Geologic Map of the Phoenix Mountains, Central Arizona

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Introduction

The Phoenix Mountains, located within the Phoenix metropolitan area of central Arizona, are a northwest-trending, uplifted fault block that extends for about 13 km (8 miles) from Moon Hill in the northwest to Camelback Mountain in the southeast (Fig. 1). The area includes a main range, with 420 m (1,378 ft) of local relief, as well as several isolated peaks. The geologic mapping for this study covers the main part of the range, including (from northwest to southeast) Moon Hill, Shaw Butte, North Mountain, Stoney Mountain, Dreamy Draw, Squaw Peak, and the informally named Quartzite Ridge.

The main goals of this study were to document the bedrock geology, reconstruct the geologic history, and produce a 1:24,000 geologic map of the range. The area contains a remarkable stratigraphic sequence that records the formation of continental crust in the region as it evolved from an oceanic setting to a more continental setting. The rocks have been cleaved and steeply tilted, providing a well-exposed traverse through this exceptional sequence. The range also contains spectacular Proterozoic (Precambrian) structures, which document the extreme deformation that affected the crust soon after it had formed.

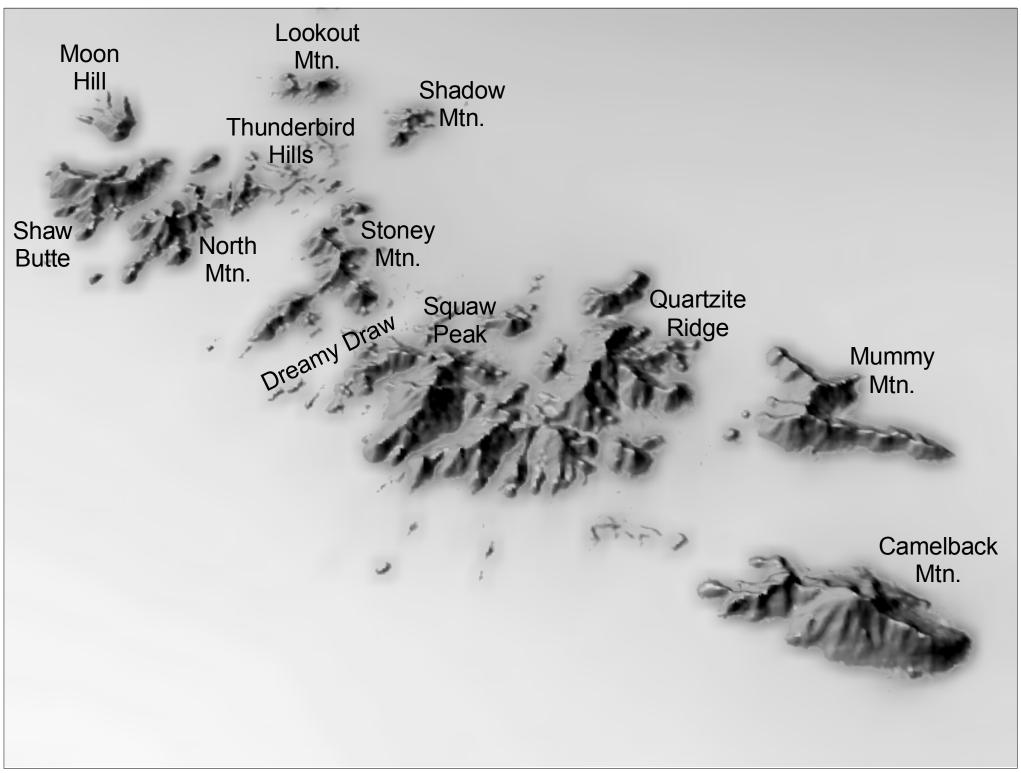

Figure 1. Three-dimensional perspective of the Phoenix Mountains, looking north.

Prior to this study, there was no comprehensive view of the geology of the range. Early studies in the Phoenix Mountains were mainly concerned with water resources and the scattered mines and prospects (Lee, 1905; Schrader, 1918; and other references cited in Johnson, 2000). Wilson et al. (1957) produced a 1:375,000 geologic map of Maricopa County. Several master's theses focused on aspects of the range (Aylor, 1973; Shank, 1973; Cordy, 1978; Thorpe, 1980;

Thorpe and Burt, 1978, 1980). The Proterozoic geology of the Phoenix Mountains has been studied in reconnaissance as part of several regional works (Anderson, 1989a, b; Karlstrom et al., 1990; Reynolds and DeWitt, 1991; Reynolds and Grubensky, 1993).

Mapping for the present study was carried out in 1995-1996 (D.A. Jones and S.J. Reynolds) and 1999-2002 (J.K. Johnson and S.J. Reynolds), utilizing 1:12,000-scale enlargements of the Paradise Valley and Sunnyslope U.S. Geological Survey 7.5-minute quadrangles as a topographic base. Geologic mapping in the Squaw Peak area is from D. Jones (1996), whose mapping covered the area between the Squaw Peak Parkway and the first large ridge of quartzite east of Squaw Peak. The rest of the range was mapped by J. Johnson and S. Reynolds. The geologic map was compiled by Johnson and Reynolds, and an early version was included in the thesis by Johnson (2000).

Geologic Overview

The geology of the Phoenix Mountains is dominated by Proterozoic low-grade metamorphic rocks that display a northeast-striking, steeply southeast-dipping cleavage. A 12-km-thick sequence of Precambrian metamorphic rocks is exposed in the Phoenix Mountains, but internal strain and duplication of beds by faulting and folding have obscured the original thickness; most units have been thinned by the deformation. Two distinct Proterozoic sequences are preserved, separated by the north-northeast-trending Squaw Peak structure in the center of the range.

