GEOLOGY OF THE SQUAW PEAK PORPHYRY COPPER-MOLYBDENUM DEPOSIT, YAVAPAI COUNTY, ARIZONA

by

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ABSTRACT

Sulfide mineralization and irregularly zoned alteration assemblages hosted by Precambrian granodiorite are associated with an irregularly seriate Laramide (?) quartz monzonite porphyry plug. An inner zone of pyrite-chalcopyrite-molybdenite concentration, quartz-sericite alteration, and weakly developed secondary biotite-orthoclase alteration sub-concentrically surround the sulfide-deficient porphyry stock. An erratic outer zone of weak pervasive chloritization and vein-controlled quartz-epidote-chlorite-K-feldspar-calcite alteration envelopes the stronger alteration and mineralization along northwest-trending pre-mineralization fractures. The alteration and geochemical anomalies are elongate in a northwesterly direction.

The Squaw Peak deposit is generally sulfide-deficient and poorly developed in terms of intensity and extensiveness of mineralization and alteration. Alteration and mineralization occurred in a relatively continuous phase in response to the porphyry intrusion. Lateral and vertical mineral assemblage relationships suggest the deposit is a moderately to deeply eroded remnant of a small porphyry system.

Geologic reserves at Squaw Peak are estimated at 20 million tons averaging 0.36 per cent copper with substantial molybdenum. The potential for additional copper ore reserves in the Squaw Peak area is remote.

CHAPTER 1

INTRODUCTION

This investigation deals with the geology of the porphyry copper-molybdenum occurrence near Squaw Peak, in central Arizona, and its surrounding area. Particular emphasis is given to the mineralization and alteration zonal relationships of the Squaw Peak deposit itself, and to the potential for base metal reserves in the area. Speculations are made regarding the size of the original Squaw Peak deposit and regarding the geologic evolution of the Squaw Peak area.

Voluminous data concerning "porphyry copper" deposits have accumulated in recent years, creating some confusion regarding the criteria which are used to define a "porphyry copper" deposit. A porphyry deposit as defined by Lowell and Guilbert (1970, p. 374) is "...a copper and/or molybdenum sulfide deposit consisting of disseminated and stockwork veinlet sulfide mineralization emplaced in various host rocks that have been altered by hydrothermal solutions into roughly concentric zonal patterns," features certainly applicable to the Squaw Peak deposit. Other characteristics of the Squaw Peak deposit which unify it with other recognized porphyry deposits include: 1) relatively homogeneous distribution of sulfide mineralization;

2) association of the mineralization and alteration with a passively emplaced quartz monzonite porphyry stock; 3) gradational distribution of mineralization and alteration; 4) locally shattered areas of structurally weak host rock which appear to have been influenced by the porphyry intrusion and mineralization; 5) presence of significant molybdenum apparently genetically associated with the copper mineralization; 6) a direct relationship between the intensity of sulfide mineralization and the fracture density of the host rock; and 7) relatively low concentrations of copper at less than 1 per cent but greater than 0.3 per cent persisting over a relatively large volume involving more than 20 million tons. In the light of these observations, the Squaw Peak deposit adequately represents a small porphyry deposit, according to contemporary usage of the term "porphyry copper."

Previous Work

Previous published work concerning the Squaw Peak area is limited. The area is covered on the Arizona State Geologic Map (Wilson, Moore and Cooper, 1969) and the Geologic Map of Yavapai County, Arizona (Arizona Bureau of Mines, 1958). Portions of the Squaw Peak area are mentioned by Twenter and Metzger (1963), who deal with some of the regional geological aspects, specifically with the major acquifers and drainage characteristics of the area. An Arizona State University Master of Science thesis by Wadell (1972)

deals principally with the late Cenozoic history of the Verde Valley. A thorough geologic investigation of the northern Black Hills by Anderson and Creasey (1958) involves the geology of the United Verde Extension orebodies in the context of the regional geology.

Exploration and mining endeavors at the Squaw Peak deposit have produced most of the data utilized in this investigation. These data are largely owned by the Squaw Peak Copper Mining Company and were made available by Essex International, Inc. Most of the unpublished data used for this report were inherited from drilling and geochemical and geophysical surveys produced by and for the Phillips Petroleum Company.

Methods of Investigation

This study encompasses both the geology of the Squaw Peak area and the more detailed geology of the Squaw Peak deposit. A general lithologic and structural study of the Squaw Peak area is supplemented by a specific analysis of the Squaw Peak deposit. The extent of the mineralization and alteration are the basic objectives for the investigation of the porphyry deposit. The overall structure of the area is significant on a regional scale, and may have an important bearing on the emplacement and post-mineralization history of the Squaw Peak deposit. It was the intent of this investigation to synthesize aspects of the Squaw Peak deposit with the geologic evolution of

the surrounding area. A total area covering 15 square miles was mapped at a scale of one inch equals 1000 feet, or 1:12,000. Approximately 60 per cent of the area was covered by aerial photographs of various scales, usually between 500 feet and 1000 feet to the inch. The remaining area was mapped on enlarged topographic maps. A more detailed geologic map of the Squaw Peak deposit was completed at a scale of one inch equals 200 feet, or 1:2400. This mapping was done using topographic sheets provided for Phillips Petroleum in 1967 by Intermountain Aerial Survey. The field work was accomplished during February, March, and April 1974. An approximate total of 20 days was consumed by field mapping.

Drilling of the Squaw Peak deposit and its immediate area provided over 16,000 feet of drill core and over 8,000 feet of rotary drill representative rock chips. Core from pertinent drill holes and rock chips from most rotary holes were mesoscopically inspected and sampled for this study. Thin sections from 42 core specimens and 13 rock outcrop specimens were studied with a Lietz Ortholux petrographic microscope. Polished blocks of 8 mineralized drill core specimens were observed in vertically incident light. Detailed laboratory work was not used to any great extent. Some X-ray work was performed to assist in the analysis of the alteration mineralogy. Field and petrographic observations were applied to determination of three-dimensional characteristics of the mineralization and alteration

of the Squaw Peak deposit to other known porphyry occurrences and to speculate on the genesis of the deposit.

Geochemical sampling data gathered by Phillips Petroleum was used further to analyze the nature of the Squaw Peak mineralization. Copper, molybdenum, and zinc geochemical contour maps are presented. Seismic evidence supplied by Phillips Petroleum aided in the determination of the approximate magnitude of structural disturbance in the Squaw Peak region. The geophysical information is also useful in speculation concerning the future exploration potential of the area.

Location and Geography

The Squaw Peak deposit is located approximately six miles south of Camp Verde, Yavapai County, Arizona (Figure 5). Camp Verde is approximately 35 miles east of Prescott, Arizona, and 75 miles north of Phoenix. The area studied covers parts or all of Sections 24, 25, and 36 T.13N., R.4E.; Sec. 19, 20, 29, 30, 31, and 32 T.13N., R.5E.; and Sec. 1 T.12N., R.4E.; in addition to land of unestablished status within the Prescott National Forest. The area is contained in the Camp Verde, Horner Mountain, Arnold Mesa, and Middle Verde 7.5 minute series topographic maps.

The Squaw Peak deposit may be reached from Camp Verde by traveling south on Main Street to the Salt Mine Road, then west

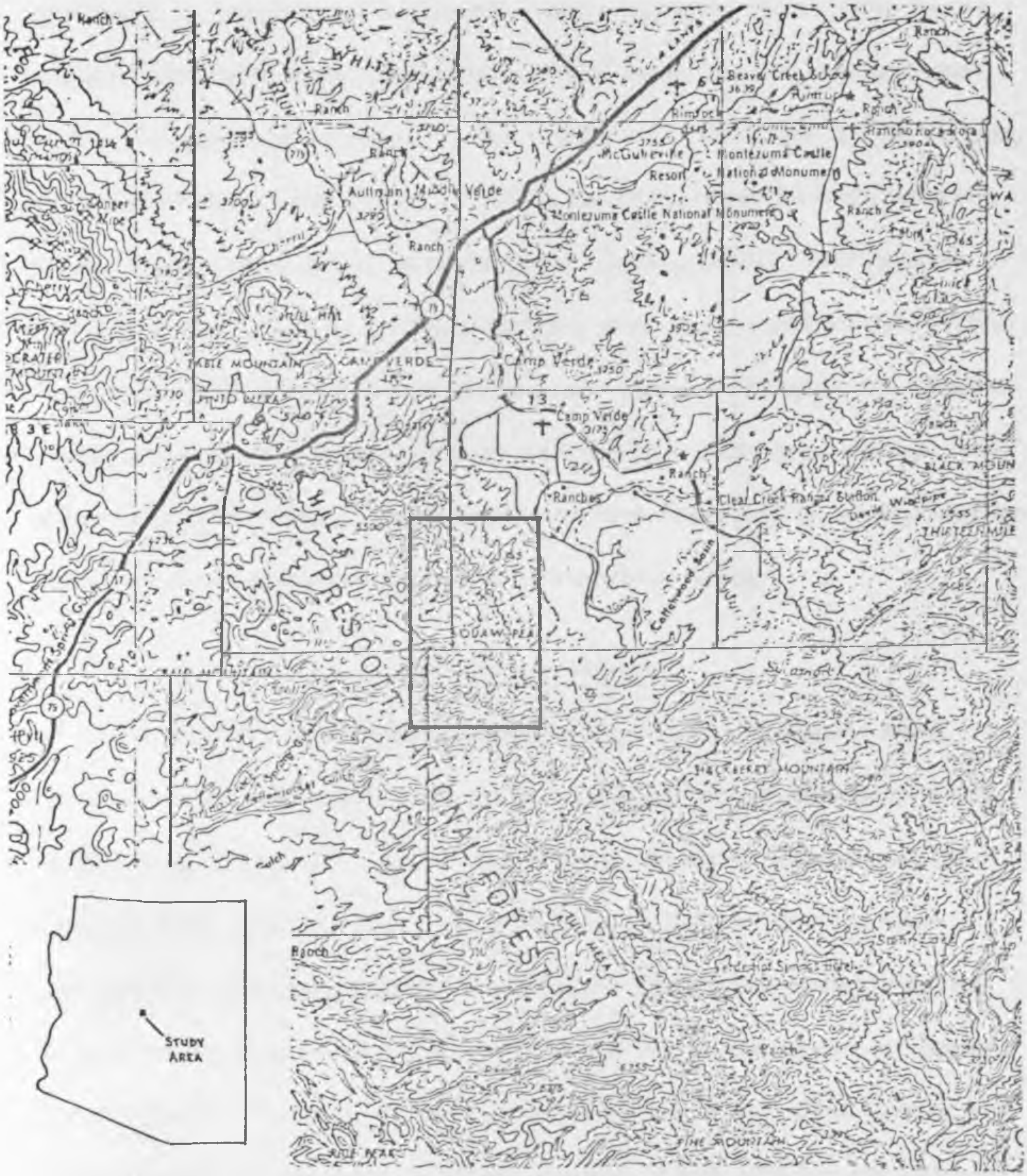


Figure 5. Location Map of the Squaw Peak Area (1:250,000).

and south on the Salt Mine Road for approximately eight miles to the Squaw Peak Mine road. The Squaw Peak Mine road is one and one-half miles long and terminates in a network of dirt roads in the vicinity of the old Squaw Peak Mine. The Squaw Peak area is on the eastern flank of the Black Hills, a northwest-trending range which bounds the Verde River valley on the southwest and rises 2,000 to over 3,500 feet above the valley floor in the Squaw Peak area (Figure 6). Squaw Peak is the highest point in the southern Black Hills and reaches an elevation of 6525 feet. The Black Hills are dissected by steep canyons and washes which drain eastward to the Verde River.

Exploration History

The earliest recorded mining claims on the Squaw Peak prospect were located in 1877 by M. L. Olden, a Harvard University mineralogy professor. Olden discovered copper-stained outcrops of granite below Squaw Peak and began prospecting in an area now occupied by the Main Tunnel level portal. Olden contended that the Squaw Peak deposit "would one day prove one of the greatest copper properties in the country" (Arizona Bureau of Mines mine files), and was reported to have turned down an offer of $50,000 for his claims. Following Olden's death, several individuals attempted to continue the exploration of the deposit but were discouraged due to lack of working capital, instability of the rock, and the remoteness of the area.

Squaw Peak

Chasm Creek

Squaw Peak Canyon

Fig. 6. Squaw Peak Area.

Note drill roads below and to the right of Squaw Peak. View southwest from Verde Valley.

Serious interest in the property was renewed in 1916 with the incorporation of the Squaw Peak Mining Company under the direction of J.J. Cain, H.W. Thacker, Edison Thacker, and R. Thacker. Edison Thacker later became the president of the company and initiated an aggressive promotion campaign. Samples of Squaw Peak ore were displayed in Jerome, Arizona and New York City to encourage the purchase of Squaw Peak Mining Company stock. Assays as high as 29.5% Cu and $4 per ton in gold were reported (Arizona Bureau of Mines mine files).

Most of the underground workings which exist today were developed in the late 1920's and early 1930's, at which time the deposit was considered to be a potential gold producer as well as a promising copper and molybdenum property. Promotion and development of the deposit seems to have subsided during the remainder of the 1930's and early 1940's. Work was resumed during World War II, when the underground drifts and some diamond drilling were completed with the help of a $20,000 federal government loan.

Underground workings at the Squaw Peak Mine constitute about 4160 feet of drifts and about 200 feet of raises (Figure 7). Two levels of drifts known as the Main Tunnel level and the Haulage Tunnel level were driven at elevations of 4150 feet and 3850 feet, respectively. The Main Tunnel level consists of 2175 feet of drifts, and the Haulage Tunnel level is approximately 1985 feet long. Only about 500 feet of

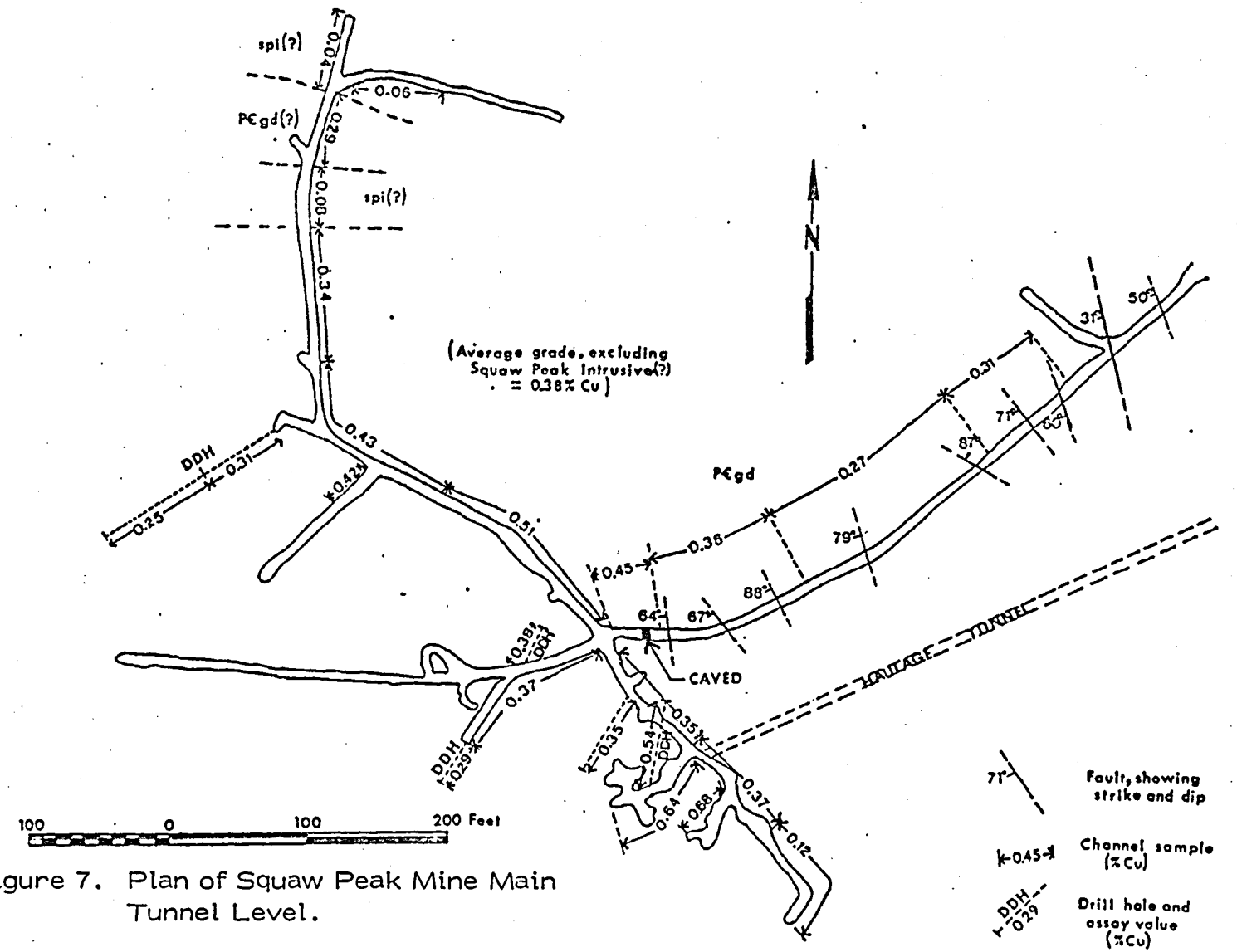


Figure 7. Plan of Squaw Peak Mine Main Tunnel Level.

Average grade computed from all cross-cut walls and drill holes. Data from Squaw Peak Copper Mining Company files.

the Main Tunnel are now accessible. The first recorded ore shipments were in 1944. Production at the Squaw Peak Mine during 1944, 1945, and 1946 (Squaw Peak Copper Mining Co. files) amounted to 5.40 tons of concentrate containing 98.82% molybdenite and 36.03 tons of concentrate containing 22.85% copper, 1.92 ounces per ton of silver, and 0.016 ounces per ton of gold. These concentrates were produced from approximately one thousand tons of ore, most of which was removed from raises on the Main Tunnel level.

Only minor exploratory drilling was undertaken from 1947 to 1967. Intermountain Exploration Company drilled two diamond drill holes totaling 601 feet from the Main Tunnel level about 450 feet from the portal during June and July, 1961. In August, 1963, Boyles Brothers Drilling Company completed a 723.6-foot vertical hole from the surface northeast of the mine. During March and April, 1964, Callahan Mining Company drilled an angle hole from the Haulage Tunnel. The hole (Figure 7) was drilled at 40° to the west to a depth of 1132 feet.

