology	ben	mon dio	haw	p mug	haw
Analyst	UT	UT	UT	UT	UT
SiO2	54.60	51.56	47.13	49.94	46.96
TiO2	0.96	2.09	1.98	1.48	1.68
Al2O3	17.16	16.08	13.32	15.73	13.53
Fe2O3	7.63	8.88	12.01	9.88	11.05
FeO	-	-	-	-	-
MnO	0.14	0.13	0.16	0.14	0.15
MgO	2.47	2.94	7.21	4.62	8.59
CaO	6.53	6.45	8.76	9.55	9.15
Na2O	5.15	4.37	4.16	3.85	3.71
K2O	2.56	3.10	0.96	1.64	1.43
P2O5	0.68	1.20	0.76	0.57	0.76
LOI	0.92	2.16	1.03	1.54	0.68
Total	98.80	98.96	97.48	98.94	97.69
Sc	-	-	-	-	-
V	127	230	187	216	181
Cr	6	3	247	58	335
Co	-	-	-	-	-
Ni	3	36	190	54	171
Cu	-	-	-	-	-
Zn	109	132	133	98	121
Rb	31	27	16	21	15
Sr	1819	3816	1454	1192	1405
Y	21	21	20	20	21
Zr	237	249	190	157	175
Nb	24	7	18	18	25
Ba	1398	3647	1139	1010	900
La	-	-	-	-	-
Ce	-	-	-	-	-
Pb	-	-	-	-	-
Th	-	-	-	-	-

Analysts:

UH Dr. Gerburg Larsen,
Universitat Hohenheim,
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UT Dr. Ing Muharrem Satir,
Universitat Tubingen,
Tubingen, Germany

WSU Washington State University
GeoAnalytical Laboratory
Pullam, Washington, USA

Lithology abbreviations:

bas ande	basaltic andesite
bas neph	basanitic nephelinite
ben	benmoreite
feld ijo	feldspar ijolite
haw	hawaiite
mon dio	monzodiorite
h mug	hornblende mugearite
p mug	pyroxene mugearite
ne mon	nepheline monzosyenite
q mon	quartz monzonite
syen	syenite
sy urt	syenitic urtite

Sample	S-191-1	S-192-1	S-193-1	S-194-1	S-196-1	S-198-1	S-199-1	S-200-1
Map Unit	Tlu	Tib	Tll	Tlu	Tlu	Tipm	Tipm	Tib
Lithology	haw	haw	haw	bas ande	p mug	p mug	p mug	bas ande
Analyst	UT	UT	UT	WSU	WSU	UT	UT	UT
SiO2	47.46	48.40	48.79	53.68	52.74	49.38	50.29	50.95
TiO2	1.70	1.90	1.95	1.54	1.48	1.49	1.49	1.43
Al2O3	13.73	13.97	14.50	15.35	16.25	16.03	16.42	15.65
Fe2O3	11.09	11.01	12.28	-	-	9.71	9.64	10.08
FeO	-	-	-	9.11	8.16	-	-	-
MnO	0.15	0.15	0.15	0.15	0.17	0.15	0.14	0.17
MgO	8.30	7.22	6.26	5.68	4.89	4.70	4.39	4.66
CaO	9.43	8.24	8.33	9.13	9.71	8.50	9.50	9.09
Na2O	3.65	4.18	3.63	3.38	3.79	3.63	4.29	3.60
K2O	1.48	1.94	1.20	1.43	1.70	1.96	1.93	1.31
P2O5	0.76	0.75	0.51	0.39	0.43	0.61	0.62	0.40
LOI	0.82	1.08	2.47	-	-	1.77	1.44	0.83
Total	98.57	98.84	100.07	99.84	99.32	97.93	100.15	98.17
Sc	-	-	-	25	22	-	-	-
V	179	188	205	218	218	217	208	185
Cr	314	252	294	112	70	22	74	76
Ni	170	177	271	68	47	33	35	63
Cu	-	-	-	153	137	-	-	-
Zn	127	126	124	106	114	100	101	99
Rb	15	24	17	19	20	23	22	19
Sr	1484	1441	856	920	935	1333	1352	1001
Y	20	21	20	21	22	20	22	19
Zr	177	200	165	149	148	166	170	129
Nb	23	21	15	18	21	21	23	14
Ba	887	1028	626	742	879	1151	1108	874
La	-	-	-	50	37	-	-	-
Ce	-	-	-	57	76	-	-	-
Pb	-	-	-	8	6	-	-	-
Th	-	-	-	3	6	-	-	-