West of the structure is a 7-km-thick, nonrepeated sequence of greenstones, felsic volcanics, ferruginous quartzite, and metasedimentary rocks that become younger toward the southeast. The oldest unit in this sequence is the North Mountain Greenstone exposed near Shaw Butte and North Mountain. The greenstone is intruded to the west by the Proterozoic Shaw Butte Granodiorite. To the east is a north-trending belt of felsic volcanic and volcaniclastic rocks that straddle 7th Street. Further east are more greenstones, a sequence of interbedded phyllite and rhyolitic tuff along Cave Creek Road, and a cover of basalt and Tertiary conglomerate. Stoney Mountain to the southeast exposes a thick package of Stoney Mountain Greenstone, which contains interbeds of ferruginous quartzite and graywacke. Upsection to the southeast, near Dreamy Draw, the greenstone is overlain by southeast-dipping, metasedimentary phyllite, volcaniclastic rocks, and local quartzite. The progression toward more mature rocks continues southeast of Dreamy Draw, where the phyllite is overlain by conglomeratic quartzite and quartzite. In this area, the sequence is folded around the isoclinal, steeply plunging Dreamy Draw syncline; the units reappear, but are overturned, on the eastern limb of the syncline. The eastern limb is truncated by the north-northeast-trending Squaw Peak structure, which is somewhat enigmatic because it is a fault near Squaw Peak (Jones, 1996), but elsewhere is a shear zone or a foliated contact juxtaposing dissimilar rock types or sequences with opposite facing directions.

East of the Squaw Peak structure are several kilometers of quartzite, phyllite, and rhyolite, repeated by several large folds. The oldest parts of this sequence are in the eastern part of the range and consist of interbedded quartzite, phyllite, volcaniclastic rocks, and metarhyolite. Facing directions in the quartzites are to the southeast in exposures east of 32nd Street and to the northwest from 32nd Street west to Squaw Peak. We conclude that a large, isoclinal fold (32nd Street fold) separates the outward-facing sections and repeats several thin metarhyolites within the phyllites. Another large isoclinal fold, the steeply plunging Squaw Peak syncline, causes altered metarhyolite at Squaw Peak to wrap around a core of younger quartzite (Jones, 1996). The west limb of this syncline is truncated by the Squaw Peak structure. Some boundaries between quartzite and phyllite just east of Squaw Peak are probably in part shear zones because they truncate folded bedding in the quartzites.

The Proterozoic rocks nearly everywhere display a well-developed slaty cleavage or schistosity that generally strikes northeast and dips steeply or moderately to the southeast. This planar fabric is defined by the preferred orientation of mica grains, segregated felsic and mafic minerals, and flattened crystals and clasts. It is best developed in fine-grained metavolcanic and metasedimentary rocks, but is less developed in quartzites and coarse greenstones. A southeast-plunging, down-dip lineation is defined by the long axes of stretched clasts and phenocrysts. Associated with the cleavage are countless small folds and several large, steeply plunging isoclinal folds. The Shaw Butte Granodiorite is cut by ductile shear zones that are parallel to cleavage in the adjacent metavolcanic rocks. Deformation in the range was accompanied by low-grade, greenschist-facies metamorphism. Small post-metamorphic faults, most of which trend east-west, typically offset units tens of meters.

Primary bedding in the Proterozoic rocks is expressed by lithologic contacts, compositional variations, dark mineral laminations, graded bedding, and cross-bed sets. Facing directions shown on the map are largely based on cross beds and rare graded bedding and scour features. Bedding is generally parallel to the northeast-striking cleavage, except in the hinges of folds where bedding cuts across cleavage at a high angle.

Tertiary rocks in the Phoenix Mountains include conglomerates and gently tilted basalt flows and basalt breccias exposed in the northern and western parts of the range. These overlie the Proterozoic rocks along an angular unconformity. Basin-fill sediments that postdate some or perhaps all of the basalts form low, rounded hills along the north flank of the range. The youngest map units are relatively flat-lying Quaternary surficial deposits that surround the range and were deposited unconformably over all rock types in the area.

Area Summaries

Introduction: The mapped area can be divided into 10 subareas, based on physiography and geology. Each area is described briefly below, more or less from the northwest to the southeast (Figure 1).

Moon Hill: This small hill in the northwestern part of the range is composed entirely of flat-lying to gently northeast-tilted Tertiary basalt flows, flanked by talus.

Lookout Mountain: Lookout Mountain is the northernmost peak in the range. It consists of an older Tertiary basalt flow, successively overlain by Tertiary sediments and a younger Tertiary basalt flow and basalt breccia. The lower basalt has been estimated to be approximately 20 Ma (Leighty, 1997).

Shaw Butte: Shaw Butte, located in the northwestern end of the range, consists of Proterozoic granodiorite and tonalite (Shaw Butte Granodiorite) overlain by two basalt flows similar to those at Moon Hill. An older basalt has been dated at approximately 20 Ma, whereas the younger basalt caps the butte and has been estimated to be 13 Ma to 16 Ma (Leighty, 1997).

The east side of the Shaw Butte Granodiorite intrudes Proterozoic greenstone and has a complex suite of fine-grained to porphyritic granodiorite, interpreted to be a chilled border phase of the main pluton. If the pluton has been tilted along with the rest of the Proterozoic rocks in the range, then the fine-grained phase could represent the original top of the pluton. The granodiorite contains numerous shear zones and is locally well foliated.