In May 1967 Phillips Petroleum Company optioned the property from the Squaw Peak Copper Mining Company for a term of ten years. Phillips conducted an exploration program which included 16,206.5 feet of diamond core drilling, 2756 feet of rotary drilling, 43,000 line-feet of induced polarization surveys, and 6500 feet of

reflection seismic lines. Phillips terminated their option on the property in May, 1973, after a total exploration expenditure of $269,736.00.

In August, 1973, an option agreement was reached between the Squaw Peak Copper Mining Company and Essex International, Inc., which permitted Essex to explore the property for six months. Essex conducted an exploration program which yielded 5380 feet of rotary drilling. A ten year lease-option agreement was made in February, 1974, which gave Essex sole exploration rights which are annually renewable until 1984. Essex currently (May, 1975) owns exploration rights to 153 unpatented claims on the Squaw Peak property. Essex has committed approximately $60,000.00 on the property to date (May, 1975).

CHAPTER 2

GEOLOGIC SETTING

The Squaw Peak area lies on the northeastern perimeter of the Basin and Range physiographic province within the mountain region of Arizona as defined by Ransome (1903). The Mogollon Rim, approximately seven miles east of Squaw Peak and on the northeastern flank of the Verde Valley represents the southwestern extremity of the Colorado Plateau province.

The mountain region is a broad zone of short, sub-parallel, north to northwestward trending mountain ranges extending from the Colorado River southeasterly to the southeastern corner of the state, and characterized by relatively extensive exposures of Precambrian crystalline granitoid and metamorphosed volcanic rocks. The region geologically represents a transition phase between the Colorado Plateau and the Basin and Range Provinces. Structural deformation has separated the mountain region in central Arizona from the Colorado Plateau (Lindberg, 1974), and subsequent erosion has created valleys which have been partially filled by fluvial and lacustrine sediments (Anderson and Creasey, 1958). The southern Black Hills are bounded by southeastward flowing drainages of the Verde River on the eastern side of the range and the Agua Fria River on the west.

Rocks of Precambrian to Quaternary age crop out in central Arizona. Precambrian rocks are subdivided into Older Precambrian and Younger Precambrian units (Butler & Wilson, 1938), the Older Precambrian in Arizona being represented by a thick sequence of metamorphosed felsic to mafic volcanic rocks. These rocks underwent mild to intense structural deformation and generally greenschist facies regional metamorphism during the Mazatzal Revolution which ended the Older Precambrian (Wilson, 1963). The Mazatzal disruption culminated in a batholithic invasion of rocks of granitic to gabbroic composition. This intrusive activity probably produced a huge mountainous region, the roots of which are unconformably overlain by Paleozoic strata (Wilson, 1963).

The Paleozoic rocks in central Arizona generally dip gently to the northeast. The Paleozoic section attains a total thickness of thousands of feet on the Mogollon Rim side as opposed to hundreds of feet in the Black Hills. Lower Paleozoic rocks in the Black Hills are horizontally opposite from upper Paleozoic rocks on the Mogollon Rim, thereby creating the illusion that the Black Hills have undergone substantially more uplift than the edge of the Colorado Plateau. A long hiatus separates Paleozoic sedimentary rocks and Tertiary rocks of sedimentary and volcanic origin. Intrusive dikes and plugs of Laramide (?) age are exposed locally. Widespread late Tertiary alkaliolivine basalt flows cover the region south of the Colorado

Plateau. Two periods of extrusion are separated by a period of faulting and uplift of the Colorado Plateau province (McKee and Anderson, 1971). Considerable uplift of the Black Hills during this period is demonstrated by Tertiary movement along the Verde fault zone along the northeastern front of the range. The Verde River valley was created during this period. The development of the valley was interrupted by the formation of a volcanic dam and the subsequent accumulation of lake deposits of the Verde formation (Jenkins, 1923).

The principal structural feature of the region is the Verde fault zone which extends from Jerome southeastward through the Squaw Peak area to approximately fifteen miles south-southeast of the Squaw Peak deposit. The Verde fault is a normal fault which parallels the northeastern base of the Black Hills and dips eastward into the Verde Valley.

Copper metallization is known to occur at several locations in the Squaw Peak region, notably at Jerome, Arizona. The Precambrian United Verde massive sulfide orebody at Jerome has yielded over 1.8 million tons of copper in addition to substantial quantities of gold, silver, lead, and zinc. Other Precambrian mineralization in the Black Hills include the Iron King massive sulfide lead-zinc mine at Humboldt, copper-bearing quartz veins at the Yaeger Mine southwest of Jerome, and the Cherry Creek auriferous veins approximately twelve miles northeast of the Squaw Peak deposit. The nearest known occurrence

of a major "porphyry copper" deposit is at Copper Basin, Arizona, approximately 40 airline miles west of the Squaw Peak deposit. The Bagdad porphyry copper mine is approximately 80 miles west of Squaw Peak, and the Globe-Miami porphyry copper district is 90 miles to the southeast.

General Geology of the Squaw Peak Area

The oldest exposed rocks in the Squaw Peak district are a metamorphosed andesitic to basaltic volcanic sequence of the Older Precambrian Ash Creek Group. The Ash Creek Group was originally described from exposures in the northern Black Hills by Anderson and Creasey (1958). In the Squaw Peak area, the Ash Creek Group was intruded by a portion of a large Precambrian batholith which ranges in composition from granite to quartz diorite with a probable average composition of granodiorite.

The granodiorite is intruded about 300 feet west of the old Squaw Peak Mine portal by a quartz monzonite porphyry stock which forms an irregular outcrop 300 to 400 feet in diameter (Figure 2, in pocket). At least 13 dikes of quartz monzonite porphyry extend north-south from the parent stock. Surrounding the intrusive quartz monzonite porphyry is a zone of strong to moderate alteration and associated low-grade copper and molybdenum mineralization. Porphyritic quartz monzonite rocks which are texturally and

compositionally similar to the quartz monzonite porphyry stock are exposed as north-west-trending dikes near the contact of the Precambrian granodiorite and the Ash Creek metavolcanics. Local brecciation, quartz stockworks, and copper-bearing quartz veins and fractures are spatially related to these dikes in two areas along the granodiorite/metavolcanic contact.

Nearly horizontal Cambrian and Devonian sedimentary rocks over 200 feet in thickness are exposed at the western margins of the Precambrian exposures. The base of the Paleozoic section west of the Verde fault zone is in most places at about 5000 feet elevation; however, a series of step faults in the southern portion of the mapped area have lowered the section of Paleozoic rocks by approximately 600 feet. Large blocks of the Paleozoic section in contact with Precambrian rocks are also exposed on the eastern margin of the Verde fault zone. Paleozoic rocks in the hangingwall of the fault range up to 1500 feet thick. The vertical separation of the Paleozoic rocks by the Verde fault exceeds 1000 feet throughout the area and locally may exceed 4000 feet.

The lowest Paleozoic unit in the Squaw Peak area is the Cambrian Tapeats (?) formation (Figure 1, in pocket). The Tapeats is a coarse-grained sandstone which is overlain by dolomitic limestone of the Devonian Martin formation. Several hundred feet of basalt flows of the Tertiary Hickey formation are deposited on an

erosional surface upon the Martin limestone. The thickest exposure of the basalt forms the prominent pinnacle known as Squaw Peak. The Hickey basalt is exposed to a limited extent east of the Verde fault, where it overlies the Martin formation in the downthrown block of the fault zone.

A series of low-rounded hills which lie on the east side of the Verde fault in the Squaw Peak Mine area (Figure 12, p. 43) are composed of sub-rounded limestone fragments (up to boulder size) of the Martin formation and lesser amounts of unconsolidated Tertiary basalt, Tapeats sandstone, and Precambrian rocks. These rocks probably represent a marginal facies of the Pliocene-Pliestocene Verde formation. Weakly to moderately consolidated limestone, siltstone, and conglomeratic limestone and siltstone of the Verde formation are exposed locally in the drainages east of the Verde fault. The Verde formation was deposited as lake beds and associated fluvatile deposits throughout the upper Verde River Valley.

The youngest unit in the area, other than alluvium, is a large rhyodacitic extrusive rock which crops out in a group of prominent hills in the northeastern portion of the mapped area. The volcanic center penetrates an exposure of the Verde formation in Squaw Peak Canyon. Elsewhere, rhyolitic flows up to 300 feet thick overlie the Verde formation. This occurrence constitutes the only known Quaternary volcanic rocks in the upper Verde Valley region (Twenter and Metzger, 1963).

CHAPTER 3

LITHOLOGY

The geology of the Squaw Peak region presents a diversity of igneous, metamorphic, and sedimentary rock-types, the study of which has provided a detailed picture of the events which have created central Arizona geology. The rock units of the Squaw Peak area are presented here in the inferred order of their chronological succession.

Precambrian Rocks

Ash Creek (?) Metamorphosed Volcanic Rocks

The Ash Creek group is the lowest stratigraphic unit of the Yavapai Series, a sequence of Older Precambrian metamorphosed sedimentary and volcanic rocks exposed in central Arizona. The group has been divided into seven formations (Anderson and Creasey, 1958). The Ash Creek group is a sequence of metamorphosed basaltic, andesitic, dacitic, and rhyolitic flows and pyroclastic rocks, locally interbedded with tuffaceous sedimentary rocks. The representative section of the Ash Creek group is exposed in Ash Creek, approximately 15 miles west-northwest from Squaw Peak. The stratigraphic sequence of the Ash Creek group, from youngest to oldest, is: the Gaddes basalt, the Buzzard rhyolite, the Shea basalt, the Burnt Canyon

dacite, the Brindle Pup andesite, the Deception rhyolite, and the Grapevine Gulch metasediments (Anderson and Creasey, 1958). The Shea, Burnt Canyon and Brindle Pup units are of approximately the same age (Anderson and Creasey, 1958). Zircon dating of the Cleopatra member of the Deception rhyolite at Jerome, Arizona, has shown the unit to be 1820 $\pm$ 10 million years old. Metamorphosed andesitic and basaltic volcanic rocks crop out north of the Squaw Peak deposit on the western side of the Verde fault and form a broad, northwest-trending belt along the eastern flank of the Black Hills. The rocks are bounded on the south by granodiorite, to the west by Paleozoic sedimentary rocks, and to the north and east by Tertiary basalt, Paleozoic limestone, and Quaternary alluvium on the downthrown side of the Verde fault. These rocks, tentatively assigned to the Ash Creek group, are perhaps Shea basalt and Brindle Pup andesite.

Stratigraphically above the Ash Creek group in central Arizona is the Big Bug group, formerly assigned to the Alder group (Anderson et al., 1971). The Big Bug group forms extensive outcrops west of Squaw Peak in the Jerome and Prescott areas but does not crop out in the Squaw Peak area. The type section of the Alder group is in the Mazatzal Mountains about 40 miles southeast of Squaw Peak.

The metavolcanic rocks in the Squaw Peak area (Figure 1, in pocket) consist primarily of andesite and basalt flows which have been

metamorphosed to a greenschist facies. They are generally poorly foliated to non-foliated and aphanitic. The andesite is dark green to greenish gray weathering to a light brown surface and characterized by abundant fractures and very weakly developed foliation. Thin sections (Figure 8) reveal that the foliation is probably derived from small, sub-parallel flakes of chlorite in a microcrystalline base of epidote (?) and sericite (?). The foliation is cut at random orientations by numerous calcite and quartz veinlets. Local outcrops of non-foliated dacite may represent interbedded or separate flow units within the andesite. The andesite unit is cut by several northwest-trending dikes of fine-grained granite or quartz monzonite which are spatially associated with an irregular, faulted contact between the metavolcanics and the granodiorite to the south. The foliation in the andesite near the contact is destroyed, and the constituent minerals are shattered. Exposures of the contact exhibit considerable mixing of the metavolcanic rocks and the granodiorite over a distance of several meters from the fresh granodiorite.

North of the andesite is a massive basalt unit which forms approximately 80 per cent of the exposure of the Ash Creek (?) group in the Squaw Peak area. The basalt is a dark greenish-gray to black rock which weathers to a grayish-brown surface. The exposed basalt is characterized by massive, blocky outcrops. Porphyritic textures are common, with scattered plagioclase phenocrysts up to 1 mm long

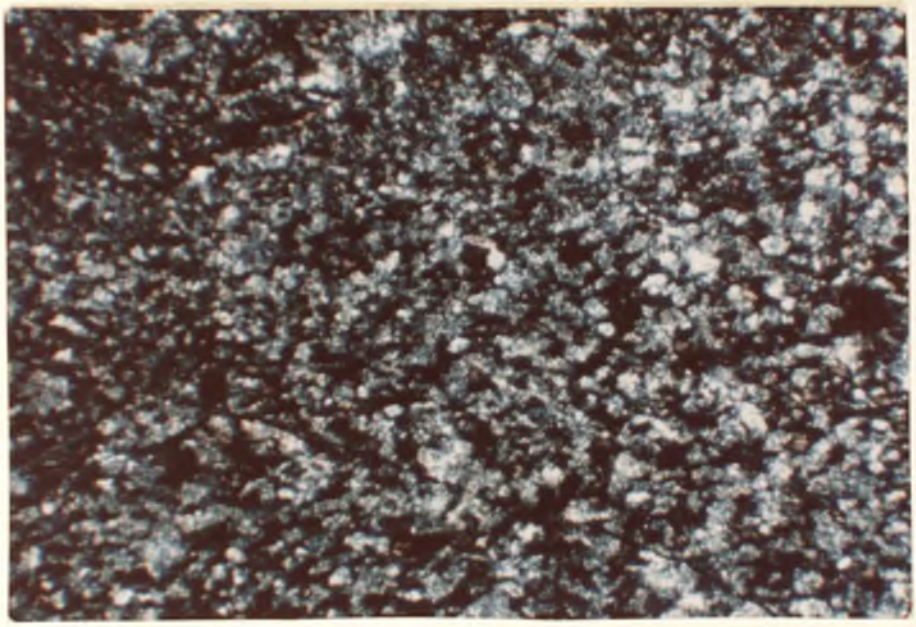


Fig. 8. Photomicrograph of Ash Creek (?) Metamorphosed Volcanic Rock.

Fine grains of chlorite are oriented horizontally in microcrystalline matrix of biotite, quartz, sericite, and calcite. Crossed nicols, x 3.5.

in a dense aphanitic groundmass. The rock is locally cut by stringers of quartz, calcite, or quartz-epidote.

North of the basalt outcrop and extending into Allen Canyon is a weakly schistose andesite which is very similar to the andesite exposed at the metavolcanic-granodiorite contact. These rocks are characterized by dark greenish-gray outcrops and by poorly developed foliation.

Absence of well-defined foliation permits only approximations of the thickness of the metamorphosed volcanic rocks in the Squaw Peak area at several thousand feet of the sequence. The Ash Creek group section exposed at Jerome (Anderson and Creasey, 1958) may be 20,000 feet thick.

Precambrian Granodiorite

The dominant intrusive rock in the Squaw Peak area is granitic rock of elongated exposure cropping out in a north-south direction through the central portion of the area. These rocks range in composition from quartz diorite to granite (Figure 9), with an average composition of granodiorite, and herein are referred to as granodiorite or as Precambrian granodiorite. The granodiorite exposed at Squaw Peak is part of a large Precambrian pluton which crops out in a broad, northwest-trending belt across central Arizona. It intrudes the metamorphosed volcanic rocks north of the Squaw Peak deposit (Figure 1,

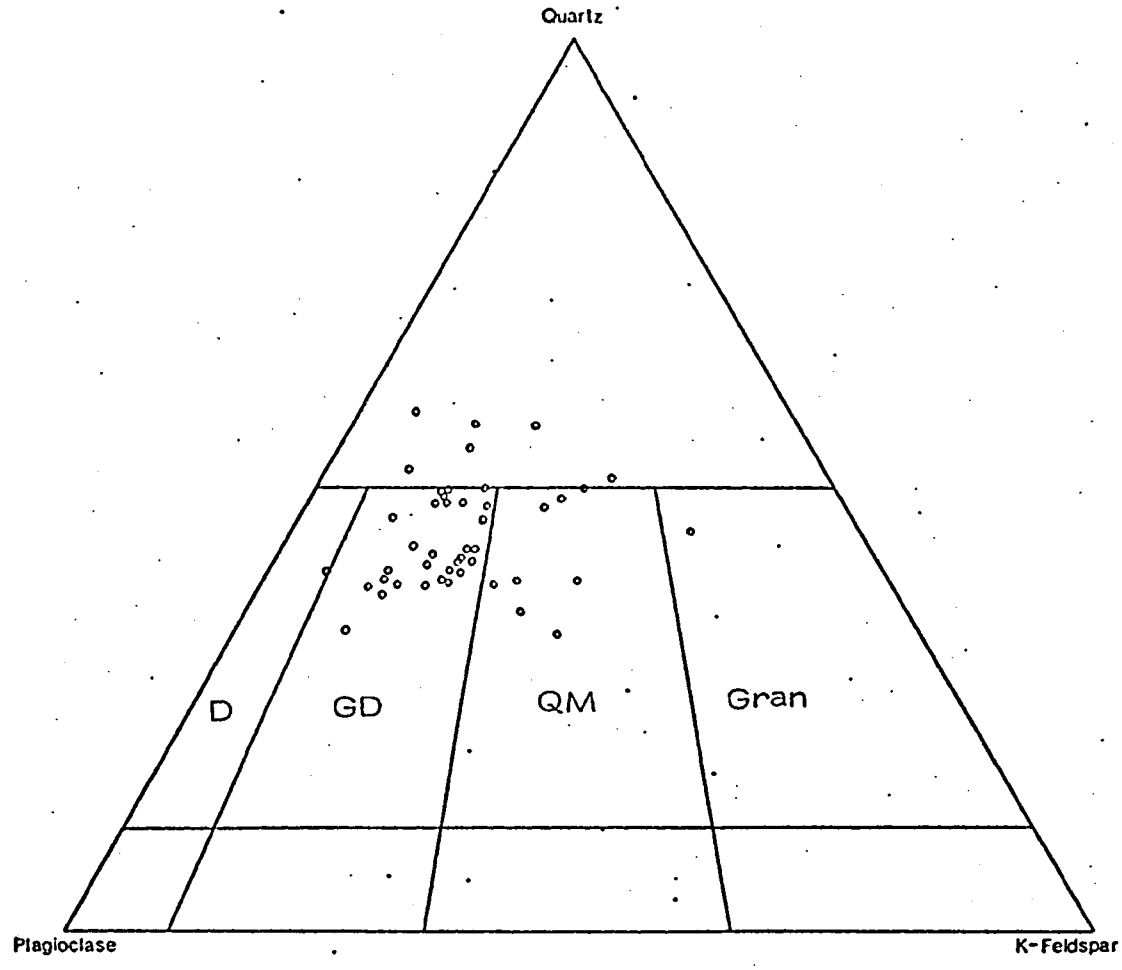


Figure 9. Relative Compositions of 45 Specimens of Precambrian Granodiorite from Thin-Section Petrographic and Binocular Microscope Estimates of Rough and Sawed Surfaces.

in pocket). An irregular contact between the granodiorite and the metavolcanics extends from the Verde fault west-northwest for a distance of about 1.5 miles, where it is covered by Paleozoic and Tertiary rocks. The granodiorite exposure terminates to the east against Cenozoic sedimentary rocks and gravels in the eastern block of the Verde fault. The granodiorite is also exposed in the upper drainages of Chasm Creek, west of the Verde fault.

