University of Nevada

Reno

The Geology and Ore Deposits of the Antelope (Majuba Hill) Mining District Pershing County, Nevada

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Geology

by

David Lee Stevens

June 1971

The thesis of David Lee Stevens is approved:

Anthony L. Payne
Thesis advisor

George B. Maxey
Department chairman

T. D. O'Brien
Dean, Graduate School

University of Nevada

Reno

June 1971

CONTENTS

ILLUSTRATIONS

Figure Page

ABSTRACT

The Antelope (Majuba Hill) mining district is credited with 1.6 million dollars of production between 1905 and 1936. The Majuba Hill mine, in the center of the district, was the major producer with nearly 3 million pounds of copper. The presence of tin mineralization in the Majuba Hill mine makes the district anomalous among mining districts in the western United States.

Sedimentary rocks of the district consist of argillites and quartzites of the Triassic "Grass Valley Formation". Early Cretaceous compressional deformation, and perhaps thrusting, produced the north-easterly trending fabric of the beds and folds. Emplacement of intermediate igneous rocks as large concordant intrusions and sill swarms during the mid-Cretaceous followed the main stage of deformation. During the Tertiary, a large explosive vent developed in response to violent volatile release from a buried magma chamber. Following volatile release, the upper siliceous portions of the magma chamber ascended the explosive vent. Upon reaching the surface, the viscous rhyolite magma welled into a large fan shaped extrusive dome. Sulfide mineralization in the throat of the vent was localized in a tensional fault produced by subsidence of the magma column. Mineralization in the district, outside of the Majuba Hill plug, appears unrelated to the rhyolite intrusion and may represent an earlier hydrothermal phase from the same parent magma.

The interior of the Majuba Hill rhyolite plug is intensely altered to quartz, sericite, and tourmaline. Alteration is most intense where localized in intrusive breccias. The presence of high tempera-

ture ore and gangue minerals in a low pressure, near surface environment classifies the mineralization associated with the Majuba Hill plug as xenothermal.

Mineralogically and genetically the Antelope mining district has many similarities with the tin districts of central Bolivia.

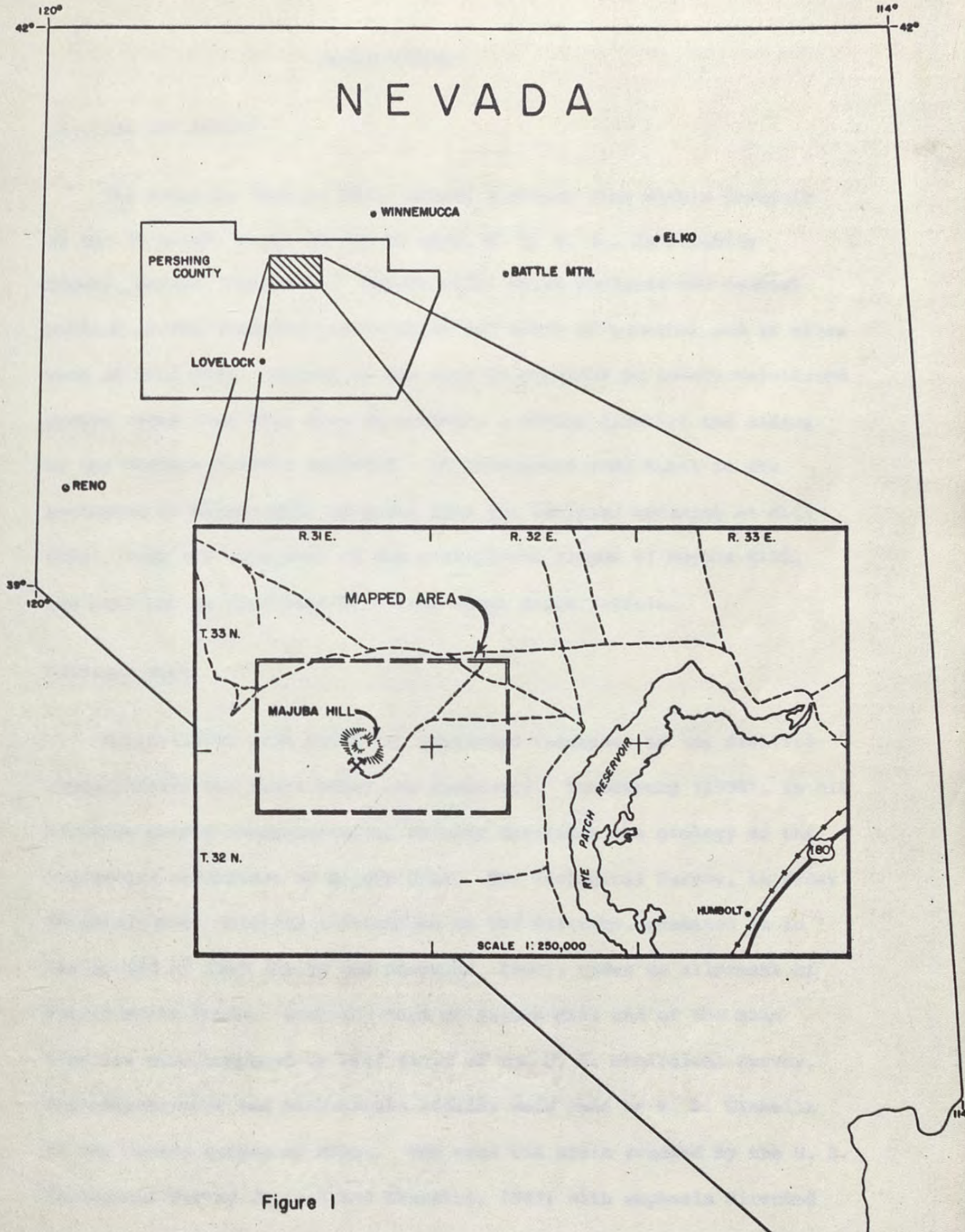


Figure 1

LOCATION OF THE ANTELOPE MINING DISTRICT

INTRODUCTION

Location and Access

The Antelope (Majuba Hill) mining district lies within township 32 and 33 north, range 30 and 31 east, M. D. B. M., in Pershing County, Nevada (Figure 1). Majuba Hill, which occupies the central portion of the district, is 34 miles due north of Lovelock and 18 miles west of Mill City. Access to the area is provided by county-maintained graded roads from Mill City to Sulphur, a mining district and siding on the Western Pacific Railroad. An unimproved road turns to the southwest to Majuba Hill 14 miles from the railroad crossing at Mill City. With the exception of the precipitous slopes of Majuba Hill, the area can be traversed by a four-wheel drive vehicle.

Previous Work

Knopf (1917) made the first published reference to the district approximately ten years after its discovery. Vanderburg (1936), in his Pershing County reconnaissance, briefly describes the geology of the copper-tin occurrence at Majuba Hill. The Geological Survey, in order to obtain more detailed information on the district, examined it in the spring of 1939 (Smith and Gianella, 1940), under an allotment of Public Works funds. Geologic Maps of Majuba Hill and of the mine workings were prepared by Ward Smith of the U. S. Geological Survey, and petrographic and mineralogic studies were made by V. P. Gianella of the Nevada Bureau of Mines. The area was again studied by the U. S. Geological Survey (Trites and Thurston, 1942) with emphasis directed toward the minor uranium occurrence exposed in the middle adit of the Majuba Hill mine. The most recent work in the area is of Tatlock (1969), the 1:200,000 preliminary geologic map prepared in cooperation with the Nevada Bureau of Mines and published by the U. S. Geological Survey in the open file. The area was mapped in reconnaissance (1:24,000) in 1958 by the Southern Pacific Mineral Survey as an evaluation of the mineral potential of land owned by the Southern Pacific Railroad Company.

Purpose of Thesis

The Antelope district presents an opportunity to study a class of ore deposit formed by relatively high temperature and low pressures. It is also unusual as one of the few hydrothermal tin occurrences in the western United States. The domestic shortage of tin invites a careful evaluation of all occurrences to define the environment and nature of the mineralization. Previous work did not adequately relate structural conditions, geologic history, and hypogene mineralization of the district as a whole. Underground work in 1969-1970 provided additional exposures which aid in the structural interpretation of ore controlling features at the Majuba Hill mine.

Approximately 16 square miles were mapped at a scale of 1:12,000, and the central area of a square mile was detailed at 1:6,000. Over a mile of combined underground workings were mapped at a scale of 1 inch to 50 feet. Emphasis was placed on structure, alteration, mineralization, and the development of a genetic model for the Majuba Hill intrusive and related mineralization.

Acknowledgements

The writer is grateful for the assistance of many individuals and organizations. Dr. Anthony L. Payne visited the area and provided many valuable suggestions during the course of the mapping. The Southern Pacific Land Company provided the Topographic base on which the geologic map is presented. Mr. Alan Jager accompanied the writer to the field and gave constant encouragement during the course of mapping. Dr. Frederick Schwarz offered valuable suggestions on numerous occasions. Messrs. Donald Decker and Frank Sonderman assisted with the underground mapping. Special thanks to Mine Finders, Inc., of Denver, Colorado, for the permission to map on their properties. Mr. G. J. Carter drafted the illustrations and maps. Mr. E. J. Murphy of the Nevada Bureau of Mines, prepared the thin sections and polished surfaces used in the study.

Humble Oil and Refining Company generously supported all aspects of the work.

History and Production

The occurrence of tin and copper mineralization at Majuba Hill was known as early as 1907 (Smith and Gianella, 1942, p. 39). The discovery is credited to an unknown prospector who found a piece of cassiterite-bearing float on the flanks of the hill. The area was located in 1907 by A. J. McCauley of Imlay, Nevada, (Matson, 1948, p. 2) and later acquired by C. A. Copley and A. L. Gilmet (Trites and Thurston, 1949, p. 186). Mason Valley Mines optioned the property in

1917 and conducted most of the underground development in the lower and middle adits on Majuba Hill (Plates 4 and 5). The work by Mason Valley Mines, in 1917, is credited with the discovery of the tin occurrence in the middle adit. A minor amount of copper ore, principally chalcocite, was discovered in the hanging wall of the Majuba fault, the main structure explored by Mason Valley Mines. Mason Valley Mines shipped 4,000 tons of 12 percent copper ore to its smelter at Mason Valley (Vanderburg, 1936, p. 8). All work ceased from 1918 until 1928 when A. J. McCauley shipped two cars of ore averaging 14 percent copper (Vanderburg, 1936, p. 10). This ore came from the chalcocite zone discovered during the Mason Valley work.

Again, the mine remained idle until 1941 when Freeport Sulphur Company obtained an option and conducted development work and core drilling to explore the tin potential. This project was abandoned in October, 1941 (Trites and Thurston, 1949, p. 186).

In May of 1942, E. J. Myler leased the property from Harvey Reber, who had purchased the property from A. J. McCauley. Myler subleased the mine to J. O. Greenan and G. W. Kerr of Reno, Nevada, who mined 23,000 tons of ore from 1942 to 1945. The ore averaged 4 percent copper and was shipped to a smelter at Garfield, Utah. Approximately 350 tons of 2-4 percent tin ore was also mined at this time (Matson, 1948, p. 1).

In 1969, the property was optioned to California Time Petroleum Company. Approximately 250 feet of drifting was done in the lower adit and 300 feet in the middle adit. These efforts failed to locate significant mineralization.

In December, 1970, California Time Petroleum subleased the mine to Mine Finders, Incorporated, of Denver, Colorado, who are currently conducting surface and underground mapping. (Wallace, 1971, personal communication).

The Last Chance Mine is located 2 miles southeast of the Majuba Hill mine and has been of sporadic interest since its discovery in 1905. Approximately 1,000 tons of lead-silver was shipped from 1906 to 1928 by leasees (Vanderburg, 1936, p. 8). The property is currently under option to Mr. E. Stode of Imlay. He is preparing to gravity separate the dump which is reported to contain 5,200 tons of ore averaging 12 ounces of silver and 8 percent lead (Vanderburg, 1936, p. 9).

A small gold-silver-arsenic prospect is located 1.5 miles northwest of the Majuba Hill Mine. According to Vanderburg, (1936, p. 11), the prospect consists of one patented claim owned by N. Adamson, Reno. A minor amount of arsenic ore was shipped during World War I.

Total recorded production from the Antelope district, based on current metal prices, is as follows:

Antelope District Production

1907-1942	2,849,000 lbs Cu	$1,424,500
	400,000 lbs Pb	52,000
	38,000 lbs Zn	4,940
	21,000 lbs Sn	33,800
	74,000 oz. Ag	111,000
Total		$1,626,240

GEOLOGY

General Statement

The Antelope district is situated within a monotonous sequence of thin-bedded shales, mudstone, and sandstones which have been regionally metamorphosed to argillites, slates, and quartzites. Owing to their lithologic homogeneity and lack of fossils, the rocks have not been assigned discreet formational names. The author proposes that similarities to lithologies exposed in the West Humboldt and Santa Rosa Ranges tentatively assign the rocks to the "Grass Valley Formation" (Compton, 1960) and (Silberling and Roberts, 1962), considered to be upper middle Triassic or Norian (Silberling and Roberts, 1962, p. 21).

The sediments have experienced four phases of igneous activity. The earliest phase of intrusive activity is represented by two small bodies of biotite diorite, exposed in the extreme southwest portion of the mapped area. One of these bodies is cut by dikes of the later intrusive rocks. Cretaceous(?) monzonite to granodiorite intrusives form sills and irregular stocks with minor contact metamorphism which locally converts the sediments to a low-grade hornfels. These early intrusives are concentrated in the southern portion of the mapped area. The second period of intrusive activity resulted in the near surface emplacement of the topographically conspicuous quartz porphyry rhyolite plug and related apophysis occupying the center of the district. A minor swarm of rhyolite sills accompanies this phase of intrusion. The plug is tentatively dated as Middle Tertiary because of petrographic similarities with rhyolites of this age in Northern Lander County. The final igneous phase is extrusive and represented by small exposures of olivene basalt which apparently extruded along a basin and range fault. These rocks are tentatively dated as Late Tertiary due to their localization along a basin and range structure.

Regional Setting

Throughout early and middle Paleozoic time, Nevada was a broad, well developed, northeasterly trending geosyncline with a pronounced eastern miogeosynclinal assemblage consisting of 15,000-20,000 feet of carbonate rocks. In the corresponding eugeosyncline, west of the 117th meridian, over 50,000 feet of volcanic and clastic rocks were deposited (Silberling and Roberts, 1962).

During late Devonian, the first of three major orogenic disturbances interrupted geosynclinal sedimentation. The first orogeny, known as the Antler orogenic belt, produced a gradual persistent uplift within the eugeosyncline, approximately parallel to its northeasterly axis. The most significant structural feature of this uplift was the eastward sliding of submarine thrust sheets in response to gravitational adjustment on an inclined surface. This series of sheets or complex lobes advanced eastward, placing Ordovician eugeosynclinal rocks over Silurian and Devonian miogeosynclinal assemblages (Larson, 1964, oral communication). This feature, which is known to extend from near Tonopah northward to the Idaho boundary, is known as the Roberts Mountain thrust fault (Roberts, 1958). Continued uplift of the orogenic belt resulted in emergent source lands for clastic sediments which were shed to the east and west. Near Eureka, over 5,000 feet of coarse Pennsylvanian clastics were deposited on top of the leading edge of the Roberts Mountain thrust fault. Eastward, orogenic sediments were shed into the Pumpernickel-Havallah basin, (the depositional position of this basin is uncertain due to thrust faulting complication produced during younger orogenic episodes).