North Mountain and 7th Street Area: Greenstone and felsic metavolcanics dominate North Mountain and the 7th Street area. The greenstones are intermediate to mafic in composition and have both a finely crystalline and coarsely crystalline component, probably representing extrusive and intrusive protoliths. The coarser phase of the greenstone is to the west, in the lower, perhaps the originally deeper, parts of the sequence. At North Mountain, the cleavage bends from vertical at the base of the hill to moderately west-dipping at the crest. A belt of metamorphosed rhyolite tuff and felsic volcaniclastic rocks trends northward along both sides of 7th Street.

Thunderbird Hills: The low-relief hills near Thunderbird Road and 7th Street are composed of Tertiary sediments that unconformably overlie greenstone on the west and Tertiary basalt on the east. The sediments are weakly consolidated and contain clasts of basalt, crystalline rock, greenstone, fine-grained quartzite, ferruginous quartzite, and metarhyolite. Southeast of these Tertiary sediments is ferruginous quartzite overlain by a sequence of very fine-grained metasiltstone and metarhyolite.

Shadow Mountain: Rocks at Shadow Mountain cannot be correlated with rock units in the rest of the range. Most of Shadow Mountain is a sequence of metamorphosed volcanic, volcaniclastic, and sedimentary rocks interbedded with metamorphosed flow-banded rhyolite and tuff. Exposed at the tip of the northwest ridge is an unusual massive quartzite containing quartz-kyanite-andalusite rock.

Stoney Mountain: Stoney Mountain is mostly composed of an intermediate-composition greenstone intermixed with abundant ferruginous quartzite, graywacke, phyllite, and a few tuffaceous units, all of which contain carbonate in varying amounts. The greenstone varies from fine to medium grained, with the finer parts originally being intermediate to mafic volcanics and the coarser parts probably being gabbroic to dioritic intrusions. The ferruginous quartzite has abundant chert clasts and numerous small, but well-developed, steeply plunging folds, especially in the southern Stoney Mountain area.

Dreamy Draw Area: The Dreamy Draw area straddles the Squaw Peak Parkway. It is composed mostly of gray and tan phyllite, but also includes a lens of orthoquartzite. This area represents the transition from a more oceanic setting down section to a more continental setting up section, as greenstones and ferruginous quartzite pass upward into continental quartzite. The section is repeated by the steep-plunging Dreamy Draw syncline.

Squaw Peak: Squaw Peak is the highest peak in the range, with an elevation of 782 m (2608 ft.). West of Squaw Peak is a large, northeast-striking reverse fault or shear zone, the Squaw Peak structure, across which units cannot be correlated. To the north and northwest are greenstone, greenschist, phyllite, and conglomeratic quartzite, whereas east of the structure are more continental units, including cross-bedded quartzite, metarhyolite, and metamorphosed tuff breccia. The large, northeast-plunging Squaw Peak syncline folds the quartzite and metarhyolite east of the structure near Squaw Peak.

Quartzite Ridge: Quartzite Ridge extends east of Squaw Peak to Tatum Boulevard. The most prevalent rock types are cross-bedded quartzite, phyllite, foliated and nonfoliated greenstone, and discontinuous metarhyolite, which are repeated by several large- and small-scale folds. The largest fold is a nearly isoclinal fold, probably a north-plunging anticline near 32nd Street, that separates opposite-facing sequence of quartzite, phyllite, and discontinuous metarhyolites.

Correlation of Proterozoic Rock Units

Proterozoic rocks cannot be correlated, unit for unit, across the Squaw Peak structure, but relative ages can be inferred from facing directions, overall stratigraphic trends, and correlations to regional units. The oldest Proterozoic rocks are exposed in the northwest, including the North Mountain and Stoney Mountain areas. These units are interpreted to represent submarine volcanics, volcanic-related sediments, and local intrusions related to the volcanic rocks. Ferruginous quartzites are interpreted to represent silica deposited by submarine hot springs. The entire assemblage of these oldest rocks is oceanic in character.

Phyllites and quartzites of the Dreamy Draw area overlie the greenstones and are clearly younger. They mark a change from oceanic settings to more continental ones dominated by quartzose and volcaniclastic sediments deposited in shallower water or on land. Quartzites and phyllites of Quartzite Ridge are similar to these units, but the stratigraphies do not match in detail; nevertheless, the two sequences are probably similar in age. Metarhyolite and quartzite at Squaw Peak are the youngest Proterozoic units, except for diabase, some thin intrusive greenstones scattered across the range, and perhaps the Shaw Butte Granodiorite. The stratigraphic position of rocks at Shadow Mountain is unknown.

Regional correlation of rock units in the Phoenix Mountains has not been well established because of a lack of geochronologic data, but the overall sequence clearly correlates with rocks of the 1.7 b.y. Mazatzal Province (Anderson, 1989b; Karlstrom and Bowring, 1991). The Mazatzal Province contains four main rock units: Union Hills Group, Alder Group, Red Rock Group, and Mazatzal Group (Anderson, 1989; Conway and Silver, 1989).

The Phoenix Mountains contain similar lithologies and a similar stratigraphy to the four groups in the Mazatzal Province. The oldest unit is the North Mountain Greenstone, which we correlate to basaltic andesite to dacitic volcanics of the Union Hills Group (Anderson, 1989b). Overlying greenstones, ferruginous quartzite, felsic tuffs, and volcaniclastic rocks exposed between North Mountain and Dreamy Draw could correlate with intermediate volcanics, graywacke, and felsic volcanics of the upper Union Hills Group. Younger phyllites and quartzites of the Dreamy Draw and Quartzite Ridge areas are correlative with the Alder Group, which is characterized by purple slates, impure quartzite, siltstone, graywacke, ferruginous quartzite, volcaniclastic strata, and felsic volcanic rocks (Anderson, 1989b; Conway and Silver, 1989). Metarhyolite and overlying quartzite at Squaw Peak have been correlated with the Red Rock and Mazatzal Groups (Karlstrom et al., 1990), respectively, and these correlations are reasonable but uncertain.

