PRELIMINARY GEOLOGIC MAPS OF THE EASTERN BIG HORN AND BELMONT MOUNTAINS, WEST-CENTRAL ARIZONA

Richard C. Capps, Stephen J. Reynolds, Curtis P. Kortemeier,
James A. Stimac, Elizabeth A* Scott, and George B. Allen

Arizona Geological Survey
Open-File Report 85-14

November, 1985
(Revised June 12, 1986)

Arizona Geological Survey
416 W. Congress, Suite #100, Tucson, Arizona 85701

Jointly funded by the Arizona Bureau of
Geology and Mineral Technology and the
U.S. Geological Survey COGEOMAP Program
Contract No. 14-08-0001-AO229
Principle Investigators: Stephen Jo Reynolds Larry D. Fellows

This report is preliminary and has not been edited
or reviewed for conformity with Arizona Geological Survey standards

INTRODUCTION

This report presents preliminary 1:24,000-scale geologic maps of the eastern Big Horn and Belmont Mountains in west-central Arizona. The mapping, completed between January and April 1985, was jointly funded by the U.S. Geological Survey and the Arizona Bureau of Geology and Mineral Technology as part of the cost-sharing, Cooperative Geologic Mapping Program (COGEOMAP). The aim of COGEOMAP is to produce high-quality geologic maps for areas that have been inadequately mapped. The Big Horn and Belmont Mountains were chosen because neither range had been previously mapped, except in broad reconnaissance for previous State geologic maps, and because both ranges have substantial mineralization and exploration activity.

The mapping was done on 1:24,000- and 1:50,000-scale topographic maps and on 1:24,000-scale color aerial photographs provided by Ray Brady, U. S. Bureau of Land Management, Phoenix. This study was done in conjunction with U.S. Geological Survey geologists Floyd Grey and Robert Miller, whose geologic mapping of the Big Horn Mountains Wilderness Study Area begins at the western limit of our mapping and covers the remainder of the Big Horn Mountains to the west. Geologic mapping of the northwestern Big Horn Mountains was completed at a scale of 1:50,000 by George B. Allen (in prep.), and is not included here. K-Ar dates on the Big Horn volcanics and Cretaceous granodiorite were determined by Jon E. Spencer.

The study area was mapped with a planned final-presentation scale of 1:50,000. The 1:24,000-scale maps are being released because of the keen interest exploration companies have shown in both ranges, and because of the extremely complicated nature of the structure and volcanic stratigraphy of the area.

GEOLOGIC OVERVIEW

The Big Horn and Belmont Mountains, like many mountain ranges in western and central Arizona, are composed of a metamorphic-plutonic basement that is overlain by middle Tertiary volcanic and sedimentary rocks. The oldest rocks in the Big Horn-Belmont Mountains are Proterozoic gneiss, schist, amphibolite, and several generations of plutonic rocks. These rocks have been intruded by a large Upper Cretaceous granodioritic to granitic pluton related to the Wickenburg granodiorite of the adjacent Vulture Mountains (Rehrig and others, 1980). A large, locally fluorite-bearing granite of probable middle Tertiary age forms most of the topographically rugged Belmont Mountains. Additional plutons of unknown age, including a garnet-muscovite granite, occur locally. The entire assemblage of crystalline rocks is crosscut by numerous felsic to mafic dikes of inferred middle Tertiary and Late Cretaceous age.

The crystalline rocks are commonly overlain by a thin sequence of sandstone and conglomerate that is variably arkosic or volcaniclastic in composition. Several meters of moderately to poorly welded ash-flow tuff locally occurs within the basal clastic section. The clastic rocks and ash flow are generally too thin to map separately from the overlying Big Horn volcanics.

The lower to middle Miocene (21 to 16 Ma) Big Horn volcanics are the dominant rock unit of the map area. The volcanics consist of a complex sequence of basalt flows, rhyolite flows, lithic tuffs, and lesser amounts of andesite and sedimentary rocks. Basalts are common throughout the section and are interlayered with a number of areally restricted rhyolite flows and associated lithic tuffs. Stratigraphic relationships and subtle differences in phenocryst assemblages in the rhyolites have been used to designate

informal members, each of which represents products from multiple vents but within spatially separate, individual, rhyolitic eruptive centers. Thin fluvial conglomerate and sandstone are interbedded with the volcanics in several areas.

Volcanism was accompanied by low- to high-angle, normal faulting and rotation of the older volcanic units and subjacent crystalline basement. Slight to moderate angular unconformities within the volcanic sequence attest to synvolcanic tilting and faulting. Large outcrop areas of the volcanics are brecciated because of the intense faulting and layer-parallel slippage due to oversteepening during rotational faulting. Most normal faults trend northwest and are associated with northeast-trending faults, which are probably strike-slip faults that accommodated differential rotation and northeast-southwest translation of adjoining fault blocks. In the eastern part of the area, most northwest-striking normal faults dip southwest and most beds dip northeast. In contrast, normal faults in the western half of the area dip northeast and bedding dips southwest. The boundary between these different tilt domains is structurally complex and somewhat irregular; it locally occurs along the northeast-trending structures. Tilting and normal faulting continued after the Bighorn volcanics were erupted because the stratigraphically highest volcanic units are overlain by coarse sedimentary breccia and landslide-related megabreccias that occur in the larger half grabens. The sedimentary breccias grade upward into slightly tilted to flat-lying semiconsolidated conglomerate, sandstone, and gravel. Essentially flat-lying 15-m.y.-old basalts occur to the north and south of the main mountain mass.