The second orogeny to affect the Cordilleran geosyncline was during late Permian. An uplift parallel to and considerably west of the Antler orogenic belt thrust clastics shed to the west side of the Antler orogenic belt eastward on a series of large submarine(?) thrust sheets known as the Golconda thrust fault. These sheets over-rode the former axis of the Antler orogenic belt and transported Pennsylvanian-Permian sediments of the western facies. This period of activity is known as the Sonoma Orogeny and was defined by Ferguson and others (1952), in the China Mountain area south of Golconda.

Following the Sonoma orogeny, marine sedimentation with intermittent vulcanism persisted from Late Permian to Early Triassic. According to Compton (1960), the Triassic sedimentary rocks of northwestern Nevada were subjected to tight folding during an Early Jurassic to Early Cretaceous orogeny, with metamorphism to slates, argillites, and phyllites, and other low grade rocks over an area of tens of thousands of square miles. Igneous bodies ranging from sill swarms and small stocks to batholiths intruded the low-grade metamorphic terrain at many localities. Intrusive rocks range from granodiorite to monzonite in composition, similar to the Sierra Nevada batholith. The Jackson mountains, twenty-five miles north of the Antelope district, expose clear evidence of mid-Cretaceous folding and early Tertiary thrusting (Willden, 1958), but the extent of Laramide deformation elsewhere in Northwestern Nevada is poorly understood. Middle to late Tertiary eruption of a varied volcanic sequence was followed by tilting and basin and range block faulting, giving the area its present physiographic characteristics. Internal drainage patterns developed in response to the block faulting and large interconnecting lakes occupied the intermontane bolsons during the Pleistocene epoch. Lake Lahontan, as the inundated area is known, covered over one third of northwestern Nevada and parts of adjacent California. Evaporation of the lake at the close of the Pleistocene lowered the level and resulted in isolated bodies of water occupying the lowest portion of the bolsons which had been smoothed by lacustrine sedimentation. Continued evaporation formed the alkali-rich baked playas now known as Carson Sink, Black Rock Desert, Desert Valley, and Granite Springs Valley. Oscillatory filling and recession of the lakes is suggested by the conspicuous strand lines, bars, and wave-cut benches which flank most of the mountain ranges in the area.

STRATIGRAPHY

Triassic(?) System

"Grass Valley Formation"

The "Grass Valley Formation" (Rgv) is the only sedimentary unit exposed in the Antelope District. It is similar in lithology and structure to typical exposures in the Humboldt Range (Silberling and Wallace, 1969), and at the type locality in the northern East Range (Ferguson and others, 1951). Lithologically similar units have been mapped in the Santa Rosa Range, 50 miles northwest of the Antelope District. The Grass Valley formation is here identified by stratigraphic positioning within younger and older sedimentary rocks. In the Antelope District, the formation consists of dark argillite and minor phyllite interlaminated in part with micaceous siltstone and fine-grained sandstone. It is black when fresh and characteristically weathers a shade of olive gray. Minor interbedded quartzite units, which form less than five percent of the section, occur as lenses and continuous beds, as much as 40 feet thick. These units form dark craggy outcrops on otherwise smooth slopes. Owing to the lithologically repetitious, poorly exposed, unfossiliferous, and structurally complex nature of these rocks, true thickness and stratigraphic succession of the sequence is not certain (Silberling and Wallace, 1969).

The Grass Valley Formation crops out in the low hills of the northern part of the Humboldt Range. The incomplete section of the Grass Valley Formation and the upper part of the underlying Natches Pass formation form the upper plate of the Humboldt City thrust fault

(Silberling and Wallace, 1967). Isoclinal folds in the upper plate stike northeasterly in this area, parallel to bedding attitudes of the "Grass Valley Formation" exposed in the Antelope District.

In the Pershing district, 16 miles west of Lovelock, the contact between the Grass Valley Formation and the overlying Dun Glen carbonates is transitional. The contact is normally placed at the base of the lowest laterally persistent carbonate unit (Silberling and Wallace, 1967).

In the Antelope District the "Grass Valley Formation" is formed of metapelitic, silty, and sandy rocks with minor amounts of calcareous cement, representing the same source, and differing only in the nature of sorting and regional low grade metamorphic effects. Fine-grained rocks (Ŧgva) make up over 80 percent of the section and consist of argillite, distinguished from slate by the fissillity parallel to the bedding rather than slaty cleavage, phyllite, and micacious siltstone. All of these rocks are black in fresh exposure, weathering olive black (5Y 2/1) to light olive gray (5Y 6/1) and greenish gray (5GY 6/1). Intercalated laminations of quartzite range from less than one inch to massive sections of several tens of feet. The fine-grained units are not laterally persistant, and because of poor outcrops cannot be traced as discrete beds. The argillites and related fine-grained rocks consist primarily of well rounded, slightly flattened grains of quartz (0.01 to 0.03 mm) to 40 percent set in a lamallar matrix of chlorite, sericite, heavy minerals, and interminate opaque clay aggregates. Texturally, the sericite and chlorite appear metamorphic and may represent alteration of sedimentary iron-bearing montmorillonite and illite (Compton, 1960). The heavy minerals are generally smaller than the quartz grains and consist of rutile, sphene, and minor tourmaline. They usually constitute less than 1 percent of the rock volume. These fine-grained rocks contain up to 5 percent carbonate that has been remobilized during regional metamorphism and commonly occurs as optically continuous cementing material or complex twinned porphyroblasts (Figure 3).

Quartzites intercalated in the fine-grained units, and occuring as minor lenses and discrete beds of sandstone, comprise the remaining 20 percent of the sedimentary section. The sandstones, regionally metamorphosed to quartzites, exhibit two modes of occurrence. The more common occurrence is an impure, crossbedded lenticular mass from 10 to 100 feet in length and up to 6 feet thick. The uppermost portions characteristically contain well developed linguoid ripple marks (Figure 2), with amplitudes up to several inches, and various sizes and textures of flute casts. Worm tracks may or may not be present but are always seen in association with some sort of current feature. The lenticular quartzite masses commonly weather light olive gray (5Y 6/1) and locally support topographic prominences. These lenticular quartzite bodies are interpreted as representing sinuous channels in a large deltaic complex deposited under brackish conditions and tidal fluctuations, as indicated by channeling, absence of graded bedding, and occasional worm tracks.

Quartzite also occurs as relatively thick, continuous beds (TRgvq). Only two units of this type are exposed in the mapped area. A large overturned isoclinal anticline, plunging to the west, is defined by a conspicuous outcrop of a quartzite bed 40 feet thick in the southeast

Figure 2

Linquoid current marks in argillite of the "Grass Valley Formation", the compass is pointing in the direction of flow.

Figure 3

Magnification 20X, Polarized Light

"Grass Valley Formation" argillite, three distinct micro-beds are present. Detrital minerals consist of quartz, muscovite, clay, chlorite, and calcite. Note the large polysynthetic twinned grain of calcite (C) in the upper right corner.

portion of the area. A similar thin unit defines the north limb of the above structure and strikes under cover to the south. The lateral extent of these units suggests migrating beach lines formed by base level adjustment to fluctuating sea level.

The quartzites consist of well-rounded, slightly flattened quartz grains that range from 0.08 to 0.12 mm in diameter (Figure 4). The rock is cemented by patchy interlocking overgrowths of silica on the quartz grains. Carbonate occasionally occurs as intergranular material, locally amounting to 10 percent. Well-rounded grains of albite (Ab 68-72) form from 5 to 15 percent of the rock and are the same size as the quartz grains. Although not argillized, the quartzites are conspicuously micaceous. Detrital flakes of muscovite and minor shards of biotite form up to several percent of the matrix material. Chlorite occurs both as a metamorphic replacement of biotite shards and as a detrital constituent. Total chlorite ranges from 5 to 10 percent of the rock. Heavy minerals, which generally form less than 1 percent of the rock, consist of, in order of abundance, leucoxene (after rutile and sphene?), zircon, and tourmaline.

Paleogeographic Implications

According to Silberling and Wallace (1969), the Grass Valley Formation is part of a much larger, lithologically similar unit that ranges in age from Late Triassic to Early Jurassic. These strata overlie the Star Peak Group and form the upper part of the "Winnemucca Sequence" of Silberling and Roberts (1962).

The thickest and most complete section is described by Compton

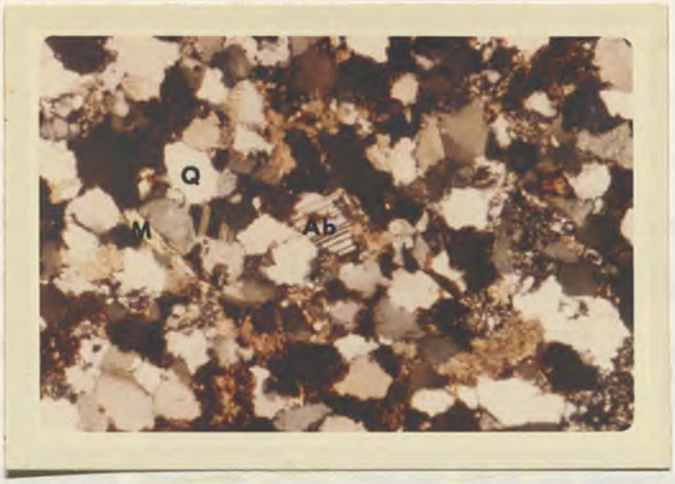


Figure 4
Magnification 20X, Polarized Light

"Grass Valley Formation" quartzite. Note the albite (Ab) grain in the center of the photograph, patchy overgrowths on the quartz grains (Q), detrital muscovite (M), and calcite cement.

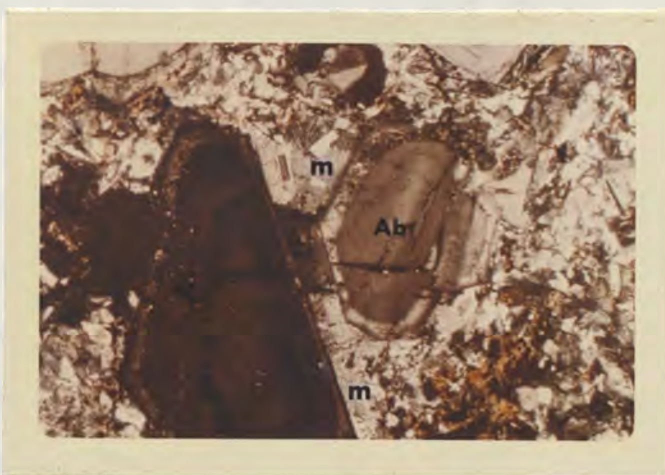


Figure 5
Magnification 20X, Polarized Light

Monzonite porphyry from sill swarm. The matrix is altered to chlorite, quartz, and sericite. Between the two zoned plagioclase (Ab72) phenocrysts (Ab) is a well developed myrmekitic texture (m).

(1960) in the Santa Rosa Range 50 miles northwest of the Antelope district. The oldest sediments are assigned to the Grass Valley Formation. Five characteristics of the sequence apply to the exposures in the Antelope district (Compton, 1960): 1) pelitic rocks (commonly metapelitic) predominate; 2) the coarser-grained detrital constituents are the same throughout and consist of quartzose, somewhat albitic silt and sand and conspicuous amounts of micaceous material; 3) terrigeneous clastic sediment, coarser than medium sand is generally absent; 4) first cycle volcanic debris is not a significant constituent; and 5) cross-bedded rather than graded sandstones predominate, suggesting sediment transport by tractional currents rather than a turbidity mechanism.

The interpretation of the Grass Valley Formation as part of a nearshore deltaic complex is thought to best fit its combined characteristics and position in a much larger assemblage of similar fine-grained terrigenous clastic sedimentary rocks (Silberling and Wallace, 1969). This interpretation implies deposition of the entire assemblage of fine-grained rocks along a northwesterly prograding shoreline. It also implies a major river drainage into northwestern Nevada as a source for these sediments. As no pre-existing clastic sediment was available as a source, and the Paleozoic terrain of central Nevada could not have provided the necessary sediment, a major Late Triassic drainage flowing from the Rocky Mountain province is postulated. The Colorado Plateau, Rocky Mountain province, and eastern Great Basin are known to have been alluviated areas of low relief at this time. Sediment delivered to the sea in north central Nevada was further sorted and spread by marine depositional processes--the result being a thick extensive internally diverse assemblage of pelitic, silty, and sandy rocks (Silberling and Wallace, 1969).

IGNEOUS ROCKS

Biotite Diorite (Kd)

The oldest igneous rocks in the area occur as two small semi-circular plugs of intrusive biotite diorite exposed in the extreme southwestern portion of the mapped area. The surrounding argillite is contorted, brecciated, silicified, and locally iron-stained as much as several hundred feet from the contact. Field relationships suggest a forceful intrusion of the plugs upward along relatively narrow conduits, as the sediments show no areal distortion. The larger of the two plugs is cut by a granodiorite sill (Kgm) (locally forming a dike within the diorite), and a younger rhyolite (Tr_2) dike. Cross-cutting relationships of other igneous rocks establish the diorite as the oldest intrusive in the mapped area.

The diorite is medium greenish gray (5G 6/1) having a somewhat speckled appearance in outcrop. At least four sets of joints contribute to its rapid weathering and blocky appearance. The rock decomposes into a granular olive gray (5Y 4/1) soil.

Petrographically, the diorite has a medium grained hypidiomorphic granular texture and consists of 60 percent plagioclase (An50), with subordinate amounts of clinopyroxene, and biotite both of which are moderately to strongly replaced by chlorite. Accessory minerals include apatite and magnetite. A few of the plagioclase exhibit "kinks" in the twin lamellae indicative of forceful intrusion of a rather viscous magma.

Dates of similar plutons in northwestern Nevada tentatively assign the diorite intrusion to the Late Jurassic or early Cretaceous (McKee, oral communication, 1971).

Granodiorite (Kgm)

A large and diverse suite of intrusive rocks ranging in composition from granodiorite to monzonite forms a complex northerly dipping sill swarm and elongate intrusive in the southeastern portion of the mapped area. Ten thin sections studied from this suite of sills indicate that the rocks vary markedly in modal quartz content and degree of alteration. The rocks were grouped together and classified as granodiorite to monzonite (Kgm).