Elevations of granodiorite exposures generally range from over 5000 feet on the ridges overlooking the Verde Valley to approximately 3800 feet at the Verde fault zone. The unit is well-exposed and forms a moderately to deeply weathered, light brown, grusy erosional surface. Large, rounded or blocky outcrops occur locally, principally in drainages.

The granodiorite is a uniformly massive, holocrystalline, phaneritic rock, composed predominantly of medium-grained anhedral quartz and subhedral plagioclase feldspar with subordinate amounts of fine to medium grained orthoclase, biotite, and hornblende. Apatite is ubiquitous as microscopic prisms. Muscovite, microcline, and pyroxene are rare. The plagioclase is primarily oligoclase, and is usually internally zoned. Polysynthetic albite twinning appears in most crystals, locally appearing to cut relict "shadow" zoning. Carlsbad-twinning and some pericline twinning are less common. The plagioclase grains range in size up to 5 mm in length, creating local

porphyritic phases in the rock. Quartz is generally equal in abundance to plagioclase (Figure 4, in pocket). The most common mode of occurrence of quartz in the granodiorite is as interlocking aggregates of anhedral grains interstitial to the plagioclase. Undulose extinction of quartz grains is rare. Orthoclase usually occurs as subhedral crystals which tend to be much smaller than the plagioclase crystals. The orthoclase content occasionally exceeds one-third of the total feldspar volume. Much of the orthoclase in the central portion of the Squaw Peak deposit is interstitial.

The mafic mineral content of the granodiorite rarely exceeds 15 per cent of the total volume of the rock. Throughout most of the exposed granodiorite, amphibole--dominantly hornblende--is approximately equal in abundance to biotite. Biotite is anomalously high with respect to amphibole in the vicinity of the Squaw Peak deposit. The abundance of mafic minerals in the granodiorite increases to 10 to 15 per cent near its contact with the metavolcanic rocks.

In general, the southern half of the exposed granodiorite ranges in composition from quartz diorite to granodiorite, and the northern half is predominantly granodiorite, with local variations to quartz diorite, quartz monzonite, and rarely granite. Nearer the contact with metavolcanic rocks, the granodiorite contains increased amounts of subrounded gabbroic to dioritic inclusions. The

northern edge of the exposed granodiorite mass is also distinctly coarser grained with respect to the medium grained southern portion of the unit.

The granodiorite exhibits at least three major joint orientations. These are: 1) a NNE strike, dipping gently eastward; 2) an ENE strike, dipping moderately to steeply northwestward; and 3) a NW strike, dipping vertically to steeply southwestward. The joint attitudes vary greatly throughout the Squaw Peak area, but at least two orientations are preferentially displayed. In the vicinity of the Squaw Peak deposit, the predominant joint strike direction is north to northwest, dipping steeply to the southwest.

A sample of mineralized granodiorite was dated for Phillips Petroleum by Teledyne, Inc., using the potassium-argon method, at 1,643 million years old. This age presumably represents the time of Precambrian plutonism in the Squaw Peak area. Correlation of the Squaw Peak Precambrian granodiorite to other rocks of the central Arizona batholith is uncertain. It is petrographically similar to the "quartz diorite" described by Anderson and Creasey (1958) and by Anderson and Blacet (1972).

Paleozoic Rocks

Cambrian Tapeats Sandstone

A basal Paleozoic sandstone unit unconformably overlies Precambrian rocks. The Tapeats formation crops out on the high

northeastern flanks of the southern Black Hills (Figure 1, in pocket) at an altitude of approximately 5000 feet. Small exposures of Tapeats (?) are also exposed on the eastern side of the Verde fault at elevations of 3800 to 4100 feet. In the western end of Chasm Creek, the Tapeats (?) has been downdropped by easterly-striking faults to elevations of 4000 to 4800 feet.

In the Squaw Peak area, the Tapeats (?) consists of two distinct lithologic members. A lower member of medium to coarse-grained sandstone is generally 30 to 35 feet thick, and is overlain by an upper calcareous siltstone member, varying from 10 to 15 feet in thickness. The upper member locally appears to grade into the overlying Martin limestone.

The color of the lower member ranges from dark reddish brown to light yellowish gray. The reddish color, which appears to be due to ferruginous cement, generally decreases from north to south across the Squaw Peak area. The lower unit consists of thin beds of poorly sorted, subrounded to subangular grains of variable diameters up to 3 cm in a calcareous to siliceous cement. The sandy layers are interbedded with thin, calcareous siltstone layers which are lithologically similar to the upper Tapeats (?) member. The lower sandstone layers are characterized by deep reddish color and abundant cross-bedding. The upper member grades from a reddish siltstone which conformably overlies the basal member to a light yellowish-gray

shaley layer. The upper member is easily recognizable as a slope-forming unit between the cliff-forming lower Tapeats (?) member and the cliff-forming basal member of the Martin formation.

The basal Tapeats (?) member forms conspicuous cliffs which overlie a weathered Precambrian surface. The upper member forms a sloping surface between the lower Tapeats (?) member and the Martin formation.

The attitude of the Tapeats bedding is nearly random and horizontal, with dips rarely exceeding 15 degrees. Directly west of the Squaw Peak area, the unit dips gently to the northeast (Figure 2, in pocket).

The total thickness of the Tapeats (?) in the Squaw Peak area is generally consistent at 35 to 55 feet. The unit is slightly thicker in Chasm Creek, where up to 65 feet are exposed. Variances in the thickness of the unit are attributed to irregularities in the eroded Precambrian surface. One prominent ancestral hill of Precambrian granodiorite protrudes through the Paleozoic and Tertiary rocks west of Squaw Peak. The relative consistency of the thickness of the Tapeats unit, however, suggests that the early Cambrian surface was nearly level.

The Tapeats (?) formation appears to be lithologically consistent and relatively continuous throughout the Black Hills. Descriptions of the unit in the Jerome area (Anderson and Creasey, 1958) are

equally applicable to outcroppings of the Tapeats in the Squaw Peak area. The unit is lithologically and stratigraphically similar to the Lower Cambrian Tapeats sandstone exposed in the Grand Canyon, and is tentatively assigned to the Tapeats formation.

Devonian Martin Limestone

The Devonian Martin formation is present throughout the Black Hills and is well exposed in the Squaw Peak area. The basal member of the Martin forms a continuous approximately 200 feet high cliff fronting most of the high ridges below Squaw Peak at elevations of approximately 5000 feet. Exposed sections of the Martin range locally from nil north of Squaw Peak, where the unit is obscured by boulders of the overlying Hickey basalt, to over 600 feet thick in the upper drainages of Chasm Creek. Variation in thickness is due to cover by erosionally transported boulders and debris from the overlying Hickey basalt and by faulting in the southern portion of the area. The thickness of the Martin in the Jerome area ranges from 441 to 505 feet (Anderson and Creasey, 1958). Approximately 390 feet of the Martin were measured by Huddle and Dobrovolny (1945) in the headwaters of the East Verde River about 30 miles east-southeast from Squaw Peak. The formation also outcrops at two localities east of the Verde fault, two miles north of Squaw Peak in the downdipped block of the fault on slopes of low relief and in small canyons and two miles

southeast of Squaw Peak where a massive fault block of Martin limestone is well exposed in a deep gorge cut by Chasm Creek.

The Martin formation consists of limestone, dolomitic limestone, silty limestone, and sandstone. In the Black Hills it has been divided into as many as six sub-units (Twenter and Metzger, 1963) which appear to correlate well throughout the Verde Valley. A lower light gray dolomitic basal member composed of fine to coarse grained beds commonly forms nearly vertical cliffs of up to 30 feet. This lower member directly overlies an apparently unconformable Tapeats surface. The upper Tapeats member and this basal Martin member are readily distinguishable by the shaley character of the Tapeats and the greater density of the Martin. The dense individual beds of the basal Martin member range from less than one inch to three to four feet in thickness. Fragmental beds in the basal Martin member appear locally, particularly in the southern part of the Squaw Peak area.

Overlying the lower Martin member is a pinkish gray to very light gray dolomitic limestone ranging in thickness from 100 to 150 feet. This member is characterized by platy beds less than one inch in thickness, and by steep to moderately steep slopes above the cliffs of the basal member.

Approximately 150 to 200 feet above the base of the Martin is a distinctive brown to brownish gray sandstone member two to four feet in thickness. The sandstone consists of thin beds of medium to

coarse-grained calcareous sandstone. This member was recognized as a key bed in the Martin sequence in the Jerome area (Anderson and Creasey, 1958); it appears to be continuous throughout the Squaw Peak area.

Above the sandstone member is a thick sequence of light gray to light brownish gray limestone, dolomitic limestone, and dolomite, with minor interbeds of calcareous siltstone and shale. These beds are partially exposed or absent throughout most of the northern two-thirds of the Squaw Peak area due to erosion and cover by rubble from the overlying Hickey basalt. Local fossiliferous beds containing abundant silicified compound corals are exposed.

Laramide (?) Rocks

A Laramide age of the Squaw Peak Intrusion and apparently related rocks is unconfirmed. Until a positive date is determined for the age of these rocks, they are assumed to be Laramide or approximately 65 million years old based on interpolations of Livingston's (1973) trend.

Squaw Peak Intrusion

The Precambrian granodiorite is intruded by a small quartz monzonite porphyry stock, referred to herein as the Squaw Peak Intrusion. The Squaw Peak Intrusion crops out approximately 100 to 300 feet west of the Main Tunnel (Figure 2, in pocket) as an irregular

mass with approximate surface dimensions of 400 feet by 250 feet. Drilling at the Squaw Peak deposit indicates that the stock plunges to the southwest at a moderate to steep angle (Figure 4, in pocket). The Squaw Peak Intrusion is more resistant to erosion than the enclosing Precambrian granodiorite and stands as a conspicuous, buff-colored outcrop. Numerous north-trending dikes of quartz monzonite porphyry extend from the parent intrusive. A gradational silicified contact between the Precambrian granodiorite and the Squaw Peak Intrusion exists at the western end of a small ravine west of the Main Tunnel portal of the Squaw Peak Mine. Elsewhere, the contact is sharper.

The Squaw Peak Intrusion is a holocrystalline, porphyritic rock containing anhedral to subhedral plagioclase feldspar phenocrysts up to 0.5 cm long in a fine grained phaneritic to locally aphanitic groundmass of essentially anhedral quartz and subhedral orthoclase, with minor biotite. Very minor disseminated apatite and pyrite are present. Secondary sericite, kaolinite, epidote, chlorite, and leucoxene are locally abundant. The orthoclase also appears as phenocrysts with plagioclase. The Squaw Peak Intrusion generally is composed of 35% to 50% quartz, 20% to 35% plagioclase, 20% to 30% orthoclase, and less than 5% biotite. The rock is characterized microscopically by a very fine matrix of interlocking quartz and orthoclase (Figure 23, p. 68). The Squaw Peak Intrusion is relatively unoxidized and unfractured except at its margins and along

at least one northwest-trending shear plane which cuts the stock. An area of high fracture density in the granodiorite surrounds the edges of the body (Figure 15, p. 53). A three-directional joint pattern is reflected in a "blocky" appearance of the Squaw Peak Intrusion outcrop.

A subelliptical zone of hydrothermal alteration and sulfide mineralization surrounds the Squaw Peak Intrusion stock (Figure 2, in pocket). These aspects are dealt with in a later section entitled "Mineralization and Alteration." Quartz monzonite porphyry dikes usually less than one foot in width are abundantly exposed in this zone, generally striking northwest and dipping gently to steeply southwest.

The age of emplacement of the Squaw Peak Intrusion is undetermined. There are no age determinations on the Squaw Peak Intrusion. Based on the assumptions that the copper-molybdenum mineralization at Squaw Peak is approximately the same age as other porphyry deposits of central Arizona and that the Squaw Peak Intrusion is genetically related to the mineralization, the age of the Squaw Peak Intrusion is inferred to be Laramide. The mineralized host granodiorite dated by Phillips Petroleum using the potassium-argon method is 1.643 billion years old. This age is not believed to be the age of mineralization, in which case the Squaw Peak deposit would be considered a geologically unique occurrence with respect to the ages of other porphyry deposits in the southwestern United States.

Quartz Monzonite Dikes

Numerous fine grained quartz monzonitic to granitic dikes crop out near the contact between the Precambrian granodiorite and the Ash Creek (?) metavolcanic rocks. Two areas referred to later in this report as "aplitic shattered zones" are preferentially invaded by these dikes. The dikes generally form distinct light pink to buff colored irregular outcrops. The dikes range up to 20 feet in width, although most of them are less than two feet wide.

The quartz monzonite dikes are petrographically similar to the Squaw Peak Intrusion, except that the dikes are non-porphyritic and less siliceous than the Squaw Peak Intrusion. The quartz monzonite dikes are holocrystalline, aphanitic to finely phaneritic, and generally composed of 35 to 40% quartz, 30 to 50% orthoclase, and trace amounts to 30% plagioclase. Minor biotite and veinlets of zoisite or epidote are common. The plagioclase content appears to increase from the center of the dikes to their contact with the country rock. The plagioclase also appears to be more abundant in the quartz monzonite dikes which intrude the metavolcanic rocks than in dikes intruding the granodiorite. The dikes usually appear to become progressively coarser outward from the dike center to the margin.

Two dominant orientations of quartz monzonite dikes are trending northwest, dipping vertically to steeply southwest and trending

east-west $\pm$ 20°, dipping gently to steeply south. Many of the dikes, particularly those which are exposed in the vicinity of the Squaw Peak deposit, are characterized by close proximity to fractures and quartz veins containing copper mineralization.

Pebble Dike

A small pebble dike is exposed in a road cut approximately 500 feet north of the Squaw Peak Intrusion (Figure 10). The dike is three to four feet wide and strikes northwest, dipping gently to the southwest. A similarly oriented small dike of quartz monzonite porphyry is exposed 50 feet south of the pebble dike.

The pebble dike contains abundant sub-spherical to sub-angular fragments of Precambrian granodiorite up to two inches across. The fragments are weakly epidotized and mineralized by green copper minerals, and are cemented by a shattered granodiorite matrix.

Latite Porphyry Dikes

Several northwest-trending latite porphyry dikes are exposed southeast of the Squaw Peak Intrusion (Figure 2, in pocket). The dikes generally dip southwesterly at moderate angles. The strike length of the dikes ranges up to almost 2000 feet, and their width varies from a few inches to five feet. The latite porphyry dikes consist of plagioclase phenocrysts up to two-thirds of one inch in length in a pinkish

Fig. 10. Exposure of Pebble Dike in Road Cut.

Note the rounded fragments of Precambrian granodiorite. View west.

gray to brown aphanitic matrix. Amphibole crystals up to one-third inch and irregular quartz phenocrysts are locally abundant. The contact between the dikes and the enclosing granodiorite is usually sharp. The phenocrysts in the dikes are generally smaller near their contacts than at their centers.

As the dikes approach the Squaw Peak deposit, they appear to ramify (Figure 2, in pocket) into many smaller dikes. The dikes in the vicinity of the deposit are strongly sheared in a direction parallel to their strike, and are characterized by white argillic road-cut exposures.

Cenozoic Rocks

Tertiary Hickey Basalt

Overlying the Martin limestone in the Squaw Peak area are up to 1200 feet of Tertiary (Pliocene?) volcanic basalt flows. These rocks crop out at elevations of 5000 feet to over 6500 feet about two miles west of the Squaw Peak deposit and at elevations of about 3800 feet to 4300 feet on the east side of the Verde fault (Figure 1, in pocket). Anderson and Creasey (1958) apply the name "Hickey Formation" to these rocks in the northern Black Hills, and include 50 feet of Cenozoic sedimentary rocks underlying the basalt in the type section. Twenter and Metzger (1963) noted that over 1000 feet of Cenozoic sedimentary rocks locally underlie the basalt in the Verde

Valley, and did not recognize the name "Hickey Formation" in their investigation. The term "Hickey Formation" is used in this report in reference to the basalt in light of the name's general acceptance in central Arizona geology.

The Hickey basalt in the Squaw Peak area generally forms relatively horizontal cliff-forming flow units, locally exhibiting crudely defined vertical columns on the steep upper slopes of Squaw Peak. The basalt is further characterized by dense dark reddish brown to dark brown outcrops. West of Squaw Peak the basalt is locally interbedded with tuffaceous sedimentary rocks up to several feet thick.

Paleozoic rocks in the southern portion of the Squaw Peak area are locally cut by basalt dikes which have recrystallized the Martin limestone in places. A sill approximately 15 feet in thickness exposed in Chasm Creek on the east side of the Verde fault is petrographically identical to the Hickey basalt.

The Hickey basalt is a finely porphyritic, alkali olivine basalt, containing phenocrists of olivine and minor augite in a dense, aphanitic matrix. The matrix is microscopically revealed to be a very fine mesh of sub-parallel plagioclase laths in a submicroscopic mafic base (Figure 11). A slightly poikilitic texture is created by scattered, fine, subhedral magnetite grains.

Fig. 11. Photomicrograph of Hickey Basalt.

The large, twinned olivine crystal at left is surrounded by tiny plagioclase laths. Crossed nicols, x 10.

The thickness of the Hickey formation in the Squaw Peak area is variable, presumably due in part to an irregular pre-Hickey surface. Accurate measurement of the basalt is impeded by recent erosion. Up to 1400 feet of the volcanic sequences were measured by Anderson and Creasey (1958) in the Jerome area.

Verde Formation

A thick mass of white to light gray lacustrine and fluvatile deposits blankets most of the Verde Valley in the Squaw Peak area. These deposits were named the Verde Formation by Jenkins (1923). The Verde formation occupies a northwest-trending elliptical area of about 325 square miles in the Verde Valley (Twenter and Metzger, 1963). The unit is cut by the present Verde River drainage, and forms conspicuous large white cliffs.