Sample	S-201-1	S-203-1	S-204-1	S-204-2	S-205-1	S-205-2	S-205-3	S-209-1
Map Unit	Tib	Tpm	Tinm	Tinm	Tinm	Tinm	Tinm	Tibn
Lithology	bas ande	p mug	ne mon	sy urt	feld ijo	ne mon	feld ijo	bas neph
Analyst	UT	UT	UT	UT	UT	UT	UT	UH
SiO2	51.90	49.82	43.85	42.42	43.03	44.60	41.28	43.46
TiO2	1.49	1.46	1.19	1.55	1.83	0.74	1.76	1.93
Al2O3	15.87	15.82	19.73	19.01	17.53	18.74	17.78	11.78
Fe2O3	10.31	9.59	8.78	9.41	10.37	9.72	9.99	12.66
FeO	-	-	-	-	-	-	-	-
MnO	0.15	0.14	0.17	0.17	0.18	0.21	0.16	0.19
MgO	4.34	4.68	2.53	3.06	3.50	2.44	4.13	13.46
CaO	8.82	9.36	6.94	8.77	9.54	6.22	10.22	12.22
Na2O	3.63	3.79	5.07	5.21	3.19	4.85	5.25	2.96
K2O	1.28	1.89	4.51	3.24	3.39	4.17	2.87	1.25
P2O5	0.37	0.61	0.87	1.13	1.23	0.60	1.38	0.89
LOI	0.48	1.42	5.00	3.88	4.82	5.76	3.11	-
Total	98.64	98.58	98.64	97.85	98.61	98.05	97.93	100.80
Sc	-	-	-	-	-	-	-	-
V	252	211	113	186	263	29	229	23
Cr	61	50	27	8	9	56	9	65
Co	-	-	-	-	-	-	-	58
Ni	47	41	17	29	48	14	33	365
Cu	-	-	-	-	-	-	-	86
Zn	108	98	127	119	121	125	118	116
Rb	20	23	75	48	68	64	40	28
Sr	892	1508	2701	3356	3259	2858	2162	1070
Y	21	19	24	22	25	18	28	21
Zr	132	169	231	228	257	208	242	230
Nb	14	19	131	95	107	102	89	43
Ba	737	1338	3950	3332	3440	4608	2404	1390
La	-	-	-	-	-	-	-	-
Ce	-	-	-	-	-	-	-	-
Pb	-	-	-	-	-	-	-	23
Th	-	-	-	-	-	-	-	-

Sample	S-210-5	S-210-7	S-211-1	S-212-1	S-213-1	S-214-1	S-216-1	S-218-1
Map Unit	Tinm	Tinm	Tlu	Thm	Thm	Tlu	Tlu	Tlu
Lithology	ne mon	feld ijo	bas ande	h mug	h mug	bas ande	bas ande	bas ande
Analyst	UH	UH	UT	UT	UT	UT	UT	UT
SiO2	50.21	44.89	51.61	52.39	52.14	51.62	51.49	51.69
TiO2	1.01	2.08	1.52	1.23	1.18	1.43	1.44	1.50
Al2O3	23.04	16.78	15.27	17.17	16.90	14.20	14.17	14.36
Fe2O3	5.81	10.32	10.20	8.53	8.61	10.77	10.71	10.75
FeO	-	-	-	-	-	-	-	-
MnO	0.10	0.15	0.15	0.15	0.15	0.15	0.15	0.15
MgO	2.96	5.43	4.89	3.17	2.92	6.98	6.99	7.08
CaO	6.85	12.96	8.86	7.48	7.16	8.50	8.49	8.47
Na2O	5.27	3.61	3.50	4.39	4.50	3.16	3.04	3.31
K2O	4.13	2.25	1.26	2.49	2.46	1.34	1.48	1.56
P2O5	0.72	1.91	0.40	0.70	0.74	0.37	0.40	0.44
LOI	-	-	0.66	1.00	0.96	0.27	0.92	0.30
Total	100.10	100.38	98.32	98.70	97.72	98.79	99.28	99.61
Sc	-	-	-	-	-	-	-	-
V	62	274	210	147	157	189	193	191
Cr	96	123	90	14	10	266	282	281
Co	20	29	-	-	-	-	-	-
Ni	51	76	61	18	12	213	211	211
Cu	129	166	-	-	-	-	-	-
Zn	67	83	104	108	113	105	106	105
Rb	59	51	12	29	30	15	18	21
Sr	5290	4220	945	1691	1735	933	940	976
Y	18	29	22	23	20	19	20	17
Zr	243	254	139	225	226	133	136	150
Nb	108	56	14	26	26	10	9	11
Ba	3280	2690	780	1380	1439	760	826	841
La	-	-	-	-	-	-	-	-
Ce	-	-	-	-	-	-	-	-
Pb	16	10	-	-	-	-	-	-
Th	-	-	-	-	-	-	-	-