Although the greatest density of Kgm sills is in the southeast portion of the district, isolated tabular masses occur widely throughout the sedimentary section, ranging in thickness from 6 inches to 50 feet, averaging 10 feet. They are quite persistent along strike and many can be traced for over two miles. The Kgm sills and intrusives are generally well-jointed parallel to the attitude of the enclosing sediments and form poor outcrops that range in color from cream (5Y 8/4) to light tan (10YR 6/6). Mapping is facilitated by the distinctive yellow brown (10YR 6/2) granular soils resulting from decomposition. Cross-cutting relationships with sediments are rare, and intrusion is by passive dilation of previously deformed sediments. The thinner sills, though granitoid in texture, occasionally exhibit convoluted flow structure in their interior portions. The sediments (argillites) adjacent to the sills are commonly sheared for several feet on either side of the sill.

An elongate intrusive, generally conformable with the enclosing sediments, forms the northwestern limit of the swarm exposed in the southeastern portion of the district, and can be traced for over three miles along the crest of the ridge which overlooks the Last Chance Mine. The overall shape is that of a large sill, ranging in thickness from a few hundred to over a thousand feet. Irregularities along the contact produce local contortions in the enclosing sedimentary sequence. The intrusive contains a large inclusion of argillite bounded on the southeast by a large sill. On each end, the intrusive body horsetails into the sediments and forms a sill swarm of considerably less volume than the parent igneous mass.

The rock is medium grained hypidiomorphic granular although locally porphyritic with abundant orthoclase phenocrysts in the monzonite facies, and plagioclase phenocrysts in the granodiorite facies. The plagioclase ranges from An30 to An50 and exhibits well-developed oscillatory zoning, indicating a magmatic origin (Williams, et al, 1954, p. 143). The unaltered Kgm contains from 10 to less than 2 percent modal quartz. Orthoclase ranges between 25 and 5 percent and may occur as phenocrysts or anhedral matrix material. Mafic minerals, consisting of hornblende and biotite have been intensely chloritized in all specimens examined. Accessory minerals consist of fine-grained magnetite and scattered rods of apatite. Figures 5 and 6 are typical of the Kgm intrusive. All specimens of the Kgm examined under the microscope were affected by hydrothermal alteration. Coarse-grained sericite replaces the more calcic portions of the zoned plagioclase. Chlorite replaces hornblende leaving long rods of leucoxene in a mottled green chlorite matrix, biotite is weakly chloritized and gradations between the two are

Figure 6
Magnification 20X, Polarized Light

Biotite monzonite from sill swarm. Well zoned plagioclase (Ab70) phenocrysts are partially replaced by sericite (S). The red birefringent mineral in the upper center is biotite (B).

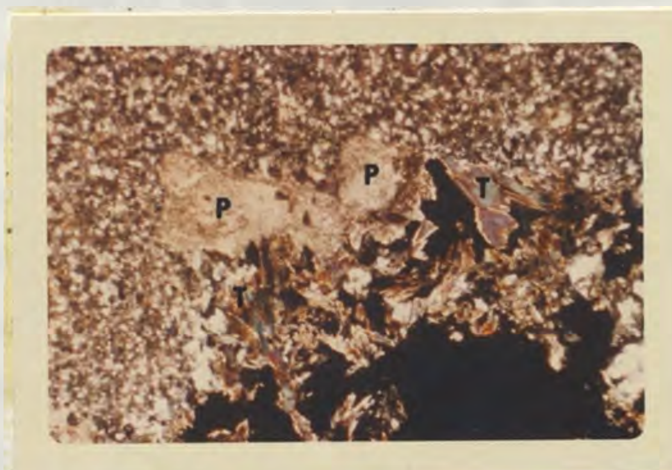


Figure 7
Magnification 20X, Polarized Light

Older rhyolite from middle adit, Majuba Hill Mine. The matrix is fine grained quartz and sericite. Note the argillized plagioclase phenocrysts (P) partially replaced by tourmaline (T).

common. Up to 8 percent calcite occurs in the matrix and is interpreted to be an alteration product. The secondary mineral assemblage indicates the alteration to be propylitic (Lowell and Guilbert, 1970).

The elongate intrusive mass and sill swarm of Kgm exposed in the southeastern portion of the district is interpreted to represent offshoots from the hood zone of a larger discordant stock at a moderate depth (Plate 1, Section A-A). This interpretation is supported by the geometric distribution and diverse rock types of the sills, which could be produced by contamination of the upper magma chamber during emplacement. Compton (1960), has reported similar situations within the Jurassic of the Santa Rosa Range. The propylitic alteration is quite uniform and no evidence for gradation to higher grade facies were noted. This alteration may be deuteric and owe its origin to volatiles concentrated in the upper portions of the magma chamber. An alternative source for the altering solutions might be the connate and ground water of the engulfed and intruded sediments by a mechanism similar to that proposed by Sheppard and others (1969).

McKee (1971, oral communication) has dated numerous intrusives of similar composition in Pershing and Humboldt County, ranging from 83 to 105 million years and corresponding well to the 85 to 105 million year range of the Sierra Nevada batholith. A granodiorite stock, approximately 4 miles north of the Antelope district was dated at 95 million years. Similar intrusives in the general area range from 92 to 103 million years. The proximity and lithologic similarity of the Kgm exposed in the Antelope district suggests an Early Cretaceous age for the intrusive activity.

Andesite (Tha)

Two minor bodies of porphyritic hornblende andesite are mapped within the Antelope district. They occur as a northwesterly trending dike 10 to 20 feet wide exposed in the Last Chance Mine and as a small pod-like sill, 20 feet wide, in the northeastern portion of the mapped area (Plate 1). The dike in the Last Chance Mine forms a westward-dipping horse between two mineralized shear zones that occupy the hanging and foot wall of the dike.

The andesite is pilotaxitic with phenocrysts of plagioclase (An50) and hornblende in a propylitized matrix of plagioclase (An50) microlites. The propylitic alteration is most intense in the Last Chance Mine area where the dike is clearly pre-mineralization. Due to the small size of the other andesite outcrop, and distance from the Last Chance dike, it was not studied in thin section.

Older Rhyolite (Tr_1)

The older rhyolite forms 70 percent of the intrusive complex of Majuba Hill, as well as numerous sills extending to the argillite surrounding to the main intrusive mass (Plates 1 and 2). The older rhyolite is cut by the younger rhyolite, aplite, and numerous breccia dikes and pipes. Near the contact with the sedimentary rocks, abundant inclusions of argillite and quartzite occur in the rhyolite. This contact zone is mapped as a separate unit (Tr_1cbx) and is discussed in detail in the section on the intrusion and brecciation of the Majuba Hill plug.

Field and petrographic identification of the older rhyolite is based on size and abundance of the quartz phenocrysts. The older rhyolite contains between 2 and 10 percent dipyramidal quartz phenocrysts set in an exceedingly fine-grained quartz-sericite matrix. The rock ranges in color from very light gray (N8) to white (N9) on fresh surfaces and from buff (10YR8/2) to yellow gray (10YR 6/6) on weathered surfaces. The overall tan to light brown (5YR 6/4) color of Majuba Hill, as viewed from a distance, is due to small amounts of exotic iron oxide which coat fracture surfaces in the rhyolite. Tourmalinized portions of the rhyolite appear mottled in various shades of gray to black.

Two isolated extrusive or very near surface intrusive phases of the older rhyolite were mapped in the district (Tr_1c). The matrix of this phase is fine-grained and intensely argillized and sericitized. The fine-grained nature of the matrix and jointing indicative of a rapid cooling environment suggests a surface extrusion. The larger of these two bodies is well exposed in the main drainage of the district 2,500 feet northeast of the Last Chance mine. Primary flow fabric in the body suggests a source in the area to the immediate northwest now covered by the younger alluvium (Qya). The other somewhat smaller body of Tr_1c is less well exposed and may be localized along a feeder sill of Tr_1.

Petrographically, the rhyolite is porphyritic with phenocrysts of dipyramidal quartz (1-2 mm) and smaller phenocrysts (.5-1 mm) of sanidine and plagioclase (Ab70), set in a very fine-grained matrix (.02 mm) of polygonal secondary quartz with varying amounts of sericite and clay. The plagioclase is highly altered and almost completely replaced by sericite and clay. Tourmalinization is widespread through this early unit and preferentially attacks the plagioclase (Figure 7). The quartz phenocrysts are often moderately embayed and occasionally the borders are ragged and indistinct due to resorption and alteration to sericite. The dipyramidal habit and resorbed nature of the phenocrysts are indicative of high quartz with a crystallization temperature between 573° and 870° C. (Frondel, 1962, p. 257). The quartz phenocrysts also contain numerous fluid inclusions with gas vapor and liquid phases present.

Younger Rhyolite (Tr_2)

The younger rhyolite intrudes the older rhyolite as a northwesterly trending lenticular dike near the crest of Majuba Hill. The younger rhyolite also forms numerous sills and dikes in the surrounding sedimentary rocks. The outcrop pattern of the younger rhyolite, as well as the pattern of the older rhyolite, suggests that the Majuba Hill plug is the source for the various sills and dikes. The contact between the younger and older rhyolite on Majuba Hill is modified by faults containing abundant rounded clasts within a highly comminuted matrix. Mineralogically, the fragments and matrix are similar and consist of quartz and sericite exhibiting a wide variety of textures.

On the southwest flank of Majuba Hill, near the contact of the main intrusive mass and enclosing argillite, a large dike of younger rhyolite cuts the argillite - older rhyolite contact. Numerous inclusions of older rhyolite and argillite occur in the younger rhyolite. This unit has been separated and designated (Tr_2cbx) on plates 1 and 2. A detailed description of this unit will be made in the section on intrusion and brecciation of the Majuba Hill plug.

In hand specimen, the younger rhyolite is distinguished from the older rhyolite by the higher percentage and larger size of the dipyramidal quartz phenocrysts. The phenocrysts compose from 10 to nearly 50 percent of the rhyolite and are from 2 to 6 mm in diameter. Weathering characteristics and colors are identical to the previously described older rhyolite (Tr_1).

Petrographically, the younger rhyolite is porphyritic and mineralogically similar to the older rhyolite. Ten to fifty percent of the rock is composed of dipyramidal quartz phenocrysts that range from 2 to 6 mm in diameter (Figure 8). The groundmass is a fine-grained polygonal mosaic of secondary quartz with varying amounts of fine-grained sericite. The average grain size for the matrix is 0.05 mm. Though intensely sericitized and replaced by secondary quartz, occasional relict pheno-

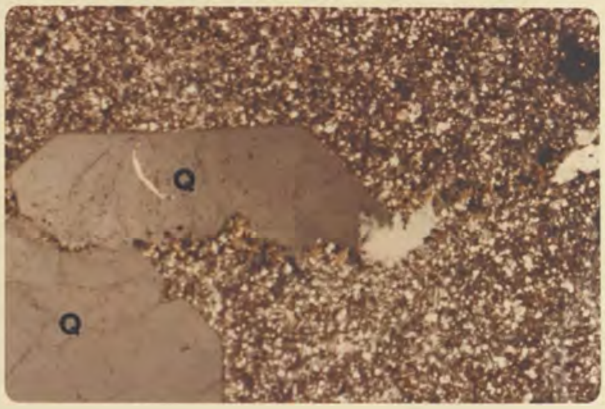


Figure 8
Magnification 20X, Polarized Light

Younger rhyolite from middle adit, Majuba Hill Mine. The matrix is a fine grained polygonal mosaic of quartz and sericite. The quartz phenocryst (Q) has been displaced along a micro-fracture filled with tourmaline.

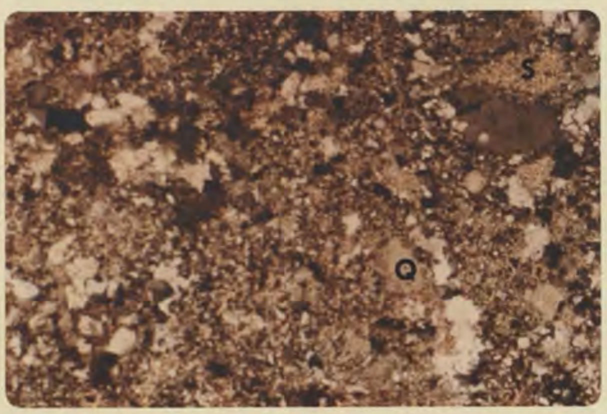


Figure 9
Magnification 20X, Polarized Light

Aplitic rhyolite from lower adit, Majuba Hill Mine. Badly resorbed and overgrown quartz crystals (Q) are set in a matrix of quartz and sericite. The large clot of sericite (S) is probably a replaced plagioclase phenocryst.

crysts and a matrix mineralogy similar to the older rhyolite, would suggest a differentiation relationship between the two rhyolites.

Aplitic Rhyolite (Ta)

The aplitic rhyolite is exposed only in the lower and middle adits of the Majuba Hill mine. Its limited exposure and confinement to the interior portions of the plug suggests that it is the youngest of the three phases of rhyolitic intrusive. Contacts between the older rhyolite and aplitic rhyolite are intensely brecciated and due to mixing of breccia fragments and locally gradational. Due to the limited exposures, the geometry of the aplitic rhyolite is not known. The configurations shown on Plate 1, Sec. B-B', and Plate 3 are interpretative.

In underground exposures, the aplitic rhyolite is aphanitic and very light gray (N8) to white (N9). The rock is locally mottled various shades of gray to black due to tourmalinization.

Petrographically, the rock is a very fine-grained interlocking mosaic of quartz and sericite ranging from 0.01 to 0.2 mm in largest grain dimension (Figure 9). The presence of patches of sericite and occasional larger grains of quartz suggests that the aplitic texture is a function of intense alteration with the feldspar totally replaced by sericite and the quartz phenocrysts greatly reduced due to resorption. The aplitic rhyolite is uniformly cut by a micro-stockwork system of minute fluorite-tourmaline veinlets. Deep purple fluorite forms the cores of the veinlets and strongly pelochroic blue-gray tourmaline coats the walls (Figure 10). The uniform distribution and close spacing of the veining suggests it was formed by shattering of the

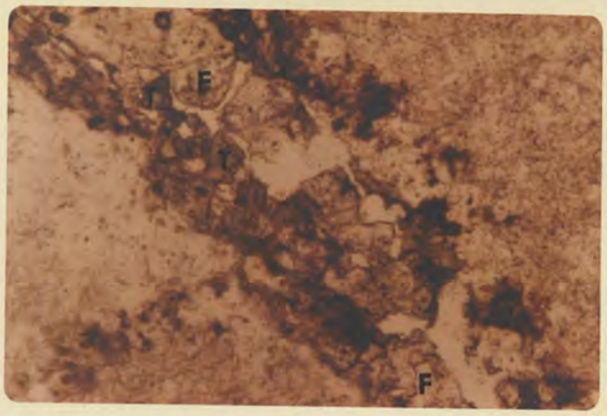


Figure 10
Magnification 128X, Transmitted Light

Aplitic rhyolite from middle adit, Majuba Hill Mine. The veinlets cuts matrix material as in Figure 9. The core is fluorite (F) flanked by tourmaline (T).