Precious- and base-metal mineralization in the area can be subdivided into a number of distinctive types of deposits (Allen, in prep.). Base- and precious-metal occurrences in the northwestern part of the Big Horn Mountains,

northwest of the present study area, occur within the crystalline rocks and are, in part, pre-mid-Tertiary. Other mineral deposits in this area and throughout the rest of the range, including significant occurrences of gold, manganese, and barite-fluorite mineralization, are associated with middle Tertiary faults and intrusive-volcanic centers. The relationship of mineralization to the fluorite-bearing Belmont granite is unknown (Reynolds and others, 1985).

UNITS YOUNGER THAN THE BIG HORN VOLCANICS

Qs **YOUNGER ALLUVIUM (HOLOCENE)** -- Unconsolidated sand and gravel in modern channels or on low-lying terraces adjacent to these channels.

Qt **UNCONSOLIDATED TALUS (HOLOCENE)** -- Unconsolidated, poorly sorted, angular gravel and blocks that generally flank high topography.

Qso **MID-LEVEL ALLUVIUM (HOLOCENE)** -- Unconsolidated gravel-poor sand and sandy gravel deposits in flood plains elevated 0.5 to 2 m above the modern channels. Deposits typically host mature mesquite trees.

QTs **OLDER ALLUVIUM (UPPER MIOCENE TO HOLOCENE)** -- Unconsolidated to semiconsolidated and caliche-cemented sand and gravel deposits that commonly underlie dissected terraces elevated 2 m or more above modern drainages. These deposits are being incised by the present drainage system and host palo verde trees, saguaros, and other cacti.

Thr **HOT ROCK BASALT (MIDDLE MIOCENE)** -- Dark-gray, homogranular, moderate- to fine-grained, moderately vesicular basalt flows. Basalt contains rare phenocrysts of pyroxene and very fine-grained, altered olivine in intergranular cavities between plagioclase laths. Zeolites occur as secondary minerals in vesicles and within the interstitial matrix. The principal

outcrops are in the far northern and southern parts of the map area where these basalts overlie very gently dipping Tertiary fanglomerates. The basalt has yielded K-Ar whole-rock ages of 15.01 ± 0.42 Ma on Hot Rock Mountain, south of the Belmont Mountains (Shafiqullah and others, 1980), and 15.62 ± 0.35 Ma at Black Butte in the western Vulture Mountains (Scarborough and Wilt, 1979). Hot Rock basalt is the stratigraphically highest volcanic unit in the Big Horn Mountains and was erupted along the northern and southern margins of the range after most significant regional tilting. The maximum thickness at Hot Rock Mountain is about 20 m.

Tf **UNDIFFERENTIATED FANGLOMERATE, SEDIMENTARY BRECCIA, MEGABRECCIA, AND LAHAR DEPOSITS (MIDDLE TO UPPER MIOCENE(?)** -- Consolidated to semiconsolidated fanglomerate, conglomeratic sandstone, conglomerate, sedimentary breccia, landslide-formed megabreccia, and laharic breccia; generally includes overlying, less consolidated, sand and gravel deposits equivalent to unit QTs. Moderately tilted sedimentary breccia, megabreccia, laharic breccia, and consolidated conglomerate occur in the lower parts of the section and commonly grade upward into less tilted, less consolidated fanglomerate, conglomeratic sandstone, and conglomerate, and stratigraphically high gravel deposits. The contact between the lower, tilted sequence and higher, untilted units is variably an angular unconformity or a gradational contact. Mapping of this contact is hindered by complex erosional incisement by present drainages and by overall poor exposure, except along the larger modern channels.

Tbx **MEGABRECCIA AND SEDIMENTARY BRECCIA (MIDDLE MIOCENE)** -- Shattered landslide blocks (megabreccia) derived from various older rock units, including most of the volcanic members of the tilted Miocene section, Cretaceous intrusions, and Proterozoic metamorphic and intrusive rocks. Volcanic stratigraphy is locally preserved in individual blocks as large as several kilometers long and 100 m

thick. Other areas of megabreccia display interlayering of blocks derived from Precambrian metamorphic units and Tertiary volcanic units. Megabreccia is locally associated with monolithologic and polylithologic sedimentary breccias.

BIG HORN VOLCANICS (LOWER TO MIDDLE MIOCENE)

The Big Horn volcanics include all volcanic units above the crystalline basement and basal clastic unit, but below the fanglomerates, megabreccias, sedimentary breccias, and nearly flat-lying Hot Rock basalt. The Big Horn volcanics, dated at 16 to 21 Ma (J. Spencer, 1985, written communication) are composed of six multiple-flow rhyolite members intercalated with phenocryst-rich basalts, aphyric basalt, andesite flows, tuffs, and volcaniclastic rocks. The volcanics have been subdivided into the following informal members (from youngest to oldest):

(1) Beer Bottle rhyolite member

(2) Moon Anchor volcanic member

(3) Upper aphyric basalt member

(4) Mine Wash andesite member

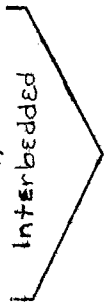
(5) Sugarloaf rhyolite member

(6) Blue Hope rhyolite member

(7) Hummingbird rhyolite member

(8) Old Camp volcanic member

(9) Morningstar rhyolite member



(10) Dead Horse basalt member

The lower four felsic members (numbers 6-9) are interbedded with basalts of the Dead Horse member, and some of the lower rhyolite members may be partly time equivalent. There are minor to major angular unconformities within the section.

Most rhyolite flows are underlain by lithic tuffs that are poorly welded

and contain abundant accessory and accidental lithics. These tuffs do not extend more than a few tens of meters beyond the margins of the overlying rhyolite flows. Some tuffs have low-angle cross-bedding structures and others contain accessory lithics as large as 2 m. Accidental lithics are generally derived from local sources. Most tuffs probably represent phreatic or phreatomagmatic pyroclastic surge deposits.

