NBMG BULL. 86

NEVADA BUREAU OF MINES AND GEOLOGY

BULLETIN 86

GEOLOGY OF THE MAJUBA HILL AREA, PERSHING COUNTY, NEVADA

W. BRUCE MacKENZIE
ARTHUR A. BOOKSTROM

MACKAY SCHOOL OF MINES
UNIVERSITY OF NEVADA • RENO

1976

GEOLOGY OF THE MAJUBA HILL AREA, PERSHING COUNTY, NEVADA

MacKENZIE AND BOOKSTROM

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First edition, first printing, 1976: 2000 copies
Composed in IBM Press Roman type at the Nevada Bureau of Mines and Geology
Printed by Reno Printing, Reno, Nevada
Composition: Georgianna Trexler
Cartography: Susan L. Nichols

For sale by the Nevada Bureau of Mines and Geology, University of Nevada, Reno, Nevada, 89557

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Plate 3–Geologic sections through Majuba igneous complex

Plate 4–Geology of Majuba Mine

Aerial photograph of Majuba Hill showing a portion of the circular drainage pattern. White outlines mark the extent of the Majuba Hill intrusive center. Approximate scale: 1 in. equals 400 m (1250 ft.)

ABSTRACT

Majuba Hill is the surface expression of a subvolcanic complex of rhyolitic porphyries and breccias intruded during mid-Tertiary time into a series of steeply dipping, northeast-trending Triassic(?) argillites. The main development of the igneous complex is on Majuba Hill (the Majuba Hill intrusive center), and a smaller composite body (the Majuba Canyon intrusive center) is exposed on the east side of Majuba Canyon, approximately one mile east of Majuba Hill.

The northeast grain of the argillite country rock imposed a northeast elongation on the individual intrusives of the complex and on the igneous complex as a whole. Textural and structural features indicate shallow emplacement for the Majuba rocks. Diamond drilling shows the Majuba Hill intrusive center to be somewhat fan shaped in vertical section; the different magmas appear to have been introduced through a constricted conduit and to have spread laterally to the presently observed size not far beneath the present surface.

The intrusives of the complex exhibit a progression with decreasing age from large elongated masses of weakly porphyritic rock to dikes and sills of strongly porphyritic rock. The oldest breccias formed large, irregular masses; breccias of intermediate age formed dikes, sills, and pipes, some of which contain abundant tourmaline; the youngest breccias are pebble dikes and pods.

Most observed faults dip steeply; northeast and northwest trends are the most common. With the exception of one large and several subsidiary faults in the Majuba Hill Mine area, faults appear to have had little disruptive or controlling effect on distribution or shape of intrusive units or mineralized zones.

Most, if not all, Majuba intrusives were accompanied by episodes of hydrothermal mineralization and alteration, but three intrusives—the Felsite stock, the Majuba Porphyry, and the Late Rhyolite Porphyry—have the most intense mineralization and alteration halos.

Chalcopyrite, associated with pyrite, arsenopyrite, and pyrrhotite, occurs in and near the Felsite stock; assays show the presence of tin and silver in the same area.

The Majuba Porphyry and surrounding rocks have been strongly silicified. The silicification appears related to extensive but weakly mineralized zones of molybdenite-quartz veinlets.

Mineralization associated with Late Rhyolite Porphyry produced high-grade copper ore and minor amounts of high-grade tin ore. In the main copper stope of the Majuba Hill Mine, apophyses of Late Rhyolite Porphyry that intruded a tourmaline breccia pipe near a large fault contain chalcocite-rich pods as large as ten inches across.

Majuba rocks are ubiquitously, but weakly, iron stained, and widely scattered zones of green copper-stained rocks occur throughout the intrusive center.

INTRODUCTION

Location and Physical Features

Majuba Hill is approximately 100 miles northeast of Reno in the Antelope (Majuba, Cedar) mining district and is easily accessible via 18 miles of good gravel road from the town of Imlay (fig. 1). The hill forms a prominence on the east side of the Antelope Range and can be readily distinguished on the skyline by its jagged profile in contrast to the rounded form of neighboring peaks, as viewed looking west from U.S. Highway I-80 between the Humboldt and Imlay exits. As a topographic feature, Majuba Hill is about three miles across and is surrounded by a circular drainage pattern, the major part of which is defined by Majuba Canyon on the east and south sides of the hill (frontispiece and pl. 1). The top of the hill is at an altitude of 6881 feet and local relief is about 1700 feet.

Most maps incorrectly label Majuba Hill as "Majuba Mountain." The name Majuba Hill comes from a South African battle site of the Boer War and presumably dates from about 1900, the time of that battle.

History and Production

The first recorded activity at Majuba Hill was in 1907 when A. J. McCauly of Imlay located the Majuba Copper Mine. It was leased in 1914 (Matson, 1948) to the Mason Valley Mines Company which developed the property and mined some direct shipping ore during the First World War. Except for a few cars of high grade ore shipped by McCauly in 1928, the property was idle in the period between the World Wars I and II. Freeport Sulfur Company secured an option in 1941, conducted a sampling program and drilled several exploratory holes before returning the property in October of that same year. The property was then acquired by E. J. Myler of Reno and leased to J. O. Greenan and G. W. Kerr, both of Reno, who reactivated the mine and shipped ores of both copper and tin during the period between October 1942 and May 1954. At this point the Majuba Mine reverted to E. J. Myler who worked the property on a small scale for several years.

Total production to date, according to Stevens (1971), is approximately 2,849,000 lbs. of copper and 21,000 lbs. of tin. Approximate production figures for the two main periods of operation are shown in table 1.

Previous Work

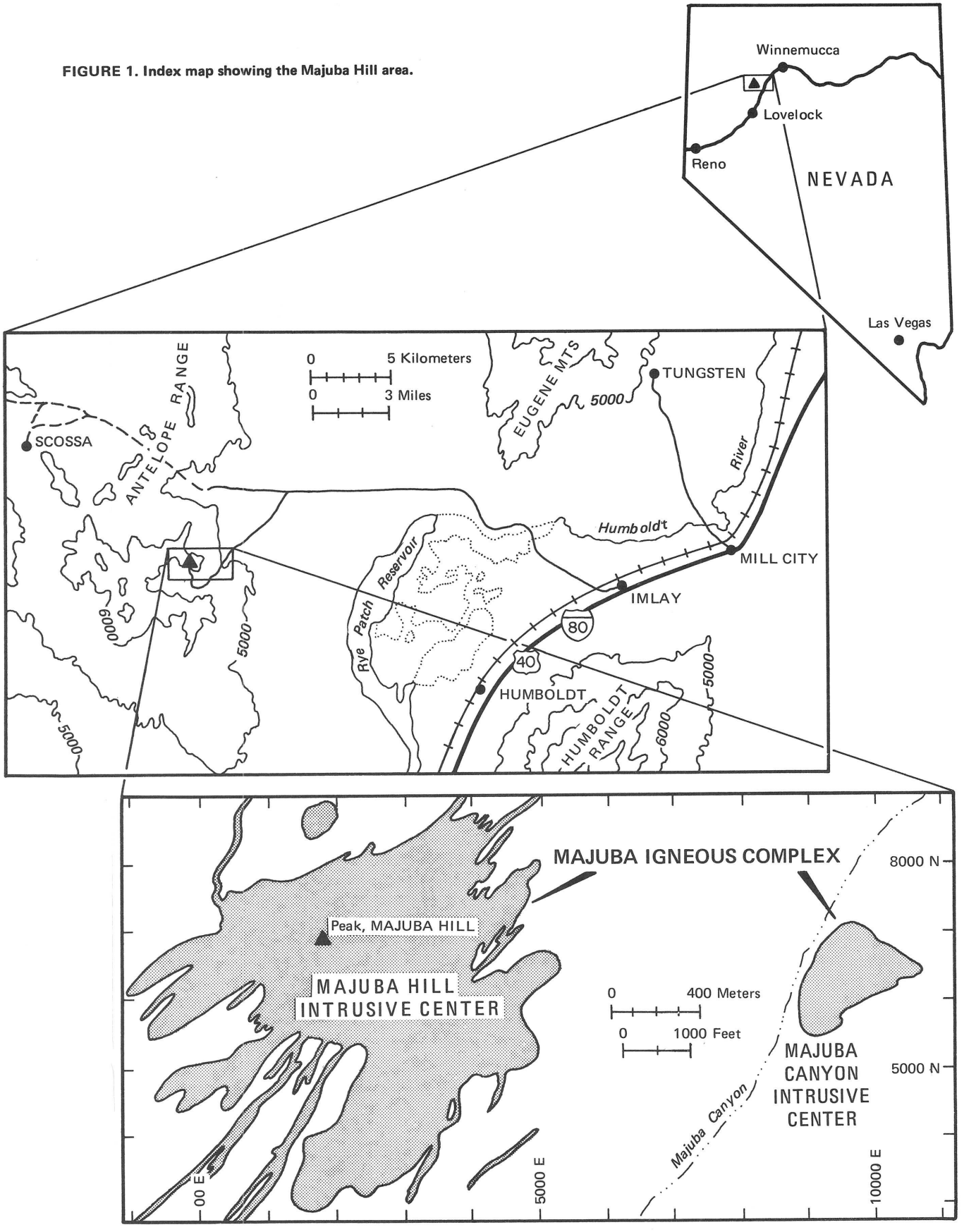
Over the years Majuba Hill has attracted the attention of many prospectors and geologists, and the number of reports of various kinds resting in company files is probably large. Brief summaries of the mine geology are included in reports by the U.S. Bureau of Mines (Vanderburg, 1936, and Maston, 1948), and more comprehensive studies of the geology of Majuba Hill were conducted by the U.S. Geological Survey (Smith and Gianella, 1942; and Trites and Thurston, 1958). The most recent work was done by Stevens (1971) who mapped and studied Majuba Hill and the adjacent area as a thesis at the Mackay School of Mines.

TABLE 1. Production of Metals from Majuba Mine*

Period	Operator	Copper Tons Produced	Copper Grade Cu	Tin Tons Produced	Tin Grade Sn
WWI	Mason Valley	4,000	12%	—	
WWII	Greenan and Kerr	23,000	4%	350	2–4%

*The copper ores carried good values in silver, but total production is not recorded.

FIGURE 1. Index map showing the Majuba Hill area.



Present Investigation

In 1971 Mine Finders, Inc. of Lakewood, Colo. optioned the mine on a sub-lease from California Time Petroleum and signed agreements with A. L. Gilmet of Daly City, Calif., and E. and F. Strode, who live in Majuba Canyon, to explore the mine area and adjacent ground. From 1971 to 1974, Mine Finders conducted an exploration program on the optioned properties and on additional claims located in the immediate area. Approximately 4000 feet of underground workings were surveyed and mapped at a scale of 1 inch = 20 feet, and about 2 square miles on and near Majuba Hill were mapped on 200-scale enlargements of aerial photographs. Surface mapping was compiled on a topographic base developed from the aerial photographs. The area was sampled geochemically on a 300-foot grid and more than 20,000 feet of drilling was completed in 13 holes.

Acknowledgments

We gratefully acknowledge the contributions of our coworkers from Mine Finders, Inc. William Oriel, George Eliopulos, Richard Wendlandt and James Krumhansl worked on the geochemical sampling and geologic mapping of Majuba Hill. Neil Muncaster and Stewart Wallace helped with the underground mapping, and Robert Dahl and Archie Beard provided survey control.

Our thanks go to David LeCount Evans of Reno, who shared his reports on, and knowledge of, Majuba and also to A. L. Gilmet of Daly City, Calif., one of the property owners, who has been for many years closely associated with the Majuba Hill property. We also extend our thanks to the E. Strode family of Majuba Canyon, who contributed to the exploration effort.

Finally, we express our appreciation to S. R. Wallace and George W. Walker who patiently reviewed this report. We are responsible for any errors, inconsistencies and deficiencies that remain.

REGIONAL AND LOCAL GEOLOGIC FEATURES

Majuba Hill is the surface expression of a subvolcanic complex of rhyolitic porphyries and associated breccias intruded during Oligocene-Miocene time into a series of steeply dipping, northeast-trending Triassic argillites. The argillites are part of a siliceous eugeosynclinal assemblage that constitutes the principal country rock of northwestern Nevada. Granodioritic stocks and batholiths, that are of regional extent and for the most part Cretaceous in age, have intruded the argillites. The Antelope Range lies along a northeast-trending boundary that separates the eugeosynclinal assemblage from a broad belt of siliceous and carbonate rocks that are transitional into a miogeosynclinal suite to the south and east (Roberts, 1966).

Small, scattered dikes and sills of fine- to medium-grained diorite, quartz-diorite, and quartz-monzonite are present throughout the Antelope Range. These rocks predate those of the Majuba igneous complex and are thought to be of Cretaceous or early Tertiary age.

Near Majuba Hill the argillites range from massive, compact mudstones to highly fissile slates and are interbedded with lenses of shaly sandstone and limy siltstone. Where freshly broken the argillite is dark gray to black, but weathered surfaces are generally medium gray.