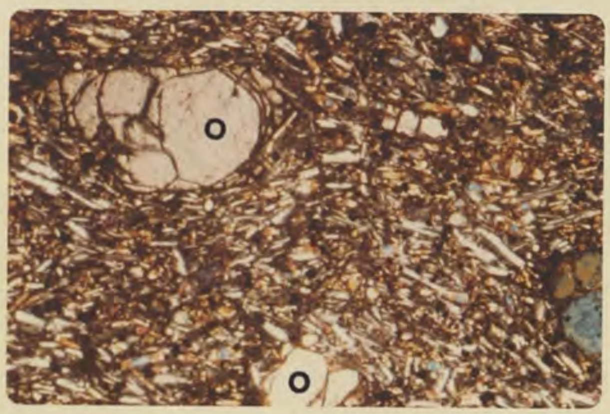


Figure 11
Magnification 120X, Polarized Light

Alkali-olivine basalt. Olivine phenocrysts (O) are set in a matrix of olivine, clinopyroxene, and plagioclase (An52) microlites. The matrix contains 5 percent anhedral orthoclase.

aplitic rhyolite after crystallization.

Alkali-Olivine Basalt

A thin flow of alkali-olivine basalt is intercalated with older alluvium in the eastern portion of the district. The flow is 10 to 40 feet thick and mantled by a thin pediment venner. Localization of the basalt outcrops near a large northwesterly trending basin and range fault suggest that the basalt may have intruded along the fault. The moderate topographic expression of the fault scarp and the association of the post alluvial basalt suggest that these are geologically quite recent features.

The upper surface of the basalt flow is quite platy and jumbled. Weathered surfaces range in color from rust brown (10R 4/6) to reddish brown (10R 3/4). Fresh surfaces are uniformly dark gray (N3). The rock is aphanitic in hand specimen.

The basalt has a pilotaxitic porphyritic texture, olivine phenocrysts are set in a matrix of olivine, clinopyroxene, and plagioclase (An52) microlites (Figure 11). The matrix also contains 5 percent anhedral alkali feldspar with accessory apatite and magnetite. The high potash content classifies the rock as an alkali-olivine basalt.

UNCONSOLIDATED DEPOSITS

Talus

Steep talus slopes composed of angular fragments of rhyolite mantle the middle and upper portions of Majuba Hill. In places the talus extends to the crest of the hill along major fault zones (Plate 1). The talus fragments range in size from 4 feet to less than 1 foot in diameter. The upper talus slopes are active and the lower slopes grade into the older alluvium.

Older Alluvium

Unconsolidated silt, sand, and gravel covers the northeastern portion of the district. The older alluvium is primarily thin pediment veneer, as indicated by erosional exposures of the underlying bedrock. The pediment surface extends up the main drainage of Majuba Hill and encircles the southern portion of the hill. The older alluvium has been markedly deepened and the main drainage from Majuba Hill now flows due east across the pediment surface. This change in the drainage pattern suggests uplift and tilting of the older alluvial surface from a gentle northeasterly gradient to a steeper easterly dipping gradient.

Younger Alluvium

Unconsolidated deposits of sand, gravel, and boulders fill the seasonally active drainages in the district. The younger alluvium consists of reworked older alluvium in which the finer fractions have been washed away. Recent rainstorms have gullied the younger alluvium of the main Majuba Hill drainage forming an impassible vertical walled ravine as much as 12 feet deep.

STRUCTURE

Deformation of the Sedimentary Rocks

The "Grass Valley Formation" sedimentary rocks strike from east-west to nearly north-south and dip steeply to the northwest throughout the Antelope district. The overall form is that of a large arcuate fold with the southwestern portion striking northerly and the northeastern portion striking easterly. Near the locus of the arcuate fold, an anticline overturned to the northwest strikes northeasterly and plunges gently to the southwest. The anticline is defined by a conspicuous bed of quartzite near the core of the structure. It is quite probable that other tight folds occur in the sedimentary rocks but were not detected due to lack of marker horizons and bedding attitude features. Similar patterns of folding occur throughout the southern portion of the Antelope Range (Olcott, 1958). The regional northeasterly strike and northwesterly dip and presence of folds overturned to the southeast suggest a northwest to southeast compressional mechanism of deformation. Willden (1958, p. 2396) has described similar regional deformation fabrics in the Jackson Mountains 25 miles north of the Antelope district. The deformation has been dated as pre-Cretaceous as younger rocks do not exhibit the same fold patterns. On the northern end of the West Humboldt Range, Silberling and Wallace (1967) have mapped northeasterly fold axes in the Grass Valley formation which forms the upper plate of the Humboldt City thrust fault. It is tempting to visualize the Grass Valley formation of the Antelope district as the upper plate of a large thrust fault which crops out at the Humboldt City thrust fault 15 miles to the southeast. Silberling and Roberts (1962, p. 39) have speculated on the extension of the Gillis thrust, a feature of a Jurassic and Cretaceous orogeny exposed in Mineral County, into northwestern Nevada. The age and direction of deformation is similar between rocks of the upper plate of the Gillis thrust and the rocks of the upper plate of the Humboldt City thrust fault but connection of the two features lacks documentation by mapping.

Intrusion of the Granodiorite

As illustrated on Plate 1, Section A-A', the numerous sills and an elongate intrusive body of granodiorite in the southeastern portion of the district are interpreted to be offshoots from the hood zone of a larger intrusive mass at depth. In addition to numerous sills and concordant intrusive bodies, the granodiorite forms minor dikes, many too small to represent on Plate 1, that cut the fold fabric at low angles. These discordant relationships indicate that the granodiorite was emplaced after the deformation of the sedimentary rocks.

Tatlock's (1969) compilation of the Pershing County geology shows numerous granodiorite stocks intruded into the lower Mesozoic sedimentary rocks of the Antelope and Trinity Ranges. The stocks are circular to elliptical discordant bodies that range from 8 to less than 1/2 miles in diameter. According to McKee (1971, oral communication) these intrusives range from 90 to 103 million years old. This date also supports the pre-Cretaceous age of the deformation of the sedimentary rocks.

Intrusion of the Majuba Hill Plug, General Statement

Majuba Hill, a rugged topographic prominence occupying the center of the Antelope district, is a rhyolite plug roughly circular in plan and 4,000 feet in diameter. The plug consists of three rhyolite phases and five types of breccia. The argillites of the "Grass Valley formation" immediately around the plug strike uniformly between 40^{o} and 60^{o} to the northeast dip between 50^{o} and 80^{o} to the northwest. The apparent lack of deformation in the sedimentary rocks, in view of the large body of intrusive rhyolite, is unusual as the rhyolite was quite viscous during intrusion.

Three possible mechanisms of intrusion are considered for the emplacement of the plug without dilation of the surrounding sedimentary rocks; assimilative stoping, convective stoping, or fluidization drilling.

Assimilative stoping involves the upward migration of a magma column by engulfment and melting of the hood zone of the magma chamber. While this process could result in physical emplacement of the rhyolite without deformation, the uniform mineralogy and lack of xenoliths suggests an alternative mechanism.

Convective stoping of the rhyolite magma could effectively transfer portions of the magma chamber roof to the floor of the chamber and result in the upward movement of the column. The lack of xenoliths of argillite or other wall rock lithologies within the rhyolite and unlikelihood of active connective cells within a column of viscous magma make this a questionable mechanism.

Both before and after Reynolds's (1954) discussion of fluidization as a geological process, investigators called upon this process to explain the emplacement of volcanic necks and plugs by explosive drilling (Bohmer, 1965, p. 1312). Among them are Williams (1936) for necks of the Navajo-Hopi country in northeastern Arizona; Rust (1937) for diatremes in southeastern Missouri; and Barrington and Kerr (1961) for a breccia pipe near Cameron, Arizona. McBirney (1959) suggested that processes operating in the eruption of intrusions to the surface differ from emplacement processes at depth due to a decrease in lithostatic loading and the presence of connate and magmatic water in near surface environments.

The term"diatreme" is frequently used as an equivalent to "breccia pipe". According to the A. G. I. Glossary (1962, p. 81) a diatreme is a "pipe or vent drilled through enclosing rocks (usually flat-lying sedimentary rocks) by the explosive energy of gas-charged magmas." Williams (1953, p. 316) describes the formation of diatremes as follows: "Rising gases 'lubricate' the roof rocks; pulsating magma brecciates the cover; repeated explosions comminute the cap rocks so that frothing magma is intimately mingled with them and, near surface, steam eruptions caused by heating of ground water facilitate the drilling process while slumping of slabs from the conduit walls enlarges the conduits."

Proposed Mechanism of Emplacement

A mechanism similar to that suggested above is proposed for the emplacement of the Majuba Hill rhyolite plug. Fluidization drilling, proceeding in the upper volatile charged portion of a silicic magma, eventually breached the surface when the vapor pressure of the magma exceeded the lithostatic load. A violent but short-lived surface eruption ensued which released the vapor pressure and mechanically eroded the conduit to its present shape.

Following surface breaching and release of the volatile phases of the magma, the diatreme conduit localized the emplacement of several pulses of rhyolite magma. The earliest rhyolite or older rhyolite (Tr_1) forms the main mass of Majuba Hill as well as numerous sills in the surrounding sedimentary rocks. During this phase of viscous intrusion, fragments of the wall rock and possibly ejecta which had fallen back into the diatreme were mixed with the rhyolite magma and concentrated near the outer margins of the plug. This unit has been separated and mapped as a contact breccia (Tr_1cbx). Locally, up to 50 percent of the rock is composed of angular fragments of argillite and previously solidified rhyolite. The fragments range from microscopic to over one foot in diameter.

As the older rhyolite magma (Tr_1) welled up the conduit and onto the surface, it rapidly chilled and formed a large rhyolite dome. Early chilled zones within the dome were re-brecciated by the still viscous and mobile interior. These autobreccias (Tr_1abx), consist of rounded to angular fragments of Tr_1 in a Tr_1 matrix, and form arcuate lenses in plan that strike northwesterly and dip into the hill (Plates 2 and 3). They define a northwesterly trending fan-like configuration for the intrusive rhyolite. Figure 12 is a distant photograph of Majuba Hill looking northwest. Though the photograph is poor, the fan shaped configuration is defined by the trace of the steeper ledges around the

Figure 12

Majuba Hill looking northwest. Note the fan shape as defined by the trace of the steep ledges around the eastern flank of the hill. The ledges are composed of the older rhyolite and the more gentle portions of the slope by the older rhyolite autobreccia.

eastern side of the hill. The trend of these bodies of autobreccia stimulated the funnel shaped or ethmolithic interpretation of the main intrusive mass (Plates 1, Section B-B' and 3).

Following the intrusion and emplacement of the older rhyolite (Tr_1) was the intrusion of the younger rhyolite (Tr_2). The younger rhyolite intruded the older rhyolite while the latter was in a semi-viscous condition. This is evidenced by the lack of brecciation along the intrusive contacts. The younger rhyolite forms a northwesterly-trending lens-like dike near the crest of the hill, as well as persistent sills extending several miles northeasterly and southwesterly from the center of intrusion (Plate 1). Contacts between Tr_1 and Tr_2 on Majuba Hill are obscured by faults occupied by pebble dikes. The pebble dikes consist of well-rounded clasts of silicified and sericitized rhyolite in a highly comminuted matrix. The rounded clasts or "pebbles" range from an inch to a foot in diameter. A thin section of the core of a pebble is shown in Figure 13. Lovering (1949, p. 12) has described pebble dikes at Tintic, Utah, formed by attrition from material riding on top of monzonite or dragged along the edge of viscous monzonite bodies. This hypothesis agrees well with the observed relationships of pebble breccias on Majuba Hill. The truncation of dikes of Tr_2 within Tr_1 by pebble breccias indicates a still viscous and active body of Tr_1 during the intrusion of Tr_2.

A minor body of contact breccia with a Tr_2 matrix was observed on the southwest side of Majuba Hill. The breccia (Tr_2cbx) is localized by the intersection of a Tr_1cbx with a Tr_2 dike.

A small body of autobrecciated younger rhyolite is exposed in the

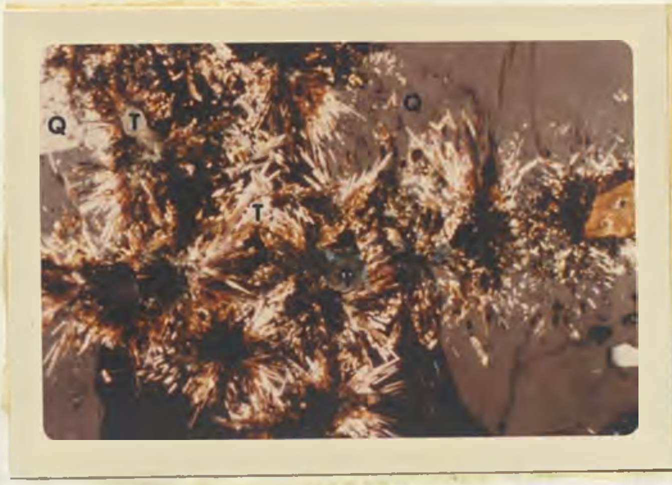


Figure 13
Magnification 20X, Polarized Light

Explosive breccia, surface exposure, Majuba Hill. Two generations of tourmaline (T) are intergrown with coarse grained quartz (Q).