Four major stratigraphic members within the Verde Formation have been distinguished by Wadell (1972). These are: 1) a basal and basal-marginal sandstone and conglomerate member; 2) a lower mudstone-evaporite-carbonate member; 3) an upper carbonate-sandstone member; and 4) a volcanic member. The depositional facies of the Verde Formation vary laterally as well as vertically (Twenter and Metzger, 1963). In the Squaw Peak area, the Verde Formation is represented by coarse grained conglomerate and calcareous siltstone. The best exposure of the formation in the area is in Squaw Peak

Canyon, where up to 75 feet of poorly consolidated stratified conglomerate and siltstone are exposed. Thinly bedded siltstone and limestone are exposed in minor drainages which cut the pediment in the northeastern portion of the Squaw Peak area.

Several large hills (Figure 12) of low topographic relief on the east side of the Verde fault contain poorly sorted and poorly consolidated boulders and smaller particles of Tapeats sandstone, Precambrian rocks, Martin limestone, and Hickey basalt. These rocks are regarded as a marginal facies of the Verde Formation. The bedding dips consistently to the northeast.

The thickness of the Verde Formation in the Squaw Peak area may be as much as 3000 feet (Cooksley, 1971). The formation appears to be much thicker on the southwest side of the valley than on the northeast (Wadell, 1972). Several rotary drill holes completed by Phillips Petroleum, the deepest of which reached a depth of 972 feet, failed to penetrate the Verde sediments.

Andesitic and Basaltic Volcanic Rocks

Numerous minor exposures of mafic volcanic rocks are found in the Squaw Peak area in addition to the voluminous Hickey basalt. Outcrops of massive gray to reddish brown basalt and andesitic basalt are spatially related to the Verde fault zone. Two large outcrops of dark reddish brown andesite (?) are exposed in low hills approximately

Fig. 12. Verde Fault.

Verde fault is at the center of the photograph, at the break of the slope. The Verde formation is at the left side of the fault, with Precambrian granodiorite on the right. Foreground is hill composed of unconsolidated material of the Verde formation. At the left center is the dump from the Haulage Tunnel.

one mile northeast of the Squaw Peak deposit. These rocks appear to intrude sediments of the Verde formation. Core drilling by Phillips Petroleum established that this unit persists to a depth of over 950 feet.

Pleistocene (?) Rhyodacite

A massive rhyodacite volcanic dome intrudes the Verde formation about one mile northeast of the Squaw Peak deposit (Figure 1, in pocket). The irregular outcrop covers an area approximately 4500 feet long and 3000 feet wide. The unit forms prominent, buff-colored outcrops at elevations ranging from 3100 to 3750 feet. The rhyodacite consists of fine grained quartz and K-feldspar, with minor amphibole and plagioclase phenocrysts. Local vugs are lined with calcite.

Tuffaceous rhyodacitic rocks are exposed in minor drainages which penetrate the rhyodacite mass. Fragments of the rock up to boulder size are found in tuffaceous sedimentary rocks adjacent to the rhyodacite exposure.

The rhyodacite is the youngest known volcanic occurrence in the Squaw Peak region. No age date had been determined for the unit, but since it intrudes the Verde formation (Pliocene-Pleistocene) the rhyodacite dome near the Verde fault and related faults (Figure 1, in pocket) suggests that it was extruded after the major Verde fault movement.

Pleistocene (?) Gravels

A thin veneer of unconsolidated gravel and sand blankets most of the Verde Valley in the Squaw Peak area forming an eastward sloping pediment overlying the Verde formation. The thickness of the gravel cover varies from zero to a few feet thick on the eastern side of the Verde fault to a probable thickness of 100 to 300 feet between the fault zone and the Verde River. The gravels are derived primarily from Precambrian rocks, with minor amounts generated from Paleozoic and Cenezoic rocks. The size of the gravel fragments generally decreases towards the center of the Verde Valley.

Quaternary Riverwash

The term "riverwash" is used in this report to define sediments deposited by the Verde River which overlie the Quaternary gravels. Unconsolidated gravel, sand, and silt derived from numerous sources are present on the flanks of the Verde River in the northeastern corner of the area investigated.

CHAPTER 4

STRUCTURE

Structural elements in the Squaw Peak area are separated into pre-Laramide, Laramide, and post-Laramide deformation. Certain assumptions are necessarily made regarding the age of some structures, although it is felt that these assumptions are reasonably correct.

The dominant structural element in the Squaw Peak area is the Verde fault. Traditionally, the Verde fault zone has been interpreted to have been active since Precambrian (Anderson and Creasey, 1958). Numerous recent investigations of central Arizona (Lindgren, 1974, and others) have suggested that all or most of the movement along the fault zone has occurred during the Cenezoic era and after the deposition of the Hickey basalt. Field data from the Squaw Peak area do not support any substantial pre-Hickey disturbance along the fault zone, although the post-Hickey deformation may have obscured any earlier movement. In this report the Verde fault will be regarded as a post-Laramide feature. Faults which cut the Squaw Peak Intrusion and associated mineralization are assumed to be post-Laramide. Minor structures which received Squaw Peak mineralization are interpreted as pre-Laramide features.

The rhyodacite is the youngest known volcanic occurrence in the Squaw Peak region. No age date has been determined for the unit, but since it intrudes the Verde formation (Pliocene-Pleistocene) the rhyodacite is younger than 5 m.y. The location of the rhyodacite dome near the Verde fault and related faults (Figure 1, in pocket) suggests that it was extruded after the major Verde fault movement.

Pre-Laramide Structure

Lack of well-defined foliation in the Ash Creek (?) metamorphosed volcanic rocks restricts structural analysis of these rocks beyond a few general observations. Variable orientation of foliation where the metavolcanic rocks are more schistose suggest that the sequence may have been strongly folded at least once after its deposition. The extreme irregularity of the contact between the Precambrian granodiorite and the metavolcanic rocks may reflect further Precambrian disturbance, although the granodiorite is not cataclastically deformed.

The dominant structural grain of the Precambrian granodiorite trends northwest. Minor faults and fractures generally trend N. 10° W. to N. 75° W. and dip moderately to steeply southwest. Granitic shear dikes, shear breccia dikes, and latite porphyry dikes surrounding the deposit trend north to N. 25° W. Joint fractures in mineralized and unmineralized Precambrian granodiorite are generally strongest in a

N. 40° W. to N. 70° W. direction, with southwesterly dips to 60° to 80°. The northwest trending, southwest dipping orientation is most strongly reflected in the mineralized veins and fractures within the Squaw Peak deposit (Figure 13). The average mineralized plane in the deposit strikes N. 33° W. and dips 69° to the southwest.

Quartz monzonite porphyry dikes emanating from the Squaw Peak Intrusion trend roughly north-south. The deposit itself is also elongate to the north. No north trending structural feature is recognized as the localizing mechanism for the Squaw Peak Intrusion.

Laramide Structure

Several structural features appear to be genetically related to the Squaw Peak Intrusion emplacement, and are interpreted as Laramide. These structures almost certainly follow pre-Laramide structurally weak zones, but internally they exhibit apparent Laramide shearing and brecciation.

"Aplitic Shattered Zones"

The term "aplitic shattered zones" in this report refers to two structurally weak areas along the contact of the Precambrian granodiorite and the Ash Creek metavolcanics. These zones are characterized by local brecciation (Figure 14, p. 50), moderate fracturing, local stockworks of quartz veins, abundant "aplitic," or

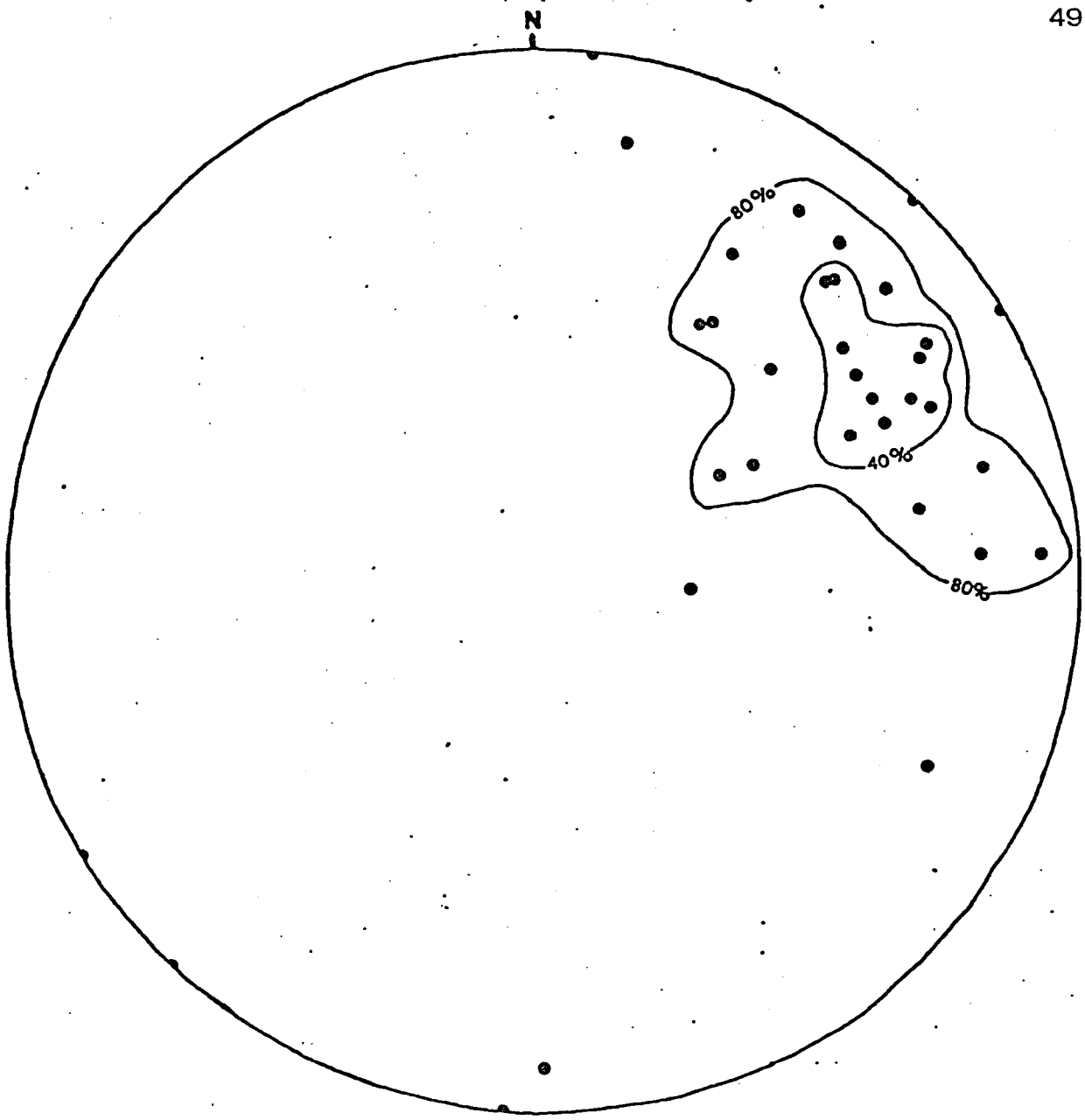


Figure 13. Poles to Mineralized Fracture Planes and Veins at the Squaw Peak Deposit.

Plotted on a Wolfe equal-angle net, taken from 31 field measurements. Contours represent relative concentrations of points. Average orientation of mineralized plane is: strike N. 33° W., dip 69° SW.

Fig. 14. Outcrop in Aplitic Shattered Zone.

Rock is mostly granodiorite (PCg), with large, angular block above the pick of green metamorphosed volcanic rock (PCac). Both the granodiorite and the meta-volcanic rock are cut by irregular quartz monzonite ("aplite") dikes exposed in the lower left and center of the picture as a light tan rock with smooth surfaces.

fine grained quartz monzonitic dikes, and sparse copper mineralization. The zones from extremely irregular indistinct outcrops which vary from over 1500 feet in length to less than 200 feet in width, generally elongate parallel to the Precambrian contact.

The easternmost aplitic shattered zone is the larger of the two zones, and is truncated on its eastern margin by the Verde fault (Figure 1, in pocket). The zone contains dozens of fine grained quartz monzonite to granite dikes which normally strike north to northwest and dip moderately southwest. Most of the dikes are less than one foot in width. The dikes are commonly irregularly intruded in areas of weakly shattered rock containing angular blocks of granodiorite and metavolcanic rocks. The southwestern corner of the zone is characterized by locally strong quartz veining. The quartz veins generally occur as barren "bull quartz" veins which display random strikes and moderate to steep dips. The veins vary in size from small stringers to veins of several centimeters in width. Epidote and pink feldspar are locally common accessory minerals. Copper mineralization--malachite and minor chrysocolla--is primarily restricted to areas of strongest fracturing.

The western aplitic shattered zone (Figure 1, in pocket) is similar in most respects to the eastern zone. The quartz monzonite dikes in the western zone appear to be larger, often over one foot

wide. Copper mineralization in the western shattered zone is less abundant than in the eastern zone.

Granitic Shear Zones

Extending southward for 1500 to 2000 feet from the Squaw Peak Intrusion are two subparallel zones (Figure 15 and Figure 16) herein referred to as granitic shear zones. The zones strike north to northwest and dip steeply to the southwest, and range in width up to 30 feet in road cut exposures near the Squaw Peak Intrusion and gradually diminish southward to an indistinct shear zone only a few inches wide. The zones coalesce at one point approximately 850 feet south of the Squaw Peak Intrusion. These granitic shear zones are intensely sheared in the vicinity of the Squaw Peak deposit forming distinct white to light gray exposures in road cuts (Figure 15). Southward the zones are characterized by massive, dark gray to brown outcrops which exhibit moderate shearing, particularly at the margins. The less sheared portions of the zones consist of a shattered locally porphyritic, granitic rock which is compositionally similar to the Precambrian granodiorite. The rock is composed predominantly of medium grained quartz and plagioclase, with minor K-feldspar and biotite. Trace amounts of chlorite, epidote, limonite, pyrite, and chalcopyrite are mesoscopically visible on minor fractures. Fragmentation of quartz and feldspar crystals

Fig. 15. An Exposure of a Bleached Granitic Shear Zone South of the Squaw Peak Intrusion. At the right and left of the zone is consolidated granodiorite. View south.

Fig. 16. Granodiorite Exposure at Contact with Granitic Shear Zone.

Near south edge of Squaw Peak Intrusion. Rock is weakly brecciated and re-healed. View west.

is microscopically evident. Sericite is common both in veinlets and as coarse-grained masses.

The granitic shear zones are mineralized by chalcopyrite, pyrite, molybdenite, and secondary copper minerals for up to one thousand feet south of the Squaw Peak Intrusion. The sulfide mineralization is commonly localized by quartz veins up to three feet wide and by fracturing within the dikes.

Post-Laramide Structure

Verde Fault

The post-mineralization deformational history of the Squaw Peak area is dominated by the development of the Verde Valley graben and by movement along the Verde fault. The Verde fault in this report refers to a conspicuous shear zone of about forty feet in width which is either exposed in drainages or is intrinsically obvious above covered exposures. The Verde fault at Squaw Peak is the western-most break of a series of normal faults which trend northwest at the base of the Black Hills (Cooksley, 1971). It trends north to northwest through most of the mapped area and parallels the base of the Black Hills. The Verde fault zone consists of the Verde fault and several sub-parallel and hinge faults. Most of the subordinate faults are east of the main zone, and some are obscured by recent volcanic rocks and alluvium.

The Verde fault is a normal fault with the east fault block displaced downward with respect to the rocks on the west. Where exposed, the dip of the Verde fault is 40° to 70° to the east.

Sedimentary rocks of Quaternary age are generally exposed on the east side of the Verde fault and are in fault contact with Precambrian rocks on the west. North of Squaw Peak, Paleozoic sedimentary rocks and Tertiary basalt are exposed to the east of the Verde fault and in contact with Precambrian metavolcanic rocks on the west side of the fault. In the Chasm Creek area, Paleozoic rocks are exposed east of the fault zone in contact with Precambrian granodiorite and lower Paleozoic units on the west.

The most conspicuous displacement on the Verde fault zone in the Squaw Peak area resulted from movement after the displacement of the Tertiary Hickey basalt which blankets the higher ridges in the western portion of the mapped area. Where the Hickey basalt is exposed on the east side of the Verde fault, the base of the unit is 1100 to 1300 feet lower than the base of the basalt west of the fault Seismic evidence (Cooksley, 1971) indicates that the total vertical displacement east of the Squaw Peak deposit may be over 4000 feet (Figure 30, p. 93).

Structures Cutting the Squaw Peak Intrusion

A northwest-striking, southwest-dipping fault cuts the Squaw Peak Intrusion surface exposure almost in half. Mineralization and

alteration appear to persist to a lower depth on the southwest side of this fault (Figure 4, in pocket), suggesting that the southwest side has been dropped with respect to the northeast side. The economic significance of this structure is discussed under the heading "Exploration Potential." Several other sub-parallel, steeply dipping faults cut the Squaw Peak Intrusion.

Shear Breccia and Shear Breccia Zones

Three shear breccia zones and one irregular weakly brecciated zone outcrop east and northeast of the Squaw Peak deposit. The dikes (Figure 17) strike northwest and dip vertically to steeply northeast. The width of the zones ranges up to nearly 20 feet. The shearing is spatially related to the Verde fault, and the trend of the zones is sub-parallel to the trend of the Verde fault, although the zones are possibly related to the Squaw Peak mineralizing event. The shear breccia is characterized by irregular, rusty brown outcrops, a sheared granitic texture, and shattered quartz and feldspar crystals. Mafic minerals are commonly argillized and chloritized.

The Verde Fault Related to Regional Structure

The Verde fault is located in the center of a large-scale northwest-trending fracture system which divides the Colorado Plateau from the Basin and Range Province (Figure 18, p. 58). This structure is considered (Jerome and Cook, 1967, and others) to be part of a major

Fig. 17. Shear Breccia Zone.

Outcrop is approximately 1500 feet northeast of the Squaw Peak Intrusion. View north.