Isoclinal folds occur within some discontinuous limy siltstone lenses; fold axes, where observed, plunge steeply southwest. Slaty cleavage, bedding(?) and the discontinuous limy siltstone and shaly sandstone lenses all strike N. 30° E. to N. 60° E. and dip generally 60° to 70° NW.

The consistent attitude of well-developed planes of weakness in the country rock had a marked control on the distribution and configuration of the rocks of the Majuba igneous complex.

THE MAJUBA IGNEOUS COMPLEX

The subvolcanic rocks of the Majuba igneous complex consist of rhyolitic porphyry stocks and associated dikes, sills, and irregular breccia bodies. The main development of the complex is on Majuba Hill (the Majuba Hill intrusive center). A smaller composite intrusive body (the Majuba Canyon intrusive center) is exposed on the east side of Majuba Canyon approximately one mile east of Majuba Hill (pls. 1 and 2). The major intrusive units of the Majuba Hill center are elongated in a northeast direction and have coalesced to form an irregular lobate mass roughly 6000 feet by 3000 to 4000 feet, also elongated in a northeast direction. Dikes that might have assumed a definite radial habit in a more structurally isotropic host have been guided into a northeast-southwest pattern of sills by the attitude of the enclosing argillite. Most of the Majuba rocks are essentially identical in mineralogical and chemical composition and have been distinguished on the basis of subtle differences in textures, alteration, appearance and structural habit.

Brecciation occurred repeatedly throughout the brief, but clearly violent series of events that produced the Majuba igneous complex. The breccias range widely in intrusive style, fragmental content and probable origin.

The textures of the Majuba rocks, the abundance and diversity of breccias, and the intricate pattern of dikes all suggest that the rocks of the Majuba igneous complex were emplaced at shallow depths.

Although the rocks record a complicated history of intrusion, the duration of igneous events that produced them was probably brief in terms of geologic time. K/Ar isotopic age determination by the USGS (Silberman, written communication, 1975) on selected Majuba specimens place the age of the Majuba rocks at about 24 to 25 million years (Oligocene-Miocene).

To facilitate presentation and discussion of Majuba geology, the various plugs, dikes and breccias have been grouped into "assemblages" of rocks that are close in relative age and genetically related. Table 2 lists the assemblages and the rock units that comprise each assemblage.

The names of all Majuba rock units are capitalized throughout this report even though they are local names.

The Majuba Hill Intrusive Center

The Majuba Hill intrusive center is clearly the principal center of the Majuba igneous complex. Most of the rock units are well-exposed on surface or in the underground workings of the Majuba Hill Mine, but two of the major intrusives—the Felsite stock (Tf) and the Majuba Porphyry (Tmj)—are known principally from diamond drill core.

TABLE 2. Correlation chart for rocks of the Majuba igneous complex (*indicates major intrusive units).

Majuba Hill Intrusive Center

youngest — relative age — oldest

Latite Assemblage
- *Latite-Tl

Late Rhyolite Assemblage
- *Late Rhyolite Porphyry-Tlrp
- *Q-T Rhyolite Porphyry-Tqt

Black Breccias-Tbb (Most are post-Q-T Porphyry)

Pebble Breccias-Tpb (Most are post-Late Rhyolite Porphyry)

Majuba-Ballpark-Moldy Assemblage
- Silicic Breccias-Tsb
- *Moldy Porphyries-Tm; Moldy Autobreccia-Tmab
- Bull-Quartz Breccia-Tbqb
- Ballpark Megabreccia-Tbmb
- *Ballpark Porphyry-Tbp
- *Majuba Porphyry-Tmj (largely unexposed at surface)

Felsite Assemblage
- Limonitic Breccia-Tlb
- Porcelanite Porphyry-Tpp (dikes)
- Late Felsite Breccia-Tlfb
- Porcelanite-Tp (dikes)
- *Felsite-Tf (largely unexposed at surface)
- Early Felsite Breccia-Tefb

Early Rhyolite-Pinhead Assemblage
- Pinhead Breccia-Tphb
- *Pinhead Porphyries-Tph
- *Early Rhyolite-Ter — ? — Majuba Canyon Intrusive Center

Majuba Canyon Assemblage
- Columnar Felsite-Tcf
- Rhyolite Autobreccia-Tra
- Porphyritic Rhyolite-Tpr
- Majuba Canyon Rhyolite-Tmcr

Figures 2a through 2g graphically portray, in much generalized form, the sequence of intrusions that collectively formed the Majuba Hill intrusive center.

Early Rhyolite-Pinhead Assemblage

Rocks of the Early Rhyolite-Pinhead assemblage comprise the earliest known intrusives of the Majuba Hill intrusive center. The Early Rhyolite (Ter) is the southernmost of the major intrusive masses and is believed to be the oldest. No contact has been observed between it and the Pinhead Porphyry (Tph) but inclusions that resemble Early Rhyolite in the Pinhead Porphyry suggest the suspected age relationship.

Early Rhyolite. The Early Rhyolite intrusive is elongated in a northeast direction, approximately parallel with the trend of the Triassic(?) argillite (see pl. 2 and fig. 2a). In places the Early Rhyolite superficially resembles a tuff, but steeply dipping foliations and crosscutting contacts confirm its intrusive origin.

The texture and lithologic character of the Early Rhyolite change with distance from its contacts. Nearest the contact it is an aphanitic, inclusion-choked, strongly flow banded, tuffaceous appearing quartz porphyry (fig. 3). Toward the center of the mass, it is a fine-grained, relatively homogeneous quartz porphyry.

Flow banding near the contacts is sinuous but generally dips steeply and strikes northeast reflecting the northeast elongation of the intrusion. The flow bands consist of alternating segregations of slightly different-sized groundmass material that wrap around quartz phenocrysts, argillite fragments, and cognate porphyry inclusions. The inclusions are parallel to flow banding, and in some places near the contact are so abundant that the rock resembles an intrusive breccia.

Pinhead Porphyry. The Pinhead porphyry received its name from its pinhead-sized quartz phenocrysts where first mapped in surface exposure. It forms a large intrusive mass that occupies a central position in the Majuba igneous complex, and contact relationships clearly show it to be one of the earliest intrusives.

Pinhead Porphyry is the principal and common variety of the Pinhead Porphyry mass. It is characteristically light gray on broken surfaces, and dark gray or brown (iron-stained) on weathered surfaces. The rock contains evenly distributed and sub-rounded, small quartz phenocrysts set in a fine-grained to aphanitic groundmass of quartz and alkali feldspar. In nearly all surface exposures Pinhead Porphyry is moderately to strongly silicified and stockworked by quartz-tourmaline veinlets.

Several gradational varieties of Pinhead Porphyry were mapped; they are shown on plate 2 and include Pinpoint

Porphyry (Tppp), Tuff-Block Porphyry (Ttbp), and Match-Head Porphyry (Tmhp) (fig. 3).

Pinpoint Porphyry has small (pinpoint-sized) quartz phenocrysts set in an aphanitic, strongly silicified groundmass and occurs only in certain marginal areas of the intrusive. We interpret Pinpoint Porphyry to be the remnant of an early-formed, chilled and silicified margin of the Pinhead intrusive. In the marginal areas that lack Pinpoint Porphyry, we believe that the original chilled rock was stripped from the walls of the existing conduit and reincorporated into the advancing Pinhead magma.

Tuff-Block Porphyry is a variety of Pinhead Porphyry that contains abundant, block-shaped inclusions of flow banded porphyry that resembles Early Rhyolite. The blocks range from one inch to four feet across and are diversely oriented. Tuff-Block Porphyry occurs in two areas within the Pinhead intrusive mass and in a roughly circular satellitic area near the north margin of the Majuba Hill intrusive center (pl. 2). We interpret the Tuff-Block Porphyry to represent fragments of an early, flow banded phase of Pinhead Porphyry—closely akin to the Early Rhyolite—that may have been caught up and preserved in the slightly later, main phase of the Pinhead intrusion.

Match-Head Porphyry is identical to Pinhead Porphyry in all respects except for its characteristically larger (2 to 3 mm) quartz phenocrysts set in a coarser grained groundmass. Two areas of Match-Head Porphyry, shown on plate 2, may represent a more coarsely crystalline final stage in the intrusion of the Pinhead stock. Much of the rock shown as Pinhead Porphyry on plate 2 between the two areas of Match-Head Porphyry may be the latter variety, but poor exposures and strong alteration prevent its positive identification.

Pinhead Breccia. Pinhead Breccia (Tphb) occurs as pods and dikes of breccia that are spatially related to and cut all phases of Pinhead Porphyry. The breccia consists of Pinhead Porphyry fragments in a sericitized rock-flour matrix. The fragments generally are silicified and sericitized and both fragments and matrix material contain clots and rosettes of tourmaline.

Pinhead Breccia more nearly resembles an ill-defined porphyry than a breccia. All fragments and the matrix material are sericitized and bleached. The closely compacted white fragments cemented by white matrix gives the rock a slightly "lumpy" appearance that partly masks its identity as a breccia.

Felsite Assemblage

The Felsite assemblage includes Porcelanite dikes (Tp), Porcelanite Porphyry dikes (Tpp), Early Felsite Breccia (Tefb), Late Felsite Breccia (Tlfb) and Limonitic Breccia pipes (Tlb); all of which are related to an extensive and largely unexposed felsite stock (Tf). (We recognize the incorrect usage of the term *porcelanite*, but have decided to retain this highly descriptive field name for these particular rocks).

Early Felsite Breccia. Early Felsite Breccia is the oldest and most extensive member of a large (approximately 2400 feet by 700 feet) breccia complex that truncates the northeastern end of the Early Rhyolite and trends northeasterly between the Pinhead and Ballpark intrusives (pl. 2). Early Felsite Breccia includes several distinctive varieties of breccia that differ principally in color, alteration, and composition of fragments. The most common variety is a gray breccia that consists of small subangular fragments of argillite and Early Rhyolite in a matrix of gray pulverized rock.

Felsite. Two diamond drill holes passed through parts of a subsurface stock of Felsite. These two intersections, together with a small area of surface outcrop (pl. 2), and less direct evidence in the form of extensive brecciation, indicate a subsurface stock of Felsite that is at least 600 feet wide and as much as 2000 feet long. The stock is elongated in a northeast direction and intrudes the Early Felsite Breccia between the Pinhead and Early Rhyolite intrusives.

The Felsite is composed of microscopic grains of quartz, potassium feldspar, and sericite. Most of the rock is light gray in color, but shades of white and pale green are also common. The rock breaks with a conchoidal fracture and in places is faintly flow banded.

Porcelanite. Porcelanite forms the oldest dikes of the Majuba Hill intrusive center. Dikes of Porcelanite cut the Early Felsite Breccia. The age of Porcelanite relative to that of Felsite is not known, but the two rocks are so similar that we believe them to be co-magmatic.

The Porcelanite dikes are most abundant in the area underlain by the Felsite stock, but extend throughout the Majuba Hill center in a radial pattern.

The dikes vary in thickness from one to twenty feet, have steep, sinuous contacts, and characteristically display irregular, sinuous flow banding that is subparallel to their contacts.

Porcelanite breaks with a conchoidal fracture and has an aphanitic groundmass with very rare and small (less than 1 mm) quartz phenocrysts. In places, it is lightly stockworked with tourmaline and limonite veinlets.

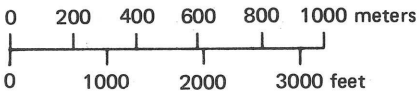
Late Felsite Breccia. Late Felsite Breccia is generally interior to, but in places extends beyond, the Early Felsite Breccia. Together they form the large, elongated composite breccia mass that overlies the subjacent Felsite stock. Late Felsite Breccia cuts and includes fragments of Early Felsite Breccia, Felsite and Porcelanite. Like the Early Felsite Breccia, it consists of several gradational varieties of breccia that differ primarily in color, alteration and fragmental composition.

The most common variety of Late Felsite Breccia contains abundant and closely packed inclusions of sericitized Early Rhyolite and Porcelanite (Felsite?) in a sericitized rock-flour matrix. The breccia is commonly limonite-stained on weathered surfaces and white to light gray on fresh surfaces. Weathering and leaching of matrix material impart a distinctive hackly surface (fig. 3) to most outcrops of Late Felsite Breccia.

Porcelanite Porphyry. Porcelanite Porphyry is essentially identical to Porcelanite in texture, appearance, intrusive style and distribution with two notable exceptions: 1) Porcelanite Porphyry contains more abundant and larger quartz phenocrysts; and 2) Porcelanite Porphyry is younger than and cuts Late Felsite Breccia.

Limonitic Breccia Pipes. Limonitic Breccia Pipes occur as a group of small (20 feet to 200 feet in diameter) circular to elliptical, steeply plunging pipes. They are concentrated in a roughly east-west elongated pattern within the southeastern felsite breccia mass near the southern margin of the

FIGURE 2a through 2g illustrate, in generalized form, the sequential intrusion of the igneous rocks and breccias that collectively form the Majuba Hill intrusive center.