Geologic History of the Phoenix Mountains and Vicinity

The depositional history of the Phoenix Mountains began during the Early Proterozoic, more than 1700 million years ago. During this time the area was a submarine volcanic environment, located at the southern edge of the North American continent (Anderson, 1989a; Hoffman, 1989; Wooden and DeWitt, 1991; Karlstrom and Bowring, 1991; Condie, 1992). Intense volcanic activity on the ocean floor, perhaps in an andesitic arc along the edge of the continent, contributed a thick sequence of intermediate material to the basin as well as iron-rich chert beds formed by submarine hot springs (all part of the Union Hills Group). Gradually, the ocean basin filled with volcanic material to such a degree that the deep ocean environment changed to a more shallow-marine setting, receiving mud, silt, and sand. This shallow marine environment evolved into near-shore environments that accumulated additional mudstone and sandstone in a shallow, shifting sea or a floodplain or a delta (Alder Group). Large volcanic eruptions interspersed volcanic material with the sediments and became more felsic with time, culminating in the rhyolites east of the Squaw Peak structure (Red Rock Group). The rhyolites were overrun by quartzose and arkosic sandstone and conglomerate of the Mazatzal Group. The Shaw Butte Granodiorite was probably intruded sometime near the end of this depositional sequence, but prior to any deformation; it may predate some of the higher units.

About 1650 Ma, these rocks were subjected to regional northwest-directed crustal shortening during the Mazatzal orogeny (Anderson, 1989b; Karlstrom and Bowring, 1991), which produced the northeast-striking cleavage, folds, and shear zones. This shorting was presumably accompanied by crustal thickening, which should have caused tectonic burial of some rocks and uplift of the region. Greenschist-facies metamorphism occurred during deformation and requires that at least 5 to 10 km of additional material was either deposited on top of these units or was placed over the top tectonically and subsequently eroded off.

Late Proterozoic time is represented by sparse diabase dikes, but Paleozoic and Mesozoic histories are not recorded in the rocks or structures of the Phoenix Mountains. Paleozoic and Mesozoic rocks, similar to those preserved in northern Arizona, are thought to have been deposited in the Phoenix area, but were eroded prior to the mid-Tertiary. There are no obvious manifestations of the Late Cretaceous to early Tertiary Laramide orogeny in the range, but the orogeny probably further uplifted Proterozoic rocks in the region and stripped off any remaining Paleozoic and Mesozoic sediments.

After the Paleozoic and Mesozoic rock sequence was removed, the Proterozoic rocks were covered with mid-Tertiary sediments and mafic volcanic material. Miocene volcanism in the Phoenix Mountains is distinctive in that it lacks the 15 Ma to 20 Ma ash flows and other silicic volcanic units found throughout much of central and southern Arizona. Only basaltic material was erupted in the Phoenix Mountains during the mid-Tertiary, and the Proterozoic rocks had to be exhumed by at least 20 Ma, prior to eruption of the basalts. There is no record whether older mid-Tertiary rocks, such as the red beds at Camelback Mountain, were deposited on the Phoenix Mountains and eroded away prior to deposition of the basalts. Johnson (2000) recognized that an unexposed fault, probably of mid-Tertiary age, separates the Phoenix Mountains from the red beds of Camelback Mountain.

During the Late Tertiary Basin and Range disturbance, basins on either side of the Phoenix Mountains were down dropped thousands of meters along north- to northwest-trending faults relative to the range. Except for gentle tilting of basalts in the northwest part of the range, the Phoenix Mountains do not seem to have been tilted significantly by either the mid-Tertiary event or the Basin and Range disturbance. During and after the Basin and Range faulting, erosion carved into the range, depositing sediment into the flanking basins. The youngest such deposits form alluvial fans, channels, and terraces that range in age from Pleistocene to Holocene (Demsey, 1988).

Map Units

The Phoenix Mountains are composed of a complex terrain of Proterozoic metamorphic and granitic rocks, with an overall stratigraphic progression from the oldest rocks in the northwest to youngest rocks in the southeast. The rocks occur in three distinct stratigraphic sequences: rocks east of the Squaw Peak structure, rocks west of the Squaw Peak structure, and rocks at Shadow Mountain. Tertiary volcanic and sedimentary units are preserved along the north flank of the range, and Quaternary deposits form an apron around the bedrock.

The descriptions below are extracted largely from more detailed ones in Johnson (2000) and Jones (1996). We adopt the informal stratigraphic names proposed by Johnson (2000).

Quaternary and Tertiary Units

Qal – Alluvium: undifferentiated Quaternary alluvium largely covered by development but consisting of three main units: (1) older well-consolidated and caliche-cemented gravels in the low hills of Dreamy Draw; poorly sorted with locally derived clasts; (2) widespread, unconsolidated, poorly sorted sand and angular alluvium in low areas just above modern drainages; moderate caliche development and desert pavement; and (3) young alluvium of unconsolidated gravels, sand, silt, and clay in modern drainages and channels.

Qt – Talus: aprons of coarse talus covering slopes, especially those around outcrops of quartzite and basalt; clasts derived from local bedrock; cobble sized near phyllite and angular boulders on basalt and quartzite slopes.

