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Geology of the Kingsley Mining District, Elko County, Nevada*

ROGER STEININGER

Pennsylvania State University

ABSTRACT.—The Kingsley Mining District is located in Elko County, in northeastern Nevada. The present study is an examination of the geology of the district, along with an evaluation of the future mineral economics of the area.

A Tertiary stock of quartz monzonite has intruded limestones of the Upper Garden City Formation, producing a contact aureole of marble. The stock is cut by numerous dikes of varying composition from leucorhyolite to quartz monzonite, but only a few dikes extend into the country rock. A dominate joint pattern has resulted from cooling of the intrusive, and has controlled emplacement of both dikes and hydrothermal veins.

Extrusive felsite porphyries form a large hill southeast of the district. Field and microscopic evidence indicate that these are flow rocks.

The Kingsley Mining District has produced small quantities of copper, lead, silver, gold, molybdenum, and marble, mainly during the late 1880's. Additional economic development in the area seems doubtful, unless certain of the marbles can be marketed.

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INTRODUCTION

Purpose and Scope

Until recently the only attention given to the Kingsley Mountains was related to the Kingsley Mining District. The intrusive and related areas have

*A thesis submitted to the faculty of the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, May 23, 1966.

remained unmapped, and the geology was only superficially known. The purposes of this report are to produce a geologic map of the intrusive and related areas, to describe the geology of the area, and to evaluate the economic potential of the district in light of past mining ventures.

Location and Accessibility

The Kingsley Mining District (Text-fig. 1) is located in the southeast corner of Elko County, Nevada (Secs. 13 and 14, T. 26 N., R. 67 E., and Secs. 18 and 19, T. 26 N., R. 68 E.), in the southern end of the Kingsley Mountains. The area is accessible via U.S. Alternate Highway 50 from Wendover, Utah, or from Ely, Nevada. A maintained dirt road extends 14 miles southeast through Antelope Valley, to the Kingsley Mining District (Text-fig. 1), from the Southern mine turnoff on U. S. Highway 50, 40 miles south of Wendover, or 80 miles north of Ely.

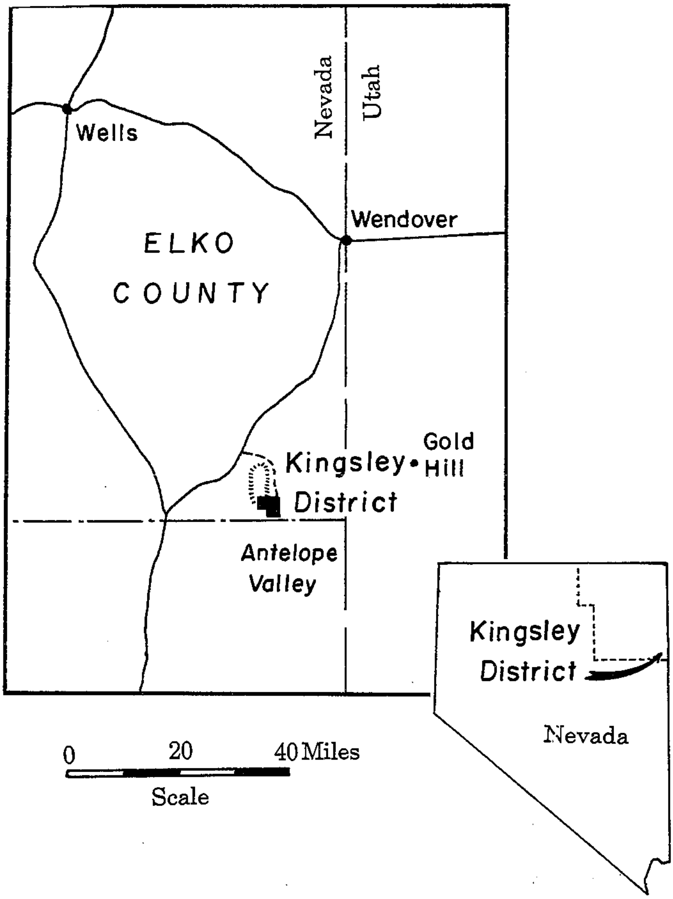
Geologic Setting

The Kingsley Mountains form a north-south trending physiographic unit about eight miles long, and one and a half miles wide, lying in the northern part of the Basin and Range Province. The mountains consist of Lower Paleozoic sedimentary rocks, mostly limestone, but with some shales, all with a gentle northeast dip. During the Tertiary Period a mass of quartz monzonite intruded the southern end of the range. An aureole of contact metamorphism, and minor metalization has developed associated with the intrusion. Antelope Valley (Text-fig. 1) is a graben which is filled with a thick series of Cenozoic alluvium. In the late Tertiary Period a thick sequence of volcanic rocks covered parts of the valley and the southern end of Kingsley Mountains. Subsequent erosion has removed most of these flows, leaving only a few isolated outcrops.

Previous Work

The first geologic report that included the Kingsley Mining District was Clarence King's United States Geologic Exploration of the Fortieth Parallel (1887, V. I, p. 61, & V. II, p. 483). His geologic map shows the western half of the range consisting of "Lower Coal Measures" limestones, and the eastern half consisting of interbedded white crystalline dolomites and broad tabular masses of granitic porphyry of Archaean age. Both sedimentary units are shown with a north strike, and a dip of 25° to the east.

A brief investigation of the Kingsley District, which included a limited description of the geology of the intrusive, was published by J. M. Hill in 1916. In 1957, B. F. Stringham presented a paper, which included description of the Kingsley Stock, resulting from research on the porphyries in the Basin and Range Province. R. L. Armstrong (1963) obtained a potassium-argon date for the intrusive, and Granger, *et al.* (1957, p. 102-104, and Plate 1) gave a brief description of the area, referring to it as the Kingsley District; most of their information was apparently taken from Hill's 1916 paper. On their geologic map (Plate 1) the limestones were indicated as undifferentiated Paleozoic, and Precambrian rocks were shown at the north end of the mountains. Three separate northwest-trending Jurassic-Cretaceous intrusives were also mapped in the Kingsley Mountains. Work by the writer failed to substantiate this information.



TEXT-FIGURE 1.—Index map of Nevada and of northeastern Nevada, showing location of the Kingsley Mining District in Elko County.