Sample	S-220-1	S-222-1	S-222-2	S-224-1	S-227-3	S-229-1	S-232-1	S-236-3
Map Unit	Tihb	Tipm	Tipm	Tipm	Tipm	Tib	Tipm	Tihm
Lithology	ben	h mug	mon dio	q mon	bas ande	haw	syen	h mug
Analyst	WSU	UT	WSU	WSU	WSU	WSU	WSU	WSU
SiO2	55.56	51.69	58.85	63.05	53.73	50.19	61.03	54.31
TiO2	0.98	1.22	1.36	1.40	1.57	1.74	1.06	1.25
Al2O3	17.29	17.16	17.43	17.06	15.56	14.07	17.64	17.68
Fe2O3	-	8.80	-	-	-	-	-	-
FeO	6.85	-	4.85	3.89	9.25	10.26	3.67	7.39
MnO	0.14	0.14	0.11	0.06	0.14	0.16	0.11	0.15
MgO	2.51	3.32	2.23	1.54	5.24	9.10	1.47	3.11
CaO	6.77	7.59	4.18	2.05	8.76	8.66	2.67	7.49
Na2O	5.08	4.39	5.53	4.59	3.70	3.90	5.88	4.91
K2O	3.10	2.26	4.47	4.81	1.43	1.26	5.43	2.49
P2O5	0.70	0.71	0.52	0.28	0.40	0.56	0.35	0.71
LOI	-	0.73	-	-	-	-	-	-
Total	98.98	98.01	99.53	98.73	99.78	99.90	99.31	99.49
Sc	7	-	8	8	14	23	-	9
V	141	175	107	87	220	165	70	181
Cr	-	40	9	11	93	275	-	2
Co	-	-	-	-	-	-	-	-
Ni	-	21	11	56	68	226	6	1
Cu	24	-	194	268	132	92	120	54
Zn	112	105	90	61	107	124	75	114
Rb	37	25	48	87	19	15	84	31
Sr	1727	1760	1055	390	921	1000	564	1676
Y	20	22	24	33	22	22	24	23
Zr	263	194	306	399	150	170	443	251
Nb	36	21	57	65	19	27	85	38
Ba	1419	1519	1975	1051	745	661	1068	1419
La	96	-	95	63	38	34	101	89
Ce	128	-	170	182	55	86	175	119
Pb	18	-	22	20	6	2	16	18
Th	9	-	14	12	3	5	22	9

Sample	S-241-1	S-245-1	S-246-1	S-247-1	S-248-1	S-249-1	S-250-1	S-267-1
Map Unit	Tipm	Tlu	Tlu	Tlu	Tlu	Tlu	Tlu	Tts
Lithology	syen	bas ande	p mug	bas ande	bas ande	bas ande	bas ande	basalt
Analyst	WSU	WSU	WSU	WSU	WSU	WSU	WSU	WSU
SiO2	60.09	53.86	52.67	54.11	53.65	52.00	53.33	49.84
TiO2	1.27	1.56	1.50	1.57	1.50	1.52	1.53	2.10
Al2O3	17.76	15.73	16.16	15.56	15.39	15.49	15.44	14.38
Fe2O3	-	-	-	-	-	-	-	-
FeO	4.80	8.81	8.93	8.61	9.19	10.22	9.02	8.93
MnO	0.12	0.15	0.16	0.15	0.14	0.17	0.15	0.13
MgO	1.35	5.02	4.94	5.15	5.66	6.13	6.31	7.79
CaO	2.94	9.10	9.43	8.87	8.98	9.04	9.10	9.54
Na2O	5.48	3.72	3.95	3.70	3.59	3.44	3.57	2.72
K2O	5.20	1.43	1.50	1.54	1.35	1.23	1.37	1.46
P2O5	0.43	0.40	0.48	0.41	0.36	0.45	0.40	0.95
LOI	-	-	-	-	-	-	-	-
Total	99.44	99.78	99.72	99.67	99.81	99.69	100.22	97.84
Sc	-	18	23	23	22	24	26	22
V	130	212	220	223	213	195	195	198
Cr	1	108	64	94	180	149	150	290
Co	-	-	-	-	-	-	-	-
Ni	2	70	41	65	118	119	119	148
Cu	47	146	129	143	193	125	123	74
Zn	82	106	102	115	102	106	108	133
Rb	78	19	19	20	17	13	15	11
Sr	720	914	1016	897	863	1015	981	1958
Y	29	22	21	23	22	22	21	18
Zr	447	148	159	150	140	152	154	258
Nb	90	18	23	20	18	18	18	27
Ba	1559	753	846	759	725	1298	778	1148
La	103	49	25	31	24	42	22	72
Ce	182	58	70	48	56	49	51	99
Pb	17	5	11	9	7	13	10	14
Th	23	4	4	5	3	5	7	9