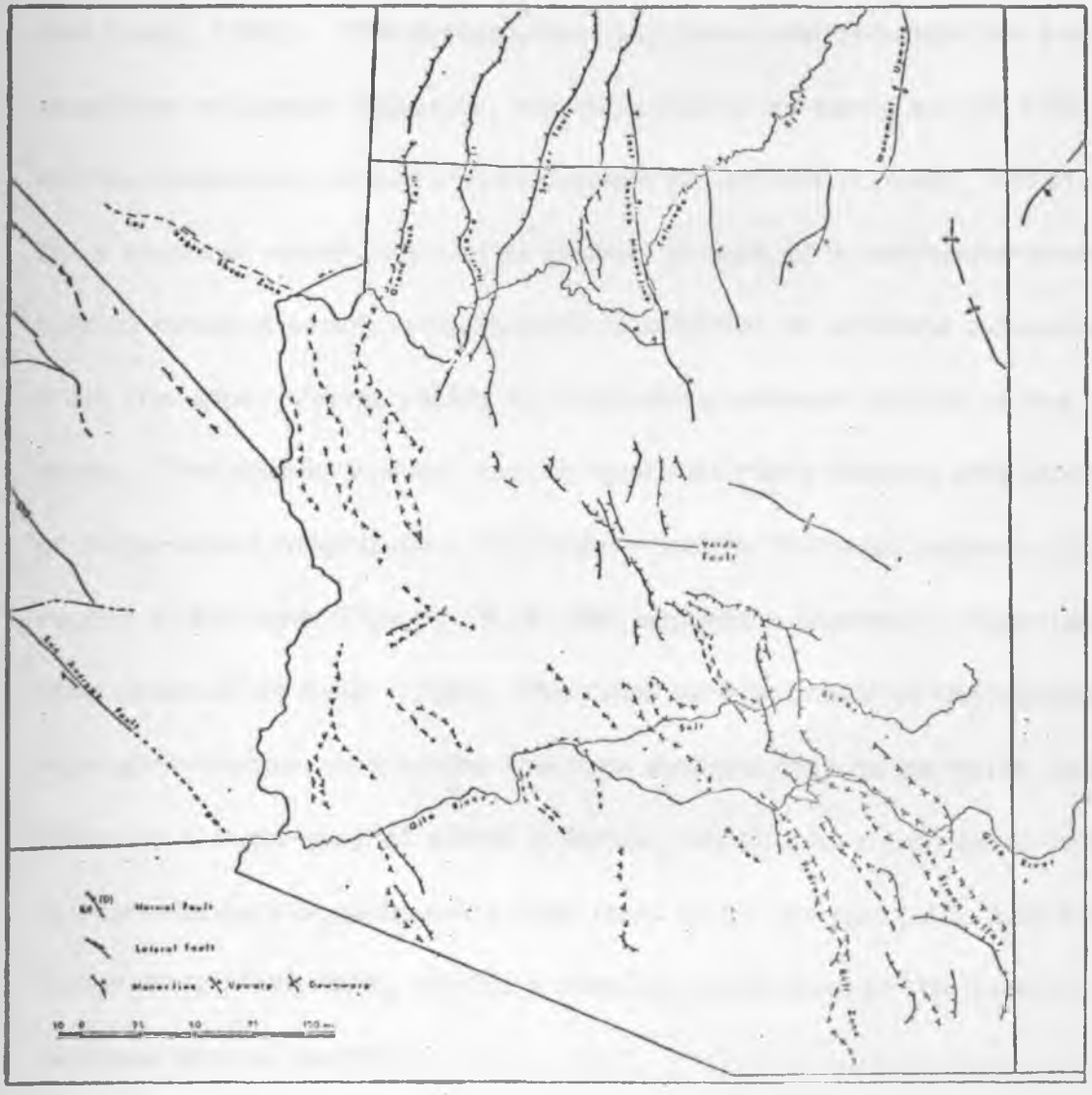


Figure 18. The Verde Fault in its Regional Tectonic Setting.

crustal break which trends west-north-westward from Texas through southern Arizona and northwestward from Arizona to Nevada (Jerome and Cook, 1967). The system has long been acknowledged as a potent localizer of copper deposits, possibly active as early as the 1680 million-year-old United Verde deposit at Jerome (Lowell, 1974). On a regional scale, the Verde graben is part of a northwest-trending belt in Arizona which is composed of a series of grabens extending from the upper Verde Valley through the southeast corner of the state. The graben system has an apparent right-lateral displacement of large-scale magnitude. Deviations in the drainage patterns of major rivers in Arizona (Figure 18, p. 58) suggest a Cenozoic right-lateral disruption of 45 to 50 miles. Possible displacement of the Cambrian Abrigo formation across the fracture system may be as much as 30 miles in a right-lateral sense (Peirce, 1974). As much as 45 miles to right-lateral displacement may have occurred along the Las Vegas shear zone (Anderson, 1973), a possible extension of the central Arizona graben system.

CHAPTER 5

MINERALIZATION AND ALTERATION

Sulfide mineralization and crudely zoned alteration assemblages in the Precambrian granodiorite are spatially associated with the Squaw Peak Intrusion. An inner zone of strong to moderate sulfide mineralization occurs with quartz-sericite alteration and local orthoclase-biotite alteration. The inner zone is sub-concentric around the Squaw Peak Intrusion stock (Figure 2, in pocket). An outer zone of vein and fracture-controlled quartz-orthoclase-chlorite-epidote-calcite alteration and sulfide mineralization encloses and overlaps the inner zone. Ore reserves are estimated at approximately 20 million tons averaging 0.36 per cent Cu (Jones, 1974).

Inner Zone Alteration and Mineralization

The inner zone of alteration and mineralization is developed in a north-trending sub-elliptical surface outline around the Squaw Peak Intrusion. In cross-section the strongest sulfide mineralization assumes the shape of a steep-sided bowl (Figure 4, in pocket). The zone is characterized by a moderate to high fracture density (Figure 19) and locally substantial mineralization.

The primary economic minerals in the Squaw Peak deposit are chalcopyrite and molybdenite. Chalcopyrite normally occurs in

Fig. 19. High Fracture Density Zone in Precambrian Granodiorite.

Outcrop is about 150 feet southeast of the Squaw Peak Intrusion. Copper content is 0.4 to 0.5 per cent, as chalcopyrite and oxidized copper minerals after chalcopyrite. View south.

quartz veinlets, in fracture coating, and as disseminated grains or masses within small mafic-rich pods, particularly in the Precambrian granodiorite and the contact zone between the granodiorite and the Squaw Peak Intrusion. Bornite is rare. Molybdenite occurs with chalcopyrite, mostly in quartz-sulfide veinlets. The strongest molybdenite mineralization is at the margin of the Squaw Peak Intrusion. Pyrite occurs ubiquitously with chalcopyrite and molybdenite in quartz veins, along fractures, and disseminated in mafic masses. Disseminated sulfide mineralization is spatially related to mineralized fractures and veins. The existence of chalcopyrite, molybdenite, and pyrite within common veins suggests that relative continuous sulfide mineralization occurred in a single phase. No consistent cross-cutting vein relationships are apparent. Minor amounts of gold, silver, tungsten, and rhenium were geochemically determined to be present within the inner zonal mineralization. Malachite, chrysocolla, azurite, and ankerite (?) are present as secondary weathering products of chalcopyrite in a relatively shallow zone of oxidation. The oxidation zone varies in thickness from 0 to 100 feet, usually not exceeding 50 feet. Chalcocite and ferrimolybdite were not observed to be present.

Moderate sulfide mineralization is exposed in a north-trending zone approximately 1200 feet long and 800 feet wide (Figure 2, in pocket). The center of this zone is occupied by the Squaw Peak Intrusion. The Squaw Peak Intrusion itself is sulfide-deficient, except

at its perimeter, where a gradational contact with the Precambrian granodiorite is abundantly mineralized by up to 0.8% copper (Figure 20) and 3-4% pyrite. Molybdenite is concentrated in areas of stronger fracturing north, south, and southeast of the Squaw Peak Intrusion (Figure 21, p. 65). Thus a barren core is enveloped by a chalcopyrite-pyrite-molybdenite assemblage which yields outward to a pyrite-chalcopyrite assemblage (Figure 29, p. 79). The sulfide content is relatively low throughout the deposit. The pyrite halo commonly associated with southwestern porphyry deposits is not evident at Squaw Peak, where pyrite seldom exceeds two per cent by volume.

Minor sphalerite occurs in areas of stronger fracture density. Zinc in surface geochemistry is crudely haloed around the deposit (Figure 22, p. 66). The zinc concentrations appear to be spatially more related to the molybdenum than to the copper mineralization.

Alteration within the inner zone is characterized by pervasive silicification, quartz and quartz-sulfide veins, moderate to strong sericitization of feldspars, secondary biotite masses, local secondary orthoclase flooding, and local chloritization and epidotization of mafic minerals. A central core of quartz-sericite and structurally localized quartz-biotite-orthoclase-sericite alteration is surrounded by a zone of quartz-sericite alteration (Figure 29, p. 79).

Figure 20. Copper Soil Geochemistry.

Figure 21. Molybdenum Soil Geochemistry.

Figure 22. Zinc Soil Geochemistry.

The Squaw Peak Intrusion forms an irregular outcrop in the center of the deposit. Although much of the surface exposure of the intrusive appears to be unaltered, it is difficult to determine the extent to which secondary effects of hydrothermal alteration were developed within the stock. The plagioclase phenocrysts in the Squaw Peak Intrusion are typically weakly to moderately dusted by sericite and some kaolin (?). Albite rims around plagioclase crystals are common (Figure 23). Quartz and orthoclase are major constituents of the rock, occurring as interlocking, subhedral crystals in a coarsely sucrose matrix (Figure 23). Biotite is the only mafic mineral in the Squaw Peak Intrusion, although biotite rarely comprises more than five per cent of the rock. Biotite occurs mesoscopically as compact, shiny crystals or "books" normally less than two millimeters in any dimension.

Enveloping the Squaw Peak Intrusion is a small, north-trending, sub-elliptical surface exposure of quartz-sericite, or "phyllic" alteration, characterized by abundant quartz veins and quartz-sericite veins and by pervasive sericitization of feldspars. Plagioclase is the most susceptible mineral to the sericitization. Sericite usually replaces 40 to 80 percent of the plagioclase in the inner alteration zone. The local orthoclase-biotite-sericite, or "potassic" alteration is characterized by shreddy masses of fine grained biotite surrounded by interstitial blebs of anhedral orthoclase

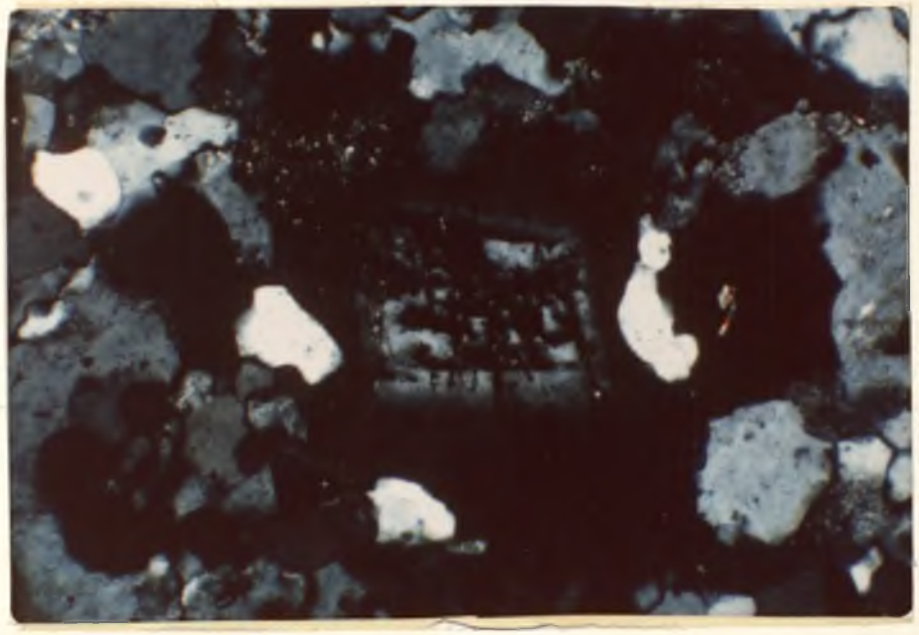


Fig. 23. Plagioclase Crystal with Albite Reaction Rim, in Squaw Peak Intrusion.

Surrounded by quartz and K-feldspar. Crossed nicols, x 3.5.

Figure 24, and Figure 25, p. 71). Sulfide mineralization is often spatially associated with the biotite-orthoclase aggregates (Figure 24).

In the potassically altered Precambrian-granodiorite secondary orthoclase and biotite typically occur as irregular patches of interlocking grains. Orthoclase less commonly occurs in veinlets with quartz and sometimes sericite and sulfide minerals. Biotite in veinlets is rare, although elongate aggregates of biotite are often localized along minute fractures.

Potassic alteration features are progressively less abundant outward from the Squaw Peak Intrusion. Flooding of K-feldspar appears to be controlled largely by faults, and the disappearance of fracture-related secondary orthoclase within the Squaw Peak alteration system may never be attained. A central zone of biotite stability and amphibole instability appears to be roughly coincident with the inner zone of alteration. Ragged aggregates of biotite grains, however, gradually decrease with distance from the Squaw Peak Intrusion as hornblende increases.

The transition from predominantly potassic to quartz-sericite, or "phyllic" alteration in the granodiorite is indistinct. Sericitization of plagioclase in the potassically altered granodiorite is as strong or stronger as in the phyllic zone. Quartz, quartz-sericite and quartz-sericite-sulfide veinlets gradually decrease in abundance with distance from the Squaw Peak Intrusion. The primary distinction between

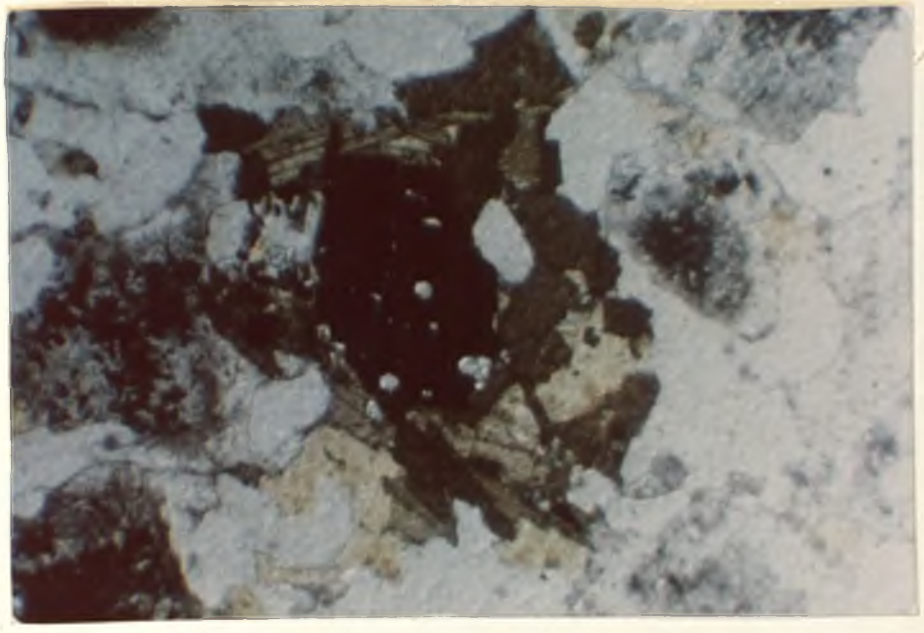


Fig. 24. Photomicrograph of Disseminated Sulfides in a Potassic Alteration Assemblage.

Black sulfide grains are envoloped by an aggregate of biotite, K-feldspar, and quartz in a matrix of sericitized plagioclase and quartz. Specimen from potassically altered Precambrian granodiorite. Plane light, x 3.5.

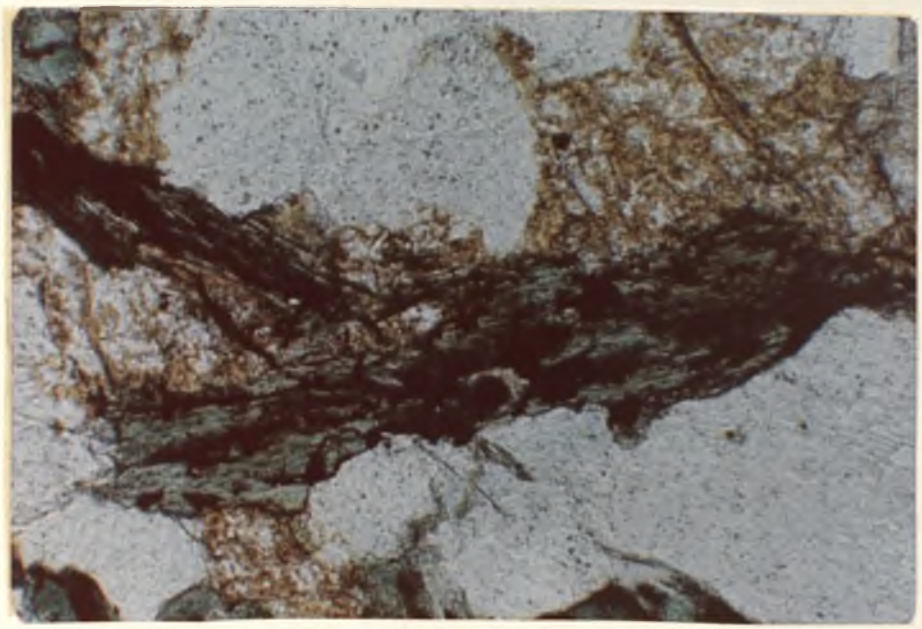


Fig. 25. An Elongate Biotite Aggregate Accompanied by Secondary Orthoclase.

Orthoclase is stained yellow. Aggregate is surrounded by quartz and plagioclase. From potassically altered Precambrian granodiorite. Plane light, x 10.

potassic and phyllic alteration in the granodiorite is the lack of secondary orthoclase and less common occurrence of shreddy biotite masses in the phyllically altered rock.

Primary biotite in the granodiorite appears to be unstable in the inner alteration zone, occurring as large corroded crystals partially replaced by sericite (Figure 26). Secondary shreddy biotite is more prevalent in the inner zone. The secondary biotite may have resulted entirely from replacement of other mafic minerals, principally hornblende, by biotite and subsequent migration of the biotite through fractures and pore spaces in the granodiorite.

Albitization, a common feature of the inner zone, is developed both in the Squaw Peak Intrusive and in the Precambrian granodiorite. Plagioclase feldspars are often albitized around the edges of crystals. More commonly, the albite occurs in tiny quartz-albite veinlets, with albitization developed in plagioclase cut by the veinlets. Trace amounts of anhydrite and magnetite occur within the inner alteration zone.