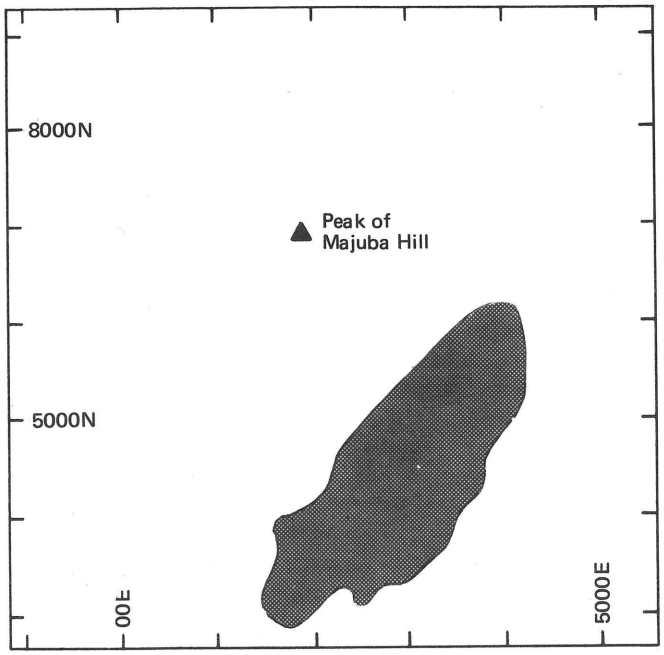


FIGURE 2a. Early Rhyolite. The Majuba Canyon intrusive center, one mile east of the area shown, probably is of the same age.

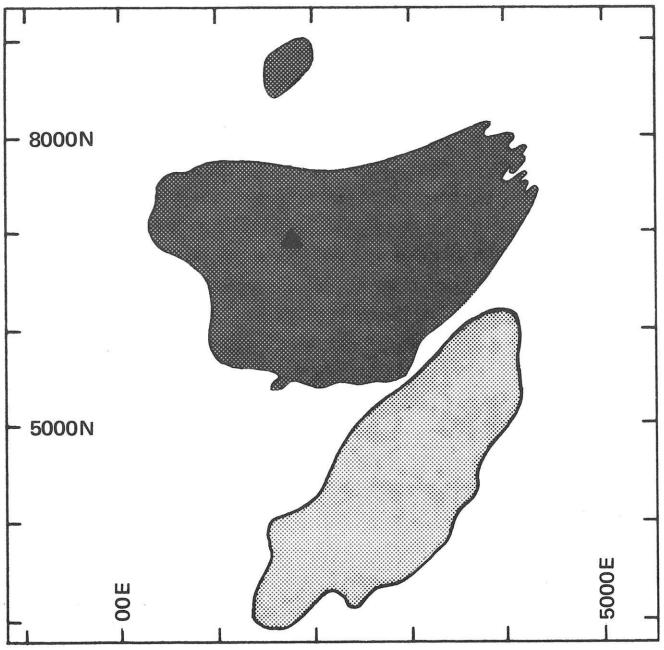


FIGURE 2b. Pinhead Porphyry intrusives. Early Rhyolite (fig. 2a) is shown in gray.

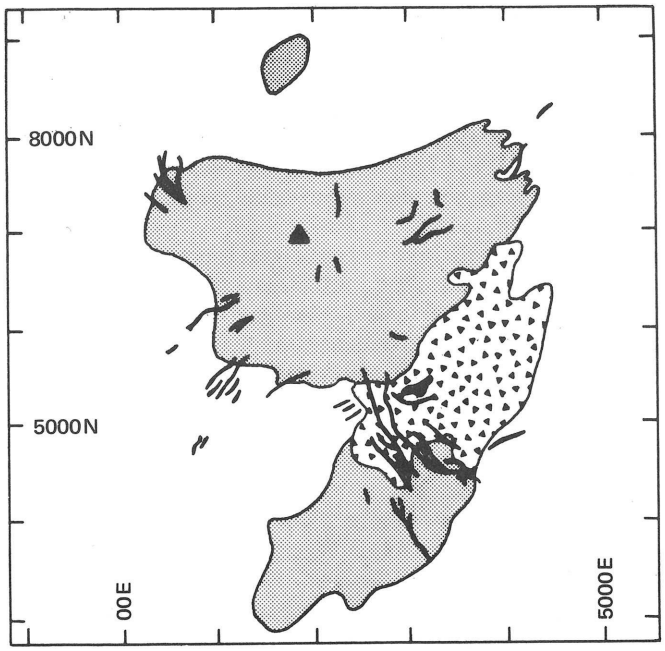


FIGURE 2c. Felsite assemblage. Felsite stock, Porcelanite and radial Porcelanite Porphyry dikes are black; Early and Late Felsite Breccias and Limonitic Breccias are shown collectively by solid triangles.

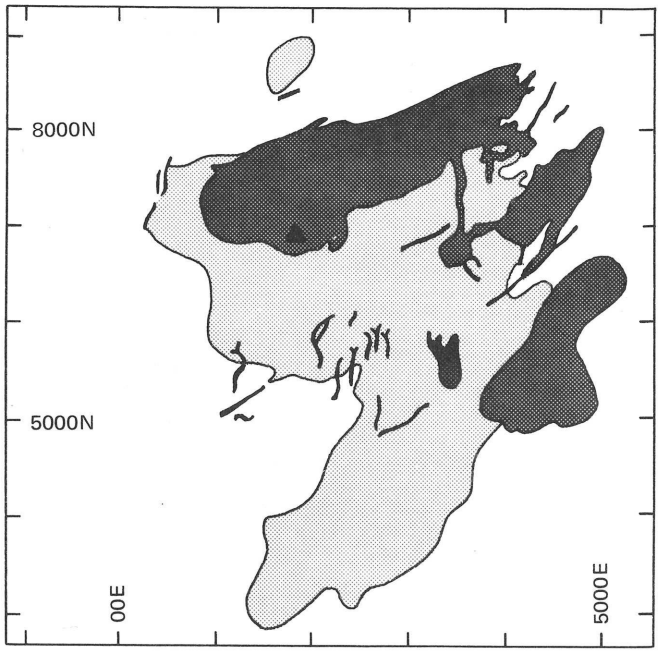


FIGURE 2d. Majuba-Ballpark-Moldy assemblage. Dikes of these rocks are black; larger bodies are dark gray.

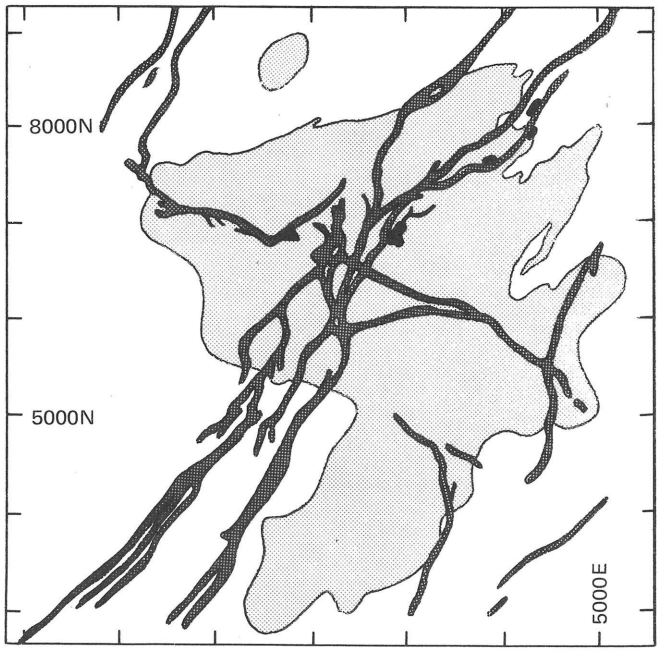


FIGURE 2e. Q-T Rhyolite Porphyry. Porphyry is dark gray; associated Black Breccias are shown in black.

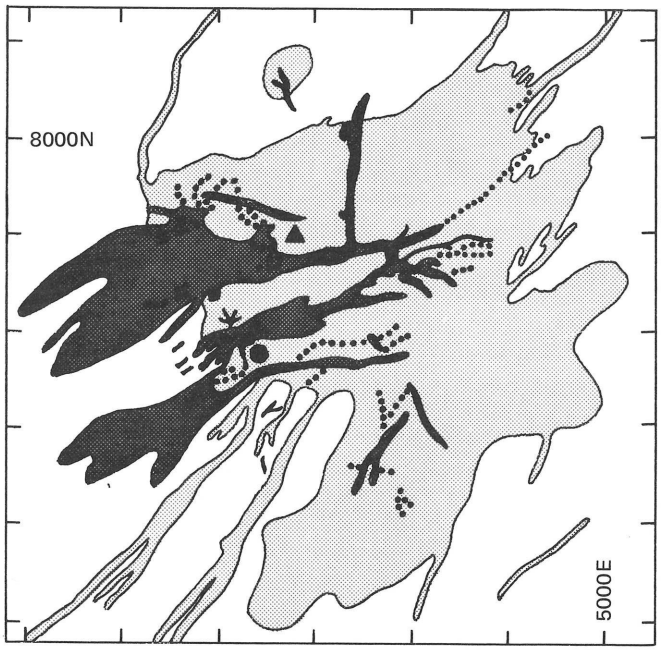


FIGURE 2f. Late Rhyolite Prophyry. Porphyry is dark gray; associated Black Breccias are black, and Pebble Breccias are shown as rows of black dots.

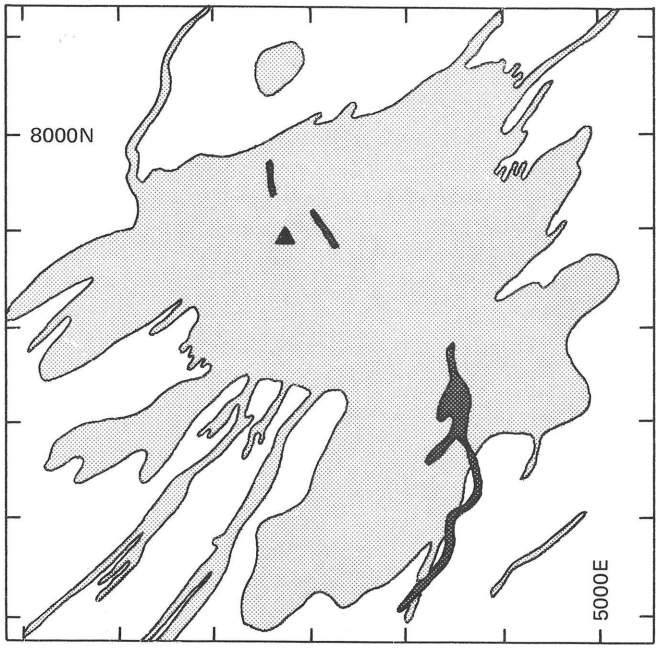


FIGURE 2g. Latite assemblage. All earlier Majuba Hill intrusives are shown in gray.

