PEGMATITE DIKES OF THE BRIDGER MOUNTAINS, WYOMING*

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CONTENTS

ABSTRACT 46
INTRODUCTION 47
COUNTRY ROCK 49
Pre-Cambrian 49
Area 49
Description 49
Structure 50
History 50
PEGMATITE DIKES 51
Distribution 51
Age 51
Older Dikes 52
Description 52
Structural relationships 53
Contact metamorphism 53
Mineral descriptions 54
Younger Dikes 55
Description 55
Structural relationships 56
Contact metamorphism 56
Mineral descriptions 56
Zoning 60
Banding 62
Paragenesis 64
REPLACED SCHIST 65
HISTORY OF MINERALIZATION 67
REFERENCES 68

ABSTRACT

The central area of pre-Cambrian rocks in the Bridger Range of central Wyoming consists predominantly of black hornblende schist. The schist has been invaded by large masses of coarsely crystalline granite. The granite invasion was followed by two distinct intrusions of granite pegmatite. The older pegmatite dikes were intruded along a steeply-dipping joint set which is parallel to the plane of foliation of the schist. The younger pegmatite dikes have a lesser dip and were intruded along a joint set which was formed subsequent to the intrusion of the older dikes.

The intrusion of the older dikes was followed by an invasion of silica-rich and potash-rich hydrothermal solutions which replaced the black schist with quartz and sericite. The intrusion of the younger dikes was followed by an invasion of hydrothermal solutions which partially replaced the original dike minerals and precipitated cleavelandite, muscovite, tourmaline, beryl, garnet, columbite, tantalite, chalcopyrite, lepidolite and petalite.

* A portion of a Ph.D. thesis, University of Kansas, 1939.

Several of the hydrothermal minerals were deposited in parallel bands which strike and dip nearly parallel to the strike and dip of the dikes. The semi-concentric arrangement of these bands and their uniform parallel arrangement indicates a rhythmic precipitation similar to "Liesegang rings."

After a removal of the overburden by erosion, several supergene minerals were formed, including quartz, sericite, malachite and limonite.

The purpose of this study was to determine the history of the country rock, the structural relationships between the dikes and the country rock, the relative ages of the two types of dikes, and the paragenesis of the minerals within the dikes.