The rhyolite flows and minor welded tuffs are ridge-and-cliff formers and the more easily eroded basalts and poorly welded tuffs usually form valleys and hummocky terrain. Abundant section-repeating normal faults make estimation of the total thickness of the volcanic section difficult; however, the average thickness of these areally restricted volcanics probably varied from 500 to 700 m. There could have been a maximum of 1,000 to 3,500 meters of Tertiary volcanic rocks in the most complete, northwest-striking, Dead Horse Wash section.

Abundant hypabyssal rhyolite dikes intrude the prevolcanic basement and Big Horn volcanics and commonly have phenocryst assemblages similar to those in the adjacent or overlying volcanics. Some of the dikes contain abundant vesicles in their higher levels and probably represent conduits for the volcanics.

Tbb **BEER BOTTLE RHYOLITE MEMBER** -- Very pale-gray and pale-pink, phenocryst-poor rhyolite flows, flow breccias, and minor tuffs. Phenocrysts (<1 to 5 percent; <2 mm) are biotite, quartz, and opaques. The groundmass exhibits a medium-grained granophyric texture. Incipient argillic alteration, moderate silicification, and fine-grained limonite pseudomorphs after pyrite are present within matrix near the U.S. mine. This member is the top of the section in its outcrop area and overlies Dead Horse volcanics, Old Camp rhyolite, and Sugarloaf rhyolite with a significant angular unconformity.

Some outcrops may be small domes. A sample taken on the west side of the Belmont Mountains yielded a K/Ar feldspar age of 16.4 ± 0.2 Ma. The maximum thickness is about 50 m in the U. S. mine area.

Tbbt LITHIC TUFF -- Light-gray and pale-pink, phenocryst-poor, lithic rhyolite tuff. The tuff underlies the Beer Bottle rhyolite, is 10 to 20 m. thick, and does not persist laterally beyond the limit of the overlying flows.

Tma **MOON ANCHOR VOLCANIC MEMBER** -- Undifferentiated, dark-gray to dark-reddish-brown, moderately to highly vesicular, porphyritic andesite flows and minor phenocryst-poor basalt. The member unconformably overlies Old Camp rhyolite, Dead Horse basalt, and Hummingbird rhyolite, and is the top of Big Horn volcanics section in the southern and west-central map area. The Moon Anchor volcanic member can be locally divided into the following three units, which are in order of decreasing age:

Tma2 PORPHYRITIC ANDESITE FLOWS WITH MAFIC INCLUSIONS -- An undifferentiated series of dark-reddish-brown and dark-gray, moderately vesicular, porphyritic andesite flows that are each less than 30 m thick with nonpersistent basal agglomerates and tuffs, and thin glassy bases. The andesite contains 4 to 10 percent fine-grained mafic inclusions and 12 to 25 percent phenocrysts, including 8 to 12 percent, medium- to fine-grained, disequilibrium plagioclase (1 to 5 mm), 2 to 5 percent biotite, and less than 2 percent each of hornblende and pyroxene. Trace amounts of coarse-grained, cumulophyric inclusions are present in addition to the fine-grained mafic inclusions.

Tma1 PORPHYRITIC, VESICULAR ANDESITE FLOWS WITH PLAGIOCLASE MEGACRYSTS -- Dark-gray, highly porphyritic, vesicular andesite flow that is less than 200 m thick and contains 20 to 30 percent phenocrysts, including 10 to 12

percent embayed plagioclase (3 to 10 mm) with abundant inclusions and reaction coronas, 5 to 8 percent equilibrium plagioclase (0.5 to 2 mm), less then 5 percent pyroxene (1 to 2 mm, small axial angles), and trace amounts of embayed quartz.

Tmab BASALT FLOW -- Dark-gray, fine-grained basalt flow with less than 2 percent altered olivine phenocrysts. Flow is less than 10 m thick.

Tub **UPPER APHYRIC BASALT MEMBER** -- Dark-gray, fine-grained, dense, nearly aphyric basalt that contains rare pyroxene phenocrysts less than 1 mm in diameter and trace amounts of cumulophyric inclusions, which locally contain orthopyroxenes. Very fine-grained, altered olivine and anhedral opaques are present in the groundmass. The basalt has a well-developed spheroidal, weathering pattern.

The principal outcrop of the upper aphyric basalt occurs near a microwave relay station in the southwestern part of the field area. Several other northwest-trending outcrops are interpreted as inverted paleovalleys. An angular unconformity exists between this member and the underlying Dead Horse basalt, Hummingbird rhyolite, and Blue Hope rhyolite. The upper aphyric basalt is overlain by the Moon Anchor volcanics.
A K-Ar whole-rock date on this unit is 16.1 $\pm$ 0.2 Ma. The member is less than 80 m thick.

Tmw **MINE WASH ANDESITE MEMBER** -- Undifferentiated dark- to light-gray and light-yellowish-brown, fine-grained, dense andesite flows, flow breccia, basal vitrophyre, and minor lithic tuffs. The groundmass is composed of interlocking plagioclase laths with as much as 10 percent hornblende crystals as long as 4 mm. Highly embayed quartz crystals are present in trace amounts.

The Mine Wash andesite overlies Dead Horse basalt and

Blue Hope rhyolite along an angular unconformity. The principal outcrops of this member occur in the southwestern part of the field area and form high rounded knobs. The maximum thickness is less than 100 m.

Tmwt LITHIC TUFF -- Undifferentiated lithic tuff conformably underlying the Mine Wash andesite.

Ts **SUGARLOAF RHYOLITE MEMBER** -- Undifferentiated, light-yellowish-brown, pale-pink, and light-brownish-gray, nearly aphyric rhyolite flows, blocky pumice flows, flow breccias, poorly welded, lithic ash-flow tuffs, and nonpersistent, moderately welded tuffs. About one-half of the outcrop area is vitrophyre. Sparse phenocrysts (<1 mm) include embayed plagioclase, biotite, and anhedral opaques. The strongly flow-foliated lavas contain abundant lithophysae, spherulites ($\leq$15 cm), and vesicles. Locally, narrow sinuous vesicles as long as one-half meter contain chalcedonic quartz.