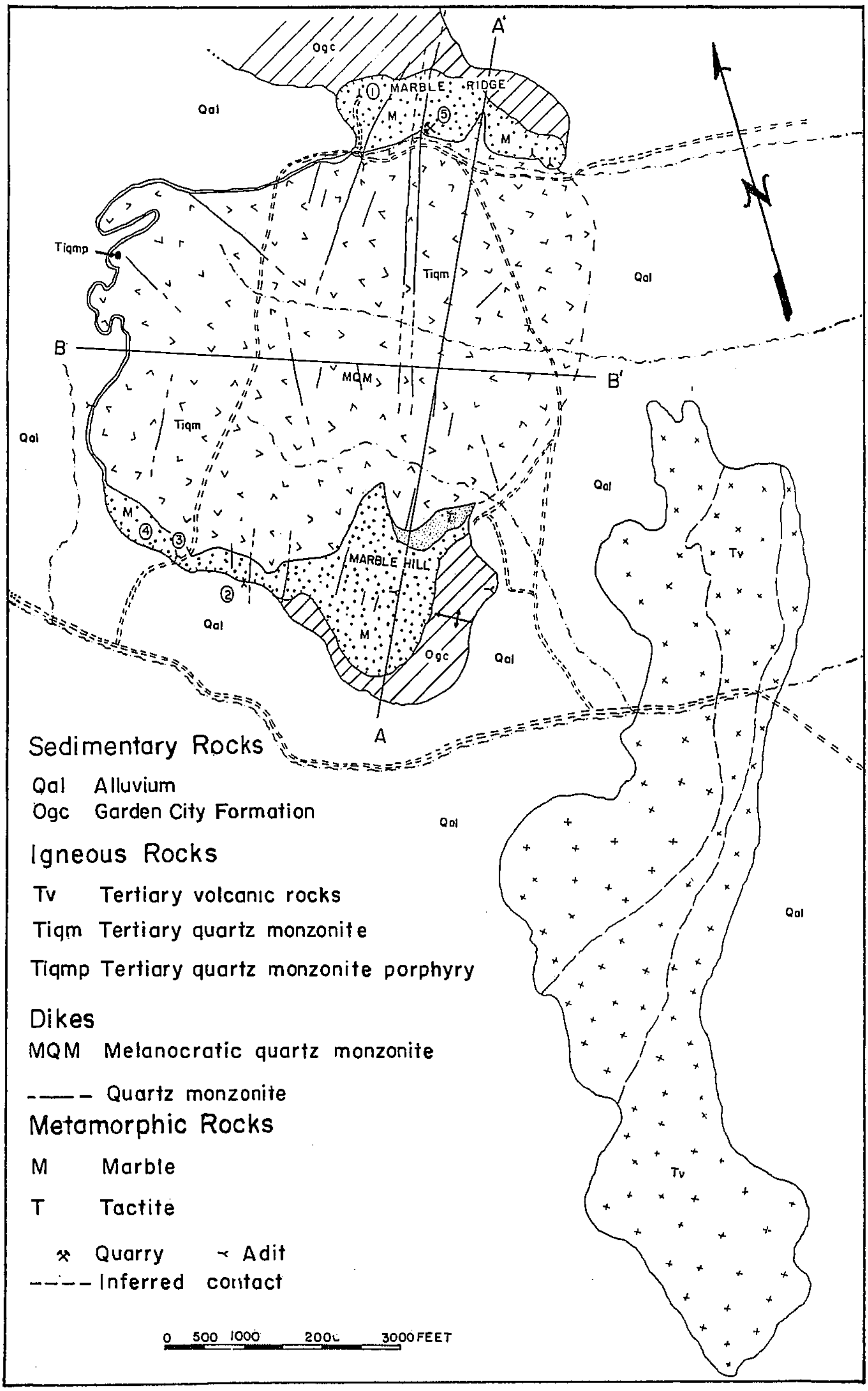
Present Work

Field work was carried out during the fall and winter of 1965. Geologic data were plotted on aerial photographs having a scale of 1:20,000. This information was later transferred to a base map of the same scale.

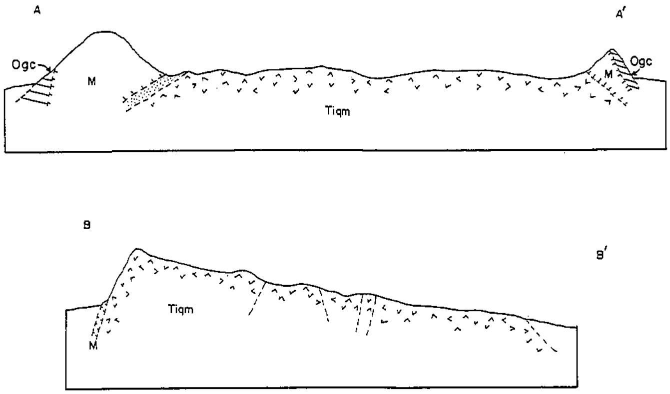
Preparation and examination of thin-sections of samples comprised the major portion of laboratory work. Descriptions of thin-sections were made using a petrographic microscope and universal stage. Identification of the ore minerals was made by means of microchemical tests and a metallographic microscope.

Acknowledgments

The writer expresses appreciation to Dr. K. C. Bullock who served as thesis chairman, and offered helpful criticism throughout the whole study.



TEXT-FIGURE 2.—Geologic map of the Kingsley Mining District, Elko County, Nevada.



TEXT-FIGURE 3.—Structure sections through the stock of the Kingsley Mining District. M, marble; Ogc, Ordovician Garden City Formation; Tiqm, Tertiary quartz monzonite. Scale same as geologic map (Text-fig. 2).

Thanks are also due to Dr. W. R. Phillips who assisted with the petrographic work. Dr. H. J. Bissell spent several hours in the field explaining the stratigraphic sequence.

Acknowledgments are accorded Shell Oil Company who supplied the aerial photographs.

STRUCTURE

Gross Pattern

The Kingsley Stock is a nearly homogeneous unit of quartz monzonite (Text-fig. 2). The only deviation from this homogeneity is in the northwestern corner of the intrusive, where a knob of porphyry about 20 feet in diameter was mapped. Contact between the two rock types is expressed by appearance of phenocrysts up to two inches long, lying in a ground mass similar in composition to the main intrusive body.

Contacts

The contact with the country rock along the eastern side of the Kingsley Stock is covered by alluvium. In the Marble Hill area a gradational contact exists between the stock and the country rock. Here the stock grades into a zone of tactite, which in turn grades into a marble zone, and then into unaltered limestone. The tactite zone varies from a few inches to a maximum of 39 feet wide. Around the rest of the intrusive, contact between the stock and marble is sharp, and does not contain a tactite zone.

Field relations along the west side of the stock indicate that the contact dips steeply. Quartz monzonite forms a nearly vertical cliff, with the country rock contact near the base of the cliff (Text-fig. 3). In one adit along this side of the intrusive, the contact dips 74° to the west. The contact along the north and south sides of the intrusive appears to be moderately dipping. A dip of 30° to the north was observed in mine #3 (Text-fig. 3).

Several saddles exist on Marble Ridge and Marble Hill, and in each of these a body of quartz monzonite occurs, with a texture and composition similar to the stock. These bodies can be traced into the main intrusive, suggesting that they are tongues of the stock. The term tongue is preferred because they are actual extensions of the intrusive. Elongation of the intrusive is further supported by the joint pattern.

Internal Structures

Jointing.—Both exfoliation and tensional joints occur in the intrusive. Throughout the Kingsley Stock the exfoliation type is prominent, probably related to release of the overlying load.

A dominant tensional joint set is apparent in all the exposures (Plate 2, Fig. 1). This pattern becomes more striking when the attitudes are plotted on a rose diagram (Text-fig. 4-A). A dominant direction of N. 40° E., with a secondary set of N. 30° E., is typical in the intrusive. Dips of both sets are nearly vertical, with an extreme variance from 75° W. to 75° E. These sets are approximately parallel to the elongation of the stock. Emmons (1939, p. 23) relates this type of fracture pattern to a pluton elongated in one of two horizontal dimensions. This fits well with the observed relationships between the intrusive and country rocks in the Kingsley area.

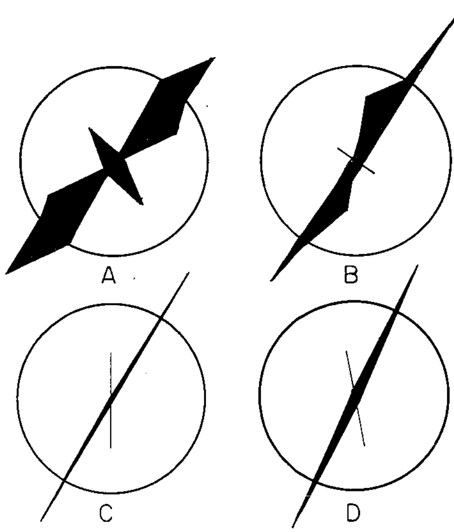
Dikes and ore veins.—Rose diagrams B and C of Text-figure 4 represent the general orientation of dikes and ore veins in the Kingsley District. Both features are roughly parallel to the dominant fracture patterns, suggesting that their emplacement was controlled by earlier jointing. As the dikes and veins pass from the intrusive into the marble, they maintain their orientation, parallel to a prominent joint set in the marble (Text-fig. 4-D). Such a situation would be expected if the quartz monzonite was close to the surface under the metamorphic areas, for the jointing system developed in the intrusive would be transmitted upward into the cover rock (Emmons 1939, p. 23). This effect would decrease with distance from the intrusion. Plate 1, figure 1, shows strong jointing in the marble, suggesting nearness to the stock beneath the exposed marble.