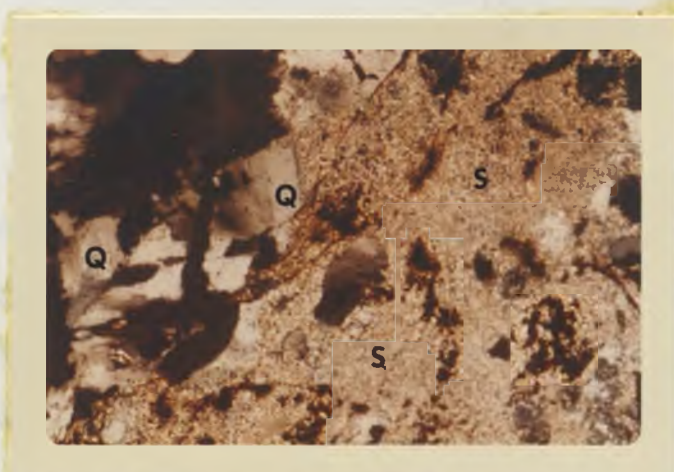


Figure 14
Magnification 30X, Polarized Light

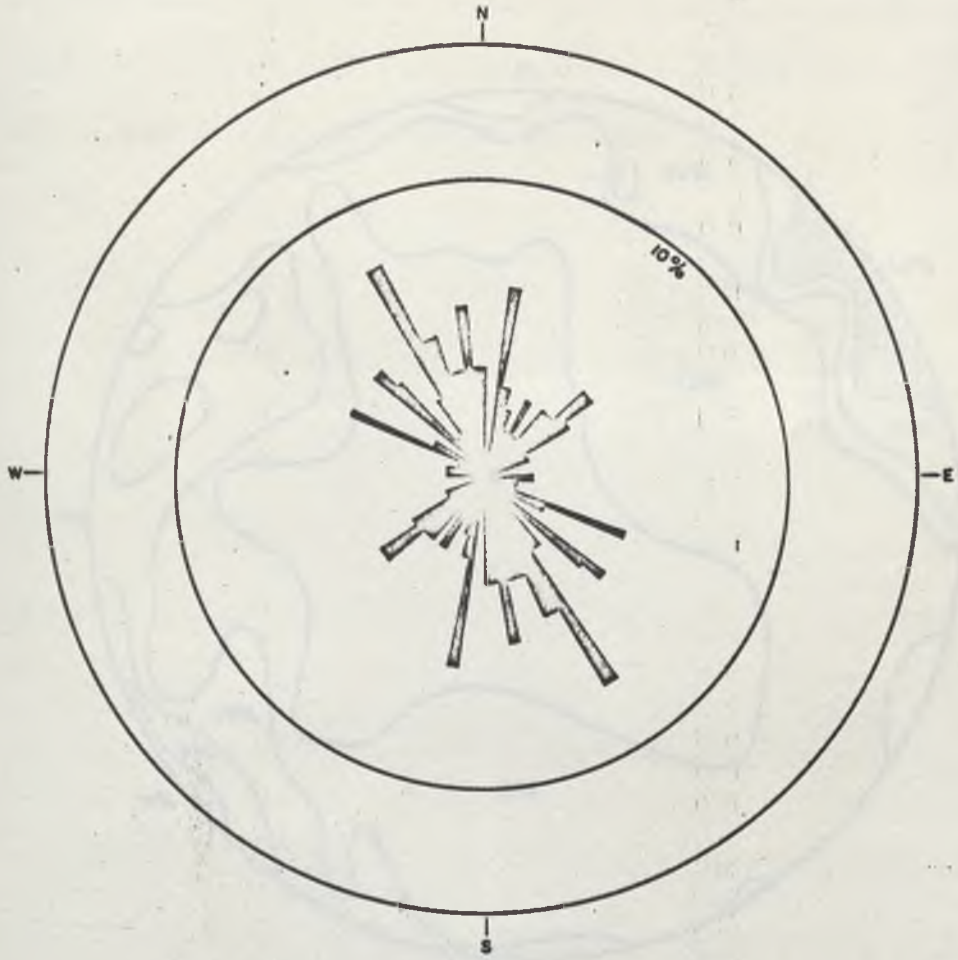
This is the core of a 4 inch diameter well rounded clast from a pebble breccia fault zone. Highly strained quartz fragments (Q) are set in a sericite matrix (S). The rock is interpreted to be a rebrecciated breccia.

middle adit of the Majuba Hill mine (Plate 4). The clasts are poorly rounded and generally less than 6 inches in diameter. Intense sericitization of the matrix of the breccia causes the clasts to weather out in relief.

The last phase of intrusive activity within the plug complex occurred after solidification of the older and younger rhyolite. A body of aplitic rhyolite (Ta) of unknown configuration is exposed in the lower and middle adits of the Majuba Hill Mine. The contacts are extensively brecciated and strongly tourmalinized.

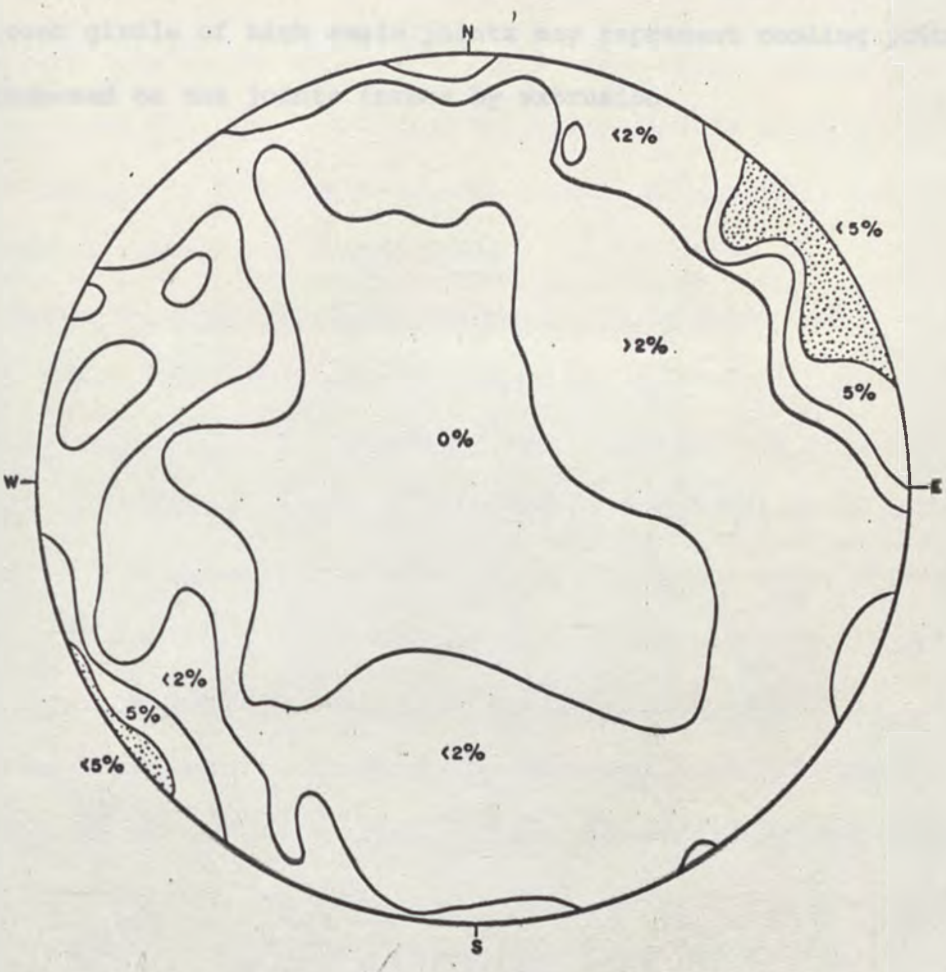
A final volatile explosive phase accompanied or followed the intrusion of the aplitic rhyolite. This type of explosive brecciation occurs as five small lenticular to fault-bounded polygonal bodies within the main mass of Majuba Hill (Plates 1 and 2). The explosive breccias (ebx) consist of rounded to angular clast of argillite, older rhyolite, younger rhyolite, and aplitic rhyolite. The matrix which composes from 20 to 70 percent of the breccia consists of quartz, tourmaline, and minor iron oxides which result from the oxidation of a small percentage of pyrite, arsenopyrite, and chalcopyrite. Figure 12 is a photomicrograph of the quartz and tourmaline from the matrix of an explosive breccia pipe.

The attitudes of 200 joints from the intrusive complex of Majuba Hill were plotted on a strike rose. The results are shown on Figure 15. The principal trend is northwest with a wide scatter. To further analyze the data it was plotted as poles of joints projected to the lower hemisphere and contoured with an equal area overlapping grid (Figure 16). The absence of flat dipping joints and abundance of



ROSE DIAGRAM JOINTS
MAJUBA HILL INTRUSIVE
200 data points

Figure 15



MAJUBA HILL INTRUSIVE DENSITY PLOT,
POLES OF JOINTS TO LOWER HEMISPHERE EQUAL AREA CONTOUR
200 data points

Figure 16

steeply dipping northwesterly striking joints support the fan-shaped intrusive model suggested by the distribution of the autobreccias. The 2 percent girdle of high angle joints may represent cooling joints superimposed on the joints formed by extrusion.

The Majuba Fault

The surface outcrop of the Majuba Fault is obscured by talus and is exposed only in the middle and lower adits of the Majuba Hill mine (Plates 4 and 5). The brecciated and tourmalinized rhyolite exposed in the upper adit is a fault-bounded segment of explosive breccia in the hanging wall of the Majuba fault.

The lower adit intersects the Majuba fault 1,500 feet from the portal (Plate 5). The fault intersects the adit at 57° and strikes north 44° west with a 57° southwest dip. The fault at this point is 12 feet in width and is filled with highly argillized gouge and angular to rounded fragments of rhyolite. It is cut by the lower adit workings at two additional places. One hundred and ninety feet northwesterly along the strike of the fault from the first exposure, it is intersected by a crosscut parallel to the main adit. At this point the strike is north 39° west and the gouge contains minor iron oxides and copper sulfates. The last exposure of the fault is in a crosscut normal to the main adit and 350 feet northwesterly along strike from the first exposure. At this point the fault strikes north 35° west and the dip has flattened to 51°. The fault is 10 feet wide in the last exposure and the gouge contains abundant iron oxide and moderate copper sulfates and silicates. The hanging wall consists of broken and contorted dark gray (N3) argillite.

In the middle adit of the Majuba Hill mine, the Majuba fault is exposed along strike for over 480 feet (Plate 4). The fault strikes uniformly north 39° west and dips 57° to 67° to the southwest. The fault zone ranges from 41 to 66 feet wide in plan and locally contains copper and tin mineralization as in the Copper Stope and Tin Stope. In the middle adit, the Majuba fault has been offset by two normal faults. A roughly parallel normal fault, dipping 53° to 78° to the northeast is observed to displace the Majuba fault 60 feet down dip and seventy feet horizontally. The fault exposed in the Myler Stope (Plate 4) is the offset upper portion of the fault exposed in the Copper Stope (Plate 4, Section B-B'). Five foot channel samples cut across the footwall side of the Majuba Fault in the Myler and Copper Stopes revealed nearly identical trace and major element concentrations by spectrographic analyses (Appendix I, smaples 2997-12, 13). Both the Majuba fault and the previously described normal fault have been offset by a north 79° east normal fault that dips 68° to the south. This fault is exposed 365 feet from the portal of the middle adit. The intersection between the Majuba fault and older normal fault has presumably been faulted out below the level of the middle adit workings. The displacement along this structure is unknown, and the position of the down-faulted segment of the Majuba fault is uncertain. It may be presumed to pass somewhere east of the main adit. The slope on the surface, above the up-dip projection of the Majuba fault, is covered by talus. Sparse fragments of mineralized material in the talus skree suggests that the fault strikes through this area.

The writer interprets the Majuba fault to have two components of movement; 1) an early reverse displacement of unknown magnitude which followed the last phase of intrusive activity, and 2) later reactivation with a normal component of displacement.

The initial reverse movement was caused by subsidence of the still mobile column of magma that occupied the throat of the vent. The 10% volume shrinkage during crystallization as suggested by Hulin (1948, p. 47), may also be responsible for the subsidence rather than a physical withdrawal of the magma. The interpretation of the Majuba fault is diagrammatically shown on Plate 3. The fault is interpreted to curve at depth and join the wall of the vent. This would have provided a conduit for the mineralizing solutions forming the ore deposits in the fault zone. The proposed roll of the fault with depth and reverse component is supported by the curving strike, as exposed in the lower adit, and increased width of the gouge zone from the lower to middle adit. The curve of the strike, concave towards the main mass of the plug, suggests subsidence of the interior portion. The increased width of the gouge zone in the upper portion of the fault, may be a result of tension produced by subsidence of the footwall.

Normal movement occurred after sulfide mineralization, for both sulfide and gangue minerals are found broken, incorporated in the gouge of the fault zone. Flutes and slickenside surfaces on the footwall of the fault as well as drag features in the gouge indicate that the last direction of movement was normal and dip slip. The normal movement was probably induced by gravitational adjustment during erosion of the surrounding argillites and slumping of the southwestern portion of Majuba Hill along Majuba fault. The amount of movement of the reverse and normal displacement is unknown. Smith and Gianella (1948, p. 48), calculated relative displacement along the Majuba fault between 30 and 150 feet, based on a displaced contact between the rhyolite and argillite exposed in the west crosscut in the lower adit.

The Last Chance Fault

The Last Chance fault is exposed in the Last Chance Mine and can be traced for over 1,800 feet on the surface. The fault trends north 45^{o} west and dips between 45^{o} and 72^{o} to the southwest. The fault is quite complex in detail containing many branching and sympathetic structures (Plate 6). The fault ranges from over 30 feet wide at the Last Chance Mine to less than 5 feet wide at the southernmost exposure. A hornblende andesite dike occupies the fault along most of the exposed strike length. Due to poor outcrops and lack of prospect pits, the fault trace is lost to the southeast beyond the ridge above the Last Chance Mine. To the northwest, it plunges under the older alluvium which mantles the pediment surrounding Majuba Hill. According to E. Strode (1971, oral communication) a drift on the 100 foot level of the inclined shaft at the Last Chance Mine extended 340 feet northwest of the shaft and was still on the structure. This would extend the exposed length of the fault to over 2,000 feet. As water stood at 40 feet in the shaft at the time of the writer's visit, an examination of the workings was impossible. Drag folds and offset monzonite sills within the argillites indicate a normal dip slip displacement of 40 feet for the fault. Mineralization at the Last Chance Mine is confined to the contact of the andesite dike along the hanging and foot walls of the fault.

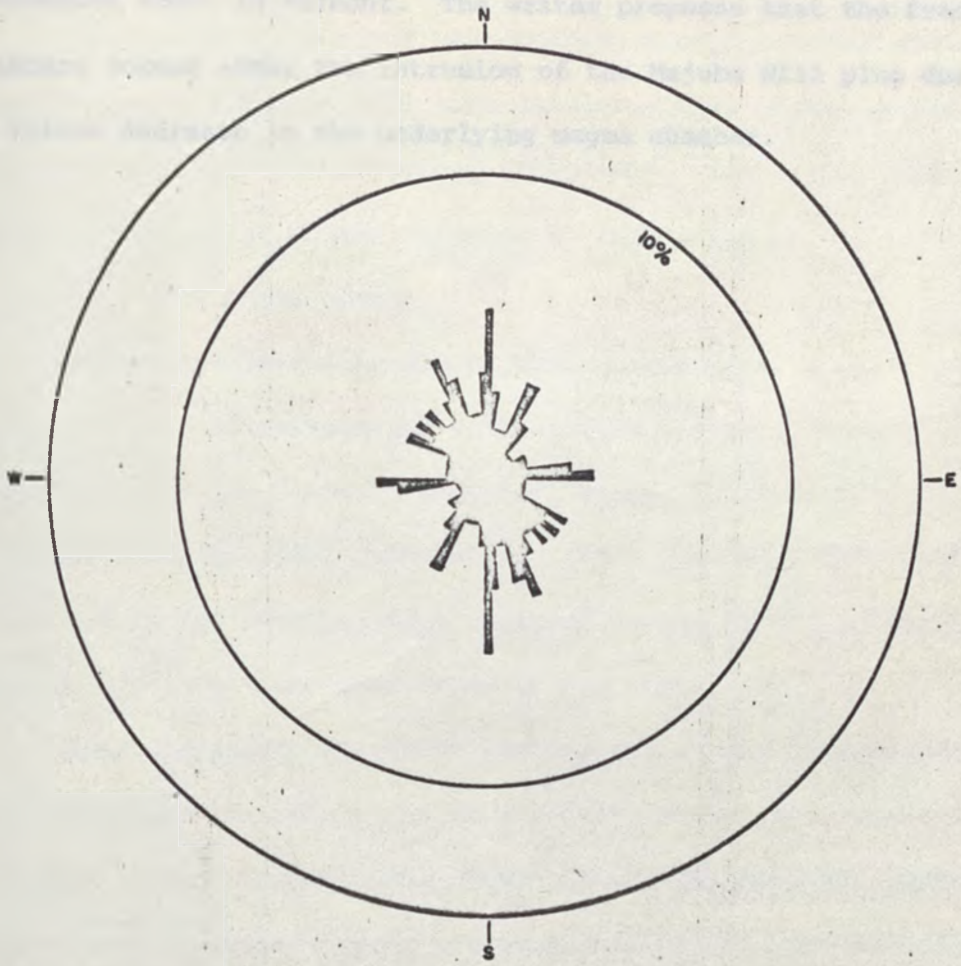
Faults and Photolinears of the District

Photolinears were defined by alignment of topographic features and vegetation textures visible on the photographs when viewed in stereoscopic pairs. The linear features were transferred to the topograph base using a Kail radial line plotter. As is so often the case, field checking failed to detect evidence on the ground for most of these features. As the photolinears were not found to contain dike or vein material, they are assumed to be faults.