Tsy – Conglomerate (~50 m): basin-fill conglomerate with subrounded to subangular cobbles and boulders in a gray to tan matrix of poorly sorted and weakly consolidated silt, sand, and gravel; moderately developed caliche; clasts mostly reddish, gray, and black basalt, with crystalline rocks, greenstone, fine-grained metavolcanics, fine-grained purple quartzite, and a minor amount of ferruginous quartzite; includes clasts up to 2 m of coarse, porphyritic granite. Unit is interpreted to represent deposits in streams and alluvial fans, including large floods or debris flows. Unit is probably late Tertiary, with a north or northeast source based on clasts of basalt and porphyritic granite.

Tsl – Conglomerate at Lookout Mountain (~50 m): subrounded to subangular cobbles and boulders set in a tan to reddish-tan, poorly sorted, and weakly consolidated matrix of intermixed gravel, sand, and silt; clasts are mostly reddish and gray basalt, with lesser amounts of greenstone, medium-grained granite, slate, rounded diabase, ferruginous quartzite, and purple quartzite; granite clasts in this unit are finer grained and more mafic than granite in unit Tsy. This unit may be older than unit Tsy, or the two units may be correlative. This unit has a slightly different mix of clast types, a redder matrix, and different crystalline clasts than unit Tsy.

Tmb – Moon Hill Basalt (~150 m): basaltic lava flows, including an older, alkaline basalt flow that comprises most of the butte and a younger subalkaline basalt that forms a thin cap along the crest (Leighty, 1997); (1) the older alkaline rocks are reddish-weathering, porphyritic, and vesicular, with a finely crystalline, dark-gray to black groundmass and phenocrysts of olivine and clinopyroxene; (2) the younger subalkaline basalts are reddish- or greenish-weathering and contain porphyritic plagioclase and olivine in a finely crystalline, dark-gray matrix. The basalts are interpreted by Leighty to be 20 Ma and 13 to 16 Ma, respectively.

Tlb – Lookout Mountain Basalt (~150 m): two sequences of basalt flows and breccias separated by a Tertiary conglomerate: (1) lower basalt unit is brown, black, or gray, finely crystalline, altered, and reddish to purplish weathering; contains abundant vesicles, many of which are filled with white calcite; (2) upper basalt capping Lookout Mountain is aphyric, light gray to dark reddish purple, with light-tan to brownish-purple weathering; mostly composed of reddish gray fragments and angular blocks of basalt up to 0.5 m across, contained in a finer red basaltic matrix; some scoria and some intrusives. Lower basalt dated at 19 Ma (Shafiqullah et al., 1980).

Proterozoic Units at Shadow Mountain

Xmgs – Metagraywacke (40-100 m for each mappable layer; ~200 m total): coarse, lithic sandstone, metasiltstone, and metamorphosed tuff; composed of 80% angular to subangular grains of quartz (50%) and feldspar (20%) and chloritic rock fragments in a micaceous matrix;

contains bedding, some of which is graded. This rock is interpreted to be intermixed volcanic and volcanic-lithic sedimentary rocks, probably deposited in a submarine environment and derived from an eroded felsic volcanic terrain.

Xrs – Metarhyolite (30-50 m): cream-colored, finely crystalline, metarhyolite containing three main components: (1) lower, tan- and reddish-brown-weathering, cream-colored, sandy rhyolite tuff, tuffaceous clastic rock, and a coarse sandstone with rounded crystals of quartz and feldspar; thin to medium bedding is locally graded; (2) massive, cream-colored metarhyolite (<5 m thick) with 10% phenocrysts of feldspar and quartz and with zones of small, greenish fragments; and (3) salt-and-pepper to grayish-green, mottled phyllite with light greenish-gray fragments 5 mm to 2 cm in diameter; contains crystals of feldspar and quartz. These units are interpreted to be bedded air-fall tuff, a submarine fragmental, and partially reworked pyroclastics.

Xvf – Metamorphosed volcanic fragmental (~150 m): grayish-white, felsic to intermediate, volcanic fragmental with flattened greenish biotitic fragments 1 to 5 cm long and fine-grained, cream-colored fragments up to 2 cm long; contains streaks and pods of brown carbonate; some parts contain fragments but few crystals; other parts contain few fragments but 40% quartz and feldspar crystals. Rock is interpreted to be a metamorphosed rhyodacite or rhyodacite-fragmental deposited on the seafloor. The green biotitic fragments and associated brown carbonate may reflect sea-water alteration.

Xmsv – Metasedimentary and metavolcanic rocks, undifferentiated (~400 m): five separate rock packages that are unmappable as separate units: (1) gray volcanic with abundant quartz and feldspar crystals and 1-cm cream-colored fragments; (2) tan to gray, thinly bedded, lithic sandstone and siltstone with beds <2 mm to 2 cm thick; (3) poorly sorted and massive conglomerate or a volcanic fragmental with 20% volcanic-rock fragments up to 4 cm long; (4) laminated greenschist of intermediate composition, probably an andesitic-dacitic tuff; and (5) volcanic-lithic sandstone composed of 50% quartz and feldspar grains. This rock package probably represents a submarine volcanic-sedimentary sequence. The conglomerate and lithic sandstone were derived from concurrent volcanism or from reworking of older volcanic rocks.

Xsq – Quartzite (<200 m): light pink to purplish, very fine grained, massive, nonbedded quartzite; locally contains small, cubic cavities filled with iron oxide (originally pyrite); includes a small, mineralized zone of quartz-kyanite-andalusite rock containing pink andalusite, white to light blue kyanite, bright blue lazulite, black tourmaline, finely divided dark pink hematite, almandine garnet, and retrograde pyrophyllite. The quartzite is probably metamorphosed hydrothermal quartz.