The rhyolite flows are generally accompanied by lithic-rich tuffs that rarely extend beyond the outcrop area of the overlying flows. At least three paired sets, each consisting of a lithic tuff and overlying lava flow, are present in the Dead Horse Wash area, and two of these pairs occur at Sugarloaf Mountain. The tuffs contain abundant accidental and accessory lithics, which are as large as 2 m in diameter, but average 2.5 to 5 cm in diameter. In the northeastern Dead Horse Wash area, these tuffs contain abundant well-rounded, but locally derived lithics of Cretaceous granodiorite. Low-angle cross-bedding structures are locally present.

The Sugarloaf rhyolites are strong ridge-and-cliff formers. This member overlies Dead Horse basalt and Hummingbird rhyolite with slight angular unconformity, and is overlain by Moon Anchor volcanics and Beer Bottle rhyolite. Nonpersistent, unmapped, gray, fine-grained basalt flows less than

one meter thick are intercalated within the lower Sugarloaf rhyolite tuff on Sugarloaf Mountain. The maximum thickness of Sugarloaf rhyolite at Sugarloaf Mountain is about 200 m and the thickness is as great as 650 m in the Dead Horse Wash area.

Tst LITHIC TUFF -- Light-yellowish-brown, light-pink and light-gray, poorly welded, nonpersistent lithic-rhyolite tuff and minor volcaniclastic, poorly indurated, sedimentary rock.

Tb **BLUE HOPE RHYOLITE MEMBER** -- Pale-yellowish-brown, pinkish-white, light- to dark-gray, and pale-greenish-gray, moderately to highly porphyritic rhyolite lava flows, flow breccias, and lithic tuffs. At least one-half of the outcrop area is vitrophyre that is a mottled, very dark gray where unaltered, but pale yellowish-brown and pale greenish-gray where hydrated. This member contains 8 to 25 percent phenocrysts (0.1 to 7 mm), including 6 to 15 percent sanidine, 2 to 10 percent quartz (as large as 5 mm in diameter), a trace to 7 percent hornblende (as long as 7 mm), a trace to 3 percent biotite (1 to 3 mm), and trace amounts of sphene. Some flows contain albite as well as sanidine. Most quartz phenocrysts are subhedral and partially embayed. Feldspar phenocrysts are subhedral to euhedral and contain few inclusions. Spherulites are locally abundant in a vitric groundmass. Flows containing significant hornblende phenocrysts occur near the base, and rhyolite flows with abundant quartz are generally high in the member. Mafic inclusions (Trace to 10 percent) are present in discrete flows and commonly mimic the flow texture of the surrounding rhyolite.

The Blue Hope rhyolite is generally intercalated within Dead Horse basalt, but also directly overlies Cretaceous granodiorite and Hummingbird rhyolite in some areas. The rhyolite is conformably overlain by Dead Horse basalt, but is unconformably overlain by Mine Wash andesite and upper aphyric

basalt. The principal outcrop area is between the Blue Hope mine and Dead Horse Wash. The Blue Hope rhyolite is a ridge-and-cliff former, and is less than 400 m thick. A K-Ar biotite date from a hornblende-bearing flow near the base of the unit is 21.4 $\pm$ 0.3 Ma.

Tb2 FLOWS WITH QUARTZ AS A DOMINANT PHENOCRYST -- Flows dominated by quartz phenocrysts.

Tb1 FLOWS WITH ABUNDANT HORNBLENDE PHENOCRYSTS -- Flows containing significant amounts of hornblende phenocrysts (quartz > hornblende).

Tbt LITHIC TUFF -- Pale-yellowish-brown and pinkish-white, poorly welded tuffs that contain accidental and accessory lithics. The phenocryst assemblage is the same as in the associated rhyolite flows. Most of the tuffs are somewhat altered to clay and zeolite minerals. Tuffs occur throughout the member, but are more abundant at the base.

Th **HUMMINGBIRD RHYOLITE MEMBER** -- Light-gray, pale-greenish-gray, and light-yellowish-brown, porphyritic rhyolite lava flows, flow breccias, blocky pumice flows, and locally abundant lithic tuffs. About one-half of the outcrop area of the Hummingbird rhyolite is pale-greenish-gray, medium-gray, and light-yellowish-brown vitrophyre. The member contains 3 to 20 percent phenocrysts (0.1 to 3 mm diameter), including 2 to 15 percent sanidine, 1 to 8 percent quartz, a trace to 10 percent biotite, a trace to 3 percent hornblende, and a trace of opaques and pyroxenes. Sanidine and quartz phenocrysts are euhedral to subhedral and moderately embayed. Biotite phenocrysts are euhedral and opaques are anhedral to subhedral. Cumulophyric inclusions (Trace to 10 percent) of augite, feldspar, biotite, and opaques are present in many of the flows, especially in lower Hummingbird rhyolite flows within northwesterly striking outcrops between Woodchopper and Dead Horse Washes. Cristobalite

occurs as incipient crystallites within a vitric matrix and spherulites are locally present. One-millimeter-diameter amethystine quartz crystals are present in small cavities in slightly to moderately silicified Hummingbird rhyolite northwest of the Moon Anchor mine, and all of the quartz phenocrysts are amethyst in a Hummingbird rhyolite flow near the head of Blue Wash in the eastern Big Horn Mountains. The lower flow at Hummingbird Springs yielded a K/Ar biotite age of 20.3 $\pm$ 0.2 Ma.