The strong northeasterly-trending bedding of the sedimentary rocks renders only the structures cutting the beds at a fairly high angle discernible from the overall bedding fabric. The resulting trend is strongly northwesterly. A rose plot of the photolinears is shown on Figure 17. The largest measured offset of any fault in the district is around 200 feet of right lateral strike slip displacement of a younger rhyolite sill. Lack of distinctive marker horizons within the sedimentary rocks makes offset estimations impossible. Within the granodiorite sill swarm, photolinears cut the sills with no apparent offset. It would appear that most of the faults and photolinears have a very small displacement.

Except for a suggestion of northeasterly trend, most of the photolinears exhibit a well-developed radial pattern centered on the Majuba Hill plug. A concentric pattern may be present in the southwestern portion of the area. In the northwestern and southeastern portions of the district, the concentric pattern is obscured by the stratification of the sedimentary rocks. The northeastern part of the district is covered by post faulting alluvial cover.

The pattern of radial and concentric fracturing centered about the Majuba Hill plug, though on a smaller scale, is similar to the subsi-



ROSE DIAGRAM
PHOTOLINEARS IN SURROUNDING SEDIMENTS
160 data points

Figure 17

dence fracture pattern described by Chapman (1954) for the Mount Monadnock stock in Vermont. The writer proposes that the fracture pattern formed after the intrusion of the Majuba Hill plug due to a volume decrease in the underlying magma chamber.

GEOLOGIC HISTORY

The geologic record of the Antelope Mining district begins sometime during the Triassic(?) with the deposition of the argillites and quartzites of the "Grass Valley Formation". Deposition took place along a prograding deltaic complex at the margin of the northeasterly trending continental margin.

During the Late Triassic or early Cretaceous, a major orogeny affected most of western and northwestern Nevada. The argillites and quartzites of the district underwent strong northwesterly to southeasterly compressional deformation. This period of deformation is recorded in the northeasterly regional fabric of the sedimentary rocks and in folds that are overturned to the southeast.

Granodiorite to monzonite plutons and stocks were emplaced as late-tectonic intrusions during mid-Cretaceous time. The sill swarm exposed in the southeastern portion of the district may represent concordant intrusions above the roof zone of a larger discordant intrusive mass at depth.

The catastrophic surface breaching of the diatreme that later became Majuba Hill probably took place during the Late Tertiary. The explosive volatile release degassed the underlying magma and provided a channel for the ascent of the upper silicic differentiate of the magma chamber. A minor dilation of the surrounding sedimentary rocks was produced by the ascent of the rhyolite magma. Numerous sills invaded the surrounding argillites as a northeasterly trending sill swarm centered at the Majuba Hill plug. As the rhyolite of the main conduit reached the surface it welled up into a fan shaped dome. Two later episodes of rhyolite intrusion are represented by a quartz phenocryst-rich phase and a siliceous aplitic phase. The final episode of intrusive activity formed a northwesterly trending alignment of explosive breccia bodies. The volume decrease in the underlying magma chamber, which took place during the extrusion of the rhyolite, resulted in partial slumping at the roof and formation of a poorly developed radial and concentric fracture pattern in the overlying sedimentary rocks. Minor subsidence of the rhyolite magma column formed the Majuba fault, which localized the ore deposition. Mineralization at the arsenic prospect and Last Chance mine appears to have preceded or been contemporaneous with the emplacement of the Majuba Hill plug and related to a parent intrusive at depth.

Following emplacement of the Majuba Hill rhyolite, the area was subject to erosion and block faulting. Erosion removed all but the central portion of the rhyolite dome and due to differential weathering, produced the conspicuous radial drainage pattern of the district. Block faulting, which is responsible for the present physiography of the area, was accompanied by minor basaltic eruptions along the major faults.

ALTERATION

Contact Metamorphism in the Sedimentary Rocks

The argillites and quartzites of the "Grass Valley Formation" are weakly calc-silicated and thermally metamorphosed adjacent to intrusive contacts. Narrow contact zones adjacent to the granodiorite to monzonite sill swarm are characterized by the conversion of iron rich illite to chlorite and thermal recrystallization of calcite. The chlorite occurs as fine-grained patchy interstitial replacements of the matrix material. The optically continuous calcite, some of which exhibits polysynthetic twinning, may be remobilized due to thermal gradients (Barnes, 1967, p. 406).

On the east side of the Majuba Hill plug, at the contact of the brecciated argillite, the argillite matrix, as well as the breccia fragments, have been extensively replaced by fine-grained tourmaline. Minor metasomatism of the calcareous matrix forms small prismatic crystals of epidote within the matrix of the argillite adjacent to the Majuba Hill plug. None of the alteration effects are visible in hand speciment due to the fine-grained texture of the sedimentary rocks and their monotonous colors.

Propylitization of the Granodiorite

All specimens of the granodiorite to monzonite examined under the microscope show secondary mineral assemblages of chlorite, carbonate, quartz, and minor sericite. This mineral assemblage is within the propylitic alteration facies of Lowell and Guilbert (1970, p. 383). The chlorite exhibits gradational replacement of rock biotite and ferromagnesian minerals. Carbonate occurs as replacements of plagioclase phenocrysts as well as discrete masses within the matrix. The more calcic portions of the zoned plagioclase show preferential replacement by the carbonate. The quartz occurs as fine-grained polygonal mosaics replacing the matrix and margins of the plagioclase phenocrysts. Occasionally the plagioclase phenocrysts form complex myrmekitic intergrowths at the contact with matrix orthoclase. Rather coarse-grained sericite fills fractures within the plagioclase phenocrysts and replaces the calcic zones and cores of the feldspar.

The more intense propylitization occurs in the thinner portions and extremities of the sill-like intrusions. The more massive interior portions of the intrusive bodies are commonly more porphyritic and less altered. Field relationships suggest concentration of volatiles within the extremities of the intrusive bodies and a deuteric or autometasomatic (Turner and Verhoogen, 1960, p. 578) development of the propylitic mineral assemblage.

Silicification, Sericitization, and Tourmalinization of the Majuba Hill Rhyolite

The intrusive rhyolite, which forms the main mass of Majuba Hill, is almost totally altered to a fine-grained polygonal mosaic of quartz with moderate amounts of intergranular fine-grained sericite. Within the central portion of the plug, fine-grained black tourmaline occurs as disseminated radial aggregates replacing relict plagioclase. In addition to the plagioclase, small xenoliths of argillaceous wall rock are selectively replaced by tourmaline. Tourmaline forms from less than one percent of the rock in areas of weaker alteration to over 80 percent as a replacement of the argillized(?) and highly comminuted matrix of breccias exposed in the underground workings. The explosive breccias are extensively replaced by tourmaline.

Silicification of the rhyolite is pervasive and effects all of the intrusive phases exposed on Majuba Hill, the rock is estimated to contain in excesses of 75 percent silica, obliterating all of the original textures. Dipyramidal phenocrysts of high quartz are markedly embayed and resorbed. Many of the phenocrysts from the younger rhyolite have reaction rims of fine-grained quartz and sericite.

The tourmaline is commonly black and very fine-grained in hand specimen. The discrete black rosettes, which replace plagioclase and sanidine phenocrysts, contrast with the white to light gray silicified matrix of the rhyolite. In thin section, the tourmaline is dark blue gray and strongly pleochroic. The color classifies the tourmaline as schorl and the strong pleochroism is suggestive of a high ferric iron content (Heinrich, 1965, p. 115).

Smith (1949, p. 189) has shown that tourmaline is stable only in weakly alkaline solutions and unstable in neutral, acid, and strongly alkaline solutions. He was successful in synthesizing tourmaline by heating the component oxides in a high pressure autoclave at 400-450^{o} C. Experimental studies in the field Na_2O-B_2O_3 have shown that plagioclase (albite) and tourmaline could not be deposited at the same time within the same system (Smith, 1949). Depending on the ratio of the above components, either plagioclase alone would be precipitated or tourmaline with mica. This phenomenon was petrographically observed at Majuba Hill within zones of extensively tourmalinized rhyolite. Former plagioclase phenocryst sites are now occupied by an inner core of sericite and outer zone of acicular tourmaline. An outer aureole of more intense silicification surrounding the tourmaline was observed in several specimens. Presumably, this represents the excess silica from the plagioclase, not incorporated in the sericite or tourmaline lattice.

The pervasive distribution and intensity of the alteration of the rhyolite suggests that it may be an autometasomatic product. The abundance of fluid inclusions within the quartz and evidence for the diatreme which provided the initial conduit indicate a volatile charged magma. While the initial eruption probably released most of the volatiles, sufficient water, boron, fluorine, and potassium salts were contained within the viscous magma during its emplacement into the conduit. The cooling and pressure release which accompanied the intrusion resulted in autometasomatic silicification, sericitization, and tourmalinization of the rhyolite.

ORE DEPOSITS

Arsenic Prospect

Approximately 4,500 feet north 75° west from the crest of Majuba Hill is a small prospect that has been intermittently worked for its copper and arsenic content. Mineralization occurs within a north 52° east bedding plane shear that dips 56° to the northwest. The mineralized zone, as defined by intermittent outcrops of gossan and alignment of prospect pits, can be traced for 1,000 feet on the surface.

The "Grass Valley Formation" of the wall rock consists of argillites interbedded with slightly calcareous thin bedded quartzites. A small discordant body of moderately propylitized monzonite outcrops 500 feet west of the main workings.

Development of the mineralized zone consists of scattered prospect pits and a few shallow caved shafts. A small pit has been excavated at the widest portion of the structure. The pit is 100 feet long and 15 feet deep and explores a mineralized zone five feet wide. There is also a caved shaft and several old ore bins in the area.

The exposed mineralized zone ranges from four to less than one foot in thickness and is completely oxidized. Mineralogy of the oxidized zone includes hematite and scorodite in a highly argillized and sheared matrix. The mineralized zone outcrops as a weakly silicified rust brown (10R 4/6) hematitic breccia. Several tons of a nearly massive dark gray mixture of arsenopyrite and pyrite have been stockpiled at the main prospect. The sulfide material was evidently taken from the caved shaft which penetrated below the oxidized zone. A grab sample from the sulfide material assayed 50 percent arsenic and contained anomalous amounts of copper, lead, and silver (Appendix II, sample 2997-54). The arsenopyrite is partially oxidized to an earthy pale green scorodite. Polished surface examination of the sulfide material (Figure 18) disclosed minor amounts of pyrite and covellite in addition to the arsenopyrite and scorodite. No hypogene lead or copper sulfides were observed in the few samples examined, but the productive record suggests that they were present.

Several other prospect pits in the area are located on bedding plane shears similar to the main arsenic prospect (Plate 1). These mineralized zones are all less than one foot wide and are weakly mineralized. Exotic copper mineralization consisting of chrysocolla, malachite, and melaconite is localized along fractures and bedding plane surfaces 1,600 feet west of the arsenic prospect (Plate 1). The total amount of mineralization is negligible and results from the oxidation and migration of copper from a few sulfide bearing bedding plane fault zones.

Last Chane Mine

The Last Chance Mine is located 7,000 feet south 62^{o} east from the crest of Majuba Hill. The mine is located on the main drainage 4,000 feet from the mouth of the canyon.

The Last Chance Mine is developed by an adit 830 feet long and an inclined shaft 100 feet deep with workings on the 40 and 100 foot levels (Vanderbert, 1936, p. 8). The accessible workings were mapped

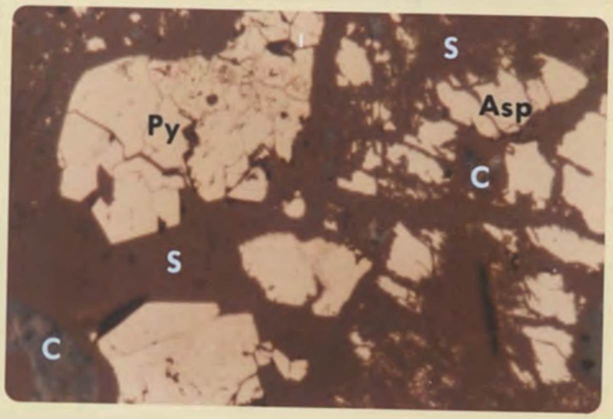


Figure 18
Magnification 200X, Reflected Light

Pyrite (Py) and Arsenopyrite (Asp) are the hypogene sulfides. The non-metallic matrix is largely scorodite (S) with a few patches of covellite (C).

with a Brunton compass and tape at a scale of 1 inch to 50 feet (Plate 6).

Mineralization at the Last Chance Mine is confined to the hanging and footwall of a well propylitized hornblende andesite dike that strikes north 45° west and dips between 45° to 72° to the southwest. The dike is 20 feet wide at the mine and thins to less than 3 feet wide 1,700 feet to the southeast. The dike is offset 20 feet by a small reverse fault exposed 180 feet from the portal of the adit (Plate 6). Mineralized structures cutting the dike suggest that the dike invaded the Last Chance fault prior to the mineralization.

Hypogene mineralization at the Last Chance mine consists of a vein deposition of pyrite, sphalerite, and galena in a mangano-calcite gangue along the hanging and footwall of the andesite dike. The veins range from 5 feet to less than 1 foot thick and average 3 feet in the larger stopes. The higher values are contained within steeply plunging ore shoots within the wider portions of the veins.

Three samples were taken for assay, two channels cut from the apparently mineralized portion of the vein and a large composite of the dump. The channel samples, 2997-42 (3 feet) and 2997-46 (2 feet) gave moderate values in silver and low values in lead and zinc (Appendix II). The dump sample failed to substantiate the values reported to Vanderburg (1936, p. 9) of 17 ounces of silver per ton and 8 percent lead (Appendix II, sample 2997-47).

A sample of sulfide ore, from the 40-foot level of the mine, was provided by Mr. E. Strode of Imlay, Nevada, for microscopic study. The sulfide ore contains equal amounts of pyrite and sphalerite intergrown in a fine-grained unoriented texture. The sphalerite contains abundant exsolution blebs of pyrite. Only minor amounts of very fine-grained galena were observed in the polished specimen.

Oxidation of the sulfides and leaching of the mangano-calcite gangue has extended to at least 60 feet below the present topographic surface. The mined ore consists of a dark reddish brown (10R 3/4) to brown (5YR 3/4) earthy mixture of hematite and various manganese oxides with minor amounts of cerussite and smithsonite.