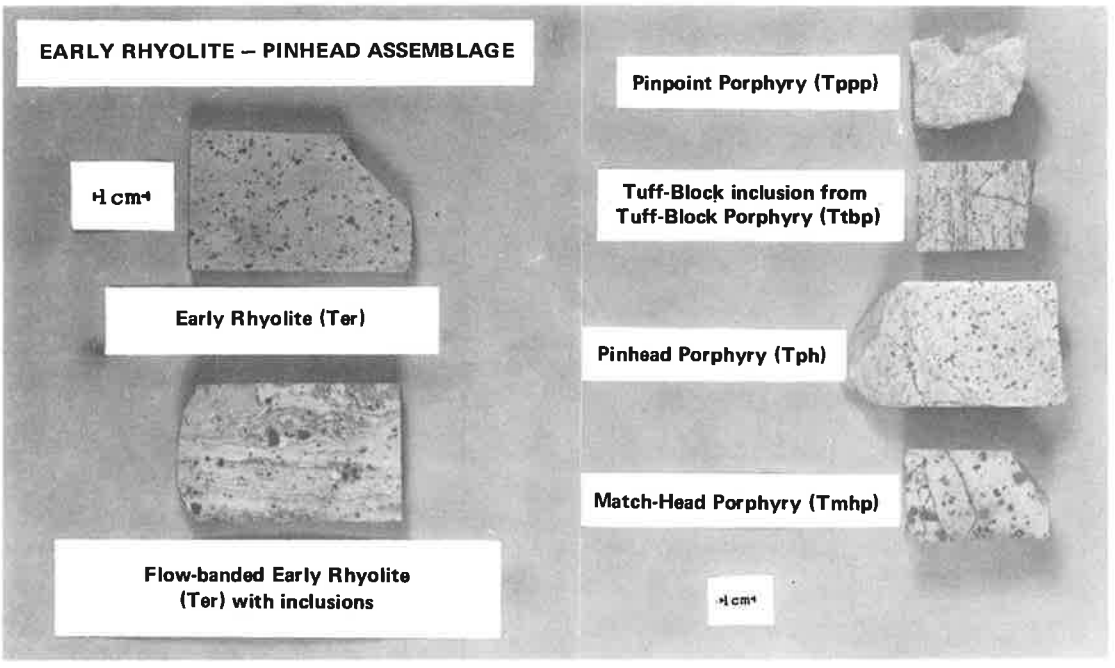
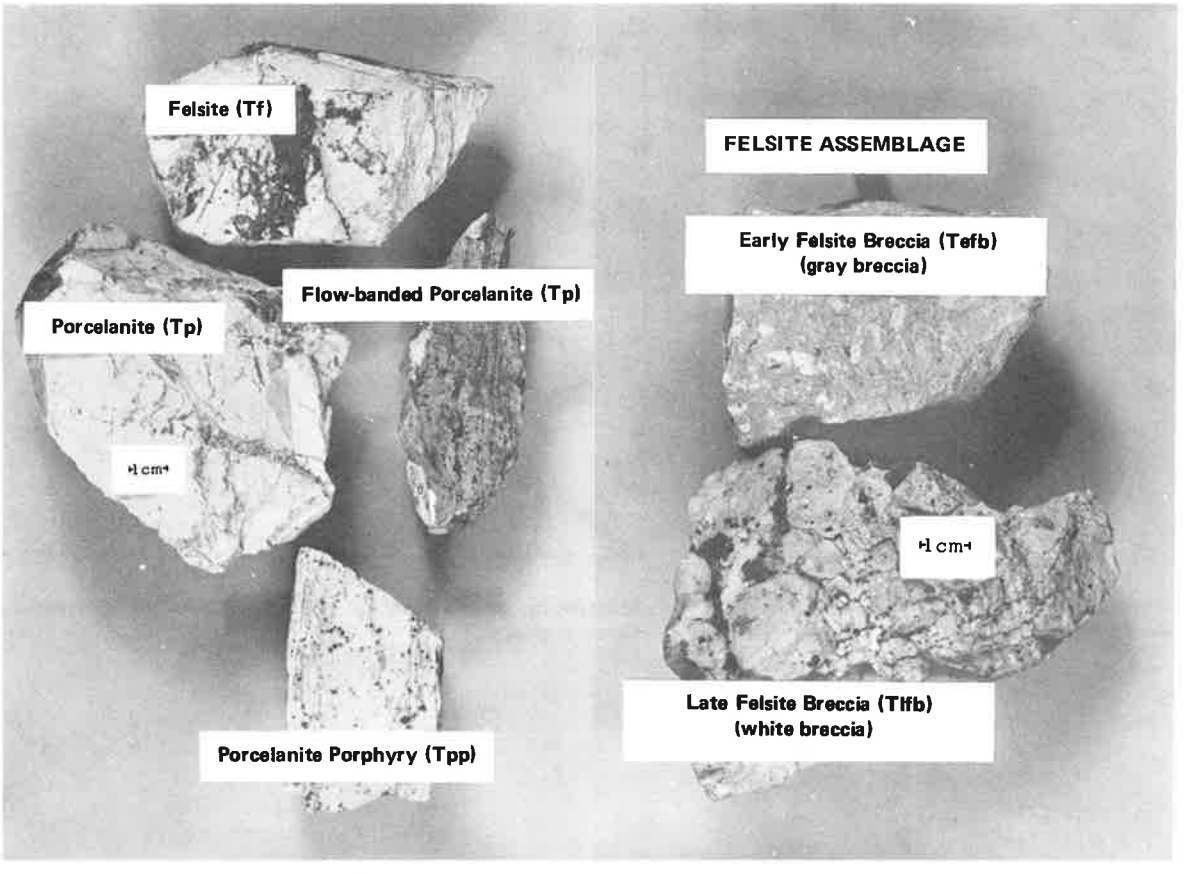
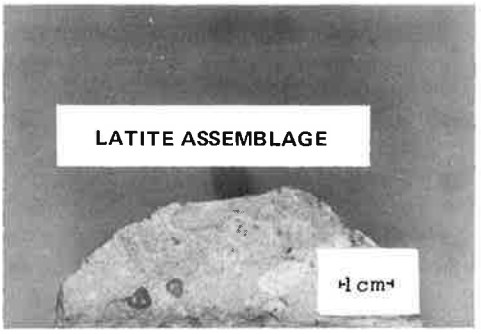
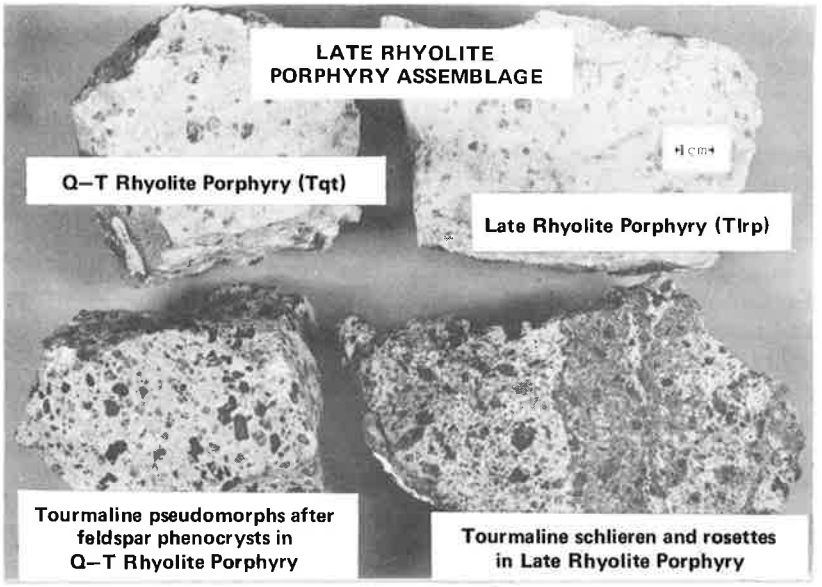


FIGURE 3. Photographs of selected Majuba rocks.





Quartz Latite Porphyry (Tlq)



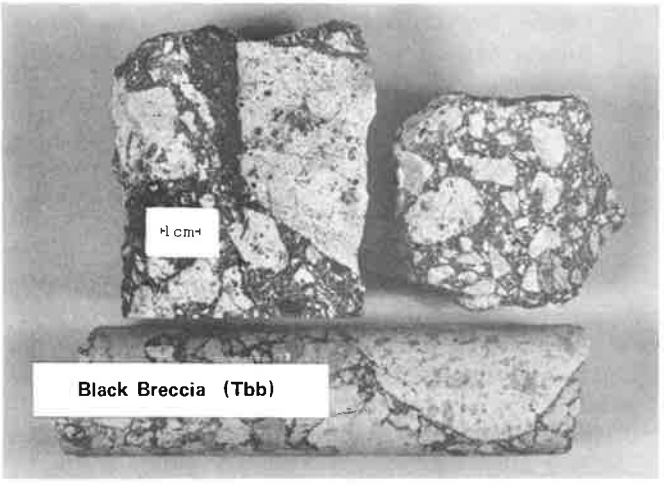
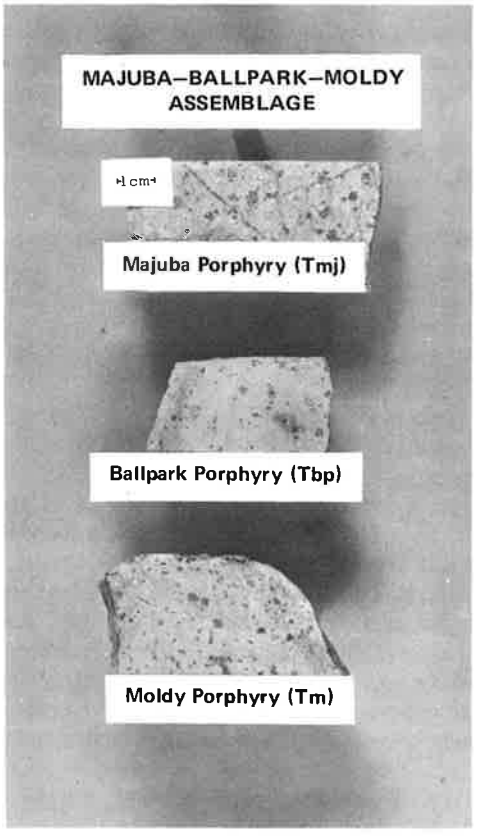
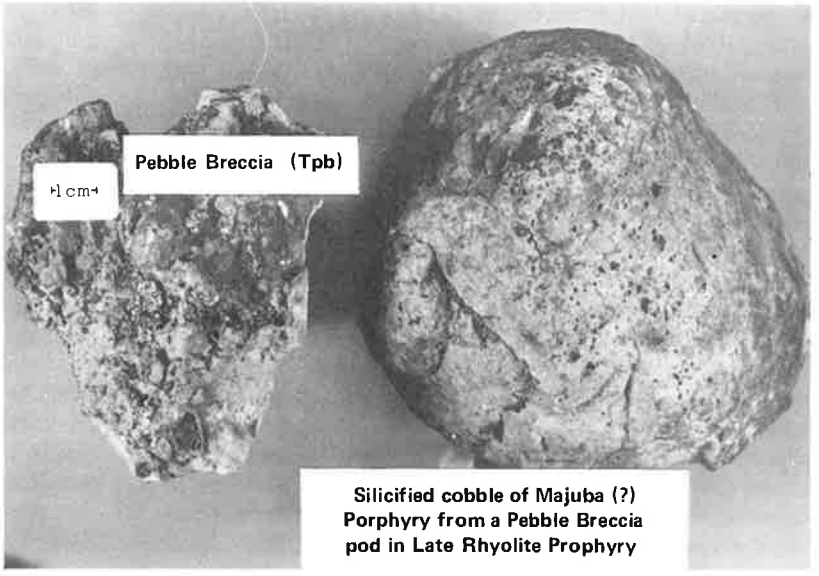


FIGURE 3
(continued)





Pinhead Porphyry stock. The pipes cut and include fragments of Early and Late Felsite Breccias and Porcelanite dike rock. Their age relationship to Porcelanite Porphyry is not certain.

The fragmental content of the breccia pipes for the most part reflects the local host rock, and the pipes shown on plate 2 principally include re-brecciated Early Felsite Breccia and re-brecciated Late Felsite Breccia. The size of the fragments varies from pieces as large as four inches to finely pulverized material. Some pipes show a crudely annular or zonal variation in fragment size. Most specimens are cemented by limonite which effectively masks any other matrix material that might be present. In addition to limonitic matrix and stain, several of the pipes display moderate to strong copper stain on fragments.

Felsite Assemblage Relationships. Based on the spatial and age relationships of the Felsite assemblage rocks, we interpret the following sequence of events:

1) The formation of Early Felsite Breccia related to rupture or collapse of roof rocks over an invading Felsite magma.
2) Continued advance of magma to intrude Early Felsite Breccia as Porcelanite dikes and Felsite.
3) Renewal of magmatic activity to produce a Late Felsite Breccia cap and invasion of Late Felsite Breccia and earlier rocks by Porcelanite Porphyry dikes.
4) Late-stage degassing of the underlying Felsite stock to produce Limonitic Breccia pipes. The pipes may have formed simultaneously or sequentially over a period of time.

Majuba-Ballpark-Moldy Assemblage

Rocks of Majuba, Ballpark, and Moldy intrusives constitute one of the most extensive assemblages of the Majuba Hill intrusive center. Age relationships and textural characteristics indicate that these rocks are closely related and probably derived from a common source.

Majuba Porphyry. Majuba Porphyry (Tmj) is known principally from deep drill holes but is also represented at surface by a dike on the southwest margin of the Pinhead intrusion. Three deep, widely spaced, angle drill holes each intersected one or more intervals of Majuba Porphyry. From the plotted intercepts in these holes, we infer a subjacent stock of Majuba Porphyry that is ovoid in plan, has upward-extending fingerlike projections and is centered within the Pinhead Porphyry stock (pl. 3). Crosscutting relations place Majuba Porphyry at approximately the same relative age as Ballpark Porphyry (Tbp) and Moldy Porphyry (Tm), and selected specimens of the rock strongly resemble these two porphyries. Alteration halos related to the Majuba Porphyry are cut by Moldy and Ballpark Porphyries, thus establishing the Majuba Porphyry to be at least slightly older.

Specimens of Majuba Porphyry exhibit shades of white, light gray, medium and dark gray, and green. The diverse colors result principally from differences in alteration type and intensity. All specimens have a seriate porphyritic texture produced by erratically distributed quartz phenocrysts that range in size from less than 1 mm to 5 mm in diameter. The phenocrysts are weakly embayed and contain microscopic inclusions of groundmass material. Small phenocrysts of sanidine(?) and altered plagioclase form clusters with quartz crystals. The groundmass consists of a microcrystalline mixture of quartz, potassium feldspar, sericite, and clay.

Majuba Porphyry is both mineralized and altered. The effects of silicification, sericitization, argillization, and K-feldspathization have all been noted in the drill core. In places the rock is so strongly silicified that it assumes a glassy appearance and consists of 90 percent of more quartz. The rock is stockworked with veinlets of tourmaline, quartz-pyrite, and quartz-molybdenite.