Hummingbird rhyolites are intercalated with Dead Horse basalt; locally, however, they directly overlie Precambrian schist, Cretaceous granodiorite, and Old Camp rhyolite. The member is variably overlain by Dead Horse basalt, Blue Hope rhyolite, Sugarloaf rhyolite, Moon Anchor andesite, and Beer Bottle rhyolite. It forms steep cliffs and ridges, and principally crops out between the Moon Anchor mine and Hummingbird Springs. In its main outcrop area, the member is over 450 m thick, although its base is not exposed.

The Hummingbird rhyolite can be locally divided into seven units. In descending order, these are as follows:

Th3 FLOW-FOLIATED, PHENOCRYST-POOR RHYOLITE FLOWS -- Sanidine- and biotite-bearing, light-gray to light-pink, flow-foliated, platey rhyolite flow with less than 3 percent phenocrysts. Trace amounts of hornblende are locally present.

Th2 PORPHYRITIC, SANIDINE-RICH RHYOLITE FLOWS -- Sanidine-, biotite-, and hornblende-bearing rhyolite flows with 10 to 15 percent phenocrysts (sanidine > biotite + hornblende).

Th2b PORPHYRITIC, BIOTITE-RICH RHYOLITE FLOWS -- Sanidine-, biotite-, and hornblende-bearing rhyolite flows with 10 to 15 percent phenocrysts (biotite > sanidine).

Th2x XENOLITH-BEARING, PORPHYRITIC RHYOLITE FLOWS -- Sanidine-, biotite-, and hornblende-bearing rhyolite flows with 10 to 15 percent phenocrysts (sanidine < biotite + hornblende). These flows contain up to 10 percent cumulophyric xenoliths of augite, feldspar, biotite, and opaques.

Th1 PORPHYRITIC, HORNBLENDE-RICH RHYOLITE FLOWS -- Sanidine-, hornblende-, and biotite-bearing flows with 5 to 8 percent phenocrysts (hornblende + biotite $\geq$sanidine).

Tht LITHIC TUFF-- Pale-yellowish-brown and light-pink, poorly welded, lithic-bearing tuff and associated volcaniclastic sediments. The lithic fragments are accessory and accidental. The phenocryst assemblage is the same as in the associated rhyolite flows.

Thwt PORPHYRITIC WELDED TUFF -- Mottled, light- to dark-gray, dark- to light-brown, and pinkish-gray, vitric-lithic to lithic-vitric, moderately to strongly welded, porphyritic tuff. Phenocrysts are similar to those in Hummingbird rhyolite flows. This unit is less than 6 m thick and is a distinctive ledge-forming marker in the area bordering and southwest of Sugarloaf Mountain.

To **OLD CAMP VOLCANIC MEMBER** -- Medium- to light-gray and reddish-brown, pale-pink, pale-purple, light-yellowish-brown, and brownish-red, moderately vesicular, porphyritic rhyolite, pheno-rhyodacite, and pheno-dacite flows and associated lithic tuffs. The rhyolite flows contain 15 to 20 percent phenocrysts, including 8 to 15 percent plagioclase (1 to 5 mm, commonly 4 to 5 mm), 5 to 12 percent biotite, 1 to 8 percent quartz, a trace to 1 percent clinopyroxene, and a trace to 8 percent hornblende. Some flows contain fine-grained mafic blebs and coarse-grained, basaltic cumulophyric inclusions with clinopyroxene, plagioclase, biotite, and opaques. Nonpersistent, light-

yellowish-brown, hydrated basal vitrophyres less than 15 m thick are associated with the rhyolite flows. Cogenetic lithic tuffs and tuffaceous sediments, 20 to 300 m thick underlie and overlie the flows.

Most of the flows are partially K-metasomatized. About one-third of the groundmass and most of the plagioclase phenocrysts are altered. In hand specimen, the alteration is recognized by a mottled appearance of the groundmass and altered plagioclase cores. Rhyolite flows in the southeastern Old Camp Wash area are least altered. K-metasomatism appears to be the most intense in Old Camp flows, but was noted in other members of the Big Horn volcanics.

The Old Camp volcanics overlie Precambrian schist, Morningstar rhyolite, Dead Horse volcanics, and the basal sandstones, conglomerates and volcaniclastic rocks. This member is intercalated with Dead Horse volcanics, and is overlain with a 20 degree or more angular unconformity by Moon Anchor andesite and Beer Bottle rhyolite. The Old Camp volcanics may be greater than 1,000 m thick in the northeastern Old Camp Wash area, but average 350 to 500 m thick. This member is a strong ridge-and-cliff former. A K-metasomatized sample taken just north of the U.S. mine area yielded a K/Ar biotite age of 19.6 $\pm$ 0.2 Ma.

To2 UNDIFFERENTIATED RHYOLITE AND PHENO-RHYODACITE FLOWS -- See description above.

To2q QUARTZ-RICH RHYOLITE FLOWS -- Light-gray and pale-pink, pheno-rhyolite flows with 12 to 18 percent phenocrysts, which include 6 to 8 percent quartz (2 to 5 mm), 2 to 10 percent plagioclase, and a trace to 2 percent biotite. Subhedral and euhedral quartz phenocrysts are embayed and most of the plagioclase phenocrysts are altered. The groundmass has a

moderately coarse-grained, granophyric texture and contains rare vesicles filled with secondary quartz. This unit overlies tuffs of the Old Camp volcanic member and is overlain by Dead Horse basalt. The principal outcrops are in the southeastern Old Camp Wash area, where the maximum thickness is less than 140 m.