Vertical alteration changes are obscure. No substantial variations in alteration appear to exist with depth; however, a few deeper holes in the deposit displayed weak chloritic alteration of secondary biotite, suggesting that potassic-phyllic alteration assemblages may yield to propylitized rock at greater depths. The chlorite may otherwise represent a late-stage propylitic alteration phase.

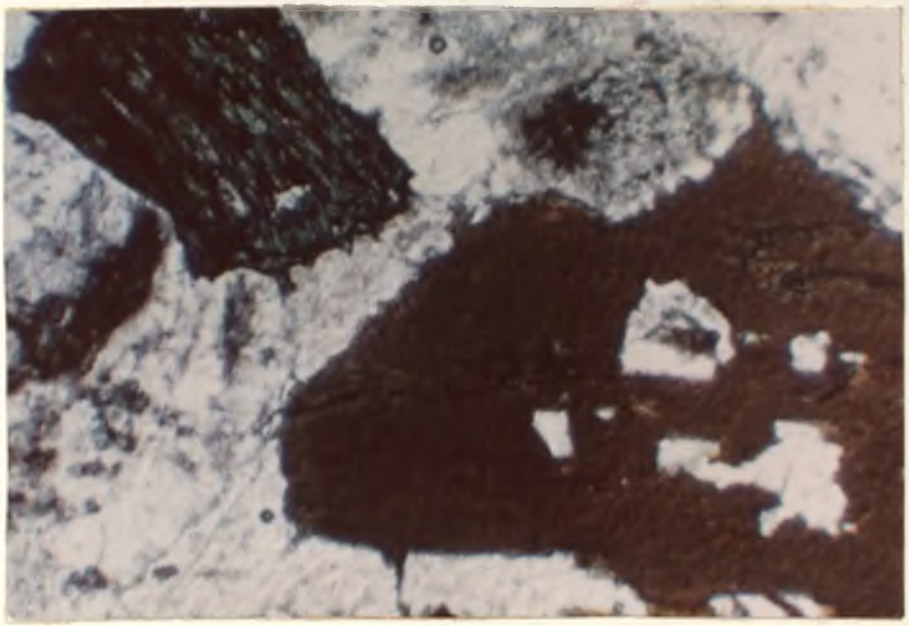


Figure 26. Photomicrograph Showing Two Modes of Biotite in Altered Precambrian Granodiorite.

A shreddy secondary (?) biotite crystal is at the upper left, in contrast to the large, corroded primary (?) crystal at the lower right. Surrounded by sericitized plagioclase and quartz. Plane light, x 3.5.

Disseminated sulfide mineralization is distinctly related to aggregates of mafic minerals. Irregular masses of pyrite, chalcopyrite, and molybdenite are commonly contained within or are peripheral to shreddy aggregates or single grains of biotite or chloritized biotite. Typically, the sulfide mineralization forms the central core of the alteration assemblage composed of variable amounts of biotite, chlorite, epidote-zoisite, orthoclase, and calcite (Figure 24, p. 70, and Figure 27). Apatite, an ubiquitous constituent of the Precambrian granodiorite, exhibits a marked affinity for recrystallation within or around the mafic alteration assemblage. Although the disseminated sulfides are almost always spatially associated with this assemblage, the sulfides are not essential for the formation of the mafic alteration clots.

Disseminated sulfide mineralization in the inner zone is outwardly succeeded by vein-related mineralization. Chalcopyrite is typically developed in quartz, quartz-orthoclase, or quartz-sericite veins as anhedral patches, usually elongate in the strike direction of the vein. Subhedral to euhedral pyrite and curved plates or poorly developed rosette-shaped aggregates of molybdenite, are common constituents of quartz-chalcopyrite veins, although molybdenite appears to be spatially more related to chalcopyrite than to pyrite. Mafic alteration patches in the wallrock of the sulfide-bearing veins are susceptible sites to sulfide mineralization.

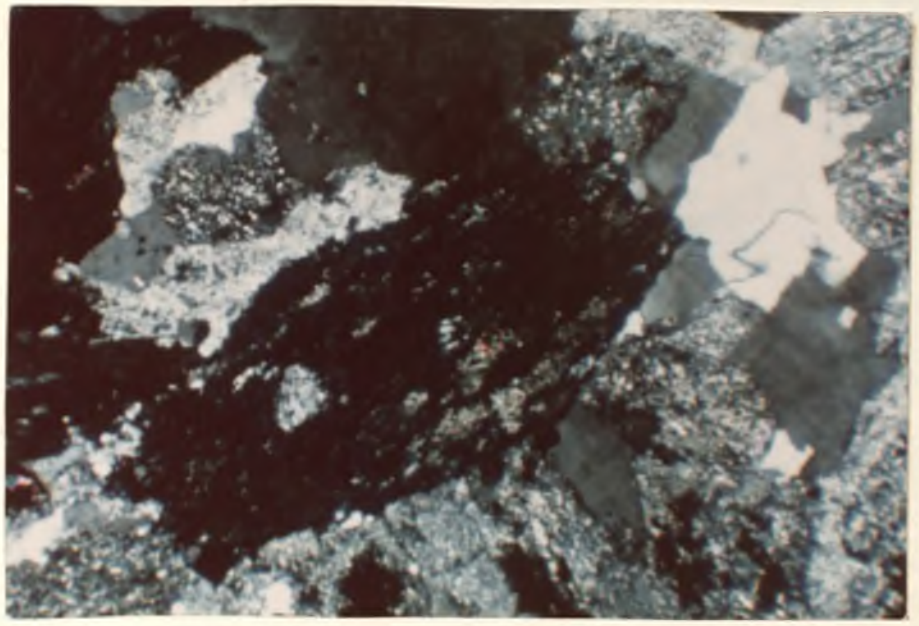


Figure 27. Amphibole Crystal Replaced by Chlorite, Calcite, and Epidote.

Surrounded by quartz, K-feldspar, and plagioclase. Plagioclase is dusted by fine grained sericite and kaolinite. From propylitized Precambrian granodiorite, drill hole DDH 13. Crossed nicols, x 3.5.

Outer Zone Alteration and Mineralization

Enclosing and overlapping the inner alteration-mineralization zone is a large "propylitized" area containing a quartz-chlorite-epidote-orthoclase-calcite assemblage and weak sulfide mineralization which is confined primarily to veins and fractures which strike predominantly northwest and dip steeply southwest. This zone is a maximum of 4600 feet long in a north-northwest direction, and up to 2500 feet wide. Sparse quartz-chalcopyrite or quartz-chalcopyrite-molybdenite veins occur in a 1500 foot by 3500 foot area within the zone. The Squaw Peak Intrusion is at the southeastern end of the outer zone.

The coincident occurrence of sulfide mineralization with alteration does not appear as generally in the outer zone as in the inner zone. Although the quartz-sulfide veins occur within the same area as the quartz-epidote-orthoclase veins, sulfide and alteration mineralization are not necessarily present in the same vein. Typical alteration veins are composed of quartz and epidote with an alteration envelope of salmon-colored K-feldspar. Calcite is present in the wallrock as thin films on microfractures. The entire assemblage seldom persists over a width of five inches. The outer assemblage veins occur within the fringes of the inner alteration zone, as close as 250 feet from the Squaw Peak Intrusion outcrop.

Local areas of pervasive chloritization, calcitization, and epidotization of amphibole and biotite occur in the outer zone in more strongly fractured rock. Locally pervasive epidote-chlorite-calcite alteration of amphibole (Figure 27, p. 75) and biotite and sericitization of plagioclase feldspar (Figure 28) persist to depths of over 1000 feet in drill core from the northwest side of the Squaw Peak deposit. Epidote is flooded up to a width of several centimeters and is spatially associated with locally complete chlorite-calcite alteration of amphibole and biotite (Figure 27, p. 75). Sericite is a common alteration product of plagioclase in the propylitized areas, but the plagioclase is seldom more than one-third replaced by sericite in the outer zone.

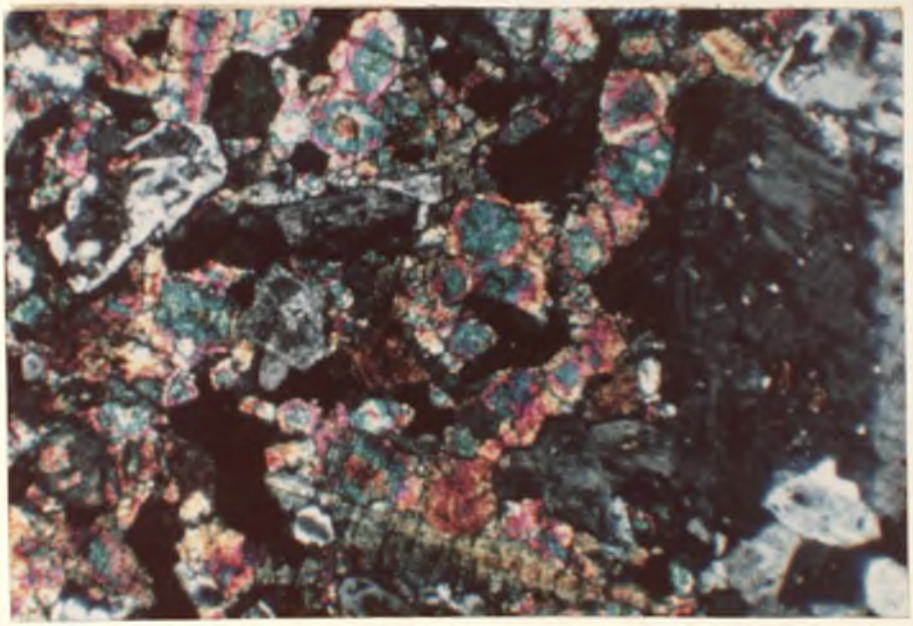


Figure 28. Quartz-Epidote Vein in Precambrian Granodiorite.

Epidote and zoisite are replacing plagioclase. Some of the darker grains at lower left are pyrite. Specimen from drill core in DDH 13. Crossed nicols, x 10.

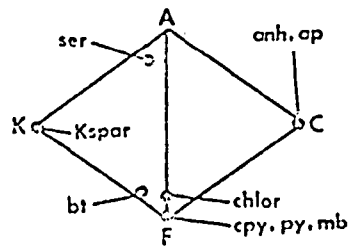
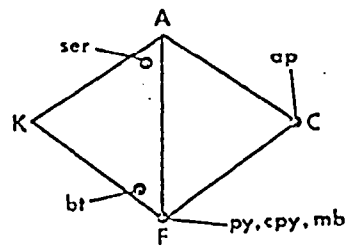
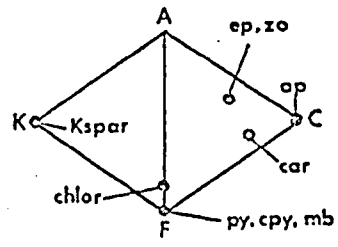
ALTERATION	POTASSIC	PHYLLIC	PROPYLITIC
Primary minerals: quartz plagioclase orthoclase biotite hornblende	Major alteration assemblage: quartz (flooded, veins) biotite (secondary interstitial masses and repl. amphibole) orthoclase (veins, repl. plagioclase) sericite (repl. plagioclase, veins). Minor alteration minerals: apatite, anhydrite, chlorite	Major alteration assemblage: sericite (veins, repl. plagioclase) quartz (veins, flooded) Py (with quartz veins, disseminated). Minor alteration minerals: biotite, apatite	Major alteration assemblage: epidote, zoisite (veins, repl. mafics and plagioclase) chlorite (repl. mafics, veins) K-feldspar (envelopes on quartz-epidote veins) calcite (veins, repl. mafics). Minor alteration minerals: sericite, apatite
Sulfide Minerals	Cpy py mb	py cpy moly	py cpy moly
A-C-K-F Diagrams A = Al_2O_3 C = CaO K = K_2O F = FeO, MgO			
Remarks	Enclosed in phyllic zone. Chlorite possibly a late-stage overprint.	Overlaps potassic zone.	Strongly vein-controlled. Weak pervasive chloritization of mafics.

Figure 29. Summary of Alteration Types in Precambrian Granodiorite.

CHAPTER 6

INTERPRETATION

The spatial and geometrical association of the mineralization and alteration with the Squaw Peak Intrusion indicate that it is responsible for the Squaw Peak deposit and suggest that the presumption that the mineralization is Precambrian is incorrect. Locally pervasive and fracture-related alteration and mineralization were introduced into the Precambrian granodiorite in response to the thermal effects of the Squaw Peak Intrusion. Overlapping of the alteration zones indicates a gradational decrease in hydrothermal activity with time and space. Weak, structurally localized potassic alteration features suggest a low K+ activity in thermally driven solutions surrounding the Squaw Peak Intrusion. Imprinting of propylitic vein assemblages upon the inner alteration assemblage indicates that weak thermal activity persisted after the main mineralizing event.

The lack of strongly pervasive mineralization and alteration in the Squaw Peak system may be due to the failure of hydrothermal solutions to freely circulate. The Squaw Peak Intrusion may have been intruded in a relatively anhydrous state, thereby preventing extensive cracking and fracturing in the host rocks (Burnham, 1967). High fracture densities are observed around the edges of the Squaw

Peak Intrusion, but the extensive shattering typical of productive porphyry copper deposits was not achieved at Squaw Peak. The broad, albeit weak, propylitic zone extending northward from the Squaw Peak deposit may be attributed to greater structural accessibility toward the Precambrian granodiorite-metavolcanic contact. A north-northwest pre-mineralization structural grain facilitated the migration of hydrothermal fluids toward the contact.

The mineralized zone at Squaw Peak appears to resemble a steep-sided bowl in cross-section (Figure 4, in pocket). The 0.1% copper "shell" is approximately 4200 feet long in a north-northwestward direction, 1900 feet wide in an east-northeastward direction, and 900 feet deep at the center of the deposit. In order to estimate the original dimensions of the Squaw Peak deposit, an analogy is drawn to the San Manuel/Kalamazoo orebody described by Lowell and Guilbert (1970). The San Manuel/Kalamazoo orebody is cylindrical in shape, $\pm$ 8000 feet high, and 2500-5000 feet wide (Lowell and Guilbert, 1970) with approximately a 2:1 height to width ratio. In a cross section normal to the dominant structural grain of the Squaw Peak area, the Squaw Peak deposit is 1500 feet wide. Assuming a cylindrical shape and a 2:1 ratio of height/width for the original Squaw Peak deposit, over 2000 feet of the mineralized body may have been eroded. Estimates of the original size of the Squaw Peak deposit are extremely speculative. The deposit bears numerous similarities to those of

documented porphyry copper-molybdenum deposits, as well as several deviations from the "typical" porphyry deposit. The gross similarities and dissimilarities may help interpret the nature of the Squaw Peak mineralization. The erratic intensity and extensiveness of the mineralization and alteration at Squaw Peak are typical of smaller porphyry occurrences (Guilbert and Lowell, 1974). The lateral alteration sequence in the Squaw Peak deposit--grading outward from potassic/phyllic to phyllic to propylitic alteration--generally correlates with the alteration scheme of the San Manuel/Kalamazoo orebody presented by Lowell and Guilbert (1970). The obvious deviations from the San Manuel/Kalamazoo model are the low pervasiveness of mineralization and alteration and the much smaller size of the Squaw Peak deposit.

The peripheral quartz-chlorite-epidote-orthoclase-calcite assemblage of the Squaw Peak deposit bears a strong similarity to the outer alteration zones of deeper portions of other porphyry copper orebodies. A peripheral quartz-K-feldspar-epidote-chlorite assemblage exists at depth in porphyry copper deposits at Sierrita, Arizona and Bethlehem, British Columbia (Guilbert and Lowell, 1974). At Squaw Peak, however, the propylitic alteration is restricted primarily to fractures, further suggesting that the Squaw Peak deposit was originally a small system.

Lateral and vertical zoning of the mineralization at Squaw Peak also imply that the deposit is moderately to deeply eroded. The

zinc mineralization is haloed around the strongest copper concentration (Figure 22, p. 66), a characteristic of outer mineralization assemblages (Lowell and Guilbert, 1970). The Mo:Cu ratio at Squaw Peak appears to increase and stabilize with depth. It has been noted (Lowell and Guilbert, 1970) that the highest molybdenum contents of porphyry deposits are concentrated in the center or lower portion of the deposit.

In summary, the lack of extensive and pervasive alteration and fracturing at Squaw Peak indicate that the system failed to develop to the extent that is observed in most productive porphyry systems. Mineral assemblages and lateral-vertical zoning of these assemblages, however, are typical of most porphyry deposits in granitic host rocks. The spatial features of the mineralization and alteration at Squaw Peak suggest that the deposit is a moderately to deeply eroded remnant of a small Laramide porphyry system.

Genesis of the Squaw Peak Deposit

Attention in this study has centered on aspects of the mineralization and alteration zoning at Squaw Peak. In the light of recent studies of porphyry copper deposits, some general theoretical interpretations are made with reference to the Squaw Peak deposit.

Observation of relatively uneroded porphyry systems (Sillitoe, 1973) indicate that porphyritic bodies associated with porphyry copper systems are emplaced at relatively shallow depths. The

Squaw Peak Intrusion at its present exposure probably represents a surface about 2500 to 3000 feet below the Laramide surface, assuming a Paleozoic and Mesozoic depositional history inferred by McKee (1951). A sudden drop in water pressure in the Squaw Peak Intrusion magma as it neared the surface is probably responsible for the crystallization of a fine grained groundmass (Fournier, 1968). Gradational contacts between the Squaw Peak Intrusion and the Precambrian granodiorite, the presence of porphyritic quartz monzonite dikes, and the relative lack of brecciation serve to indicate that the Squaw Peak Intrusion was passively intruded into the granodiorite. A small portion of forcefully released residual magmatic fluids may have created the granitic shear zones and the pebble dike at the Squaw Peak deposit and caused some shattering as they invaded structurally weak zones at the Precambrian granodiorite-metavolcanic contact.

The inner zone of the Squaw Peak deposit is characterized by quartz-sulfide-sericite veinlets, by sericitization of plagioclase, and by poorly developed secondary biotite-orthoclase alteration. Lead and sulfur isotope data, as well as zoning, suggest that ore fluids involved in porphyry copper formation travel outward from the porphyry at high K^+/H^+ ratios in the potassic field (Rose, 1970). Hydrothermal alteration in silicate rocks is controlled by variations in the metal/H^+ ratio in the ore solution, and generally proceeds in the direction of hydrolysis, consuming H^+ ions and releasing metal cations to the solution

(Hemley and Jones, 1964). Low activity of K^+ at Squaw Peak may have resulted in a low K^+/H^+ ratio, thereby promoting sericitization. Fine grained sericite alteration extends well into the propylitic zone at Squaw Peak, a common feature of porphyry systems (Guilbert and Lowell, 1974).