Inclusions.—Inclusions of melanocratic quartz monzonite are relatively abundant within the western half of the stock. They appear as dark colored ellipsoidal lumps weathering out of the quartz monzonite. The inclusions are as large as one foot long and six inches wide, but occur as small as to one inch in diameter (Plate 1, fig. 2). Generally they occur in maximum numbers along the extreme western boundary, and decrease in abundance toward the center of the intrusion. They are completely lacking from the center to the eastern margin.

Faults.—Although field relations strongly suggest the lack of faulting in the Kingsley Mining District, such structures cannot be completely discounted because of the large area of the intrusive now covered by weathered quartz monzonite debris.

Sedimentary Structure

Regionally the limestone of the district strikes N. 32°W., and dips 11° to the northeast. This general attitude persists around the intrusive except for the eastern side of Marble Hill, where folding has produced a small westward plunging anticline. Rocks of the northern limb dip about 13° to the



TEXT-FIGURE 4.—Structural trends within the Kingsley Mining District. A, joints in stock; B, dikes; C, hydrothermal veins; D, joints in the contact zone of the intrusive with country rock.

northwest, and those of the southern limb as much as 50° to the southwest. This structure is completely lost in the altered zone of Marble Hill. The structure could have resulted from doming during intrusion of the quartz monzonite. The marble zone can be traced around the intrusive, so that Marble Hill is not a xenolithic body, but outside the Kingsley Stock.

SEDIMENTARY ROCKS

An incomplete section of Lower Ordovician rocks, consisting of a thin sequence of the Upper Garden City Formation (H. J. Bissell, personal communication, 1966), comprise the only exposed sedimentary units in the mapped area.

The writer was primarily concerned with the igneous and metamorphic rocks, and economic geology of the district. The only sedimentary rocks studied are those which occur in close association with the intrusive.

Ordovician System

Garden City Formation.—Approximately 500 feet of the Upper Garden City Formation crops out around the eastern and southern base of Marble Hill, and along the north side of Marble Ridge. In the proximity of the Kingsley Stock the formation has been altered to a pure marble.

The formation consists of a calcarenite within the mapped area, in beds three to five feet thick. These units are medium- to dark-gray, weathering to a gray-brown with patches of red-brown chert. As a result of weathering, thin shale partings stand out as wavey ribs. Thinly-bedded calcarenite, from one inch to six inches thick, occurs between beds. In the region of the contact aureole the formation grades into a marble, characterized by an increase in grain size, and bleaching of the limestone.

Petrographically this formation is rather simple. The limestone consists of grains of sparry calcite ranging from 0.1 to 1 mm. in size. Small areas of organic material, possibly dead oil, are scattered throughout the calcite. Each grain is unstrained, suggesting recrystallization has occurred at some time during its geologic history. A cloudy appearance to the grains can be related to recrystallization of micrite to sparry calcite. Presence of organic material indicated that this recrystallization was not related to the intrusion. Recrystallization due to thermal metamorphism would produce bleaching, driving out organic material.

Quaternary System

Antelope Valley contains a sequence of sediments derived from the surrounding mountain ranges. These consist of unconsolidated alluvium and bajada deposits.

IGNEOUS ROCKS

General Statement

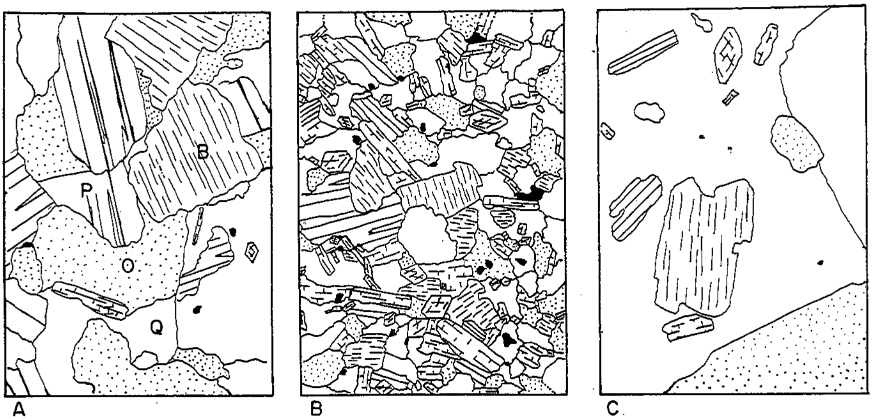
Several types of igneous rocks are found within the mapped area. Intrusive rocks consist of quartz monzonite, quartz monsonite porphyry, and dike rocks, ranging from leucorhyolite to quartz monzonite, all of which appear to be genetically related to the Kingsley Stock. Extrusive igneous rocks in the area consist of felsite porphyries. The Kingsley Stock is composed of a homogeneous body of quartz monzonite. The only exception is a small zone of quartz monzonite porphyry characterized by large phenocrysts of white orthoclase. Most of the dikes in the district are composed of quartz monzonite porphyry, and these are the only ones that intrude the country rocks. Numerous small leucorhyolite dikes and a few melanocratic quartz monzonite dikes are also found within the stock. A large outcrop of extrusive felsite porphyry occurs about one-half mile southeast of the Kingsley Stock. It forms a hill about 400 feet high, 2850 feet wide, and 8000 feet long.

Kingsley Stock

The Kingsley Stock crops out in a rough square, about one mile across. The intrusive generally forms a topographic low, relative to the adjacent limestone. Relative ease of erosion is expressed along the contact between the stock and the country rocks, and in parts of the stock that have been intruded by dikes, for in most places the contact is in a valley. Most of the dikes are found on the tops of small hills in the intrusive because of their relative resistance to erosion. Weathering of the quartz monzonite turns the light-colored rock to a rust-brown. Many inclusions of melanocratic quartz monzonite throughout the western half of the intrusion stand out as ellipsoidal nobs as a result of differential weathering.

Evidence of the magmatic origin of the intrusive is readily seen in the field. Except for a small area on Marble Hill, the contact is sharp and discordant. Lack of xenoliths similar to country rock suggest the present exposure of quartz monzonite represents a moderately deep level of the intrusive.

Quartz Monzonite.—A white to light gray quartz monzonite is the dominant rock type in the Kingsley Stock. Serrated grains from 0.5 to 4.0 mm. across have



TEXT-FIGURE 5.—Line drawings of bleached photomicrographs of intrusive igneous rocks in the Kingsley District. All are x 135. A, Quartz monzonite stock; B, Autoliths within the stock; C, Quartz monzonite dike. Minerals labeled include: Q, Quartz; B, biotite; P, plagioclase; H, hornblende and other dark minerals. Area between phenocrysts is groundmass.

a hypidiomorphic-granular relationship. Generally the largest crystals are biotite and plagioclase, with smaller subhedral grains of hornblende and still smaller euhedral quartz, orthoclase, and opaque minerals.

Essential minerals, determined by microscopic examination, are orthoclase, andesine, and quartz (Text-fig. 5-A). Andesine grains are the most euhedral and range in size from 1 to 4 mm. An average composition of An_{36} was determined from the analysis of twenty-three thin-sections comprising a representative sampling of the stock. Oscillatory zoning is common with a core of An_{40} and a rim of An_{32}, thus representing a normal zonation for the crystal as a whole. All plagioclase shows albite twinning with subordinate Carlsbad and pericline twins. A few crystals are saussuritized, but no general relationship can be drawn regarding their position in the stock.

Accessory minerals include biotite, anphibole, apatite, sphene, zircon, and magnetite, the latter four comprise about 1% of the total rock, and are listed as "others" in the following tables. Biotite occurs as subhedral grains up to 4 mm. in diameter and is pleochroic with Z-dark brown and X-light brown. A few crystals are slightly altered to chlorite along the cleavage planes. Hornblende forms subhedral grains from 0.5 to 1.5 mm. in length which are strongly pleochroic, from dark green (Z) to light green (X), and have $2V_x = 79°$, and $C \wedge Z = 18°$. A few crystals have altered to biotite in their centers.