Toᴢh HORNBLENDE-RICH PHENO-RHYODACITE FLOWS -- Light-gray, pale-pink, and light-yellowish-brown pheno-rhyolite flows and associated lithic-crystal tuff with 20 percent phenocrysts 2 to 5 mm in diameter of plagioclase, quartz, hornblende, and biotite (P+Q>B+H,H>B). Maximum thickness of flows and tuff is about 40 m. The unit is principally exposed in the southeastern Old Camp Wash area, where it overlies Dead Horse volcanics.

Toᴢht HORNBLENDE-RICH, CRYSTAL-LITHIC PHENO-RHYODACITE TUFF -- Phenocryst assemblages and the stratigraphic position of this unit are the same as the pheno-rhyodacite flows described above.

Toᴢb BIOTITE-RICH, PHENO-RHYODACITE FLOWS -- Medium-gray to light-gray and pale-pink, highly porphyritic, biotite-bearing, pheno-rhyodacite flow. This unit contains 12 to 20 percent phenocrysts, of which 8 to 12 percent are biotite (1 to 2 mm), 3 to 7 percent are plagioclase (3 to 4 mm), and the remainder consists of trace amounts of quartz, hornblende, and pyroxene. This unit conformably overlies Dead Horse volcanics and Morningstar rhyolite and primarily occurs southwest of Adobe Well. The maximum thickness is about 30 m.

Toᴢbt BIOTITE-RICH, LITHIC-CRYSTAL AND LITHIC PHENO-RHYODACITE TUFF -- Occurs with and contains the same phenocryst assemblage as the biotite-bearing lava flows described above.

Tol PHENO-RHYODACITE AND PHENO-DACITE FLOWS -- Dark-reddish-brown, fine-grained, porphyritic, xenolithic, and moderately vesicular flow. Unit is flow foliated and contains 20 percent plagioclase phenocrysts that are as large as 2 mm and are altered to clay minerals and sericite. The unit also contains 1 percent anhedral opaques and a trace biotite in the devitrified groundmass. Some secondary calcite is also present. Mafic inclusions contain fine-grained plagioclase laths and opaques. The principal outcrop area is in the extreme southeastern Old Camp Wash area. This unit conformably overlies Dead Horse basalt and Morningstar rhyolite and is less than 150 m thick.

Tot LITHIC TUFF AND TUFFACEOUS SEDIMENTARY ROCKS-- Dark- to light-reddish-brown, light-gray, light-pink, and light-yellowish-brown, moderately to poorly welded, lithic-bearing, ash-flow tuffs and tuffaceous sedimentary rocks. The principal phenocrysts are plagioclase, biotite, and quartz. Lithics in the tuffs are largely derived from previous Old Camp rhyolite flows, except in the Dead Horse Wash section where basalt and Precambrian lithics are also common. In the southeastern Old Camp Wash area, the tuff contains lithic fragments as large as 0.5 m and locally fragments of Morningstar rhyolite. The tuffs underlie and overlie discrete rhyolite lava flows and are as thick as 300 to 400 m in the southeastern Old Camp Wash area. Tuffaceous sedimentary rocks intercalated with these tuffs show normal graded and cross bedding. These tuffs are probably phreatomagmatic and phreatic pyroclastic surge, and minor air-fall deposits.

Tms **MORNINGSTAR RHYOLITE MEMBER** -- Pink, pale-yellowish-brown, dense, strongly flow-foliated, phenocryst-poor, rhyolite lava flows, minor flow breccias, and local, poorly welded, ash-flow tuffs. Rhyolite contains less than 2 percent

phenocrysts of biotite, quartz, moderately to strongly altered plagioclase (1 to 3mm diameter), and anhedral opaques in a fine- to medium-grained, granophyric groundmass. Secondary quartz and light-green fluorite fill locally abundant fractures. This member is a ledge-and-ridge former and it is the lowest rhyolite flow of the Big Horn volcanics. The principal outcrop area is about 3.3 km southwest of the western Belmont Mountains. The rhyolite variably overlies Dead Horse volcanics and Precambrian schists and is overlain by Dead Horse volcanics and the Old Camp volcanic member. The maximum thickness is about 140 m.

Tmst LITHIC TUFF -- Light-gray, white, and pink, lithic-bearing rhyolite tuffs that underlie the Morningstar rhyolite flows.

Td **DEAD HORSE VOLCANIC MEMBER** -- Undifferentiated, dark-gray and reddish-brown, vesicular to massive, porphyritic basalt flows and flow breccias interbedded with minor andesite flows, welded and nonwelded tuffs, and arkosic and volcaniclastic sandstones and conglomerates. The basalts contain 5 to 20 percent phenocrysts, including 2 to 10 percent olivine, 2 to 15 percent clinopyroxene (dominantly augite), 2 to 5 percent megacrystic plagioclase (An-68), and less than 3 percent orthopyroxene. Opaques and fine-grained olivine are abundant in a matrix of parallel plagioclase laths. Cumulophyric inclusions contain megacrysts of olivine, clinopyroxene, biotite, and plagioclase.

In outcrop, the tuffs form thin ridges and ledges, whereas the basalts form small hummocky hills. The lowest contact is with basal Tertiary sedimentary rocks and Precambrian metamorphic and Cretaceous intrusive rocks. The basalts are interbedded with the lower rhyolite flow members, but not the Sugarloaf and Beer Bottle rhyolites, and have a cumulative thickness of 300 to

1,400 m near Dead Horse Wash.

Td3 QUARTZ-RICH TUFF AND SEDIMENTARY ROCK -- Light-yellowish-brown and light-pink, poorly welded tuffs, minor sandstone, conglomeratic sandstone, and conglomerate. The tuffs contain abundant quartz and lesser amounts of feldspar phenocrysts, whereas the clastic rocks locally contain abundant fragments of Cretaceous granodiorite. This unit is 6 to 30 m thick and conformably overlies Old Camp rhyolite in the Dead Horse Wash section.