Ballpark Porphyry. Ballpark Porphyry (Tbp) is the most eastern of the large intrusive masses of Majuba Hill. It receives its name from a large (ballpark-size) bulldozed area that exposes part of the porphyry mass. Like the Early Rhyolite, the Ballpark Porphyry intrusive is elongated in a northeast direction. Diamond drilling has shown much of the Ballpark Porphyry to be a "floored intrusive." Three near-vertical holes passed out of Ballpark Porphyry into older rocks at about 400 feet in depth. We presume the intrusive to be funnel-shaped, but have not intersected a conduit in drill holes.

The Ballpark Porphyry is a white to light gray rock that is distinctly porphyritic and resembles some specimens of Majuba Porphyry. It contains phenocrysts of quartz, sanidine(?), and plagioclase set in an aphanitic, felsite groundmass. Quartz phenocrysts are subhedral, evenly distributed and commonly contain small, rounded, and irregularly shaped inclusions of groundmass material. Crystals of potassium feldspar, (sanidine?) as large as one cm in length, are common in drill core from the deeper parts of the intrusion but are rare at the surface.

Ballpark Megabreccia. Within the Ballpark intrusive, but near its southwestern margin, is an extensive oval area of coarse breccia that we have called "Ballpark Megabreccia." Ballpark Megabreccia (Tbmb) contains diversely oriented blocks of flow banded rhyolite that range in size from less than an inch to twenty feet in least dimension. The matrix of the breccia is white aphanitic material that resembles Ballpark Porphyry groundmass. The Ballpark Porphyry is chilled against the Megabreccia, and faint foliation in the chilled zone follows the contact. The breccia blocks are a fine-grained, flow banded quartz porphyry that, in hand specimen, resembles Early Rhyolite, but in thin-section more nearly resembles Ballpark Porphyry. We interpret the Ballpark Megabreccia as a collapse feature involving blocks of early, flow banded and chilled Ballpark Porphyry that collapsed downward into a still-liquid portion of the intrusive.

Bull Quartz Breccia. The Bull Quartz Breccia (Tbqb) occurs as two northeast-trending sinuous dikes near the southwestern margin of the Ballpark Porphyry. They cut Ballpark Porphyry, Late Felsite Breccia, and one of the Limonite Breccia pipes. The Bull Quartz Breccia is a coarsely fragmental, well-lithified rock that forms resistant, rounded outcrops. The breccia contains subrounded fragments of what appear to be vein quartz, Ballpark Porphyry, and sericitized argillite in silicified matrix. The rock fragments are veined by white to light gray translucent quartz. The quartz fragments and vein quartz consist of a fine-grained mosaic of diversely oriented, hydrothermal(?) quartz grains that contain abundant microscopic fluid inclusions.

Moldy Porphyry. Where first mapped, Moldy Porphyry

(Tm) occurs as a poorly exposed, narrow dike of variously-textured, nondescript rock that prompted its derogatory field name. Further mapping, however, showed it to be a principal intrusive—second only to the Pinhead Porphyry in areal extent—and the most widely exposed of the Majuba-Ballpark-Moldy assemblage of rocks. Plate 2 illustrates two relatively large, elongated masses, several smaller plugs and numerous sills and dikes of Moldy Porphyry.

Moldy Porphyry is uniformly medium-gray on broken surfaces, except in one area of the large northern mass where selective sericitization of the groundmass has produced a "mottled green" variety. Several textural varieties have been mapped, the most common of which has a fine-grained, inhomogeneous-appearing, sandy-textured groundmass that breaks with a hackly surface. The groundmass is composed of pyrophyllite(?), kaolinite(?), shreds of quartz, and microscopic spherulites of mixed, fibrous quartz and clay (after feldspar). Quartz phenocrysts are unevenly distributed in the groundmass, show strongly corroded or skeletal shapes, and contain characteristic, small, rounded inclusions of groundmass material.

Several discontinuous dikes and small patches of "Super Moldy" Porphyry (Tsmp) have been mapped within the main Moldy Porphyry intrusions. This variety has larger and more abundant quartz phenocrysts and a finer, more even-textured groundmass, but otherwise retains the diagnostic characteristics of the common variety. Chilled and weakly flow banded rock occurs on the margins of most dikes and sills, and near the contacts of Moldy Porphyry with Moldy Autobreccia.

Moldy Autobreccia. Moldy Autobreccia (Tmab) is a term given to several areas of breccia within and peripheral to the porphyry masses. The breccias differ in detail but generally contain various-sized fragments and blocks of flow banded Moldy, common Moldy, and silicified Pinhead porphyries in a fine-grained, flow banded Moldy Porphyry matrix. The Moldy Autobreccia probably resulted from brecciation along certain marginal areas of the Moldy Porphyry intrusive as well as from collapse of roof rock into the magma from which Moldy Porphyry was derived.

Silicic Breccia. Silicic Breccia (Tsb) contains fragments of silicified rock in one large (100 x 400 feet) steeply dipping and northwest-elongated pod in the central part of the Majuba igneous complex and in several narrow dikes cutting Pinhead and Moldy Porphyries to the northeast of the main mass. Crosscutting relationships fix the age of the Silicic Breccia between the Moldy Porphyry and the Q-T Rhyolite Porphyry (table 2). The breccia consists of subrounded fragments of silicified and quartz-veined Majuba Porphyry and subordinate argillite in a matrix of pulverized and partly silicified rock.

Late Rhyolite Porphyry Assemblage

Rocks of the Late Rhyolite Porphyry assemblage form the two major dike systems of the Majuba Hill intrusive center. This group also includes tourmaline-rich Black Breccias and Pebble Breccias.

Q-T Rhyolite Porphyry. The Q-T Rhyolite Porphyry (Tqt) is one of the youngest Majuba porphyries and received its name from the unusually prominent quartz phenocrysts and tourmaline pseudomorphs (after large K-feldspar phenocrysts) where first mapped underground. An original term of "quartz-tourmaline" porphyry proved to be a misnomer as surface mapping showed the tourmaline pseudomorphs to be present in the rock only in certain areas. The Q-T Rhyolite Porphyry occurs only as dikes and sills; no larger masses or source intrusives have been found by surface mapping, underground mapping or deep drilling. The Q-T Rhyolite Porphyry dikes and sills form some of the most prominent features of the Majuba igneous complex and surrounding area. Within the south-central part of the Majuba Hill intrusive center, O-T dikes form a radial pattern. Outward from this "center" the dikes form a reticulate pattern with a strong northeast component (fig. 2). Beyond the limits of the intrusive center, the porphyry forms sills in the argillite that continue as prominently conspicuous intrusive features for as much as one and one-half miles away from the Majuba Hill center. The dikes and sills vary from five feet to as much as two hundred feet in thickness, but most are in the range of twenty to sixty feet thick. Within the intrusive center, the dikes are steeply dipping to vertical, and beyond the intrusive center the sills conform to the relatively steep dips of the argillite.

Q-T Rhyolite Porphyry is a distinctive rock characterized by large and conspicuous quartz phenocrysts, K-feldspar phenocrysts, and/or black tourmaline pseudomorphs in an aphanitic, light gray matrix (fig. 3).

The rock contains approximately ten percent quartz phenocrysts that range from 1 mm to 5 mm in diameter. The larger quartz phenocrysts tend to form euhedral bipyramids, and the smaller ones tend to be subhedral and rounded. Clusters of two and three quartz phenocrysts are common. The rock also contains approximately five percent albite phenocrysts (1 mm to 5 mm in length) and approximately ten percent K-feldspar phenocrysts (2 mm to 5 mm in length). The groundmass in relatively fresh specimens appears to consist of a fine-grained equigranular mixture of quartz and K-feldspar.

The intensity of alteration varies with distance from the intrusive center; those specimens from sills distant from the intrusive center are least altered. Feldspar in phenocrysts and groundmass is commonly altered to a mixture of sericite, clay, and finely crystalline quartz. Near the center of the intrusive complex many of the feldspar phenocrysts are replaced by quartz, fluorite, and tourmaline. Where the porphyry forms sills in the argillite, the sills stand out in bold positive relief because the weakly to moderately altered porphyry is harder than the argillite with which it is in contact. Within the intrusive center, however, the common clay-sericite alteration in the Q-T Porphyry produced a rock that is considerably softer than many of the other Majuba rocks and particularly those such as Pinhead Porphyry, that are commonly silicified. As a consequence of this differential hardness, Q-T Porphyry within the igneous complex tends to produce steep-walled valleys or depressions with little or no outcrop.

The Q-T Rhyolite Porphyry dikes and sills are only weakly mineralized; minor pyrite is commonly observed with tourmaline in altered feldspar phenocrysts. In spite of the scarcity of visible sulfides, strong copper oxide staining is common in places along the contacts of the porphyry both in the intrusive center and in the argillite.

Black Breccia. Many of the late breccia dikes, pods, and pipes on Majuba Hill have hard, black, tourmaline-rich matrices (fig. 3). Predominant fragments in most Black

Breccias (Tbb) are of local derivation; Black Breccias in argillite are rich in argillite fragments, those in Pinhead Porphyry contain Pinhead Porphyry fragments, and those which cut large Q-T Rhyolite Porphyry dikes contain abundant fragments of that rock. Matrix material is, for the most part, exceedingly fine-grained and ranges from iron-gray to black, depending on the percentage of fine-grained tourmaline mixed with and replacing pulverized rock. The matrix material also contains fine-grained quartz, sericite, clinozoisite, and fluorite.

There are three major Black Breccia centers within the Majuba Hill intrusive center: 1) a northeastern center near the northeastern margin of the Pinhead intrusion; 2) a central group near the center of the Pinhead intrusion; and 3) a southeastern center near the southeastern margin of the Pinhead intrusion.

Crosscutting relations indicate a progression in age of Black Breccia intrusive centers from oldest in the northeast center to youngest in the southwest center.

The northeastern Black Breccias include a series of smaller pipes and pods clustered near a large (approximately 200 feet across), irregular, steeply plunging Black Breccia pipe. Several Black Breccia dikes extend northeastward from the pipe toward the Pinhead Porphyry-argillite contact.

The central group of Black Breccias includes a large and irregularly shaped body of Black Breccia and a series of discontinuous Black Breccia dikes, most of which trend northeast and east from the central pipe. Aligned remnants of a Porcelanite Porphyry dike in the larger breccia mass suggest a somewhat passive emplacement of this Black Breccia. This central group of Black Breccias displays contradictory age relationships with respect to Q-T Rhyolite Porphyry dikes that may indicate intrusion over a period of time intermediate between the emplacement of the northeast and southwest breccia centers.

The southwest Black Breccia center includes a large (approximately 200 feet in diameter), roughly circular pipe-like body of Black Breccia containing boulder-sized fragments of Pinhead and Q-T Rhyolite Porphyries. Portions of this breccia pipe are predominantly limonite cemented rather than tourmaline cemented, suggesting a possible relationship in style, if not in time, between tourmaline breccias and some limonitic breccias. Underground mapping has shown this breccia pipe to be in part underlain and intruded by apophyses of Late Rhyolite Porphyry. Two root zones of this pipe remain—one of which plunges steeply to the northeast and the other to the northwest. The pipe has been displaced along the Majuba fault, a prominent and well-mapped fault in the mine area.

Black Breccia dikes and pods are abundant in rocks peripheral to the large pipe; they are generally randomly oriented in the igneous rocks, but are sill-like in the argillite. Black Breccia is particularly common along, and as stretched inclusions in, the margins of Late Rhyolite Porphyry, suggesting that the Black Breccias of the southeastern center are closely related to, and perhaps immediately preceded, intrusion of the Late Rhyolite Porphyry.

Two small pods and several sills of argillite breccia that intrude argillite are included with this group, although they are deficient in tourmaline in the matrix material. Their general characteristics and location suggest an affinity with Black Breccia intrusion, but they may have resulted from a different igneous event.

Late Rhyolite Porphyry. Late Rhyolite Porphyry (Tlrp) is the youngest of the quartz rhyolite intrusives and occurs principally as two large lobate masses on the west and southwest margin of the Majuba Hill intrusive center (pl. 2). These masses have an east-northeast trend and they divide and subdivide in that direction into a complex pattern of steeply dipping dikes. In these surface dikes and most of the underground exposures and drill intersections, the Late Rhyolite Porphyry is a compact, well-crystallized quartz porphyry with relatively few inclusions. In the large lobate areas of surface exposure, however, the Late Rhyolite Porphyry is choked with partially digested inclusions that have been stretched in a direction parallel with (and in places producing) strong vertical flow banding.

The increase in the percentage of inclusions and strength of flow banding in the western lobate masses suggest that the Late Rhyolite Porphyry in this area represents the upper and outer parts of the original intrusives. The advancing Late Rhyolite magma flushed any included debris upward and outward to its presently observed location and the strong flow banding probably resulted from the freezing of viscous, inclusion-choked magma in the upper and outer extremities of the intrusion. The irregular lobate and fingerlike shapes of the western margins and the "tops" of dikes observed in the upper mine workings suggest that the present surface of Majuba Hill is near the original upper limit of this particular intrusion.