The following percentage of minerals represents an average composition of the main rock type in the stock.

Orthoclase	40%
Andesine	36%
Quartz	15%
Hornblende	5%
Biotite	3%
Others	1%

Quartz Monzonite Porphyry.—(Plate 2, fig. 2)—The groundmass has essentially the same composition and relationships as the rest of the stock. The difference between these two zones is the occurrence of euhedral orthoclase in the form of phenocrysts up to two inches in length. This zone has the following composition:

Orthoclase	44%
Andesine (An_{35})	25%
Quartz	24%
Hornblende ($2V_x = 84°$, $C \wedge Z = 26°$)	5%
Biotite	1%
Others	1%

Mafic Inclusions.—(Plate 1, fig. 2, and Plate 3, fig. 1)—Dark gray to black ellipsoidal mafic inclusions are abundant throughout the western half of the stock. They occur singly or in swarms where the majority of the outcrop is comprised of the inclusions. In the field they appear to be homogeneous in composition; contacts with the surrounding rock are sharp, the quartz monzonite showing no apparent change up to the contact. Pabst (1928) described similar inclusions in the plutonic rocks of the Sierra Nevada, which he called autoliths (= cognate xenoliths).

Microscopically (Tex-fig. 5-B) the mineralogy is the same as that of the quartz monzonite. The difference lies in the grain size and compositional percentage. Mineral grains are between 0.1 and 0.5 mm. across, biotite, hornblende, and plagioclase being the largest. The following average composition shows the greater abundance of ferromagnesium minerals compared to the host quartz monzonite.

Hornblende ($2V_x$ 74°, $C \wedge Z$ 12°)	35%
Quartz	17%
Andesine (An_{38})	15%
Biotite	15%
Orthoclase	15%
Others	3%

Dikes

General Features.—Numerous dikes traverse the Kingsley Stock, and can be grouped into three classes: quartz monzonite, leucorhyolite, and melanocratic quartz monzonite. The only dikes that were found to extend into the country rocks were those of the quartz monzonite class. These dikes are from a foot or two wide, to one that is 391 feet across (Plate 3, fig. 1). Their length is just as variable, from a few feet to two that are over a half mile long. Leucorhyolite dikes are very abundant, generally small, not more than a foot wide, and occur in groups of two or more (Plate 3, fig. 1). A few dikes of dark gray to black melanocratic quartz monzonite occur locally within the stock. Contacts between all the dikes and the stock are sharp. Nowhere were two intersecting dikes found, so their relative age relationships could not be determined.

Quartz Monzonite (Text-fig. 5-C).—These dikes consist of phenocrysts between 0.5 and 4 mm. of andesine, quartz, orthoclase, biotite and hornblende in a felsitic groundmass of crystals about 0.1 mm. in diameter. The phenocrysts comprise 53% of the rock; the remaining aphanitic portion is comprised of quartz, orthoclase, and minor plagioclase, magnetite, apatite, zircon, and sphene. The average composition of these dikes is as follows:

Orthoclase	34%
Quartz	31%
Andesine (An_{33})	27%
Biotite	5%
Hornblende	2%
Others	1%

Alteration is very extensive within these rocks. Most of the phenocrystic andesine has been saussuritized. Hornblende and biotite show all gradations from fresh minerals to a mixture of chlorite and opaque oxides.

Leucorhyolite.—This rock is composed of hypidiomorphic-granular orthoclase and quartz, with minor amounts of oligoclase, hornblende, biotite, and magnetite. These minerals occur as grains not greater than 0.1 mm. in size. The following table shows the proportions of minerals present in these dikes:

Orthoclase	46%
Quartz	41%
Oligoclase (An_{28})	9%
Others*	2%
Hornblende ($2V_x = 76°$, $C \wedge Z$ 14°)	1%
Biotite	1%

*Mainly magnetite

Quartz and orthoclase are the largest minerals present, about 0.1 mm. in diameter, and have an anhedral shape. Oligoclase, hornblende, and biotite are smaller in size, and display subhedral forms. Crystal shape indicates that all the minerals crystallized at approximately the same time.

Melanocratic Quartz Monzonite.—Dikes similar in composition to the autoliths are found within the stock, but their occurrences are very limited. They differ from the autoliths in having a porphyritic texture, and a finer grain size. Phenocrysts of subhedral andesine, 1 and 4 mm. long, comprise 10% of the rock. The groundmass is composed of subhedral biotite, hornblende, anhedral orthoclase, and quartz 0.1 mm. in diameter. The average composition of these dikes is:

Biotite	39%
Hornblende	24%
Orthoclase	21%
Quartz	14%
Andesine (An_{32})	10%
Others	2%

Owing to its larger size the andesine is considered as having crystallized first, followed by the biotite and hornblende, and lastly the rest of the minerals. The only alteration observed within these dikes was minor saussuritization around the edges of the plagioclase phenocrysts.

EXTRUSIVE ROCKS

Field Relations

Tertiary volcanic rocks are restricted to a hill approximately 400 feet high, 8000 feet long, and 2850 feet wide near the southeastern corner of the Kingsley Mountains (Text-fig. 1). The outcrops appear outwardly to be composed of a single flow, but upon close examination three separate flows can be distinguished. Each flow has the same general appearance, but at the base of each of the upper two is a layer of volcanic rubble derived from the underlying weathered volcanics. All three flows have a similar attitude, striking N. 15° W. and dipping 21° E. Field relations suggest that they were draped over the southern end of the Kingsley Mountains. Subsequent erosion has removed most of the flows from the range, leaving only a few areas containing rocks similar to those found in Antelope Valley and around the southern end of the Kingsley Mountains. This theory is substantiated by mapping of the volcanics on the west side of the Kinglsey Mountains by geologists of Shell Oil Company (personal communications, 1965), where the extrusive rocks have a westward dip.

Megascopically, the volcanic rocks are aphanitic, porphyritic and light gray on a fresh surface, weathering to a red-brown. Most of the volcanics are slightly vesicular, with the cavities about 1 mm. in diameter.

Composition

Thin-sections indicate a homogeneity of rock type throughout the whole sequence. The average modal composition of the porphyritic felsite flows, as compiled from ten representative thin-sections, is:

Andesine (average An_{47})	11%
Biotite	1%
Tridymite	2%
Opaque oxides*	2%
Hematite	5%
Groundmass	79%

*Present as grains larger than the groundmass

Andesine occurs as phenocrysts ranging from 0.5 to 1.5 mm. (Plate 4, fig. 1). Most are twinned, with the Carlsbad law being dominant over the albite law. Oscillatory zoning is obvious in nearly every phenocryst, in addition to normal zoning with a core that is more calcic than the margin.

The groundmass consists of a microcrystalline aggregate of sanidine and opaque oxides. Plate 4, fig. 1 represents a typical groundmass containing an average of 30% opaque oxides and 70% sanidine. Sanidine forms euhedral to subhedral grains with opaque oxides filling in interstitial spaces. There is a noticeable variation in grain size ranging from just above the microlite stage to a maximum of about 0.1 mm. There is a slight orientation of minerals of two of the samples. Study of the elongation in oriented thin-sections indicated a flowage in either a northeastern or southwestern direction. Presence of tridymite indicates that the rocks formed at a relatively high temperature, above 870° C. The tridymite occurs as wedge-shaped twins within the groundmass. These crystals are among the largest within the size range of the groundmass. Biotite under highly oxidizing conditions has altered to a more stable mineral assemblage. The alteration product is primarily hematite. Plate 4, fig. 2 shows a re-