TABLE 2. ***Modal mineralogy of strongly alkaline rocks, House Mountain, Arizona***

	204-1	204-2	204-3	205-1	205-2	205-3	207-1	209-1	210-2	210-5	210-6	210-7	210-9	204-8	204-9	207-2
	ne monz	sy urtite	ne monz	feld ijolite	ne monz	feld ijolite	bas neph	bas neph	ne monz	ne monz	feld ijolite	feld ijolite	feld ijolite	ne monz (ocelli)	ne monz (dike)	ne monz (dike)
N[1]	791	772	1255	1262	852	880	1200	956	1309	1061	1463	948	1347	1368	725	710
Olivine	-	-	-	1.0	6.8	2.0	12.9, 7.2[2]	16.9, 2.4[2]	-	0.1	-	1.1	3.6	0.4	0.5	0.4
Titanaugite	10.5	15.8	12.5	28.1	10.3	33.5	0.1, 55.4[2]	0.2, 48.4[2]	15.5	10.7	28.2	29.4	28.6	7.0	12.6	4.8
Brown/Green Pyroxene	6.4	7.1	4.4	2.8	0.9	-	-	-	0.5	1.2	3.6	2.5	3.3	-	-	-
Opaque Oxides	6.1	5.7	7.9	4.8	1.4	7.3	3.5	6.3	3.4	4.4	6.1	3.0	4.8	5.3	4.1	5.1
Biotite	tr	-	-	-	tr	-	1.8	2.1	1.3	0.1	-	tr	-	0.4	0.7	1.3
Amphibole	-	-	-	-	-	0.7	-	-	1.5	1.5	-	tr	-	1.0	0.4	0.4
Zeolites	10.1	8.7	12.4	12.4	18.3	7.0	-	-	10.3	10.9	7.2	4.6	4.2	6.0	5.9	11.8
Carbonate	3.5	1.9	1.3	-	3.8	0.8	0.3	0.3	-	-	1.6	-	0.1	tr	0.3	0.3
Apatite	2.1	2.7	1.8	3.5	1.3	3.8	1.2	1.7	3.1	1.7	3.7	3.0	3.0	2.2	1.5	1.1
Nepheline	33.0	37.3	25.4	27.8	15.8	32.2	9.5	8.7	33.5	41.3	32.3	40.6	31.6	9.3	35.4	19.0
Analcite	-	-	tr	1.0	0.5	1.5	2.8	4.7	2.6	-	1.8	-	0.1	27.7	5.9	16.5
Plagioclase	12.7	6.9	14.7	4.2	15.5	4.2	5.3	8.1	11.7	7.8	7.0	5.0	8.7	15.6	6.0	11.9
Anorthoclase	5.1	4.9	5.1	1.6	6.3	1.6	-	-	2.4	4.3	1.4	3.1	4.3	7.7	3.2	9.0
Sanidine	10.4	8.8	14.4	12.8	19.0	5.5	-	-	14.2	16.0	7.2	7.7	7.6	17.4	23.4	18.5
C.I.[3]	23.0	28.6	24.8	36.7	19.4	43.5	80.9	76.3	22.2	18.0	37.9	36.0	40.3	14.1	18.3	12.0
M	38.7	41.9	40.3	52.6	42.8	55.1	82.1	78.3	35.6	30.6	50.1	43.6	47.6	22.3	26.0	25.2
F	53.9	64.4	42.6	60.8	28.5	74.9	69.9	62.3	56.1	59.5	68.6	72.0	60.6	47.6	55.9	47.4
A	25.3	23.7	32.7	30.4	44.3	15.8	-	-	25.8	29.3	17.3	19.1	22.8	32.3	36.0	36.7
P	20.8	11.9	24.7	8.9	27.1	9.3	30.1	37.7	18.1	11.2	14.1	8.9	16.6	20.1	8.1	15.9

Notes. ne monz = nepheline monzosyenite, sy = syenitic, feld = feldspar, bas neph = basanitic nephelinite, tr = trace; [1] N = Number of points counted to determine mode; [2] Phenocrysts and groundmass grains, respectively. [3] C.I. = Color Index (dark minerals), M = mafic minerals, FAP = IUGS parameters (Fig. 3).

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