Where the texture is not masked by inclusions, the Late Rhyolite Porphyry is a light gray to whitish rock with abundant and prominent dark-gray quartz phenocrysts. The quartz phenocrysts are subhedral to euhedral bipyramids that range in size from 1 to 5 mm, giving the rock a distinctive seriate porphyritic texture. The rock also contains sanidine and albite phenocrysts. Both range from 1 mm to 10 mm in maximum dimension, but because of nearly ubiquitous argillic and sericitic alteration, they tend to visually blend with the fine-grained groundmass (fig. 3). The groundmass consists of a fine-grained mixture of quartz, K-feldspar, sericite, and clay.

Most occurrences of the rock appear to be moderately to strongly argillized, and for the most part, bleached.

Late Rhyolite Porphyry is younger than, but closely associated with, Black Breccias. Some dikes of Late Rhyolite appear to grade into Black Breccia dikes.

The Late Rhyolite Porphyry is a copper-bearing intrusive. Samples of this rock from a dike in the lowermost tunnel assayed as high as 0.14 percent copper, and the high-grade copper ore of the Majuba Mine appears to have been spatially and genetically related to non-outcropping fingerlike upward projections of one of Late Rhyolite Porphyry masses. Similar fingerlike projections of Late Rhyolite Porphyry were mapped on the surface due west of the mine area. Pyrite, chalcopyrite, and tourmaline occur in the groundmass and replace feldspar phenocrysts in the drill core; fluorite veinlets fill fractures in Late Rhyolite Porphyry collected from the lower tunnel.

Pebble Breccia. Majuba Pebble Breccias (Tpb) are characterized by spheroidal "pebbles" that range in size from ¼ inch to as much as 20 inches in diameter. The "pebbles" are mostly silicified Majuba Porphyry and, although only sparsely present in some Pebble Breccias, they are abundantly present in others. In addition to "pebbles," the breccias contain subangular fragments of

other Majuba Hill igneous rocks and rare argillite fragments in the sericitized, pulverized rock matrix.

Pebble Breccia occurs primarily as pebble dikes with sharp, nearly vertical contacts, but it also forms pods with gradational(?) contacts in Late Rhyolite Porphyry. Dikes of Pebble Breccia are scattered throughout the Majuba Hill intrusive center, but appear to be concentrated in a broad northwest-trending belt crossing the southwest end of the intrusive center. The dikes trend in different directions, but northeast trends predominate. Pebble Breccias are the youngest rocks mapped on Majuba Hill and are known to cut the youngest porphyry—Quartz Latite Porphyry—but they apparently formed over a span of time from immediately pre-Q-T Rhyolite Porphyry until the end of Majuba intrusive activity. The vast majority appear related in time and space to Late Rhyolite Porphyry and they form borders on, pods in, and continuations of, Late Rhyolite dikes. The spheroidal pebbles probably resulted from milling action in a tenuous and possibly gaseous magmatic fluid, and we believe them to be related to a final degassing of late-stage magma.

Latite Assemblage

Latite (Tl) includes two textural varieties; one is porphyritic (Quartz Latite Porphyry – Tlq), and the other is aphanitic (Biotite Latite – Tlbi). These two varieties differ in appearance and to a lesser extent in composition, but are clearly related and have mutually gradational contacts. The principal outcrop is a small stock in the southeast breccia complex immediately west of the Ballpark Porphyry mass (pl. 2); it is also found in drill core from holes that pass under this area. Three steeply dipping dikes radiate from this small stock, and two relatively narrow, steeply dipping dikes have been mapped on the main ridge and north side of Majuba Hill. Latite is younger than all Majuba Hill rhyolitic porphyries except possibly Late Rhyolite Porphyry, and it is probably younger than this rock as well, but no crosscutting relations have been observed.

The color of the Quartz Latite Porphyry variety ranges from greenish-gray to white to yellowish-brown to dark yellow-orange (limonite stained). The rock has been hydrothermally altered, but the alteration, in contrast to that observed in other Majuba Hill rocks, appears to be low intensity (argillic and propylitic). The most conspicuous textural feature is the occurrence of exceptionally large (for Majuba rocks), but sparsely distributed quartz phenocrysts. The quartz phenocrysts occur as single crystals or as rounded aggregates of crystals as large as 1 cm in diameter. Feldspar phenocrysts, equally as large as the quartz, are commonly altered to montmorillonite(?) and calcite; optical properties of unaltered remnants indicate that the pseudomorphs were originally albite. Accessory biotite largely altered to chlorite is scattered through an aphanitic groundmass of alkali feldspar and quartz. The Biotite Latite is most commonly olive gray in color and contains small biotite and plagioclase phenocrysts set in an alkali feldspar-quartz-chlorite groundmass.

Latite rocks are mineralized, but only weakly so. Both pyrite and chalcopyrite are disseminated in the groundmass and pyrite occurs in veinlets by itself or with chalcopyrite or fluorite. Rare veinlets containing sphalerite-chalcopyrite and arsenopyrite were also logged in drill core.

We believe rocks of the Latite assemblage to be the youngest members of the complex suite of Majuba Hill intrusives and also ones that indicate a definite and apparently final change in the composition of the parent magma from rhyolitic to latitic.

The Majuba Canyon Intrusive Center

The Majuba Canyon intrusive center is a composite body of subvolcanic rocks that forms an irregular mass 1200 to 1400 feet across. It crops out on the east side of Majuba Canyon (pls. 1 and 2) about one mile east of the Majuba Hill intrusive center and is separated from the main center by argillite. Characteristics of texture and composition suggest a genetic and probable temporal relationship to the Early Rhyolite of the Majuba Hill center.

Majuba Canyon Assemblage

Four mappable units make up the Majuba Canyon assemblage. From oldest to youngest they are: Majuba Canyon Rhyolite (Tmcr), Porphyritic Rhyolite (Tpr), Rhyolite Autobreccia (Tra) and Columnar Felsite (Tcf).

Majuba Canyon Rhyolite. Majuba Canyon Rhyolite is the principal rock type of the Majuba Canyon assemblage; it is a white to very light gray rhyolite that is very similar in composition, texture and appearance to Early Rhyolite of the Majuba Hill intrusive center. It contains small (1 to 3 mm) quartz and K-feldspar phenocrysts in a fine-grained, flow banded groundmass. Foliations are generally subparallel to the margins of the intrusive body and dip 70° to 90°. Limonite stain is commonly present on joint surfaces and in small voids.

Porphyritic Rhyolite. Porphyritic Rhyolite forms an intrusive plug, about 500 feet across, within the northwestern part of the Majuba Canyon intrusive center. This rock also is a white to light-gray rhyolite that resembles the Majuba Canyon Rhyolite which it cuts, but has more and slightly larger quartz phenocrysts. It has a dense groundmass that contains three to five percent lenticular and aligned voids that may represent stretched vesicles. Porphyritic Rhyolite has a somewhat pumiceous appearance.

Rhyolite Autobreccia. Rhyolite Autobreccia occurs in two small, distinct pods—one of which intrudes Majuba Canyon Rhyolite and the other cuts Porphyritic Rhyolite (pl. 2). Rocks from both pods are similar in appearance and consist of contorted flow layers of white rhyolite matrix containing angular to subrounded fragments of Majuba Canyon Rhyolite, Porphyritic Rhyolite and argillite that range in size from microscopic to several feet across.

Columnar Felsite. Columnar Felsite forms four west-northwest-striking, steeply dipping dikes which cut the Majuba Canyon Rhyolite and Porphyritic Rhyolite intrusives; its age relative to the autobreccia is uncertain but is tentatively shown as younger. Columnar Felsite is characterized by joint bounded columns that average three inches across and are diversely oriented with respect to flow bands and dike contacts. The plunges of the columns range from nearly flat to vertical. Most foliations in the rocks of the Majuba Canyon assemblage are steep, which suggests that the rocks are intrusive rather than extrusive, but vesicles(?) in the porphyritic rhyolite and columnar joints in the felsite dikes both suggest shallow emplacement.

EVOLUTION OF THE MAJUBA IGNEOUS COMPLEX

There is an apparent but imperfect progression in the style of emplacement and textures of both porphyries and breccias of the Majuba igneous complex. The earliest Majuba intrusives tended to form large masses with weakly to moderately developed porphyritic textures, and the later differentiates appear principally as dikes and sills with distinctly porphyritic textures (fig. 4). The concluding intrusion of latite signaled a final compositional change in the magma reservoir that produced the Majuba suite of rocks.

There is a corresponding but somewhat younger progression in the evolutionary style of Majuba brecciation. The earlier breccias tend to be large and irregular masses of breccia principally related in time and space to the margins of stocks. Breccias of intermediate age tended to form dikes, sills, and pipes characterized by relatively sharp contacts and sharp, angular fragments. This age group includes the tourmaline and limonite-cemented breccias. The youngest breccias are pebble dikes and pods that probably resulted from transport of fragments in a highly fluid and gaseous medium and during degassing of late-stage magmas.

There would also appear to have been a downward retreat of the subjacent magma reservoir during the history of Majuba intrusions. The stock centers of the early porphyries such as the Early Rhyolite-Pinhead assemblage are largely exposed at present levels of erosion. Stocks of intermediate ages such as the Felsite stock and the Majuba stock (probably parent intrusive for Ballpark and Moldy Porphyries as well) are for the most part not exposed but have been encountered in deep drill holes. Source stocks, if such exist, for the youngest dike-rocks, including Q-T Rhyolite and Late Rhyolite Porphyries, have not been penetrated by even the deepest drilling.

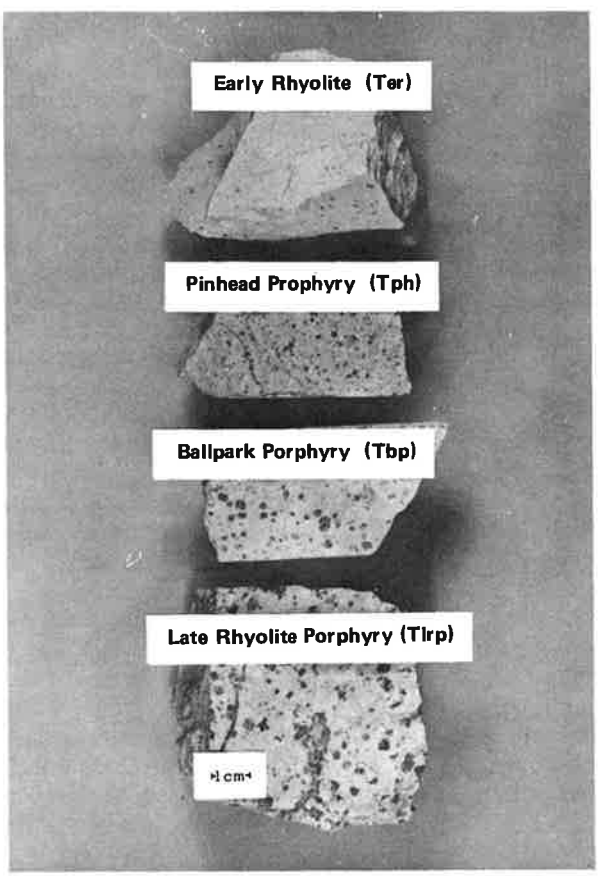


FIGURE 4. Photograph of selected Majuba Hill porphyries (oldest at top, youngest at bottom) illustrating development of increasing porphyritic texture with decreasing age of intrusion.

Several of our drill holes that started in igneous rock unexpectedly passed into argillite with depth. These drill holes show the Majuba Hill intrusive center to be considerably larger at surface than at depth. The vertical, cross-sectional shape (pl. 3), as suggested by D. L. Stevens (1971), is somewhat fanlike. The various magmas appear to have been introduced through a constricted conduit and to have spread to the presently observed size of the complex not far beneath the present surface. The Ballpark Porphyry exemplifies this fanlike habit as holes drilled into the intrusive bottomed in underlying argillite.

Rocks of the Majuba igneous complex are clearly intrusive; a number of textural and structural features, however, are suggestive of shallow emplacement; these include:

1) Columnar jointing and vesicle-like voids in rocks of the Majuba Canyon intrusive center.
2) Conspicuous flow banding in many Majuba rocks. Whereas flow banding is by no means restricted to extrusive and near-surface rocks, it is particularly characteristic of such rocks.
3) An abundance of intrusive breccia pipes, dikes and sills and pebble breccias, suggestive of near-surface and possibly explosive activity.
4) Radial, and partly radial, dike patterns that are characteristic of known volcanic centers.
5) Aphanitic and porphyritic textures of essentially all Majuba rocks. Such textures are characteristic of (but not restricted to) extrusive and shallow intrusive rocks.
6) The fanlike shape of the complex in vertical section (pl. 3). The significant increase in the average diameter of the complex near present erosion levels suggests that this level was sufficiently shallow at the time of intrusion for the invading magmas to overcome the confining pressure of the country-rock argillite and to expand laterally.