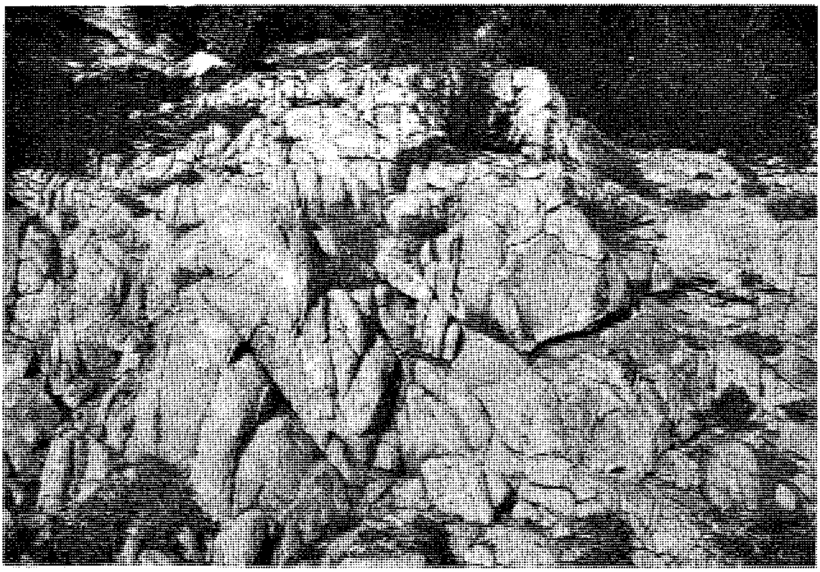


FIG. 1.—Jointing in the contact metamorphic zone.

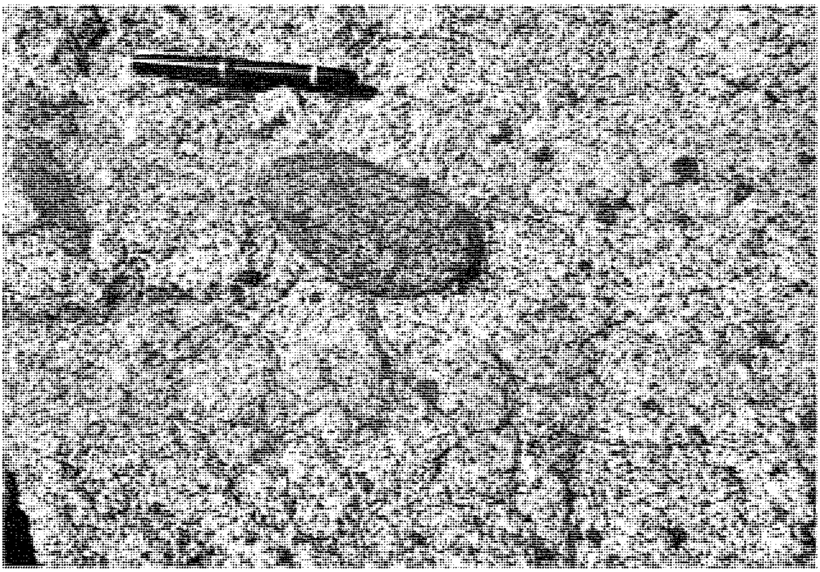


FIG. 2.—Autolith in the stock.

OUTCROPS OF THE KINGSLEY STOCK

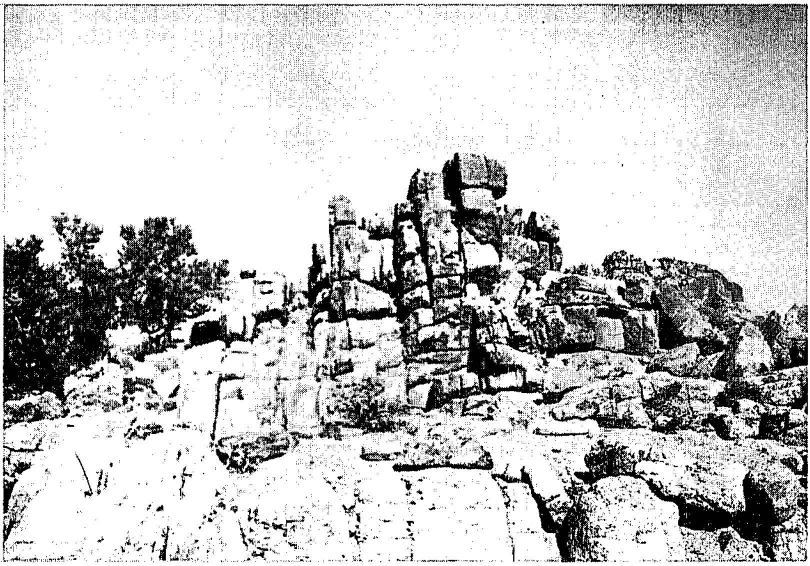


FIG. 1.—Jointing in a quartz monzonite dike that cuts the stock.

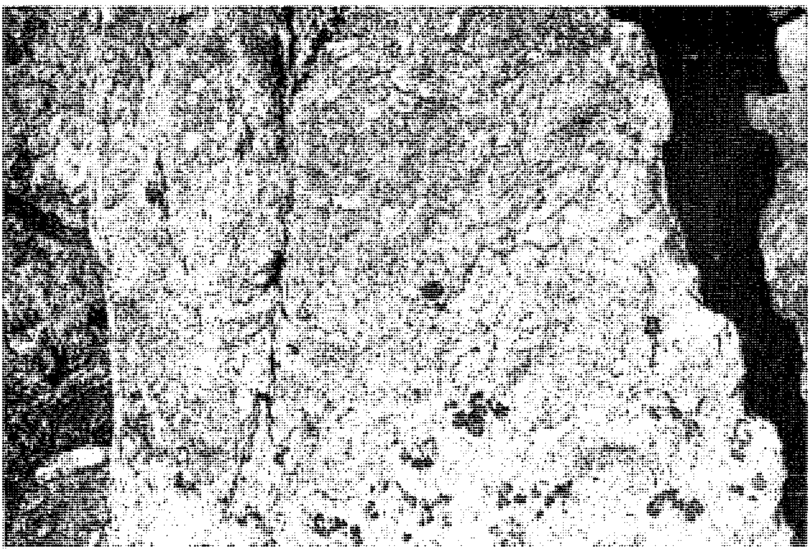


FIG. 2.—Porphyry zone within the stock

JOINTING AND PORPHYRY WITHIN THE KINGSLEY STOCK

FIG. 1.—Leucorhyolite dike swarm in the stock with autoliths present.

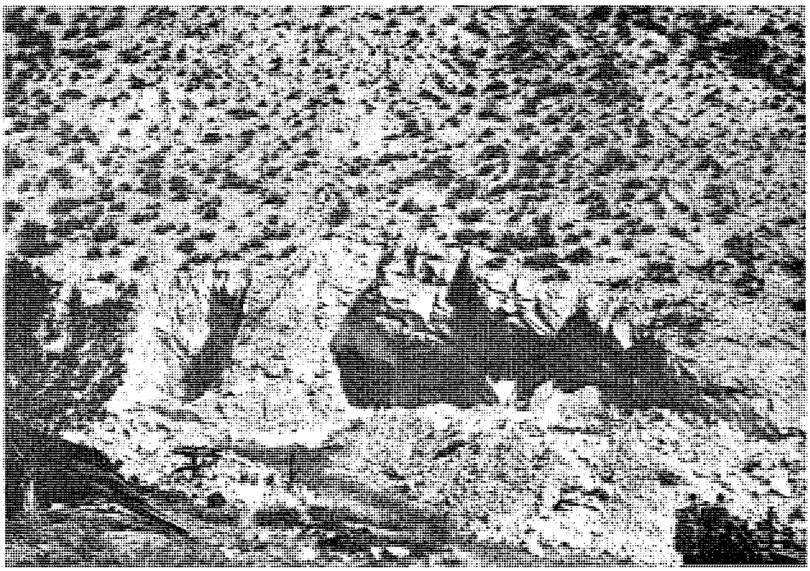


FIG. 2.—Marble quarry on the south side of Marble Ridge.