Proterozoic Units East of the Squaw Peak Structure

Xd – Diabase (<5 m): rust-colored pods and gently dipping, thin dikes of diabase that weather into rounded masses; medium crystalline, mottled black to dark gray and white, with an ophitic texture; phenocrysts of pyroxene and lath-shaped plagioclase in a groundmass of pyroxene, feldspar, iron oxide, and other minerals; unit does not contain cleavage. These diabase pods are interpreted to be remnants of post-metamorphic dikes or sills that intruded at 1.1 Ga, after Proterozoic deformation in the range.

Xad – Meta-andesite-diorite (20-100 m for each mappable belt; ~200 m total): greenish, chlorite-rich phyllite to massive, nearly unmetamorphosed igneous rock; finely crystalline to coarsely crystalline, grayish-green matrix with local, small elliptical, dark-green patches (<2 mm) and abundant light-green and white patches; matrix contains feldspar, chlorite, epidote, and actinolite; green patches consist of biotite with some chlorite and magnetite; light-colored patches are sericite and finely crystalline feldspar, and may be clasts or deformed phenocrysts; locally altered to brown carbonate. Unit is interpreted to be intermediate to mafic in composition, originating as a finely crystalline intrusive rock or a less likely as a coarsely crystalline andesitic flow.

Xqs – Quartzite at Squaw Peak (~450 m): gray to bluish-gray to reddish-brown, medium- to coarse-grained quartzite with local small pebbles, graded beds, and lenses of quartz-mica-schist; contains a dark-reddish-brown to dark-gray conglomeratic bed with cream-colored quartzite cobbles; quartzite contains small percentage of hematite and kyanite crystals near quartz veins. Unit probably represents fluvial or beach deposits.

Xmrt – Metarhyolite tuff (~350 m): metarhyolite and felsic breccia of three main types: (1) metamorphosed tuff breccia with shale and rhyolite clasts 10-15 cm long in a gray, phyllitic matrix; (2) green to cream-colored or pink metarhyolite with a fine-grained foliated matrix and randomly scattered quartz grains; and (3) lenses and pods of quartzite with quartz cobbles, shale fragments, and distinctive irregular, dark gray to black, contorted bands. Unit is interpreted as rhyolitic flows and ash flows, fine-grained and coarse-grained volcaniclastic debris, and quartz sandstones.

Xmr – Metarhyolite (~200 m): metarhyolite and altered metarhyolite with three lithologies: (1) darkly varnished, blue to blue-gray quartzite and kyanite-quartzite rocks with fine-grained quartz and 15-30% kyanite in blades parallel to foliation and as radiating masses; locally contains retrograde pyrophyllite, and unusual pinkish, gray, and black bands defining isoclinal folds and composed of opaque minerals, probably Mn-oxide; (2) pink to tan, fine-grained quartz-muscovite schist with porphyroblasts of piemontite and viridine, local quartz clasts, and black bands of Mn-oxide; and (3) tan, cream-colored, or pale-green metarhyolite with phenocrysts of quartz and K-feldspar in a matrix of fine-grained quartz and sericite. Unit is interpreted as porphyritic rhyolite ash-flow tuffs, altered by weathering or hydrothermal alteration.

Xqm – Quartz-mica and biotite schist (~250 m): medium- to light-silvery-gray, greenish-gray, and reddish-brown quartz-mica schist with dark-gray to black biotite schist and gray phyllite; contains thin quartzite beds, opaque-mineral laminations, and sparse quartz cobbles. Unit is interpreted to be a fine-grained sedimentary deposit derived from mafic to intermediate volcanic terrain.

Xqp – Quartzite-phyllite, undifferentiated (~150 m): intermixed quartzite and phyllite similar to the quartzite (Xqe) and the variable phyllite (Xpv) units; quartzite is gritty with a white mica matrix and local cross beds; phyllite is gray and fine-grained, but locally conglomeratic with dark fragments. Unit is interpreted to represent a shallow-water deposition of sand and mud, probably in a river system or delta.

Xrc – Crystal-rich metarhyolite (0-160 m): light-tan to pink, foliated homogeneous rock with 5% gray quartz and 1% pink feldspar phenocrysts in a finely crystalline matrix of quartz, sericite, and feldspar. Unit is interpreted to have been a rhyolite ash-flow tuff or flow, with an original quartz-porphyry texture.

Xra – Aphyric metarhyolite (0-30 m): pale-pink to creamy-tan, homogeneous, fine to very finely crystalline metarhyolite composed of quartz, mica, and feldspar with very few mafic minerals; locally displays slight layering defined by color and granularity; generally blocky and resistant to erosion. Rock is interpreted to have originated as a rhyolite ash-flow tuff, or less likely a flow.

Xpv – Variable phyllite (~300 m): light- to dark-gray or silvery, fine-grained phyllite with locally abundant light- and dark-colored sand- to pebble-sized, dark- and light-colored clasts; highly cleaved without preserved bedding, except locally as thin alternating shades of gray; light-colored clasts are composed of quartz and white mica, whereas the darker clasts contain more mafic minerals; some exposures are fine-grained, medium- to dark-gray, clast-poor phyllite. Unit is interpreted to have varied from a volcaniclastic unit with fragments to a clast-poor mudrock, probably formed by sediment deposition during volcanism.

Xrp – Crystal-poor metarhyolite (0-100 m): greenish-white, light pinkish-tan, or gray, cleaved homogeneous rock with 3% quartz phenocrysts and sparse feldspar phenocrysts in a finely crystalline matrix of sericite, quartz, and feldspar; contains numerous cavities <1 mm to 3 cm across; similar to the crystal-rich metarhyolite, but with much smaller quartz phenocrysts in a finer matrix. The unit originated as a slightly porphyritic rhyolitic ash-flow tuff or flow.