None of the above is conclusive proof for a shallow origin for the Majuba rocks, but collectively they offer strong supportive evidence. We interpret the suite of Majuba rhyolite porphyries, latite and related breccias to be the remnant of a complex and shallow, intrusive rhyolite dome or the subjacent portion of a former volcano. We lack direct evidence that the complex vented, and pyroclastic extrusive rocks, if they ever existed, have been eroded. We use the term "subvolcanic" in reference to rocks of the Majuba igneous complex to indicate their probable shallow origin and their similarity, in composition and texture, to extrusive rhyolites from other areas. The Majuba rocks are similar in texture, composition, intrusive forms and characteristics of mineralization and alteration to rocks that have been designated as "subvolcanic" at some Bolivian tin deposits (Turneaure, 1971; Sillitoe and others, 1975).

FAULTS

Several large faults and innumerable smaller faults, fractures, and bedding-plane shears were observed and

mapped in the course of our work, but with the exception of the Majuba fault, they appear to have had little disruptive or controlling effect on the spatial distribution or shape of intrusive units and mineralized zones. Some of the faults that slightly offset Q-T Rhyolite Porphyry dikes, but do not appear to offset Late Rhyolite Porphyry dikes, suggest that some faulting occurred between igneous intrusive events. Most observed faults dip steeply; northeast and northwest trends are the most common. Several larger faults (pl. 2) have northwest trends, and the best documented of these is the Majuba fault in the Majuba Mine area. The Majuba fault is shown in section on plate 3 and has been traced along strike for several hundreds of feet in underground workings and surface exposures. The Majuba fault is somewhat sinuous but has an average strike of N. 30° W. Measured dips range from 47° to 82° and average 66° to the southwest. The fault is irregular and composed of several strands where exposed in the original surface "discovery pit", but in the lowermost exploration level is a strong, well-defined, gouge-filled structure as much as ten feet wide. Dip-slip displacement on the fault is in the order of 100 to 150 feet.

The Majuba fault and several subsidiary faults are well exposed in the main workings of the Majuba Mine (pl. 4). Although fracturing and brecciation of primary ore minerals demonstrates post-ore movement of these faults, the concentration of primary ore minerals along the fault zones indicates the presence of pre-ore structures as well. The intersection of a pre-ore component of the Majuba fault and the large Black Breccia pipe served as a prime depositional site for ore minerals derived from hydrothermal fluids given off by the invading apophyses of Late Rhyolite Porphyry. Late movement along the fault offset the porphyry, redistributed primary ore minerals and produced a strongly fractured zone that accommodated secondary mineralization.

We made no systematic study of joints in the Majuba intrusives, but a plot of 200 joints by Stevens (1971) shows a predominant northwest trend with steep dips. In the northeast portion of the intrusive complex quartz-filled joints are abundant; most have northeast or northwest trends and steep dips (70°–90°).

MINERALIZATION AND ALTERATION

Copper-stained rocks are particularly evident on surface outcrops in the immediate vicinity of the Majuba Mine and are present at many other places on Majuba Hill. Our exploration effort was designed for and largely directed toward the discovery of large stockwork or disseminated ore bodies, and our work did not exhaust the possibility of finding such deposits, or of finding additional smaller, high-grade, Majuba Mine-type deposits.

Prior to the start of the diamond drilling program, Mine Finders, Inc. conducted an extensive soil and rock-chip geochemical survey. Samples were collected on approximately 300-foot centers in a pattern that included the entire Majuba Hill igneous complex and immediately surrounding argillite. All samples were geochemically assayed for copper, tin, silver, and molybdenum; geochemical anomaly patterns for these elements are shown in a much generalized form in figure 5. These anomaly patterns suggest that there was more than one center for mineralization and illustrate that the elements are distributed nonuniformly; molybdenum in particular appears to be separated from the higher copper anomalies.

Origin

Most, if not all, Majuba intrusive bodies were accompanied by episodes of hydrothermal mineralization and alteration. The association of hydrothermal products with the earliest Majuba intrusives is difficult to document because: 1) the masking effect of younger hydrothermal systems; 2) the oldest intrusives which are well exposed at the present surface may have lost much of their overlying mineral and alteration halos to erosion; and 3) the possibility that not much hydrothermal alteration and mineralization accompanied the early intrusives. The association in time and space of hydrothermal mineralization and alteration with younger intrusives is reasonably clear, however, and even the youngest of the Majuba rocks—the Latite, which truncates pre-existing rocks and their associated hydrothermal products—is itself mineralized and altered.

The strongest mineralization and alteration halos appear to be related to three intrusives—the Felsite stock, the Majuba Porphyry, and the Late Rhyolite Porphyry. Figure 6 graphically illustrates the relations of episodes of selected types of mineralization and alteration to specific Majuba intrusives. The effects of hydrothermal activity are far more complex than can be shown on a simple diagram, and the detailed analytical and petrographic work required to work out zonal distribution patterns has not been done. Also, the complexities introduced by repeated cycles of intrusion, mineralization and alteration make it difficult to assign certain minerals and alteration effects to a specific intrusive. Pyrite, for example, is present nearly everywhere in Majuba rocks, but is nowhere so abundant as to form a distinct pyrite halo that can be related to a specific intrusive. The general lack of strong pyrite mineralization in Majuba rocks is, in fact, one of the most notable features of Majuba mineralization. Pyrrhotite and arsenopyrite have been observed in many Majuba rocks, and their presence suggests that the Majuba igneous complex may have been deficient in sulfur which, in turn, may partly account for the lack of strong pyrite mineralization.

The relatively widely spaced diamond drill holes (pl. 1) passed through hundreds of feet of plus 0.2 percent copper mineralization. However, the close-order drill information necessary for tonnage and grade estimates is lacking.

As noted above, most of the mineralization and alteration mapped and drilled at Majuba Hill is spatially and, we believe, genetically related to three intrusives: the Felsite stock, the Majuba Porphyry, and the Late Rhyolite Porphyry.

Diamond drilling in the vicinity of the Felsite stock substantiated the presence of copper mineralization indicated by surface geochemical anomalies. The copper is

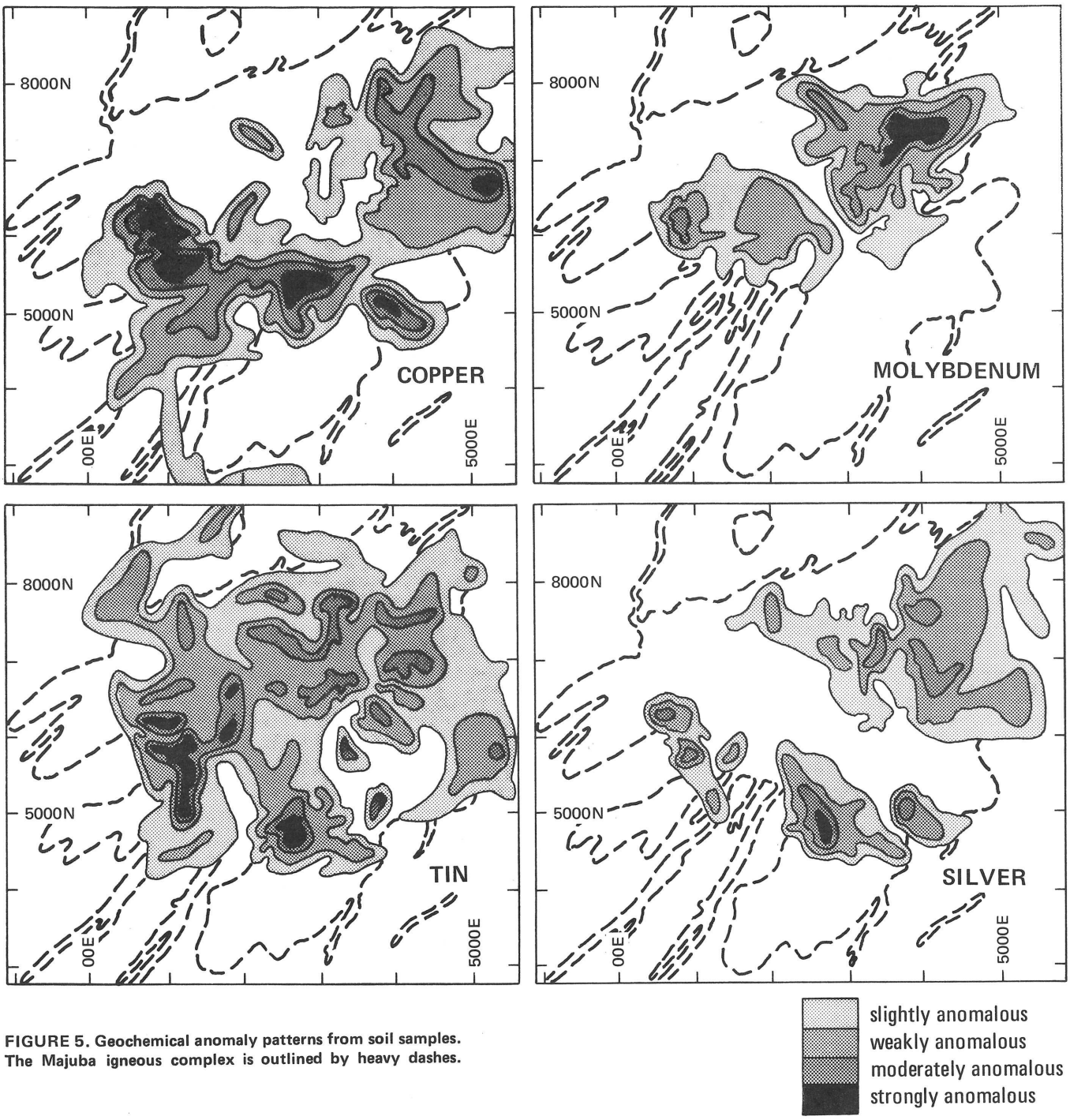


FIGURE 5. Geochemical anomaly patterns from soil samples. The Majuba igneous complex is outlined by heavy dashes.

present as veinlets of chalcopyrite with pyrite, or veinlets of very fine-grained chalcopyrite with arsenopyrite and pyrrhotite. No tin or silver minerals were recognized, but assays show these elements to be directly associated with copper in the Felsite-related mineralization. The highest copper assays occur in the Felsite, but weaker mineralization extends into the surrounding country rocks. Molybdenum is essentially absent in the Felsite mineralized zone. The rocks are largely altered to sericite and quartz with minor amounts of clay and secondary K-feldspar.

The Majuba Porphyry intrusive, like the Felsite stock, is largely unexposed and its dimensions are known principally from drill hole intersections. Geochemistry, mapping and drill core examination indicate that this intrusive is closely associated with an extensive zone of silicification and low-grade (less than 0.1% Mo) molybdenite mineralization. Copper is rare or absent near the Majuba Porphyry stock but is present in surface outcrops of related rocks (Moldy Porphyry and Ballpark Porphyry). An extensive zone of strongly altered rocks overlies and includes the upper portions of Majuba Porphyry. In places the rocks are strongly silicified and consist of little else than quartz. In general, these strongly silicified rocks overlie strongly K-feldspathized rocks, but the zoning is erratic and drill holes penetrate alternating intervals of silicified and K-feldspathized rocks.