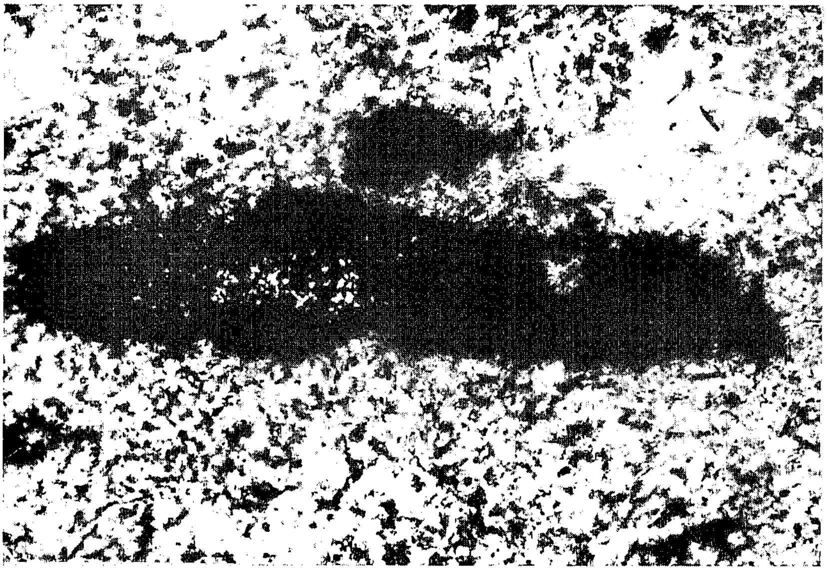


FIG. 1.—Felsite porphyry showing groundmass, and plagioclase phenocryst X 120.

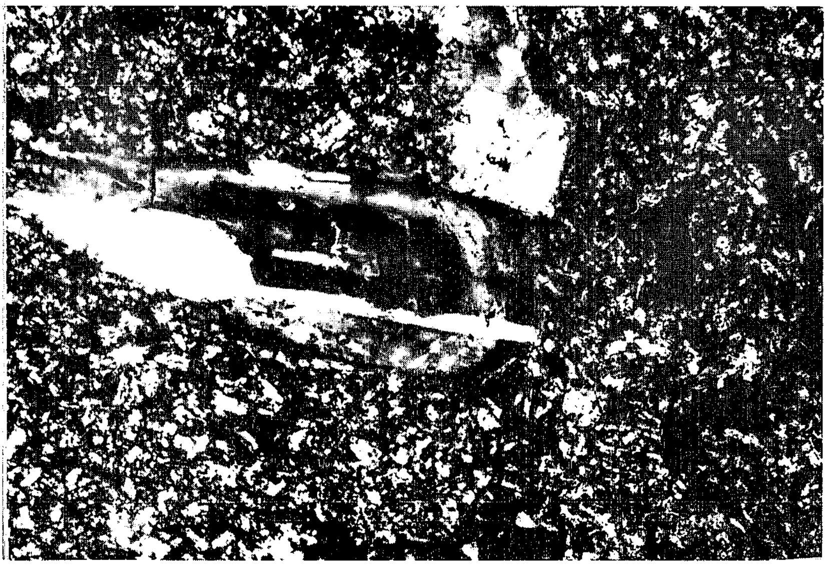


FIG. 2.—Altered biotite with a biotite core remaining X 120.

PHOTOMICROGRAPHS, KINGSLEY DISTRICT

action rim of hematite around a core of biotite. In all the thin-sections examined not one biotite phenocryst was found that did not show at least a partial reaction rim of hematite. Only the larger phenocrysts have a core of unaltered biotite.

Texture

The most striking aspect of the texture is its porphyritic nature. Phenocrysts of plagioclase, and altered biotite in the general size range of 0.5 to 1.5 mm. occur in a groundmass of 0.1 mm. or less. Phenocrystic minerals are subhedral to anhedral in shape. The hematite aggregates show only an approximation of the original biotite. Using textural terms as defined by Johannsen (1931, p. 49) the groundmass is classified as pilotaxitic-trachytic.

Conclusions

Recent work in the acidic extrusive igneous rocks of western Utah and Nevada by many geologists has resulted in the wide use of the term ignimbrite. This has lead to loose application of the term to many extrusive rocks in this part of the country. Such was the case at the onset of this study. After a field and petrographic study of the felsites in Antelope Valley, the author concluded that they are flows rather than welded tuffs. One wonders just how many of the acidic extrusive rocks of western Utah and Nevada really are ignimbrites.

Reasons for calling the felsite a flow rock can be summarized in a table comparing the characteristics of ignimbrites with the extrusive rocks of Antelope Valley. Characteristics common to ignimbrites were compiled from the paper by Ross and Smith (1961) on welded tuffs.

This table shows a complete lack of correlation between the ignimbrites and the Antelope Valley felsites. It is on this basis, and the presence of flow features, that these felsites are considered lava flows.

Characteristics of ignimbrites compared to those of the Antelope Valley felsites

Feature	Ignimbrites	Antelope Valley felsites
Pyroclastic character	Most important single criterion is the presence of pumice fragments	No evidence of pumice fragments
Degree of sorting	Unsorted from ash and dust to pumice lapilli or blocks	Phenocrysts and groundmass indicate a crystallization mode of formation.
Thickness	Any	400 feet
Layering	Within a single unit various degrees of consolidation from unconsolidated to welded. Single to multiple units.	Three homogeneous units.
Areal extent	Vast	Vast
Attitude	Gentle dips	21° E.
Devitrification and vapor-phase minerals	Devitrification within the boundaries of the glass shards. Vapor-phase crystallization takes place in open spaces. Devitrification leaves ghosts of glass structure.	No glass or evidence of devitrification or vapor-phase crystallization.

Welding, distortion and stretching	Pyroclastic origin rarely destroyed. Foliation resulting from stretching. Y & U shapes around phenocrysts.	No pyroclastic texture, or stretching. Slight flow structure.
Phenocrysts	Feldspar, quartz, biotite, hornblende, and augite.	Plagioclase, biotite, opaque oxides, and hematite.

SUMMARY OF IGNEOUS HISTORY

The first igneous event in the area was the intrusion of the Kingsley Stock during the middle Tertiary. Armstrong (1963) has determined a potassium-argon date of 35 (—2, +5) million years for the stock. He has also obtained a lead-alpha date of 41 million years, which puts the two dates in close approximation. This would place the time of intrusion in either the late Eocene or early Oligocene. From his work he suggests that the depth of intrusion was 10-15 thousand feet below the then existing surface.

Lack of faulting in the immediate country rocks indicates that the intrusion was not controlled by faults during emplacement. The most probable mode of emplacement was that of piecemeal stoping and assimilation.

During cooling gravitational settling of the early forming ferromagnesium and plagioclase minerals probably occurred, and produced a mafic zone within the stock. The mafic dikes were likely formed by tapping such a ferromagnesium-rich zone. Convection currents could conceivably exist as the melt lost heat, and could possibly move parts of the mafic zone up to higher levels within the stock, thus producing the autoliths. An alternate hypothesis for the formation of these inclusions relates to their small grain size and rich mafic composition. A chill zone around the magma would be expected to consist of an aggregate of small sized, early formed minerals. Later igneous activity could have caused a breakup of this chill zone, suppling the material for the autoliths.

As the melt began to solidify, a fracture pattern probably developed as a result of tension due to contraction with cooling. If the intrusive body is elongated, as suggested above, one would expect the dominant joint set to be the longitudinal pattern that exists. It was along these fractures that the majority of the dikes were emplaced as the result of a later magma surge.

The last event that can be related to igneous intrusion is formation of hydrothermal veins, the majority of which were emplaced along the dominant joint set.

Some time after emplacement of the stock, a series of three felsite porphyry flows were extruded over the area. Neither the source nor the age of these flows can be determined with the present information.

METAMORPHIC ROCKS

General Features

The sedimentary rocks around the Kingsley Stock have been subjected to contact metasomatism and minor thermal metamorphism. A distinct metamorphic aureole has been developed on the north and south sides of the intrusive. The east side of the stock is covered by alluvium so that the extent of metamorphism is undeterminable. Along the western margin of the intrusive the aureole is a maximum of five feet wide, and a minimum of a few inches where limestone is in contact with the stock. The intensity of metamorphism decreases away from the stock.