Tin Mineralization, General Statement

Placers, by far, contain the majority of the world's recoverable tin as detrital cassiterite. Underground mining of high grade-low tonnage deposits such have been exploited in the past are rapidly becoming uneconomic. The tin deposits of Bolivia, Cornwall, and Mexico have followed a history similar to the precious metal mines of the Western United States. It is doubtful many could be profitably exploited at modern labor prices and mining standards. Future tin reserves will consist of placers or large volumes of disseminated hypogene mineralization amenable to bulk mining methods. As the placers become depleted, the chance of developing bulk minable deposits is excellent, especially in recognized tin provinces.

The types of hypogene tin occurrences are strikingly varied in contrast to the relatively restricted distribution of tin metallogenetic provinces. Only 15 major stanniferous areas are recognized in the world (Sainsbury, 1969, Figure 1). Hosking (1965), has classified nine types of hypogene tin mineralization. Four of these occurrences may be related to specific modes of mineralization associated with biotite-rich "tin granites". Sainsbury (1969) defines six classes of mineralization by depth-temperature-host rock relationships:

<u>Pegmatite deposits</u> - Stanniferous pegmatites are usually associated with biotite granites within tin provinces. Only deep lateritic weathering has rendered this type of deposit economically important by the formation of placers.

<u>Pheumotalytic - hydrothermal deposits</u> - The bulk of the world's hypogene tin falls under this classification. Disseminated tin (cassi-

terite) occurs in greisen (quartz muscovite) zones within the host granitic intrusives. In or near the intrusives, replacement deposits and fissure filling have provided important sources for tin. Base metal sulfides and silver are common associations.

Subvolcanic or tin-silver deposits - This type of deposit characterizes the Bolivian tin belt. The deposits are restricted to near surface siliceous volcanic rocks. They are commonly "telescoped" mineralogically due to rapid precipitation prompted by a sharp pressure gradient at relatively high temperatures. Majuba Hill is within this category.

Disseminated deposits - This type of mineralization occurs in the border zones of "tin granites". Cassiterite is usally accompanied by boron and fluorine metasomatism (tourmaline and fluorite). Erosion of this type terrain contributes to the large placers of Southeast Asia.

Contact - metamorphic deposits - These deposits are relatively uncommon and consist of disseminated cassiterite or malayaite in contact tactites. Large tonnages and by-product base metals may make this type deposit economically important in the future. Grades are generally too low for present exploration.

Fumarole deposits - This category describes the minor but widespread occurrence of cassiterite associated with specular hematite which form fracture fillings in Tertiary rhyolites. This type of deposit is common in Durango, Mexico, the Black Range of New Mexico, and the Izenhood district of north central Nevada (Foshog and Fries, (1942).

The subvolcanic or tin-silver deposits of Sainsbury (1969) are geologically and geochemically very similar from district to district.

The subvolcanic deposits are typical of the Bolivian tin belt and scattered occurrences around the circum-Pacific volcanic province. All are associated genetically and spatially with a quartz porphyry felsic intrusive with volcanic affinities. The majority have explosive breccias associated with the emplacement of the intrusive. Mineralization is confined to steeply dipping veins or shear zones that primarily occur within the host intrusive. Frequently the breccia pipes are mineralized.

Tourmaline is by far the most common alteration product. Sericitization, orthoclasization, and silicification are equally widespread as alteration effects within the intrusive. Specularite, apatite, fluorite, topaz, and magnetite are less abundant but common in this type of mineralization.

Buddington (1935) proposed the term xenothermal to classify occurrences of high-temperature mineral associations deposited at shallow to moderate depths. The ore deposits are formed within a few thousand or even a few hundred feet of the surface, mainly in Tertiary surface volcanics. Precipitation of the gangue and ore minerals is promoted by an abnormally steep geothermal gradient. The net effect is the precipitation of minerals characteristic of moderate to great depth and high temperatures in a zone where epithermal mineral suites would normally be expected.

The sericitization and tourmalinization of the Majuba Hill rhyolite, and the occurrence of tin mineralization in a shallow environment indicate that the ore deposits of the Majuba Hill mine are subvolcanic and xenothermal.

Majuba Hill Mine

The Majuba Hill mine is located within the main body of the Majuba Hill rhyolite plug. Figure 19 is a photograph of Majuba Hill looking due north and showing the location of the lower, middle, and upper adit portals. The lower and middle adits of the Majuba Hill mine were mapped at a scale of 1 inch to 50 feet using a brunton compass and tape (Plates 4 and 5).

Apart from a few prospect pits and short adits scattered over the upper portion of Majuba Hill, all of the exploration and development has been limited to the mineralization within the Majuba fault zone.

The lower adit (Plate 4) contains 2,820 feet of workings, 330 feet of which were driven during an exploration program by California Time Petroleum during 1969.

The lower adit passes through 1,650 feet of rather uniform argillites striking north 55° east and dipping 60-89° to the northwest. Many minor faults strike northwesterly and represent minor compressional release during the emplacement of the Majuba Hill plug. Two major structures are exposed in the lower adit, the Majuba fault and a parallel somewhat smaller fault which crosses the main adit 1,200 feet from the portal. The contact with the main mass of the plug is at 1,650 feet. The relationship of the argillite exposed in the face of the north crosscut from the west drift is unknown. The bedding attitude suggests that this is a portion of argillite connected to the main mass of wall rock rather than a large detached block within the throat of the vent.

No sulfide minerals were observed in the lower adit. The hematite and secondary copper minerals exposed at the end of the west crosscut

Figure 19

Majuba Hill looking due north. Points L, M, and U mark the location of the lower, middle, and upper adits of the Majuba Hill Mine. The position of three bodies of explosive breccia are marked by E.

are exotic and possibly derived from oxidizing sulfide orebodies up dip in the Majuba fault.

Figure 20 was taken in a cut along the road leading from the lower to middle adit. The rhyolite dike at this point is slightly discordant to the attitude of the sedimentary rocks. This location is approximately 300 feet from the main contact of the rhyolite plug.

Brecciated rhyolite, with a dense tourmaline matrix (Figure 21), is abundant on the dump of the lower adit. Though impressive in appearance, the rock is totally devoid of sulfide mineralization.

The most striking feature of the lower adit is the uniform attitude of the sedimentary rocks which strike into the Majuba plug with little or no deformation.

The middle adit (Plate 5) contains 2,420 feet of workings on the adit level. Aside from the Myler stope, the other levels, including the raise to the upper adit, were inaccessible at the time of the writer's examination.

All of the production credited to the Majuba Hill mine came from the middle adit and in particular, the ore bodies localized by the Majuba fault. The fault is exposed for 480 feet along strike by drifts of the middle adit. Of the 480 feet exposed, 170 feet are appreciably mineralized.

Figure 20

Contact of rhyolite dike and argillite exposed in road cut between the lower and middle adits of the Majuba Hill Mine.

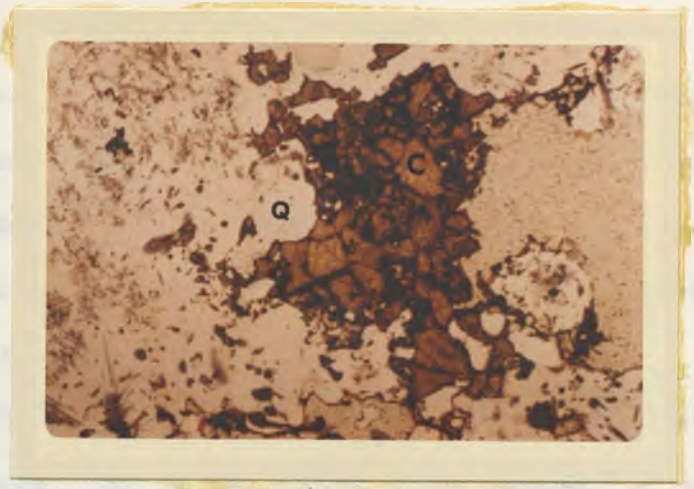
Figure 21

Boulder of tourmaline matrix breccia with rhyolite fragments exposed on the dump of the lower adit. The pick head is 6 inches long.

Two distinct ore bodies are exposed in the middle adit, the chalcocite body of the Copper Stope and the cassiterite pod in the Tin Stope. Though apparently localized by the same structure, the two ore bodies do not appear to be related and differ markedly in configuration and mineralogy.

The Tin Stope is an irregular area within the Majuba fault zone that contains abundant hematite, partially after arsenopyrite, and massive fine-grained tourmaline. Quartz is less conspicuous, but equally abundant. Cassiterite occurs as amber colored, translucent doubly terminated pyramids in a matrix of fine-grained quartz and tourmaline (Figure 22). A two foot channel sample from the ore zone assayed 3 percent tin (Appendix II, sample 2997-43). The cassiterite is fine-grained and only visible after panning and examination of the concentrates with a microscope.

The tin mineralization is localized at the intersection of the Majuba fault and a tourmaline matrix explosive breccia pipe.



Transmitted Light

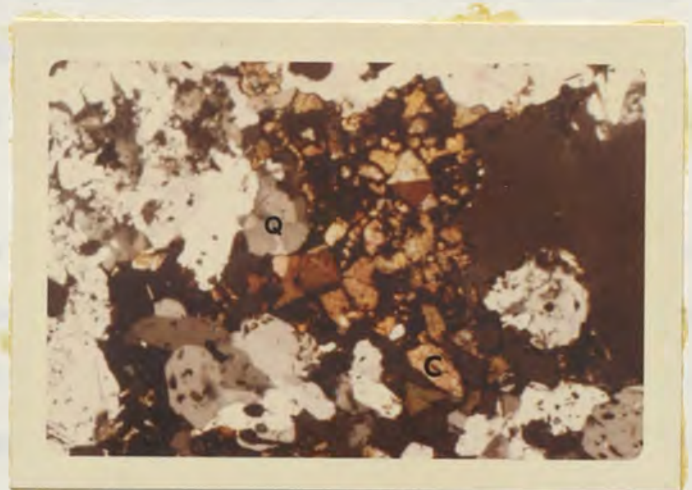


Figure 22

Magnification 20X, Polarized Light

Cassiterite (C) from tin stope in the middle adit of the Majuba Hill Mine. The cassiterite occurs in a matrix of intergrown quartz (Q) and tourmaline, the latter was almost completely plucked from the slide during grinding. Note the twinned cassiterite crystal in the upper right corner of the cluster.

Hydrothermal tin can be transported in two ways, as a stannate ion in alkaline solutions, or as a simple ion in acid solution (Smith, 1947). Tourmaline has been shown to be stable only in slightly alkaline conditions (Smith, 1949). The presence of abundant tourmaline in the Tin Stope suggests a stannate ion transfer by weakly alkaline hydrothermal solutions.

Most of the production has been from chalcocite ore mined from the Copper Stope. Ore in the copper stope consists of pod-like masses of chalcocite in a 40 foot wide breccia zone that forms the hanging wall of the Majuba fault. Due to the hazardous condition of the Copper Stope, only a brief visual appraisal of the main mineralized area was possible.

Based on limited samples collected in the Copper Stope, hypogene mineralization consists of, in decreasing amounts, arsenopyrite, chalcopyrite, and pyrite. The sulfides occur as disseminations and replacements in fragments of silicified and sericitized rhyolite within the Majuba fault zone. Figure 23 and 24 are photomicrographs of ore grade mineralization collected from a pillar in the Copper Stope. Paragenetically, arsenopyrite was the first sulfide deposited. The arsenopyrite was then broken, fractured and partially replaced by chalcopyrite. Minor pyrite was co-deposited with the chalcopyrite. Supergene processes have formed a large amount of chalcocite, the principal ore mined, in the upper portion of the Majuba fault. In both Figures 23 and 24, from the Copper Stope, chalcocite replaces hypogene pyrite and chalcopyrite. Chalcocite veinlets in arsenopyrite actually replace former chalcopyrite. The chalcopyrite is a hypogene replacement of

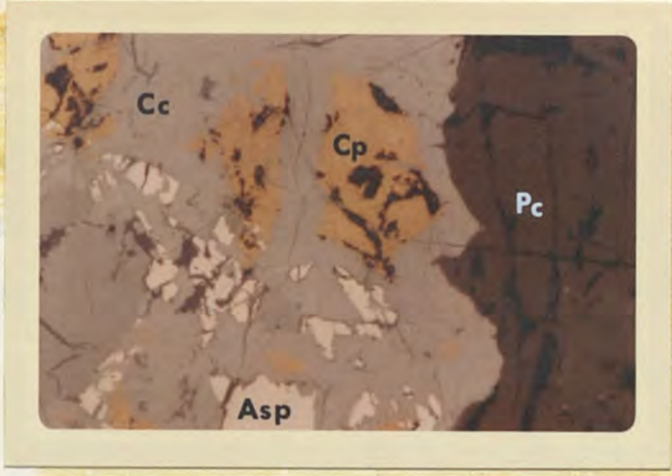


Figure 23
Magnification 128X, Reflected Light

Sulfide ore from the copper stope of the Majuba Hill Mine. Hypogene chalcopyrite (Cp) is partially replaced by supergene chalcocite (Cc). The non-metallic mineral is pharmocosiderite (Pc).

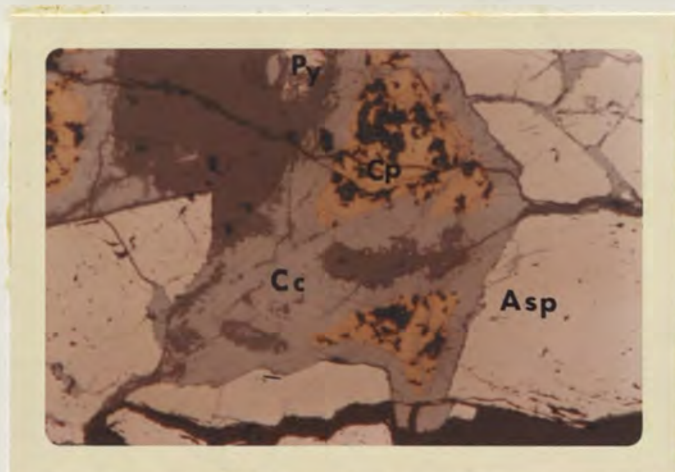


Figure 24
Magnification 128X, Reflected Light

Location same as Figure 23. Chalcocite (Cc) replacing large grain of chalcopyrite (Cp). The small grain of pyrite (Py) is surrounded by a thin rim of supergene covellite.

the arsenopyrite. Figure 25 is a photomicrograph of a supergene cuprite veinlet with relict chalcocite on the margins of the fracture. This mineralogy suite is common in oxidizing copper deposits and may be produced by Eh or pH fluctuations at the oxidizing portion of the supergene sulfide zone.

Figure 25
Magnification 100X, Reflected Light

Location same as Figure 23. The cuprite veinlet (Cup) has replaced chalcocite (Cc). Several Grains of native copper (Cu) occur in the cuprite.

Supergene Mineralization

Oxidation of the hypogene sulfides and enrichment by supergene chalcocite formed the copper ore body of the Majuba Hill mine. Though not affected by chemical enrichment of supergene sulfides, the ore mined at the Last Chance mine was oxidized and contained residual enrichments of lead and silver.