The highest copper content of porphyry deposits normally occurs within the biotite-orthoclase zone or at its outer borders with quartz-sericite alteration (Rose, 1970). Geologic and experimental data suggest that metals in most ore deposits are transported as chloride complexes stable in the presence of sulfide (White, 1968). Mixing of ore fluids with cool meteoric water may bring the solution into the quartz-sericite stability range and cause sulfide precipitation (Rose, 1970). These theories may be applicable to the Squaw Peak deposit, where the bulk of the sulfide mineralization is within the phyllic zone and where the strongest copper and molybdenum values occur near the potassic-phyllic alteration interface.

The relative absence of argillic alteration at Squaw Peak may be due to a lack of interaction of groundwater with the ore-forming fluids. The weak clay alteration which does exist at Squaw Peak appears to be the replacement of plagioclase by kaolinite rather than by montmorillonite, suggesting a low Na^+/H^+ ratio (Hemley, Meyer, and Richter, 1961).

The outer alteration zone at Squaw Peak is characterized by a moderately widespread but certainly not intensive quartz-epidote-chlorite-orthoclase-calcite assemblage. The H^+ ion consumed in the epidote-chlorite replacement of plagioclase may have sufficiently increased the K^+/H^+ ratio to produce orthoclase envelopes around the quartz-epidote veins.

The weak mineralization and alteration at Squaw Peak may reflect the small size of the Squaw Peak Intrusion. Drilling and geologic mapping indicate that the Squaw Peak Intrusion is a relatively small plug which does not appear to expand with depth. Statistically, productive porphyry copper deposits are associated with large porphyry intrusions (Stringham, 1966).

The chemical similarity between the Squaw Peak Intrusion and the Precambrian granodiorite certainly promoted a relatively subtle alteration change in the granodiorite; with the alteration expressed most extensively in veins, particularly in the outer zone. In porphyry systems in which the pre-porphyry rocks are the major hosts for alteration, the degree of alteration depends heavily upon the disequilibrium between the altering fluid and the host rock (Titley, 1972).

Comparison to Porphyry Deposits of the Prescott Area

The nearest occurrences of porphyry copper mineralization are about 40 miles west of Squaw Peak at Copper Basin, Copper Creek, and Pine Flat in Yavapai County. Although the deposits vary with regard to size, host rocks, types and extent of alteration, and many other factors, a few unifying characteristics do appear to exist.

Copper Basin. Phelps Dodge's Copper Basin orebody, approximately five miles southwest of Prescott, is by far the largest porphyry copper deposit in the area and is the only economically mineable deposit at the time of this writing. The lateral dimensions of the Copper Basin +0.1 per cent Cu area are about 1000 by 4000 feet (Christman, 1975), about eight times larger than the +0.1 per cent Cu area exposed at Squaw Peak (Figure 20, p. 64).

At Copper Basin Precambrian granodiorite and a Laramide quartz monzonite stock are intruded by a Laramide latite porphyry plug and associated porphyritic dikes. Twenty-five collapse breccia pipes outcrop and appear to coalesce with depth (Christman, 1975). Alteration is characterized by a potassic assemblage of pervasive quartz, K-feldspar, and sericite, a phyllic assemblage of pervasive sericite and quartz, and a broad propylitic assemblage of calcite, chlorite, and epidote which is imprinted upon the earlier potassic and phyllic alteration (Christman, 1975). Biotite is the only stable mafic mineral within about 3000 feet of the center of the deposit, except

where it has been replaced by sericite (Christman, 1975). Chalcopyrite followed by molybdenite are the major economic minerals, and are associated with the potassic and phyllic alteration stages. Bornite is rare. Gold may be anomalous in the orebody. Sulfide mineralization is dominantly in veins. Formation of the collapse breccias preceeded the bulk of the sulfide mineralization, and probably enhanced the permeability of the host rocks (Christman, 1975).

Copper Creek. Less information is available concerning the porphyry occurrence at Copper Creek, about ten miles south of Prescott, than for the other deposits. Precambrian granite and aplite are intruded by a Laramide (?) latite or fine grained quartz monzonite porphyry dike complex in a highly pyritic system of about 5000 feet by 2500 feet.

The Laramide (?) dikes at Copper Creek contain impressive stockwork veinlets of quartz with pyrite, chalcopyrite, and molybdenite, with very little disseminated sulfide. Local sulfide mineralization occurs in the Precambrian granite, mostly as disseminations of pyrite and chalcopyrite. Bornite again is rare. Spotty secondary chalcopyrite mineralization is exposed. Alteration of the dikes is characterized by argillization and sericitization of feldspars and clay-sericite alteration of the groundmass. The Precambrian granite is propylitized by a chlorite-epidote assemblage which replaces mafic

minerals and cuts the rock in veinlets. There appears to be an undetermined area of biotite stability in the granite.

Pine Flat. The Pine Flat porphyry copper occurrence, about 12 miles southeast of Prescott, contains approximately 20 million tons averaging 0.36 per cent copper with minor molybdenum, gold, and silver (Spatz, 1974). Precambrian metamorphosed rocks are intruded by a Laramide (?) quartz latite porphyry complex. Substantial collapse and intrusive brecciated preceeded most of the mineralization.

Copper is concentrated in breccias and is associated with a main-stage alteration phase characterized by K-feldspar veinlets, shreddy secondary biotite, and sericitization of plagioclase (Spatz, 1974). The major economic minerals are chalcopyrite and molybdenite. Bornite is rare. A quartz-sericite-pyrite alteration zone encloses a central potassic alteration zone. Near-surface copper values of +0.1 per cent are in a sub-circular zone approximately 1000 feet by 900 feet (Spatz, 1974). As at Squaw Peak, a poorly defined propylitic zone at Pine Flat is characterized by a vein assemblage of quartz-calcite-chlorite-pyrite-K-feldspar-epidote with minor chalcopyrite and by weak, pervasive chloritization of mafic minerals. Also like Squaw Peak, Pine Flat appears to be a relatively deeply eroded remnant of a larger porphyry copper system (Spatz, 1974).

Summary of Porphyry Deposit Features of Squaw Peak Region. The porphyry occurrences in the Prescott area bear several

possibly significant characteristics which are similar to features found at Squaw Peak. These include: (1) a substantial molybdenum content; (2) possibly anomalous gold concentrations, at least at Copper Basin, Pine Flat, and Squaw Peak; (3) a relatively high chalcopyrite:bornite ratio; (4) a central zone of biotite stability, generally coincident with higher grade alteration and mineralization, the size of which varies proportionately to the size of the deposit; and (5) in the cases of Copper Basin, Pine Flat, and Squaw Peak, a general alteration scheme which grades outwardly from quartz-K-feldspar to quartz-sericite to chlorite-epidote-calcite alteration assemblages. The spatial geochemical relationships at Pine Flat and Squaw Peak are most similar, with a central, relatively barren core succeeded by highest copper values which then yield to higher pyrite and gradually decreasing copper. The porphyry occurrence at Copper Creek bears only a few features found at the other three deposits. The size of the Laramide intrusions and the multi-phased potassic and phyllic alteration at Copper Basin may be significant from an economic standpoint.

CHAPTER 7

EXPLORATION POTENTIAL

Current information indicates a porphyry copper-molybdenum deposit of low tonnage and grade at Squaw Peak. Exploitation of the Squaw Peak deposit is subject to future economic circumstances. Geologic and drilling data have defined a steep-sided, bowl-shaped mineralized zone and suggest that significant copper mineralization terminates both laterally and at depth. Weak copper and molybdenum mineralization persist northwestward from the deposit to the contact of the granodiorite with the metavolcanics. Weak sericitization of feldspar extends over 1000 feet below the surface in Phillips Petroleum drill holes 13 and 14 (Figure 2, in pocket). The structurally weak northwest-trending zone provides the most favorable site for igneous activity at depth in the Squaw Peak vicinity; however, the weak alteration and mineralization probably reflect the structural control of the pre-mineralization fracture pattern upon the Squaw Peak system.

A northwest-trending fault which post-dates the Squaw Peak Intrusion cuts the deposit approximately in half (Figure 4, in pocket). Both alteration and mineralization are stronger at depth on the southwest side of this fault, suggesting that the fault has lowered the southwestern portion of the deposit. A small volume of low grade

material may be present in the hangingwall of the fault. It is doubtful that a significant amount of mineralized rock has been preserved by the fault, due to the spatial restrictions imposed by decreasing lateral alteration and mineralization and by projection of the fault itself at depth (Figure 4, in pocket).

The possibility that a fault-displaced portion of the Squaw Peak deposit exists in the eastern block of the Verde fault is geologically intriguing. Examples of fault-offset portions of porphyry copper deposits are the Lakeshore orebody near Casa Grande, Arizona and the Kalamazoo orebody at San Manuel, Arizona. The post-mineral Verde fault passes about 1800 feet northeast of the Squaw Peak deposit. The potential presence of a faulted-off portion of the deposit in the downdropped block of the fault is subject to: (1) the original vertical extent of the Squaw Peak deposit and (2) the dip of the Verde fault.

The exploration potential of the hangingwall of the Verde fault was considered by Phillips Petroleum geologists. Rotary drilling conducted by Phillips failed to penetrate the thick Cenozoic basalt and sediments in the upper portion of the downthrown block (Figure 30). The deepest drill hole east of the fault zone went to 972 feet and bottomed in Tertiary basalt of the Hickey formation. Induced polarization, ground magnetics, and seismic surveys conducted by Phillips over the hangingwall block were inconclusive. Seismic data indicated,

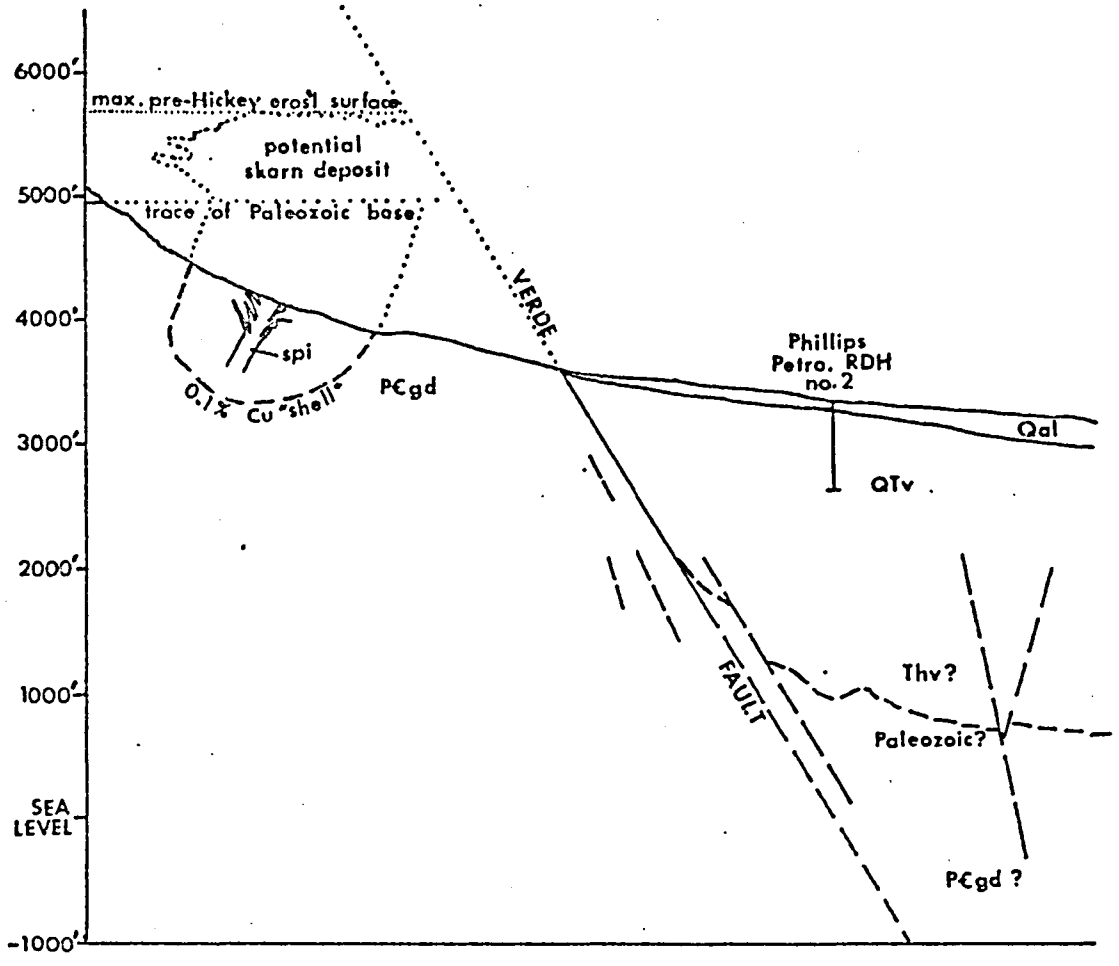


Figure 30. Hypothetical Section Showing Inferred Extent of Original Copper Mineralization and Verde Fault Displacement.

Subsurface data east of fault from Cooksley (1971). Calculated seismic velocities of Verde formation (QTv) and Hickey basalt (Thv?) are approximately equal.

however, that over 2000 feet of alluvium, lake beds, and volcanic rocks overlie the top of the Paleozoic and Precambrian units east of the fault zone (Cooksley, 1971).

Regardless of the post-mineralization cover on the east side of the Verde fault, it is doubtful that a significant segment of the Squaw Peak system extended across the fault zone (Figure 30, p. 93). Unless the trace of the eastward dip of the fault is more gentle than that predicted by observations of the presently exposed fault zone, only a small portion of mineralized Paleozoic sedimentary rocks could possibly have been down-faulted assuming that the original relative dimensions of the Squaw Peak deposit did not deviate from those of other observed porphyry systems.

The existence of other porphyry-type alteration is not indicated by geologic examination of the district. The presence of another deposit may be obscured by Tertiary volcanic and sedimentary rocks and recent alluvium. The Verde fault zone and related fractures may have been structurally weak during the Laramide orogenic period, creating a favorable site for potentially economic igneous activity, but the detection of an orebody beneath the thick post-mineralization cover would be both unlikely and extremely difficult.

The two broken zones located at the contact between the Precambrian granodiorite and the Ash Creek (?) metamorphosed volcanic rocks have inspired minor exploration interest. The inhomogeneous

nature of the rocks and the impersistent copper mineralization suggest that no substantial mineral reserves are present in these areas. The absence of strong alteration argues against the zones as potential porphyry copper targets.

The Precambrian Ash Creek (?) metavolcanics merit further consideration as a potential host for massive sulfide deposits. The Ash Creek group hosted the historic United Verde and United Verde Extension orebodies located near the Verde fault approximately 25 miles northwest of Squaw Peak. The most extensive surface exposure of mineralization within the metavolcanics at Squaw Peak is immediately west of the Verde fault, approximately 3000 feet north-northeast of the Squaw Peak deposit. The rocks here are strongly fractured, with several tens of northwest-trending quartz veins containing trace amounts of malachite, chrysocolla, azurite, and local native copper. The weak mineralization in this area may be related to hydrothermal activity from the Squaw Peak deposit. Phillips Petroleum's 601-foot-deep drill hole DDH 19 was drilled in the center of this mineralization, but it failed to encounter significant mineralization. Moreover, such recognized massive sulfide ore guides as banded iron formation, stratabound sulfide mineralization, tight folding, black shale units, pyroclastic flow units, and felsic-andesitic flow contacts do not appear to be present in the metamorphosed volcanic sequence at Squaw Peak.

CHAPTER 8

CONCLUSIONS

The geometrical zoning of alteration and mineralization assemblages around the Squaw Peak Intrusion suggest that the deposit developed in response to the emplacement of the Laramide (?) porphyry and associated hydrothermal activity. The distribution and relative abundance of sulfide and alteration minerals are typical of small porphyry copper systems. Alteration and sulfide mineral assemblages and their lateral progression from the porphyry intrusion are similar to those observed in granitic host rocks of productive porphyry copper deposits. The major deviations of the Squaw Peak deposit from productive porphyry orebodies are the erratic intensity of mineralization and alteration and the smaller dimensions of the Squaw Peak deposit. Drill hole geochemistry has documented the termination of mineralization at depth, and the potential for additional economic base metal deposits in the Squaw Peak area is remote.

Geologic History

The evolution of the Squaw Peak area and deposit is the result of a long and eventful geologic history. The following generalized

sequence of events is formulated from field observations and from literature related to the Squaw Peak region:.

1. The accumulation of mafic volcanic piles (1700 to 1900 million years(?)), marking the early orogenic state of the Mazatzal Revolution (Wilson, (1936);
2. Metamorphism of the volcanic rocks during the height of the Mazatzal Revolution, and the epeirogenic batholithic intrusion of granodiorite (1643 million years);
3. The development of a north-northwest trending structural grain due to east-west compressional forces, possibly continuing through Cretaceous time;
4. Erosion and beveling of the Precambrian surface, and deposition of the Cambrian Tapeats (?) sandstone;
5. Transgression of the early Paleozoic sea and subsequent deposition of the Martin limestone and succeeding sedimentary units, possibly through Permian;
6. Erosion and beveling of the Paleozoic rocks during the Mesozoic era;
7. Laramide (?) intrusion of the Squaw Peak Intrusion, with associated porphyry-type alteration and mineralization;
8. A widespread extrusion of the Hickey basalt during middle-late Tertiary;

9. Development of the Verde rift zone, including major displacement along the Verde fault, and concomitant uplift of the Black Hills;
10. Volcanic damming of the southern end of the Verde Valley, and subsequent formation of Lake Verde;
11. Deposition of the Verde formation and continued subsidence of the Verde Valley (Pliocene–Pleistocene);
12. Rhyodacitic volcanism northeast of Squaw Peak;
13. Minor reversal of the Verde fault; and
14. Recent rapid erosion of the Black Hills, restricting oxidation of the Squaw Peak deposit, and deposition of sand and gravel in the Verde River Valley.

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EXPLANATION

QUATERNARY

Pleistocene — Recent

Qr — Riverwash

Qal — Alluvium
unconformity

Qrd — Rhyodacite flows
unconformity

QTv — Verde formation
unconformity

QTab — Andesite and basalt volcanic rocks
unconformity

TERTIARY

Thv — Hickey formation olivene basalt flows
unconformity

Laramide(?)