Xqe – Cross-bedded quartzite (100-400 m each; ~1600 m total): heavily varnished, light- to medium-gray, fine- to coarse-grained quartzite; some beds have shades of light green, pale pink to red, and black; varies from nearly pure orthoquartzite to gritty, feldspathic-micaceous quartzite to mica-rich phyllite; beds are commonly 1 cm to 1 m thick with thin beds and cross beds defined by laminations of opaque minerals. Quartzite is interpreted to be a continental sandstone, probably deposited in a delta, river, or beach environment.

Xs – Quartz-feldspar-biotite-hornblende schist (20-50 m each; ~200 m total): dark-gray to greenish-gray, fine-grained spotted schist with visible feldspar, hornblende, and biotite (±garnet) porphyroblasts in a finely crystalline matrix of quartz, feldspar, and mica; includes some fine-grained, greenish, calc-silicate (epidote, actinolite, and carbonate) layers covered with pits by preferential weathering of carbonate and calc-silicate pods. Unit is interpreted to be a metamorphosed sedimentary rock with carbonate, mud, and clay.

Proterozoic Units West of the Squaw Peak Structure

Xsg – Shaw Butte Granodiorite: light-gray, salt-and-pepper-colored granodiorite, tonalite, and fine-grained felsic to intermediate rocks in three zones; (1) main phase to the northwest is coarse to medium grained with plagioclase phenocrysts in matrix of feldspar, quartz, and biotite; locally greenish and altered to sericite and epidote; (2) central portion displays mingling of medium- to coarse-grained main phase with fine-grained, locally more mafic granodiorite with quartz and feldspar eyes similar to those in the main phase; (3) southeast zone is a mixture of fine-grained, medium-grained, and porphyritic rocks; fine- to medium-grained, felsic to intermediate rocks have sparse quartz eyes up to 3 mm; medium-grained intermediate rock contains plagioclase, quartz, and ~40% mafic minerals altered to chlorite; porphyry has ~ 20% small, feldspar phenocrysts in a fine-grained, pale-green matrix. Most phases locally contain northeast-striking cleavage with discrete northeast-trending shear zones. Pluton was intruded after the North Mountain Greenstone, but before deformation. Magma mingling between magmas of somewhat different composition produced the complex variation in the middle of the unit, and the finely crystalline rocks along the southeast border may represent a chilled border phase at the original top of the pluton.

Xcq – Conglomeratic quartzite (~50 m): gray, sandy to gritty quartzite with quartz and jasper clasts up to 15 cm and quartzite, slate, and rhyolite rock fragments in a quartz-sericite matrix. Unit is interpreted to be metamorphosed sandstone and conglomeratic sandstone.

Xqz – Quartzite and overlying greenschist (~3-30 m): light- to medium-gray, fine- to medium-grained orthoquartzite with opaque-mineral laminations and cross beds. Unit is interpreted to have been a pure quartz sandstone, probably deposited by rivers.

Xp – Gray conglomeratic phyllite (~125 m): medium- to dark-gray, quartz-mica phyllite containing large deformed clasts of phyllite and slate, and light-green clasts that are possibly pumice or rhyolitic tuff; includes beds of homogenous, gray phyllite and cross-bedded quartzite. Unit interpreted to be volcaniclastic and pelitic material, with some sandy intervals.

Xccp – Carbonate-chlorite-feldspar-sericite phyllite (~100 m): green to greenish-gray phyllite with strongly flattened and elongated white patches up to 1 cm long of fine-grained sericite and feldspar; unit contains abundant carbonate veins and pods. Unit could be a highly altered intrusion, volcanic flow, or tuff.

Xspc – Stretched-pebble conglomerate (~ 85 m): coarsely conglomeratic quartzite and quartz-mica schist; contains up to 65% clasts as long as 15 cm in a matrix of 90% quartz and 10% sericite; clasts are flattened and elongated and include quartz, quartzite, jasper, rhyolite, and shale-slate; unit contains quartz and carbonate veins and cross beds defined by opaque-mineral laminations. Unit is interpreted to be a stream or beach deposit.

Xg – Greenschist (~25 m): fine-grained green matrix with elliptical, dark-green and light-green to white patches <1 cm long; green patches contain chlorite and biotite, white patches are sericite and fine-grained feldspar, and both types may represent clasts or deformed phenocrysts. Unit is interpreted to be a mafic to intermediate flow or intrusive.

Xqm – Quartz metaconglomerate and greenschist (~120 m): gray to silvery-gray, quartz-rich, fine- to medium-grained quartzite with small pebbles; contains opaque-mineral laminations and cross beds, graded beds, thin beds of gray phyllite, and a greenschist layer with elliptical white spots. Metaconglomerate is interpreted to be a stream or near-shore deposit.

Xsp – Sericite phyllite (~60 m): homogenous, gray, fine-grained phyllite with sericite, quartz, hematite, and chlorite. Protolith is interpreted to be pelitic, probably deposited in a near-shore environment.

Xvs – Variable schist (~60 m): lithologically variable schist, including chlorite schist, quartz-mica schist, quartz-feldspar schist, and quartzite. Unit is interpreted as sedimentary, with intermediate to felsic volcaniclastic material and local deposition of quartz sand in channels.