Molybdenite occurs in the weakly developed stockwork of tight molybdenite-quartz veinlets and is most commonly

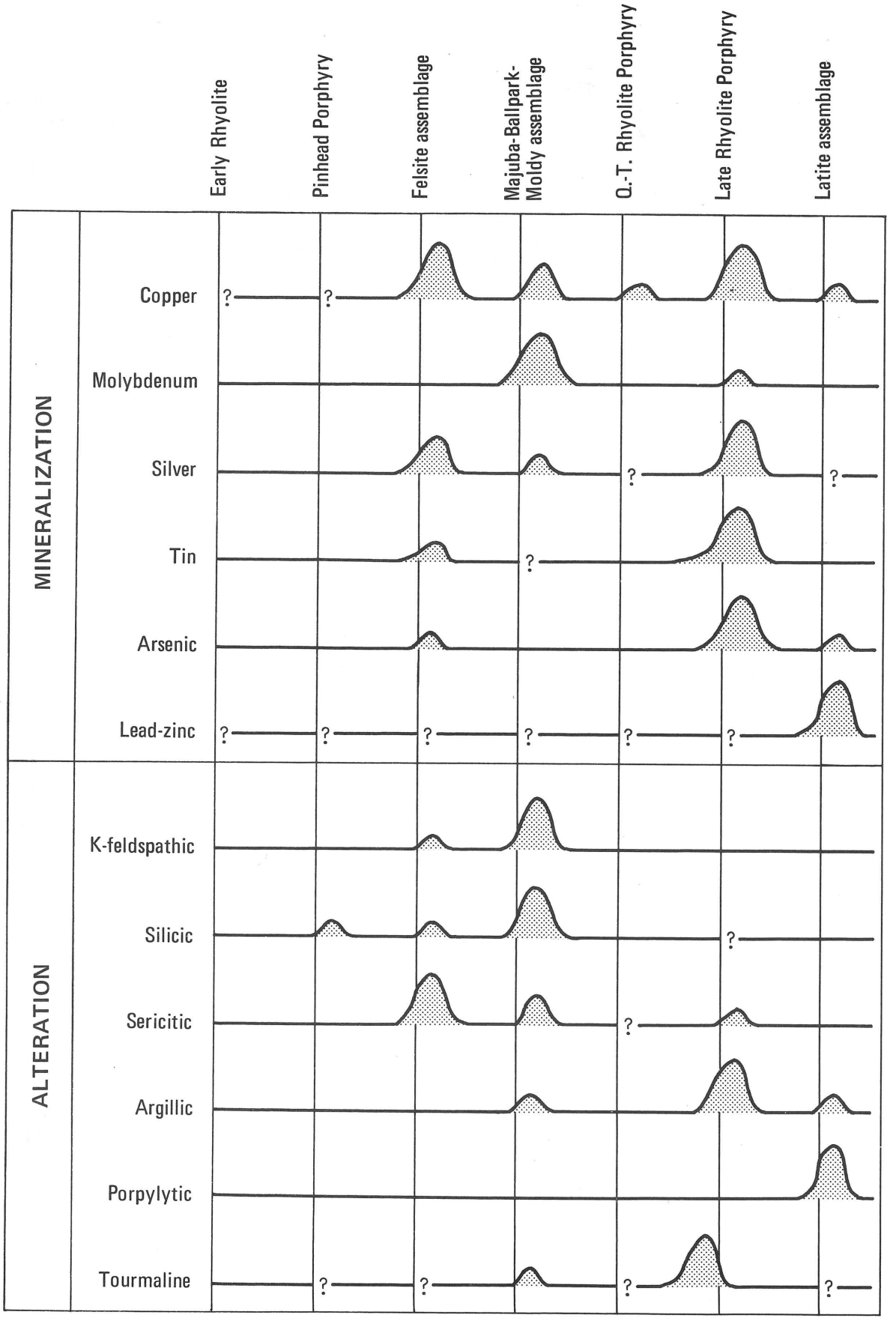


FIGURE 6. Relationship of hydrothermal mineralization and alteration to intrusive rocks. Height of shaded areas indicates only relative, and not absolute, abundance of hydrothermal products.

associated with the strongly silicified rocks. Within the zone of molybdenite mineralization, pyrite is rare and chalcopyrite occurs in only trace amounts. Where present, these two minerals and fine-grained tourmaline form stockwork veinlets that cut the quartz-molybdenite veinlets.

Mineralization that accompanied the Late Rhyolite Porphyry dikes produced the only known orebody at Majuba Hill. The high-grade copper and tin ores produced from the Majuba Mine were concentrated in and near the Majuba fault at the subsurface top of a Late Rhyolite dike. Geologic mapping indicates the following sequence of events (also see pls. 2 and 3): 1) intrusion of a Late Rhyolite-related Black Breccia pipe into the pre-existing rocks; 2) intrusion of apophyses of Late Rhyolite Porphyry into the Black Breccia and surrounding rocks; 3) concentration of ore minerals along existing fault zones and in the upper portions and above the Late Rhyolite Porphyry; 4) post-ore movement along the Majuba fault; and 5) redistribution of secondary copper ore in and near the fault.

Previous investigators related the copper and tin ores in the Majuba Mine to either the Majuba fault or the breccia pipe. Our work indicates that whereas these two geologic features influenced the distribution of ore minerals, the source of the metal was the Late Rhyolite intrusive that directly underlies most of the ore. The upward terminating apophyses of Late Rhyolite Porphyry are a subsurface part of the southern major Late Rhyolite Porphyry dike system shown on plate 2. Assays of this dike in the lowermost tunnel show it to be anomalously high in copper. The assays, some as high as 0.1 percent copper, are attributed to chalcopyrite that is concentrated with tourmaline on the margins of the dike and in faults and fractures within the dike.

On surface exposures, malachite and azurite are commonly associated with Late Rhyolite Porphyry that contains tourmaline schlieren and tourmaline pseudomorphs after feldspar. Surface geochemical patterns indicate strong copper anomalies in the vicinity of fingerlike apophyses of Late Rhyolite Porphyry 200 to 400 feet west of the mine area. Argillized Late Rhyolite Porphyry dikes encountered in deep drill holes contain minor fine- to medium-grained disseminated pyrite, chalcopyrite, and tourmaline.

In the main copper stope of the Majuba Mine, apophyses of Late Rhyolite Porphyry that intruded the Black Breccia pipe near the Majuba fault contain chalcocite-rich pods that range in size from one to ten inches across. These pods have centers of pyrite, chalcopyrite and minor enargite, surrounded by digenite and chalcocite. The pyrite and chalcopyrite were shattered before being partially to completely replaced by chalcocite and digenite. No stockwork veinlets were observed in the Late Rhyolite Porphyry, but wall rocks ranging in age from Pinhead Porphyry to Q-T Rhyolite Porphyry are tourmalinized and cut by chalcopyrite-bearing tourmaline stockwork veinlets. Such mineralization is characteristic of the southwest part of the Majuba Hill intrusive center where the Late Rhyolite Porphyry has its greatest exposure and is the youngest major intrusion. Molybdenum oxides mixed with limonite are present in the same general area and probably also are related to the Late Rhyolite Porphyry.

Most specimens of Late Rhyolite Porphyry have been moderately to strongly argillized and weakly to moderately sericitized. Because the Late Rhyolite Porphyry dikes cut strongly silicified, sericitized, and K-feldspathized older rocks, the argillization was obviously younger, and probably closely followed and is related to the intrusion of the Late Rhyolite Porphyry.

Although assays show the presence of considerable tin throughout the mine workings, the only significant production came from a single tin stope approximately 200 feet northwest along the Majuba fault from the principal copper stope. Cassiterite is the only tin mineral recognized and it occurs as irregular-shaped aggregates in a gangue of quartz, sericite and tourmaline, all of which has been heavily coated with iron oxide. The Majuba tin occurrence has been well described by W. C. Smith and V. P. Gianella (1942), and reference should be made to their work for additional detail.

Minor quantities of uranium were reported from the Majuba Hill Mine area by A. F. Trites, Jr. and R. H. Thurston (1958) of the U.S. Geological Survey. The uranium occurs as supergene metazeunerite and is associated with chalcocite, pyrite, arsenopyrite, and cassiterite in the main copper stope of the Majuba Hill Mine.

Supergene Mineralization

Majuba Hill rocks are ubiquitously, but weakly, iron-stained, and widely scattered zones of green copper stain occur throughout the intrusive center. Strong iron oxide and copper carbonate coatings on fractures are common in drill core to depths of 200 to 300 feet and extend to 1000 feet along larger faults and broken zones. Supergene alteration of rock-forming minerals is probably equally prevalent, but detailed studies of such effects have not been made.

Supergene alteration, characterized mostly by clay minerals, and mineralization (chalcocite, digenite, and a host of copper-arsenates) did occur along the Majuba fault. Probably not much supergene enrichment took place; the secondary copper minerals are concentrated near the top of the Late Rhyolite Porphyry intrusion which we believe to be the site of primary copper deposition, and the secondary copper minerals surround remnants of primary copper minerals.

Although Majuba is one of very few tin mines in North America and has also produced nearly three million pounds of copper, it is perhaps best known—especially among collectors—for its rare secondary copper- and arsenic-bearing minerals, a partial list of which appears in table 3.

Other Mineral Deposits

Two small nearby mineral occurrences, the Last Chance Mine and the Arsenic Prospect, may be related to Majuba Hill mineralization. The Last Chance Mine is approximately one and one-quarter miles southeast of the Majuba Mine and is reported to have produced about 1000 tons of lead-silver ore between 1906 and 1928 (Vanderburg, 1936). Sphalerite, pyrite, galena, smithsonite, and cerussite occur on the hanging wall and footwall of an andesite dike which was emplaced along the Last Chance fault. The fault, the dike, and the mineralized zone strike N. 45° W. and dip 45° to 72° SW.

The Arsenic Prospect is approximately one mile west of the Majuba Mine and is reported by Vanderburg (1936) to have produced a small quantity of arsenic ore during

TABLE 3. A partial list of secondary copper- and arsenic-bearing minerals reportedly collected from Majuba Hill. (Identities of most of the minerals provided by F. E. Cureton of Stockton, Calif. Also see A. F. Trites and R. H. Thurston – 1958.)

Mineral Name	Approximate Chemical Formula
Arthurite	$[Cu_2Fe_4(AsO_4)_3(OH)_7 \cdot 6H_2O]$
Azurite	$[Cu_3(CO_3)_2(OH)_2]$
Brochantite	$[CuSO_4 \cdot 3Cu(OH)_2]$
Chalcanthite	$[CuSO_4 \cdot 5H_2O]$
Chalcophyllite	$[Cu_{18}Al_2(AsO_4)_3(SO_4)_3(OH)_{27} \cdot 33H_2O]$
Chrysocolla	$[CuSiO_3 \cdot 2H_2O]$
Clinoclase	$[Cu_3AsO_4(OH)_3]$
Cornetite	$[Cu_3PO_4(OH)_3]$
Cornwallite	$[Cu_5(AsO_4)_2(OH)_4 \cdot H_2O]$
Cuprite	$[Cu_2O]$
Cyanotrichite	$[4CuO \cdot Al_2O_3SO_3 \cdot 8H_2O]$
Libethenite	$[Cu_2(PO_4)(OH)]$
Malachite	$[Cu_2CO_3(OH)_2]$
Metazeunerite	$[Cu(UO_2)_2(AsO_4)_2 \cdot 8H_2O]$
Mixite	$[Cu_{11}Bi(AsO_4)_5(OH)_{10} \cdot 6H_2O]$
Olivenite	$[Cu_2(AsO_4)(OH)]$
Pharmacosiderite	$[Fe_3(AsO_4)_2(OH)_3 \cdot 5H_2O]$
Scorodite	$[Fe(AsO_4) \cdot 2H_2O]$
Spangolite	$[Cu_6AlClSO_{10} \cdot 9H_2O]$
Tyrolite	$[Cu_9Ca_2(AsO_4)_4(OH)_{15} \cdot 9H_2O]$

World War I. The prospect consists of several small dumps, trenches, and an undetermined amount of underground workings along a mineralized bedding plane shear zone in argillite. The principal sulfide mineral is arsenopyrite that carried minor values in lead, copper and silver (Stevens, 1971).

Neither the Last Chance Mine nor the Arsenic Prospect is currently in production.

CONCLUSIONS

1. The northeast grain of the argillite country rock imposed a northeast elongation not only on the igneous complex as a whole, but also on the individual intrusive bodies of the complex.

2. The vertical, cross-sectional shape of the Majuba complex is somewhat fanlike. The various magmas appear to have been introduced through constricted conduits and to have spread laterally, especially to the southwest and northeast, at a level not far beneath the present surface.

3. A number of textural and structural features indicate shallow emplacement.

4. There is an apparent but imperfect progression in the style of emplacement and textures of both porphyries and breccias of the Majuba igneous complex:

   a. The earliest Majuba intrusives tended to form large masses of rhyolitic rock with fine-grained, weakly porphyritic texture, whereas the later intrusive bodies are dikelike, and are characterized by coarser grained and more distinctly porphyritic rock.

   b. The early breccias formed large, irregular masses related in time and space to the cupolas of stocks. Later breccias formed dikes, sills, and pipes with distinct, angular fragments; some of these breccias are tourmaline and limonite cemented. The youngest breccias are pebble dikes and pods.

5. Relative depths of porphyry emplacement and relative ages suggest a downward retreat of the subjacent magma reservoir during the history of the Majuba intrusions.

6. Three intrusives—the Felsite stock, the Majuba Porphyry, and the Late Rhyolite Porphyry—appear to have the strongest mineralization and alteration halos. All Majuba intrusives, however, probably were accompanied by at least some hydrothermal mineralization and alteration.

7. In and around the Felsite stock, copper is present as veinlets of chalcopyrite and pyrite or veinlets of very fine-grained chalcopyrite mixed with minor arsenopyrite and pyrrhotite. Assays show that tin and silver are directly associated with copper in rocks of the Felsite-related mineralized zone, but molybdenum is absent.

8. The Majuba Porphyry is the apparent source of an extensive zone of silicification and low grade (less than 0.1% Mo) molybdenite mineralization. The molybdenite occurs in a weakly developed stockwork of tight molybdenite-quartz veinlets and is most commonly associated with strongly silicified rocks.

9. The high-grade copper and tin ores produced from the Majuba Mine were concentrated in and near the Majuba fault at the subsurface top of a Late Rhyolite Porphyry dike.

10. Low-grade copper associated with tourmaline stockwork veining in the southwestern part of the Majuba Hill intrusive center probably is related to Black Breccias and Late Rhyolite Porphyry bodies in that part of the complex.

11. Although hydrothermal chalcopyrite-pyrite-enargite have been partially to completely replaced by supergene copper-arsenic-bearing minerals, supergene enrichment was not extreme or widespread.

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