Tqrd — Quartz monzonite dikes

Aplitic shatter zone

Shear breccia, sb, shear breccia dikes, sbd

Tlpd — Latite porphyry dikes

Tgd — Granitic shear dikes

Tpl — Squaw Peak intrusive quartz monzonite pby
uncontormity

Middle(?) and Upper Devonian

Dm — Martin limestone
unconformity(?)

Є? — Tapeats(?) sandstone
uncontormity

PCgd — Granodiorite
uncontormity

PRECAMBRIAN — CAMBRIAN — DEVONIAN

PCgc — Ash Creek(?) group metamorphosed basalt and andesite flows and breccia, also porphyritic andesitic flows

Contact
dashed where approximately located, dotted where concealed

Fault, showing dip
dashed where approximately located, dotted where concealed. U, upthrown side. D, downthrown side

58/15 — Minor fold
showing strike and dip of axial plane and trend and plunge of axis

34 — Strike and dip of beds

55 — Strike and dip of foliation

16 — Strike and dip of planar flow structure

76 — Strike and dip of joints

Strike and dip of vertical joints

14 ½° — TRUE NORTH / MAGNETIC NORTH

APPROXIMATE MEAN
DECLINATION 1969

Geology by R. Roe
UA M.S. Thesis, 1976

Figure 1

GEOLOGIC MAP OF THE SQUAW PEAK AREA

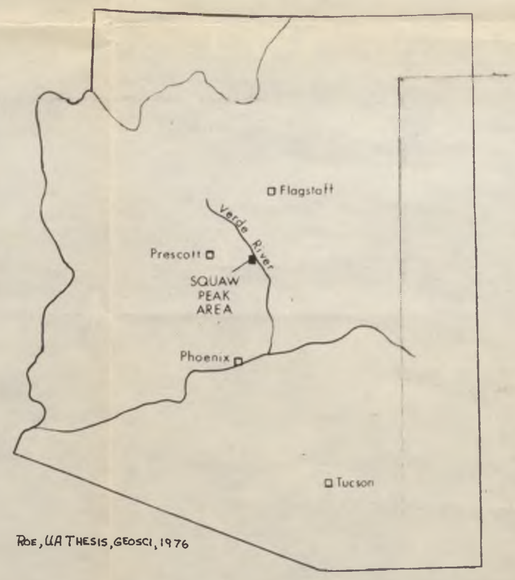
YAVAPAI COUNTY, ARIZONA

SCALE 1:12000

ONE INCH EQUALS ONE THOUSAND FEET

2000 1000 0 1000 2000 3000 4000 5000

Contour Interval 40 Feet



ROE, UA THESIS, GEOSCI, 1976

Figure 2

GEOLOGIC MAP OF THE SQUAW PEAK PORPHYRY COPPER DEPOSIT

SCALE 1:2400

ONE INCH EQUALS TWO HUNDRED FEET

200 100 0 200 400 600 800

Contour Interval
20 Feet

EXPLANATION

Approximate margin of strong sulfide mineralization

Approximate margin of copper-bearing quartz veins

Approximate limit of local potassic alteration

Approximate margin of phyllic alteration zone

Approximate margin of fracture-controlled propylitic alteration

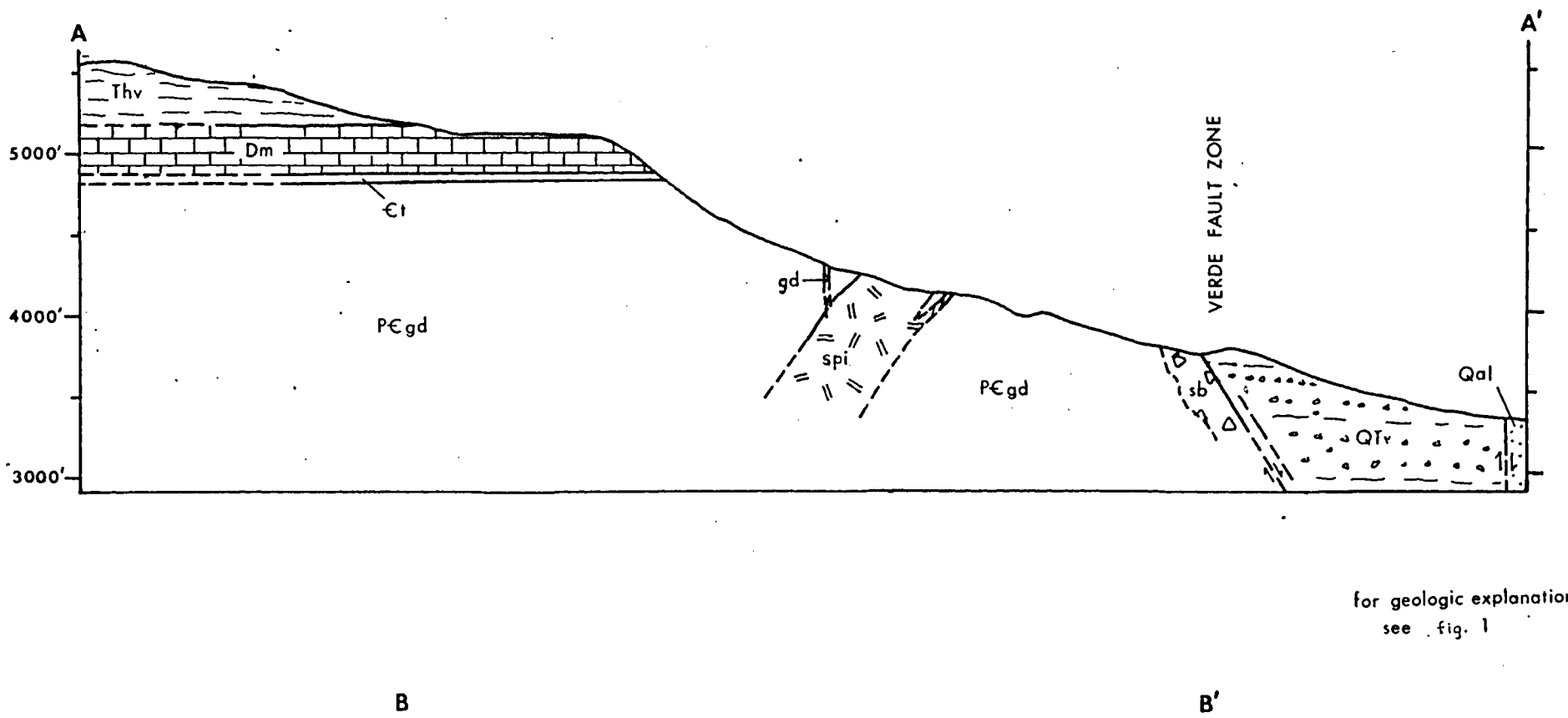
Drill site { DDH 8: Phillips Petroleum core hole; SP 5: Essex rotary hole

Dirt road

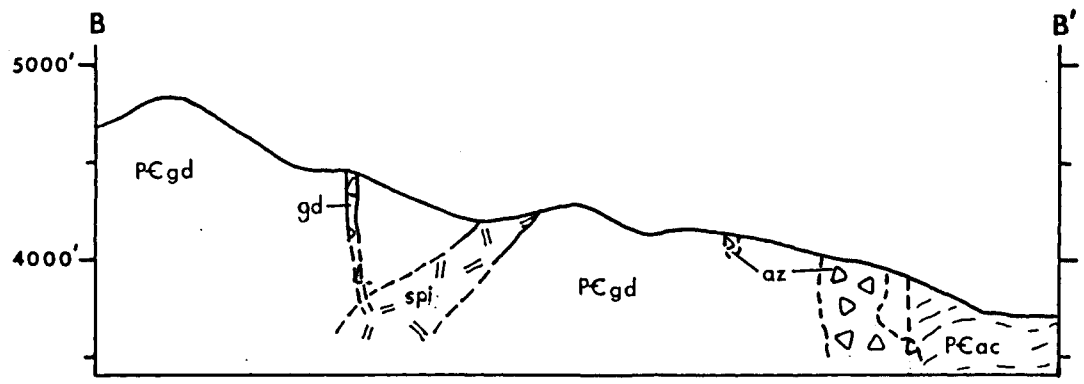
See fig. 1 for explanation of rock types and other symbols

Geology By R. Roe
UA M.S Thesis, 1976

Roe, UA Thesis, Geosci, 1976



for geologic explanation
see fig. 1



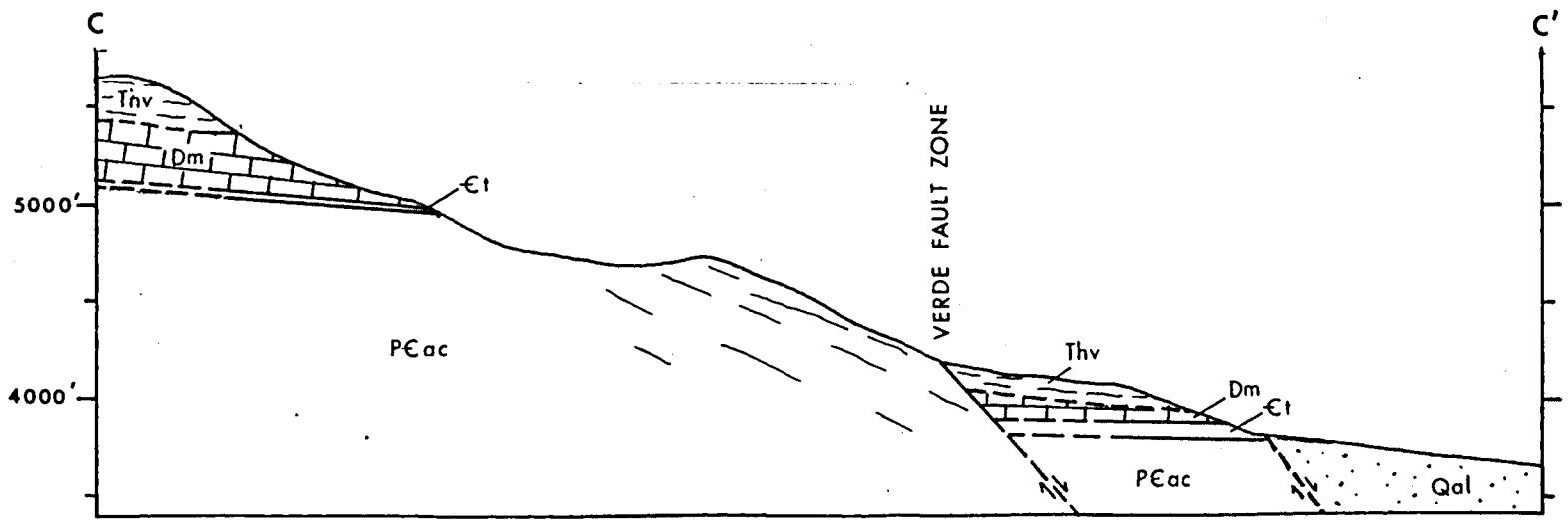
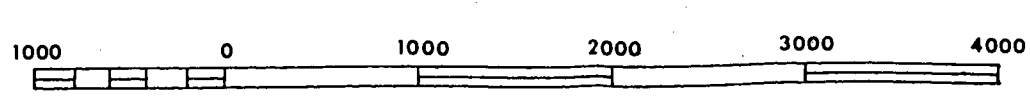


Figure 3

GEOLOGIC SECTIONS OF THE SQUAW PEAK AREA,
YAVAPAI COUNTY, ARIZONA

Scale 1:12000



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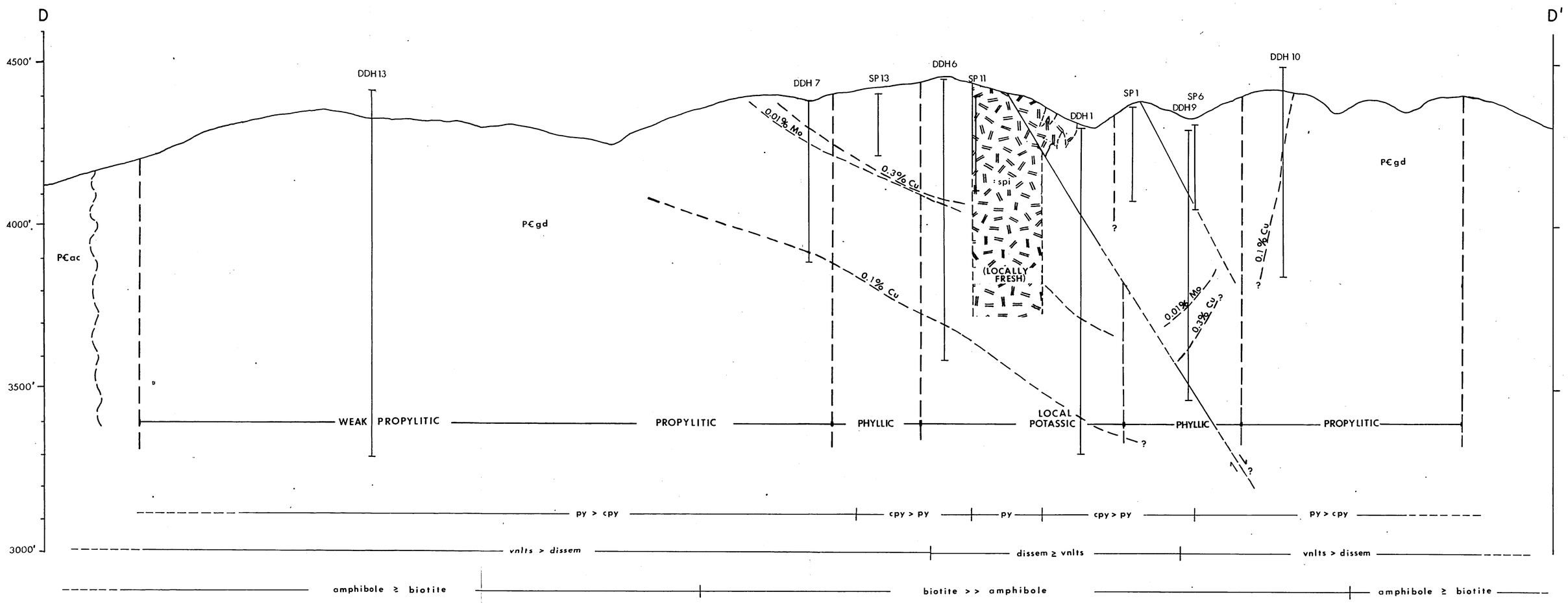
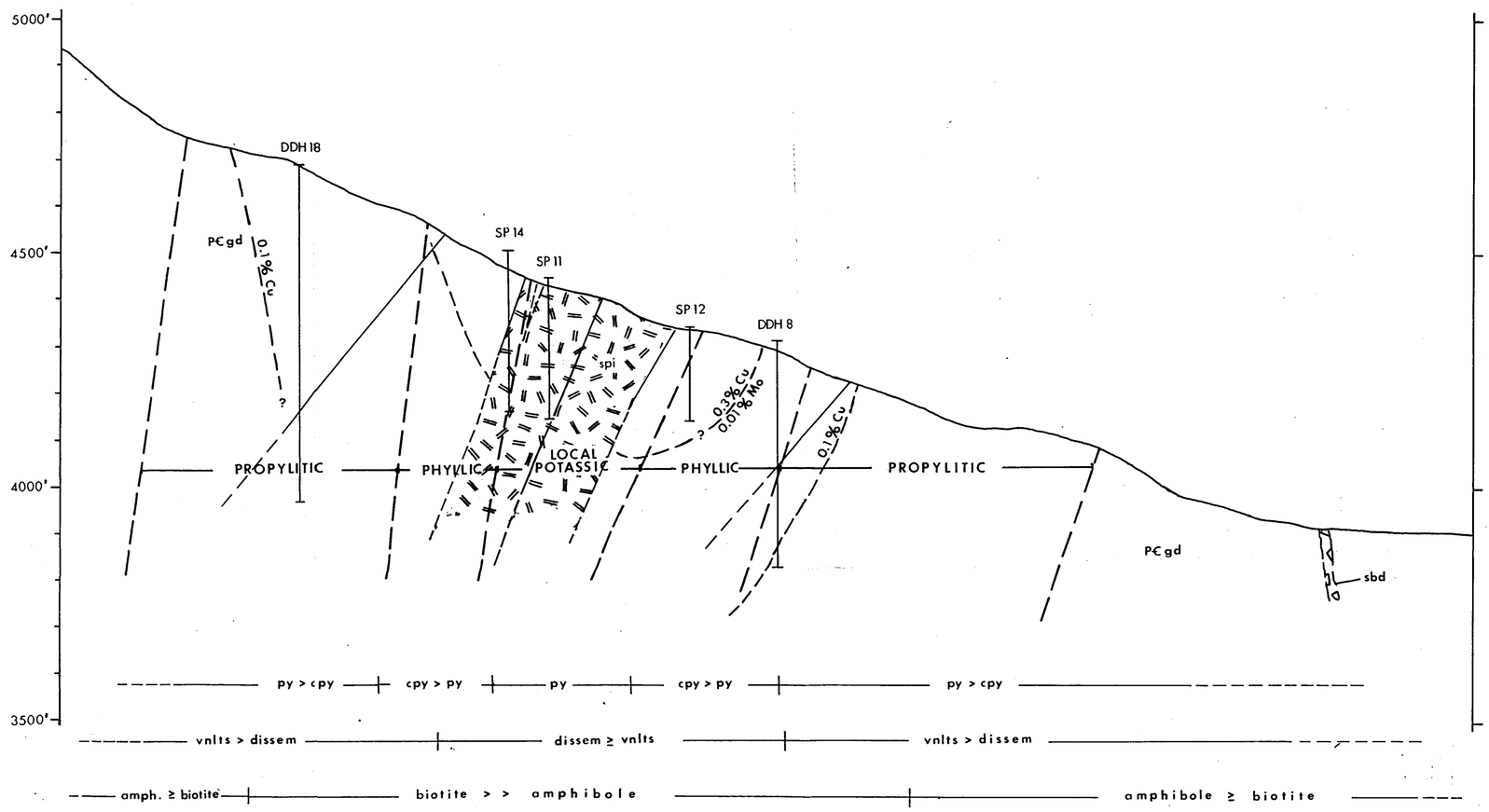


SECTION D–D'

LOOKING EAST



SECTION E–E'

LOOKING NORTH

(for geologic explanation see fig 1.)

Figure 4

ALTERATION AND MINERALIZATION ZONING OF THE SQUAW PEAK PORPHYRY COPPER DEPOSIT

ONE INCH EQUALS TWO HUNDRED FEET

ROE, UA THESIS, GEOSCI, 1976