Ore textures preserved in pillars of the Copper Stope suggest that the chalcocite formed after brecciation of the hypogene sulfides. The brecciation resulted from normal movement along the Majuba fault. The porosity developed in the fault zone by the brecciation provided channels for oxygen charged meteoric waters. The oxidation of chalcopyrite and replacement of chalcopyrite by supergene chalcocite proceeds by the following chemical reactions:

Strongly oxidizing conditions

$$2CuFeS_2 + 17/2O_2 + 2H_2O \rightarrow Fe_2O_3 + 2Cu^{+2} + 4SO_4^{-2} + 4H^{+}$$

Weakly oxidizing conditions

$$CuFeS_2 + 4Fe^{+2} + 2H_2O + 3O_2 \rightleftharpoons Cu^{+2} + 5Fe^{+2} + 2SO_4^{-2} + 4H^{+}$$

Reducing conditions

$$5CuFeS_2 + 14Cu^{+2} + 14SO_4^{-2} + 12H_2O \rightarrow 7Cu_2S + 12H^{+} + 17SO_4^{-2} + 5Fe^{+2} + 5Cu^{+2}$$

The replacement of pyrite by chalcocite is similar:

$$5FeS_2 + 14Cu^{+2} + 14SO_4^{-2} + 12H_2O \rightleftharpoons 7Cu_2S + 12H^{+} + 17SO_4^{-2} + 5Fe^{+2}$$

In the Copper Stope of the Majuba Hill mine, present oxidation of the ore body has resulted in an exotic assemblage of secondary minerals. Along the Majuba fault, in the footwall of the Copper Stope orebody, columns of blue chalcanthite coat the walls of the mine workings. Scorodite, olivenite, azurite, malachite, chrysocolla, and chalcophyllite have been reported by Smith and Gianella (1942). Metazeunerite, a copper uranium arsenate reported by Trites and Thurston (1949), was not found by the writer, but the copper stope was not examined with ultraviolet light. Pharmacosiderite was identified by the writer. X-ray analysis of samples revealed adamite and arthurite.

The isolated nature of the chalcocite body in the Copper Stope suggests that it is related to an older erosion level and water table. The ore body is "perched" relative to the present geomorphology.

Hypogene mineralization in the Last Chance mine consisted of pyrite, sphalerite, and galena disseminated in a mangano-calcite gangue. Oxidation of the hypogene assemblage resulted in an earthy hematitic ore rich in lead, silver, and manganese. All of the sulfides have been oxidized to at least 60 feet below the present topographic surface.

High grade ore mined from the vein from 1906 to 1928 averaged 40 ounces of silver per ton and 8 percent lead (Vanderburg, 1936). No representative samples of the unoxidized ore were available to the writer for chemical analysis. The grade of the hypogene mineralization is unknown. In the single sulfide sample studies, the ratio of sulfides is 50 pyrite, 40 sphalerite, and 10 lead. The mineralogy or mode of occurrence of the silver was not determined by the writer. Enrichment of the ore resulted from oxidation of the pyrite and sphalerite and leaching of the carbonate gangue. The zinc was removed due to its high solubility in supergene acid solutions, and the lead was converted to the insoluble carbonate, cerrusite.

Discussion of the Ore Deposits

Yakovlev (1967) has proposed a classification of ore deposits associated with volcanic necks. Majuba Hill and its related copper-tin mineralization fit well within his scheme and is classified as subtype B conical crater, complex ore deposit. The listed references for this class of deposit are Llallagua, Potosi, and Oruro, Bolivia. Majuba Hill is unusual as it is the only tin occurrence of this type so far reported on the North American continent.

The South Carolina tin belt extends for 70 miles along a pegmatite zone that is related to regional metamorphism (Graton, L. C., 1906). Tin mineralization at Mount Pleasant, New Brunswick, though associated with base metal sulfides, is genetically related to a biotite granite (Riddell, 1962). According to Sainsbury (1963), the tin mineralization of the Lost River area, Alaska, is related to griesenization of granitic stocks and rhyolite dikes. Many other reported tin occurrences were researched and they did not fall within the Yakovlev (1967) scheme.

Only the cassiterite-specularite pneumotolytic deposits associated with rhyolite extrusives in the western United States and Northern Mexico are similar. However, though xenothermal, they lack boron metasomatism and associated base metal sulfides. The remote possibility exists that the Majuba Hill plug is an eroded vent for a stanniferous rhyolite flow similar to those in Izenhood area of northern Lander County (Knopf, 1916, p. 127).

Sampling of select mineralized structures in and immediately adjacent to the Majuba Hill plug (Appendix II, samples 2997-48-53) indicate an erratic distribution of arsenic and tin. Due to the limited amount of mineralized structures, a hypogene zonation study of the plug was not possible.

The Last Chance mine and arsenic prospect show no direct genetic relationship and define a northwesterly trending belt through the district. The trend is structurally unsupported except by the Last Chance fault and alignment of explosive breccias on Majuba Hill (Plate 1).

The writer proposes that mineralization in the district, other than that within the Majuba Hill plug, represents an early phase of hydrothermal activity from the rhyolite parent magma at depth. As the system was vented by the pre-rhyolite diatreme, the loss of volatiles terminated further hydrothermal activity. The mineralization in the Majuba fault represents residual volatile concentrations within the plug and upper portions of the magma chamber that were tapped by the Majuba fault. Ore mineral precipitation resulted from an abnormally steep geothermal gradient.

APPENDIX I

Spectrographic analyses,* values reported in parts per million, except where noted otherwise, to the nearest number in the series 1, 1.5, 2, 3, 5, 7, etc.

Element	Sample Numbers			
	2997-12	2997-13	2997-43	2997-46
Fe	7.00%	5.00%	10.00%	15.00%
Ca	0.15%	1.50%	0.20%	10.00%
Mg	0.10%	0.15%	0.15%	0.50%
Ag	50	50	30	70
As	>10,000	7,000	2,000	1,000
B	1,500	3,000	10,000	100
Ba	100	50	<5	< 5
Be	10	10	15	3
Bi	200	150	200	> 10
Cd	<50	< 50	<50	100
Co	30	50	15	10
Cr	10	10	10	15
Cu	>10,000	>10,000	5,000	200
Ga	30	50	50	<10
Ge	< 20	<20	< 20	<20
La	< 20	<20	< 20	<20
Mn	50	100	300	>10,000
Mo	100	150	15	5
Nb	30	20	30	< 20

APPENDIX II

Geochemical Analyses,* values reported in parts per million unless otherwise noted.

Sample No.	Au	Ag	Cu	Pb	Zn	Mo	As	Sn	U	
2997-3	.04	12	750	10	920	12	500	70	15	
2997-12	.20	50	3.2%	25	370	48	2.0%	300	17	
2997-13	.25	48	3.8%	30	410	130	0.8%	500	7	
2997-42	.24	470	235	0.72%	0.82%	8	0.2%	50	2	LAST CHANCE
2997-43	.09	36	0.31%	20	60	14	1.2%	3.0%	8	MASUBA-EAST
2997-44	2.50	245	260	1.60%	420	12	1.2%	10	6	LAST CHANCE
2997-45	.08	585	225	1.00%	1.00%	8	0.1%	30	2	
2997-46	.03	58	220	0.30%	0.70%	2	0.1%	40	2	
2997-47	.02	140	105	0.60%	1.00%	12	0.2%	10	2	LAST CHANCE
2997-48	.02	8.5	0.26%	805	0.40%	20	0.2%	30	28	
2997-49	.15	90	2.75%	475	1.4%	29	4.0%	150	35	
2997-50	.02	1.0	0.75%	160	430	103	0.2%	30	5	
2997-51	.03	135	4.90%	355	0.39%	30	200	0.1%	50	
2997-52	.02	55	1.95%	0.10%	80	2	300	300	6	
2997-53	.02	6.5	455	0.10%	0.26%	49	0.1%	30	5	
2997-54	.04	95	2.10%	2.50%	55	2	50.00%	10	2	Au PROSPECT

*Analyses by Skyline Labs, Inc., Wheat Ridge, Colorado, Atomic Absorption spectrophotometry for all elements except U which was analyzed fluorimetrically.

REFERENCES

American Geological Institute, 1957, Glossary of geology and related sciences with supplement, 325 p.

Barnes, H. L., 1967, Geochemistry of hydrothermal ore deposits: Holt, Rinehart, and Winston, Pubs., 383 Madison Ave., New York 10017.

Barrington, J., and Kerr, P. F., 1961, Breccia pipe near Cameron, Arizona: Geol. Soc. Amer. Bull., vol. 72, p. 1661-1674.

Bohmer, H., 1965, Geology of a rhyolite plug, Pinal County, Arizona: Geol. Soc. Amer. Bull., vol. 76, p. 1309-1314.

Buddington, A. F., 1935, High-temperature mineral associations at shallow to moderate depths: Econ. Geol., vol. 30, p. 205-222.

Chapman, R. W., 1954, Criteria for the mode of implacement of the alkaline stock at Mount Monadnock, Vermont: Geol. Soc. Amer. Bull., vol. 65, p. 97-114.

Compton, R. C., 1960, Contact metamorphism in Santa Rosa Range, Nevada: Geol. Soc. Amer. Bull., vol. 71, p. 1386-1416.

Ferguson, H. G., Muller, S. W., and Roberts, R. J., 1951, Geology of the Winnemucca quadrangle, Nevada: U. S. Geol. Survey Geol. Quadrangle Map G. Q. - 11.

____________, Roberts, R. J., and Muller, S. W., 1952, Geology of the Golconda quadrangle, Nevada: U. S. Geol. Survey Geol. Quadrangle Map G. Q. - 15.

Foshag, W. F., and Fries, C. Jr., 1942, Tin deposits of the Republic: U. S. Geol. Survey Bull. 935-C.

Frondel, C., 1962, The system of mineralogy, vol. III: John Wiley and Sons, Inc., New York and London.

Graton, L. C., 1906, Gold and tin deposits of the Southern Appalachians: U. S. Geol. Survey House of Representatives document No. 932.

Heinrich, W. E., 1965, Microscopic identification of minerals: McGraw-Hill Book Co., San Francisco, California.

Hosking, K. F. G., 1965, The search for tin, Mining Magazine, vol. 113, No. 4, 5, and 6.

Hulin, C. D., 1948, Factors in the localization of mining districts: Am. Inst. Min. Met. Eng. Trans. vol. 178, p. 35-52.

Knopf, A., 1916, Tin ore in northern Lander County, Nevada: U. S. Geol. Survey Bull. 640 p. 125-138.

_________, 1917, Tin, Mineral resources of the United States, pt. 1, 65 pp.

Lovering, T. S., 1949, Rock alteration as a guide to ore, East Tintic District, Utah: Econ. Geol. Monograph 1.

Larson, E. R., 1964, Professor of geology, University of Nevada, Reno, Nevada, personal communication.

Lowell, J . D., and Guilbert, J. M., 1970, Lateral and vertical alteration-mineralization in porphyry ore deposits: Econ. Geol., vol. 65, p. 373-408.

Matson, E. J., 1948, Investigation of Majuba Hill copper-tin mine, Pershing County, Nevada: U. S. Bureau of Mines Report of Investigation 4378.

McBirney, A. R., 1959, Factors governing emplacement of volcanic necks: American Jour. Sci., vol. 257, p. 431-448.

Reynolds, D. L., 1954, Fluidization as a geological process, and its bearing on the problem of intrusive granites: Amer. Jour. Sci., vol. 252, p. 577-613.

Riddell, J. E., 1962, Tin in southern New Brunswick: with special reference to the Mount Pleasant deposit: Canadian Mining Journal, vol. 83, p. 69-75.

Roberts, R. J., Holtz, P. E., Guilluly, J., and Ferguson, H. G., 1958, Paleozoic rocks of north-central Nevada: Amer. Assoc. Petroleum Geologists, Bull. vol. 42, p. 2813-2857.

Rust, G. W., 1937, Preliminary notes on explosive volcanism in southeastern Missouri: Jour. Geology, vol. 45, p. 48-75.

Sainsbury, C. L., 1963, Geology of the Lost River Mine area, Alaska: U. S. Geol. Survey Bull. 1129.

________, 1969, Tin resources of the world, U. S. Geol. Survey Bull. 1301.

Sheppard, S. M. F., Nielsen, R. L., and Taylor, H. P. Jr., 1969, Oxygen and hydrogen isotope ratios of clay minerals from porphyry copper deposits: Econ. Geol., vol. 64, p. 755-777.

Silberling, N. J., and Roberts, R. J., 1962, Pre-Tertiary stratigraphy and structure of northwestern Nevada: Geol. Soc. Amer. special paper 72.

Silberling, N.J., and Wallace, R. E., 1967, Geologic map of the Imlay quadrangle, Pershing County, Nevada: U. S. Geol. Survey Geol. Quad. Map G. Q. - 660.

Silberling, N.J., and Wallace, R.E., 1969, Stratigraphy of the Star Peak group (Triassic) and overlying Lower Mesozoic rocks, Humboldt Range, Nevada: U. S. Geol. Survey Prof. Paper 592.

Smith, F. G., 1947, Transport and deposition of the non-sulfide vein minerals, II Cassiterite: Econ. Geol. vo. 42, p. 251-263.

____________, 1949, Transport and deposition of the non-sulfide vein minerals, V Tourmaline: Econ. Geol. vol. 44, p. 186-192.

Smith, W. C., and Gianella, V. P., 1942, Tin deposit at Majuba Hill, Pershing County, Nevada: U. S. Geol. Survey Bull. 931-C.

Strode, E. 1971, Imlay, Nevada: personal communication.

Tatlock, D. B., 1969, Preliminary geologic map of Pershing County, Nevada: U. S. Geol. Survey open-file map.

Trites, A. F. Jr., and Thurston, R. H., 1949, Geology of Majuba Hill, Pershing County, Nevada: U. S. Geol. Survey Bull. 1046-I.

Turner, F. J., and Verhoogen, J., 1960, Igneous and metamorphic petrology: McGraw-Hill book company, New York.

Vanderburg, W. O., 1936, Reconnaissance of mining districts in Pershing County, Nevada: U. S. Bureau of Mines information circular 6902.

Wallace, S., 1971, Mine Finders, Inc., Denver, Colorado: personal communication.

Willden, R., 1958, Cretaceous and Tertiary orogeny in Jackson Mountains, Humboldt County, Nevada: Amer. Assoc. Petroleum Geologists Bull., vol. 42, p. 2378-2398.

Williams, H., 1936, Pliocene volcanoes of the Navajo-Hopi county: Geol. Soc. Amer. Bull., vol. 47, P. 111-172.

____________, 1953, Problems and progress in volcanology: Geol. Soc. of London, quarterly journal, vol. 109, p. 311-332.

____________, Turner, F. J., and Gilbert, C. M., 1954, Petrography: W. H. Freeman and Company, San Francisco, California.

Yakovlev, P. D., 1967, Structural types of ore deposits associated with volcanic necks: International Geology Review, vol. 10, no. 3.