Td2 WELDED TUFF -- Moderately to strongly welded, light-pink, light-yellowish-brown, crystal-rich, ash-flow tuff. The tuff contains 8 to 15 percent phenocrysts of subhedral and euhedral quartz, feldspar, and biotite, and 5 to 10 percent lithic fragments, most of which are basalt. This unit is 1 to 3 m thick, and the principal outcrops are in the southeastern Dead Horse Wash area. Dead Horse basalt conformably overlies and underlies this tuff.

Td1 PORPHYRITIC ANDESITE -- Pale- to light-red, porphyritic, moderately to highly vesicular andesite. Plagioclase (2 to 6 mm, 8 to 12 percent), clinopyroxene (< 3 mm, 2 to 5 percent), and biotite are the principal phenocrysts. The unit is 3 to 30 m thick and occurs in the south-central portion of the Big Horn Mountains of the western map area. The andesite is underlain and overlain by clinopyroxene-rich Dead Horse basalt, and occurs below, but is not in depositional contact with, Hummingbird rhyolite.

Td+ NONWELDED LITHIC TUFF AND VOLCANICLASTIC SANDSTONE AND CONGLOMERATE -- Undifferentiated, light-purple, pale-pink, and light-yellowish-brown, poorly welded to nonwelded, pumiceous tuffs and poorly indurated,

volcaniclastic, coarse sandstone and conglomerate. The lithic tuffs contain felsic pumice and locally abundant, scoriaceous basalt fragments, and are moderately to strongly altered to zeolites and clay minerals. Some of the sediments show normal graded bedding. These rocks are typically interbedded with Dead Horse basalt; locally, however, they directly overlie Precambrian and Cretaceous basement rocks. The felsic tuffaceous component of this unit might be correlative with early eruptions associated with Old Camp or Morningstar rhyolite members. A maximum of 60 m of this unit is in the Dead Horse Wash section.

Tds **VOLCANICLASTIC SANDSTONE AND CONGLOMERATE** -- Light-yellowish-brown and light-pink, immature, poorly sorted, coarse volcaniclastic sandstones and conglomerates with some normal graded bedding. These sediments are moderately to strongly altered to zeolites and clay minerals. A maximum of 30 m of this unit is in the Dead Horse Wash stratigraphic section.

LOWER TO MIDDLE MIOCENE INTRUSIVE ROCKS CONTEMPORANEOUS WITH THE BIG HORN VOLCANICS

Tbg **BELMONT GRANITE** -- Light-colored, generally medium-grained, homogranular granite that forms bold, rounded outcrops with only minor soil cover. Granite is generally leucocratic (<1 percent biotite and magnetite) and contains approximately 40 percent quartz (1 to 4 mm), locally as discrete eyes. The granite is composed of the following phases: (1) medium-grained, equigranular granite that contains a trace biotite or magnetite; (2) fine- to medium-grained, leucocratic granite with abundant miarolitic cavities rimmed by terminated crystals of quartz, orthoclase, epidote, muscovite, and purple fluorite; and (3) fine-grained, leucocratic granite with scattered quartz phenocrysts and miarolitic cavities.

Tbg* SPHENE-BEARING GRANITE -- Medium-grained Belmont granite with 1 to 3 percent biotite and magnetite and a trace of visible sphene.

Ti **UNDIFFERENTIATED RHYOLITE INTRUSIONS** -- See accompanying descriptions.

Tia **APHYRIC RHYOLITE INTRUSIONS** -- Light-pink and light-gray, fine-grained rhyolite intrusions with rare quartz or feldspar phenocrysts.

Tiq **QUARTZ-RICH RHYOLITE INTRUSIONS** -- Light-gray, light-yellowish-brown, and light-pink, fine-grained rhyolite dikes. These dikes contain as much as 12 percent phenocrysts of sanidine, quartz, and hornblende, and lesser amounts of biotite, opaques, and accessory minerals. Some of these dikes contain 5 percent very fine-grained, locally irregular, mafic inclusions. In thin section, the dikes have a moderate- to coarse-grained granophyric texture. Some dikes near northwestern Old Camp Wash have a very fine-grained groundmass and contain plagioclase crystals (1 cm) with 0.25-cm reaction coronas. Several dikes in the Blue Hope mine area contain abundant vesicles in their upper portions and appear to grade into highly vesicular breccias. The nearby Miocene Blue Hope and Hummingbird rhyolites contain phenocryst assemblages nearly identical to those in these dikes. Some of the dikes may represent conduits for the nearby rhyolite flows. These dikes are most abundant in the Cretaceous granodiorite near the Blue Hope mine; however, some also intrude Proterozoic metamorphic rocks throughout the range as well as stratigraphically low Big Horn volcanics. Many of these dikes are K-metasomatized. Some are intensely brecciated within the structures that they intruded.

Tif **FELDSPAR-RICH RHYOLITE INTRUSIONS** -- Fine-grained rhyolitic dikes with feldspar phenocrysts (3 to 15 percent; 1 to 20 mm) and less abundant quartz

phenocrysts. Matrix of the dikes varies from fresh and aphanitic to extensively devitrified.

Tim **MAFIC AND INTERMEDIATE INTRUSIONS** -- Aphanitic to medium-grained basaltic, andesitic, and dioritic dikes that generally are extensively weathered and poorly exposed, except in mine workings and stream banks.

+++++++ **UNDIFFERENTIATED FELSIC INTRUSIONS** -- Aphanitic to medium-grained felsic intrusions, including cream-colored, aphanitic felsite, feldspar- and quartz-phenocryst-bearing, locally devitrified rhyolite, and fine- to medium-grained quartz porphyry and granite associated with the Belmont granite.