Three types of metamorphic rocks occur within the contact aureole; they are: dolomitic marble, marble, and tactite. A small zone of tactite exists along the northeast side of Marble Hill, dolomitic marble is restricted to Marble Hill and Marble Ridge, and the marble is located along the western side of the intrusive.

The greatest extent of metamorphism has developed in the Marble Hill area, and a smaller yet significant zone along the south side of Marble Ridge. The western contact has been affected by only a minor amount of metamorphism.

Metamorphic Aureole

Thermal metamorphism produced a rather impure, fine-grained marble, with relics of unaltered limestone, along the western contact of the stock. The marble is composed of a finely-crystalline aggregate of calcite. The only change from the calcarenite is a slight bleaching and removal of organic material.

Metasomatism has been active in production of a dolomitic marble in the Marble Hill and Marble Ridge areas. The parent rock probably was a pure calcarenite, hence, the only source for the dolomitizing solutions was the Kingsley Stock. Calcite within the limestone has been completely changed to dolomite. This would be expected during dolomitization, and Ramberg (1952, p. 225) attributes this feature to the following:

> The fact that dolomitization tends strongly to create rather pure dolomite marbles with but minor amounts of calcite may be due to the interfacial energy conditions between calcite and dolomite. It is likely that a dolomite nucleus does not form so easily in contact with calcite grains as it does in contact with other dolomite grains. Therefore, the dolomitization will most likely proceed in such a manner that a pure dolomite rock develops rather than intermixtures of calcite and dolomite marbles.

Dolomitic marbles in the area consist of an aggregate of dolomite and about 5% pyrite. Dolomite grains range in size from 0.5 to 2 mm., while the pyrite is about 0.1 mm. across. The lateral change from dolomitic marble to calcarenite is gradational, being expressed by increase in the amount of relict limestone. On the outer limits of dolomitization only a vein or two extends into the limestone. The pyrite is disseminated throughout the marble with no apparent orientation.

A small zone of tactite exists along the northeast slope of Marble Hill, and represents the highest grade of metamorphism attributed to the Kingsley Stock. The tactite is characterized by actinolite, and a complete lack of carbonate minerals. The contact between the tactite and the dolomitic marble is gradational and expressed by a narrow zone of mixed dolomite and actinolite. A gradational contact also exists between the tactite and the stock.

Megascopically, the tactite is light green, spotted by numerous white grains of quartz. A typical specimen from this area has a modal composition:

Actinolite	85%
Quartz	15%

The actinolite is from 0.1 to 2 mm. in size, whereas the quartz ranges from 0.1 to 0.5 mm. The actinolite occurs as radiating crystalline masses, with the quartz filling the interstitial areas.

Causes of Metamorphism

Two distinct types of metamorphism appear to have been active in the rocks around the Kingsley Stock. They are thermal metamorphism and contact metasomatism. Structural control seems to have played a dominant role in determining each type developed in the contact aureole.

The jointing pattern in both the stock and country rocks and the general shape of the intrusive body seem to be the controlling factors in producing the different types of metamorphism. Areas where the dominant northeast joints (Text-fig. 4 A and D) extend outward into the country rocks also coincide with areas of contact metasomatism. A general relationship exists between the size of the aureole and the extent of the fracture pattern. Where the joints die out, a metamorphic-limestone contact is found. It is felt that these joints served as channelways for the metasomatic solutions. The projected elongation of the stock places the country rock-igneous rock contact closer to the surface in these areas. As would be expected, the closer to the intrusive body, the greater the amount of metamorphism. Sedimentary rocks around the eastern side of Marble Hill dip directly into the stock. This would allow additional paths of ion migration, causing the higher degree of alteration.

Along the western boundary of the stock these structural relationships do not exist, so that the rocks were relatively impermeable to ionic movement. Thus, the only metamorphism that occurred was thermal metamorphism, causing a bleaching of the rocks.

ECONOMIC GEOLOGY

History of Development

The Kingsley (originally Kinsley) Mining District was first discovered by Felix O'Neil in December, 1862, who named it the "Antelope District." After he was driven out by local people, the district was rediscovered by George Kinsley in 1865. By 1867 some 30 claims had been worked, with a Mexican furnace in operation to process the ore. Ore running $64 to $93 a ton in silver, and 0.5 ounces of gold was reported during this period, but this mining activity was short lived, and in 1872 the area was abandoned. In 1909 the Kinsley Development Company reopened the area by starting a relatively large operation, including a concentrating mill. This development apparently was not successful, and the operations were soon curtailed. Since then only sporadic activity has been carried out in the district, with a Mr. Southam being the latest entry into the mining ventures of the Kingsley District. The preceding description of the Kingsley District has been taken, for the most part, from Hill (1916), and Granger *et al.* (1957).

Mr. J. H. Schilling (Nevada Bureau of Mines, personal communication, 1966) states that production of the district as a whole has been: 102 ounces of gold, 2336 ounces of silver, 31,711 pounds of copper, and 21,014 pounds of lead. He says that this data comes from a variety of sources, but is believed to be essentially complete. The present investigation of the district showed that the only addition to this is a small amount of molybdenum and marble shipped from the Southam properties. Recent production figures are difficult to obtain, so much of the production data is incomplete.

Ore Deposits

Contact Deposits.—Replacement bodies containing scheelite are the only metallic contact deposits in the area. Tungsten ore bodies lie in the dolomitic marble, near the contact with the intrusive, in the Marble Hill area. Scheelite occurs as a dissemination in localized areas of the metamorphosed country rocks. The deposits are all low grade and do not appear to have a large potential. It is doubtful if these deposits could be worked profitably, even with reenactment of federal government price support.

Veins in Igneous Rocks.—A few veins of white bull quartz occur within the intrusive. They are less than a foot wide, and never appear to be more than six feet long, and contain pyrite, chalcopyrite, and small amounts of galena.

Prospectors have developed workings on all the exposed quartz veins. A close investigation of these indicated no increase in tenor with depth. Unless they lead to some longer subsurface deposit, which is doubtful, these veins will never be large producers of ore.

Small amounts of copper mineralization have developed along the contact between the stock and several of the quartz monzonite dikes. Copper is present in the form of chrysocolla, probably forming from alteration of chalcopyrite. All of these deposits have been prospected with little or no success. It is doubtful that these deposits undergo any increase in tenor with depth.

Veins in Metamorphosed Rocks.—The most important deposits of the district are found in hydrothermal veins in the metamorphosed rocks. Tension joints with small amounts of breccia have served as a host for emplacement by hydrothermal solutions. Siliceous solutions containing copper, iron, lead, silver, gold, and molybdenum minerals were deposited in a gangue of quartz. Copper is the dominant metal and was originally chalcopyrite that has altered to malachite, azurite, and chrysocolla in the oxidized zones. Iron in the form of pyrite, with minor hematite, has altered to limonite, forming gossans that cap all the veins. Galena is present in the unoxidized zones, with cerussite being the oxidized product. Cerargyrite, native silver, and native gold have also been reported in the district (Hill, 1916). Molybdenite is the mineral mined most recently in the district. The mineral assemblage suggests that the ores are characteristic of mezothermal deposits. Of all the metals mentioned, the most important is copper, with lead of secondary importance. Gold, silver, and molybdenum production has been small, with silver the largest of the three.

All of these veins have been capped with a gossan making their location no problem to the prospector. Each of the veins has been tested or exploited. The future of the Kingsley Mining District is held in these veins.

Nonmetallic Products.—Marble, from the south side of Marble Ridge, recently has been quarried for use as a building stone. Owing to its highly fractured nature, the rock has been crushed to about one-half inch in size, and used as building facing.

Properties

There has been little mining activity in the Kingsley Mining District in recent years. Many of the older workings are partly or totally caved, and were not accessible to the writer. Descriptions of such workings are largely taken from Hill (1916).