Xtp – Tan phyllite (~500 m): light-gray to tan phyllite with coarse quartz grains and fragments in a finer, micaceous matrix; most has a volcanic-lithic aspect with white (volcanic?) fragments; widespread brown carbonate contributing to the rounded-weathering aspect; correlative with variable schist on the east side of the Dreamy Draw syncline. Unit interpreted to represent quartz deposition accompanied by the deposition or reworking of volcaniclastic material.

Xgp – Gray phyllite (~330 m): gray, fine-grained phyllite interbedded with thin, nonmicaceous metasandstone beds; coarser units are variably quartzose or volcanic-lithic, with quartz clasts and fine-grained white (volcanic?) clasts; top marked by spotted, gray-white-black metaconglomerate marker unit with red jasper and a volcanic-lithic aspect; some bluish-green phyllite with chlorite and brown carbonate. Unit is interpreted to represent mixed, quartzose and volcanic-derived sediments mostly deposited offshore, in part accompanied by distant volcanism.

Xqw – Quartzite (0-200 m): light-greenish-gray, pale-purple, or pinkish-orange quartzite; contains dark laminae that define bedding and cross bedding; thinner lenses are slightly micaceous; contains some coarser, gritty lenses. Unit is interpreted to represent quartz-sand deposits, possibly a beach or other near-shore setting.

Xmv – Greenstone, gray phyllite, ferruginous quartzite, and metarhyolite, undifferentiated (30 m): mixed volcanic package consisting of, from bottom to top, gray volcanic-lithic phyllite, greenstone, ferruginous quartzite, and tan, silicified, metarhyolite. This thin, undifferentiated package of rocks appears to mark the transition from oceanic to continental environments.

Xbp – Chlorite-feldspar-carbonate-biotite phyllite (~640 m): pale- to olive-gray phyllite with dark-green to black spots (up to 2 cm long) composed of medium-grained biotite, chlorite, and magnetite; contains distinct compositional layering and a 5-10 meter-thick bed of quartz-mica-schist with abundant vesicles and quartz- and calcite-filled vugs; includes thin metarhyolite, actinolite-bearing schist, and two conglomerate beds. Unit is interpreted to represent intermediate to felsic volcanic rocks with volcaniclastic deposits and quartz sand.

Xsgs – Stoney Mountain Greenstone (~800 m total, in two belts): greenstones of variable lithology intermixed with dark-weathering, ferruginous quartzite; greenish-tan greenstone and chloritic phyllite at the base, with tan carbonate, up to 10% feldspar phenocrysts, and cm- to meter-thick layers of ferruginous quartzite; upper part is gray-green to green, finely crystalline, granular, and nearly homogenous greenstone with possible pillow structures and local gabbroic intrusions. Unit interpreted to be slightly metamorphosed andesite (greenish), dacite (phyllite), submarine hot-spring deposits (ferruginous quartzite and carbonate), and subvolcanic intrusions.

Xfq – Ferruginous quartzite (0-100 m): massive to banded, reddish to dark-gray, finely crystalline quartzite and quartz-magnetite-hematite rock; resistant, dark-weathering layers centimeters to 10 m thick with mesoscopic folds. Protolith is interpreted to have formed by chemical precipitation of very fine grained iron and silica in a submarine hot springs environment near volcanism and upwelling of heated sea water.

Xcp – Chlorite-carbonate phyllite (~600 m): greenish-gray, chlorite-carbonate phyllite and greenstone with gray phyllite, metamorphosed rhyolitic tuff, and ferruginous quartzite; abundant brown, reddish-brown, and tan carbonate. Unit is probably of submarine volcanic origin, probably tuffs, with submarine hot springs (ferruginous quartzite) and sea-water alteration (carbonate).

Xmg – Metagraywacke (15-50 m): gray metagraywacke and phyllite with gray, white, and tan, coarse-grained clasts; clasts are poorly sorted, angular to subangular grains of feldspar (30%), quartz (20%), and small, dark rock and mineral fragments, in a micaceous, possibly tuffaceous matrix. Unit is interpreted to be a locally derived, immature sedimentary rock, possibly in a marine environment, such as in a submarine fan.

Xrt – Tuffaceous metarhyolite (~200 m): cream, tan, and pinkish, finely crystalline, aphyric metarhyolite and sericite (?) phyllite; some parts are pale green with a very fine, porcelain texture. Unit is interpreted to be rhyolite, in part altered volcanic ash.

Xms – Metasiltstone (~500 m total, in four belts): gray phyllitic siltstone with (1) silvery gray to dark gray, very fine grained, homogeneous, laminated phyllite; (2) medium- to light-brown, massive to laminated carbonate; and (3) tan, finely crystalline metarhyolite with small, local ferruginous quartzite and carbonate zones; metasiltone is interlayered with tuffaceous metarhyolite (unit Xrt). Unit is interpreted as marine silts interrupted by felsic volcanism.

Xmp – Muscovite phyllite and metarhyolite (~700 m): light-gray, cream-colored, and pale-green phyllite to quartz-muscovite schist; composed of finely crystalline sericite, quartz, and feldspar, with sparse quartz eyes and local rounded quartz grains; includes thinly bedded units and thicker layers of resistant, light-tan to white metarhyolite with feldspar and quartz phenocrysts. Unit is interpreted to have been rhyolite flows, ash-flow and ash-fall tuffs, and associated sediments.

Xngs – North Mountain Greenstone (~2,000 m): dark-gray to green, massive to highly cleaved, fine- to medium-grained greenstone; commonly contains 1- to 3-mm feldspar ± quartz phenocrysts in chloritic groundmass; includes fine-grained phyllitic layers ~ 1 m thick. Unit is interpreted as intermediate volcanic and hypabyssal rocks, which compose the oldest unit in the Proterozoic sequence.

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