\-\-\- **UNDIFFERENTIATED INTERMEDIATE INTRUSIONS** -- Aphanitic to medium-grained intrusions of probable rhyodacitic to andesitic composition.

***** **UNDIFFERENTIATED MAFIC INTRUSIONS** -- Dark-colored intrusions of aphanitic basalt and fine- to medium-grained diorite.

UNITS OLDER THAN THE BIG HORN VOLCANICS

Tc **BASAL SANDSTONE AND CONGLOMERATE (OLIGOCENE TO LOWER MIOCENE (?)** -- Reddish-brown to greenish-gray coarse sandstone, conglomerate, and laharic breccia. Clasts are of Precambrian metamorphic and intrusive rocks, Cretaceous intrusive rocks, and rare basalt. These clastic rocks are typically less than 1 thick, but are locally 30 m thick in the Dead Horse Wash area. They are poorly indurated and nonconformably overlie Precambrian metamorphic and Cretaceous intrusive rocks and are overlain by Dead Horse basalts and basaltic sediments.

Ka **APLITIC DIKES (UPPER CRETACEOUS (?)** -- Light-colored, fine-grained, equigranular aplitic dikes commonly associated with Cretaceous granodiorite.

Kg **GRANODIORITE AND GRANITE (UPPER CRETACEOUS)** -- Light- to moderate-gray, coarse- to medium-grained granodiorite and granite averaging approximately 30 percent myrmekitic plagioclase, 30 percent potassium feldspar, 5 to 12 percent biotite, greater than 10 percent quartz, and trace amounts of sphene, euhedral and anhedral opaques, and other accessory minerals. Some more granodioritic border phases contain more sphene than the bulk of these intrusions. Small amounts of biotite-rich xenoliths are locally present. Numerous irregular apophyses of this intrusion project into the Proterozoic metamorphic rocks. A sample of granodiorite from the Dead Horse Wash area was dated at 70.8 $\pm$ 0.5 Ma.

XTgg **GARNET-BEARING GRANITE (LOWER PROTEROZOIC OR CRETACEOUS TO LOWER TERTIARY)** -- Medium-grained, garnet-bearing, leucocratic granite locally associated with pegmatites.

~~QQQQ~~ **SPECULAR-HEMATITE-BEARING QUARTZ VEIN (PROTEROZOIC (?)** -- White, massive quartz veins occur in Proterozoic phyllite about 1.5 km north of the Moon Anchor mine. Specular hematite crystals as large as 1 mm diameter occur in moderately abundant, small, irregular vugs. These veins are typically less than 30 cm wide.

Xgb **GABBROIC INTRUSION (LOWER PROTEROZOIC (?))** -- Dark-greenish-gray gabbroic intrusion with abundant 0.5 to 2 cm pyroxene phenocrysts with lesser amounts of opaques and feldspar. Very thin quartz veins fill fractures within the intrusion, which is 60 by 120 meters in area. This unit is emplaced into Proterozoic gneisses and schists in the Dead Horse wash area.

Xg **GRANITE (LOWER PROTEROZOIC)** -- Medium- to coarse-grained, equigranular granite with several percent biotite. The granite occurs in the southern Belmont

Mountains.

Xs **SCHIST AND PHYLLITE (LOWER PROTEROZOIC)** -- Fine-grained schist and phyllite characterized by a well-developed, northeast-striking, steep foliation-schistosity-cleavage and grayish, muted colors. Unit is commonly monotonous in lithology over small areas, but displays significant lithologic variation over large outcrop areas. Unit includes gray to greenish- or purplish-gray, quartz-feldspar-muscovite-chlorite-epidote schist; greenish-gray, plagioclase-chlorite schist; greenish-gray and brown calc-silicate; and less abundant ferruginous-quartzite layers less than several meters thick. Unit represents metamorphosed silicic to intermediate volcanic rocks, volcaniclastic units, quartzose-feldspathic-lithic sandstones, pelitic rocks, and ferruginous cherts.

Xm **GNEISS (LOWER PROTEROZOIC)** -- Compositionally, banded quartz-feldspar-biotite gneiss, commonly associated with foliated granite, granitic gneiss, schist, and amphibolite.

Xa **AMPHIBOLITE (LOWER PROTEROZOIC)** -- Dark-green and greenish-gray to nearly black, massive amphibolite and associated greenish quartz-epidote layers. Unit is generally less foliated than adjacent schist, phyllite, and gneiss.

REFERENCES CITED

Allen, G. B., in preparation, Economic geology of the Big Horn Mountains west central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report.

Rehrig, W. A., Shafiqullah, Muhammed, and Damon, P. E., 1980, Geochronology, geology, and listric normal faulting of the Vulture Mountains, Maricopa

County, Arizona, in Jenney, J. P., and Stone, Claudia, eds., Studies in western Arizona: Arizona Geological Society Digest, v. 12, p. 89-110.

Reynolds, S. J., Scott, E. A., and O'Haire, R. T., 1985, A fluorite-bearing granite, Belmont Mountains, central Arizona: Arizona Bureau of Geology and Mineral Technology Fieldnotes, v. 15, no. 2, p. 3-5.

Scarborough, R. B., and Wilt, J. C., 1979, A study of uranium favorability of Cenozoic sedimentary rocks, Basin and Range Province, Arizona - part I, General geology and chronology of pre-late Miocene Cenozoic sedimentary rocks: Arizona Bureau of Geology and Mineral Technology Open-File Report 79-1, 101 p.

Shafiqullah, Muhammed, Damon, P. E., Lynch, D. J., Reynolds, S. J., Rehrig, W. A., and Raymond, R. H., 1980, K-Ar geochronology and geologic history of southwestern Arizona and adjacent areas, in Jenney, J. P., and Stone, Claudia, eds., Studies in western Arizona: Arizona Geological Society Digest, v. 12, p. 201-260.