Kingsley Consolidated Mines Co. claims (see Text-fig. 2, Loc. 1).—The main workings are about ⅛ mile north of the contact between the igneous and metamorphic rocks. A shaft 100 feet deep, and four adits comprise the major portions of the mine. A vein striking N. 21° E. and dipping 55° to 60° E. was worked, and consisted of a tight, barren fracture that had several openings up to 2 feet wide. The swells contained oxidized copper and iron minerals. Chrysocolla, malachite, and chalcocite were mined and milled on the property.

Morning Star Shaft (Text-fig. 2, Loc. 2).—Originally owned by the G. A. Lowe estate, it was last worked by leasees, E. C. Rowland and John Fasano, in 1913. A 375-foot shaft in a vein that strikes N. 86° E. and dips 50° N., produced malachite, azurite, and chrysocolla, with a little cerargyrite and gold. The last mining venture was to ship the dump that carried $25 a ton ore in silver, lead and copper.

Kingsley Mine (Text-fig. 2, Loc. 3).—Caved at the time of Hill's report; he states that a deep shaft was sunk as indicated by the large dump. Only minerals of economic importance were copper carbonates.

Southam Molybdenum Mine (Text-fig. 2, Loc. 4).—A northeast striking vein that dips 55° W. occurs within the metamorphosed rocks. The major ore mineral is molybdenite, composing up to 35% of the vein. Copper minerals scheelite, and galena are also present. At present this property is not being worked due to small tonnage.

Southam Marble Quarry (Text-fig. 2, Loc. 5, and Text-fig. 4-B).—A very pure, highly fractured dolomitic marble was recently quarried from two open pits on the south side of Marble Ridge. The material was crushed at the site, and bagged for shipment. Several tons were shipped to Denver, Colorado, for use as a facing on Denver Federal Center buildings.

Other Prospects

The preceding is a sketchy description of mining activity of the district, but it represents all the information available to the writer. The rest of the district is dotted by many small prospect pits, adits, and shafts. None of these have produced ore.

Future of the District

Ore bodies discovered to date in the Kingsley Mining District have been small, and generally, of low grade. Although the region has been prospected intermittently for over a hundred years, it has yielded less than $10,000 (Granger and others, 1957); mostly in copper and lead, with minor gold and silver. All past explorations have been on a small scale and guided solely by surface exposures. At present surface exposures appear to be mined out, and have not led to discovery of large ore bodies.

Occurrence of a large variety of metals within the district suggests that the magma may have been relatively high in metal content. Thus, the only possible future mineral development would be at depth. Short of an extensive drilling program, there is no direct method of determining the extent of subsurface deposits, if any. As an indirect method of determining extent of metallization in the veins; the writer undertook a detailed study of their gossans, for gossans should indicate their size and original mineralogy.

All of the ore veins are steeply dipping so that oxidization has produced a gossan with a minimum of "mushrooming," while length of the vein should be faithfully reproduced. None of the gossans studied were over seven feet in length, although several "trains" of cap rocks were observed in the field. This suggests that several veins of considerable length exist in the district but they undergo considerable pinching and swelling, and oxidization has produced a capping gossan over the swells. Distances between swells are usually tens of feet, suggesting the veins are narrow along much of their length. The widest gossan in the Kingsley District is about 11 feet across, but the majority are only two or three feet wide. Since these cap rocks have undergone some "mushrooming," most underlying ore veins must not be more than a foot or two wide. In areas that have been mined out under the gossans, size of the ore vein can be determined. The widest vein seen was 4 feet wide, but the average width of all veins is from 1 to 2 feet. Unless there is extensive widening with depth, little hope is held for larger subsurface deposits related to these hydrothermal veins.

In an effort to determine the original mineralogy of the veins, a detailed study of the limonite boxworks was undertaken, as summarized in Bateman (1950, pp. 258-259). The gossans are composed dominantly of limonite, with subordinate wad, quartz, hematite, and secondary copper minerals. As a means of checking the method, several adits in the unoxidized zone of the veins were sampled and compared with information obtained from overlying gossans. A very close correlation was found. Most of the larger gossans and several of the smaller ones were studied, and in these the dominant leached mineral was chalcopyrite, with smaller amounts of bornite and galena.

Development of supergene enrichment hinges on the ability of the leached minerals to leave the oxidized zone and be deposited in the zone below. The following reactions are involved in the leaching of those ore minerals present in the ore veins of the Kingsley District.

pyrite—$FeS_2 + 7O + H_2O = FeSO_4 + H_2SO_4$

$$2FeSO_4 + H_2SO_4 + O = Fe_2(SO_4)_3 + H_2O$$

$$Fe_2(SO_4)_3 + H_2O = 2Fe(OH)_3 + 3H_2SO_4$$

The leaching of pyrite will produce the needed solvents ($FeSO_4$, H_2SO_4, and $Fe(OH)_3$) for leaching the other minerals. Chalcopyrite, bornite, and galena will be leached according to the following reactions.

chalcopyrite—$CuFeS_2 + 2Fe_2(SO_4) = 5FeSO_4 + CuS$

$$CuS + Fe(SO_4)_3 = CuSO_4 + 2FeSO_4 + S$$

galena—$PbS + Fe_2(SO_4)_3 + H_2O + 3O = PbSO_4 + 2FeSO_4 + H_2SO_4$

bornite—$Cu_5FeS_4 + Fe_2(SO_4)_3 = CuSO_4 + 3FeSO_4 + CuS$

$$CuS + Fe(SO_4)_3 = CuSO_4 + 2FeSO_4 + S$$

Precipation will occur in the presence of dolomitic marble almost as soon as the sulfate is formed. Such minerals as azurite, malachite, chrysocolla, and cerussite will form. Thus one would not expect to find a major supergene enriched zone below the oxidized zone. The above end products have been observed within the oxidized zone, adding weight to the conclusion that an extensive supergene enriched zone is probably lacking.

REFERENCES CITED

Armstrong, R. L., 1963, Geochronology and geology of the eastern Great Basin in Nevada and Utah; Unpublished Ph.D. dissertation, Yale Univ., 241 p.

Bateman, Alan M., 1950, Economic mineral deposits; John Wiley and Sons, Inc., New York, 916 p.

Emmons, W. H., 1938, Gold deposits of the world; McGraw Hill, New York, 562 p.

Granger, A. E., Mendell, M. G., Simmons, G. C., and Lee, Florance, 1957, Geology and mineral resources of Elko County, Nevada; Nevada Bureau of Mines Bull. 54, 190 p.

Hill, J. M., 1916, Notes on some mining districts in eastern Nevada; U. S. Geol. Survey Bull. 648, p. 88-95.

Johannsen, Albert, 1931, A descriptive petrography of the igneous rocks, vols. I-III; Univ. Chicago Press, Chicago, Ill., 1506 p.

King, Clarence, 1878, United States geological exploration of the fortieth parallel, vols. I-II; Government Printing Office, Washington, D.C., 1693 p.

Pabst, Adolf, 1928, Observations on inclusions in the granitic rocks of the Sierra Nevada; Univ. Calif. Pub., Bull. Dept. Geol. Sci., vol. 17, No. 10, p. 325-386.

Ramberg, Hans, 1952, The origin of metamorphic and metasomatic rocks; Univ. Chicago Press, Chicago, Ill., 317 p.

Ross, C. S., and Smith, R. L., 1961, Ash-flow tuffs: their origin, geologic relations and identification; U.S. Geol. Survey Prof. Paper 336, 80 p.

Stringham, B. F., 1957, Geology of the Kingsley quartz monzonite stock, Antelope Range, Eastern Nevada (Abs.); Geol. Soc. Amer. Bull., vol. 68, No. 12, Pt. 2, p. 1873.

———, 1958, Relationship of ore to porphyry in the Basin and Range Province, U.S.A.; Econ. Geol., vol. 53, No. 7, p. 806-822.

Turner, F. J., and Verhoogen, J., 1960, Igneous and metamorphic petrology; McGraw-Hill Book Co., Inc., New York, 694 p.

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