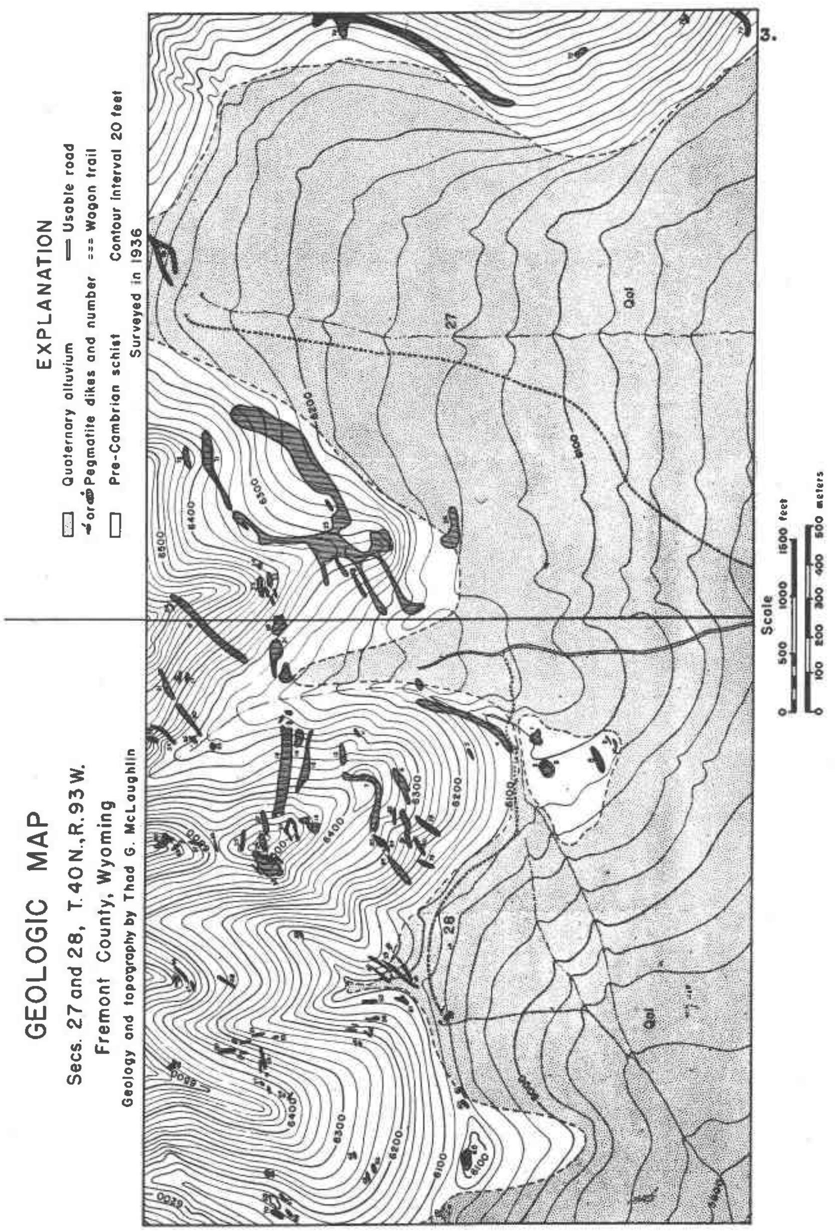
INTRODUCTION

The area which was studied lies in the northeast part of Fremont County near the center of the state. The pegmatite dikes that were mapped are intruded into the pre-Cambrian rocks east of the Wind River Canyon. They are 15 miles northeast of Shoshoni and about 20 miles southeast of Thermopolis. Field studies were made during the summers of 1936, 1937, and 1938, and were supplemented by laboratory work in the spring of 1937 and the fall and winter of 1938.

A map of sections 27 and 28, range 93 west, township 40 north, was made by a plane table survey in which both the geology and topography were mapped. The map shows the topography, with a contour interval of 20 feet, and the areal geology. Rock types mapped include the pre-Cambrian schist, pegmatite dikes, and Pleistocene (?) alluvium.

I wish to express my sincerest thanks to K. K. Landes and H. T. U. Smith for the help rendered in the field, in the laboratory, and in the theoretical discussions. Mr. LeRoy Fugitt, Mr. Bruce F. Latta, and Mr. Kenneth E. Corr assisted in the field work during the summers of 1936, 1937, and 1938, respectively. Mr. Ed Crabb and Mr. Denny Thoren of Shoshoni and Mr. Val B. Maghee of Lander furnished valuable information about the area studied.

The first mining in this area was done in 1906 when Mike Crowley filed a claim in dike 85. Some mica was taken out, but the project was soon abandoned. The present claimants, Jake Stephenson and others, filed in 1910 and mined a small amount of feldspar, beryl, and mica in dikes 3, 7, 25, 81, and 85. One of the claimants leased and did some work on dike 7 in 1928, taking out feldspar and lepidolite. The claims at present are leased by Mr. Val B. Maghee of Lander, Wyoming, who has been working on dike 86 since early in 1937 and has marketed several hundred pounds of tantalite. He is also mining beryl from the same dike.


GEOLOGIC MAP
Secs. 27 and 28, T. 40 N., R. 93 W.
Fremont County, Wyoming
Geology and topography by Thad G. McLaughlin
EXPLANATION
Quaternary alluvium
Pegmatite dikes and number
Pre-Cambrian schist
Usable road
Wagon trail
Contour interval 20 feet
Surveyed in 1936
Scale
0 500 1000 1500 feet
0 100 200 300 400 500 meters
Qal
27
28
3.
6100
6200
6300
6400
6500

COUNTRY ROCK

Pre-Cambrian

Area

The pre-Cambrian rocks outcrop in a roughly triangular area nearly 20 miles long and 10 miles wide, elongated in an east-west direction. They are also exposed several miles west of this area in the bottom of Wind River Canyon in a triangular area 1 mile wide and 1½ miles long (6).

Description

The black country rock is a fine grained schist composed dominantly of hornblende and labradorite. The schist resembles a fine grained igneous rock, but the crystals are elongated parallel to the schist's foliation. Thin sections of the country rock show that it is a hornblende schist.

Hornblende constitutes 70 to 85 per cent of the schist. It occurs in elongated lath-like subhedral crystals, which are crossed and interpenetrating. The color in thin section, because of strong pleochroism, varies from light to medium blue-green. The laths are 0.1 to 0.5 of a millimeter long and generally about one-fifth as wide. A few crystals of hornblende are slightly altered to chlorite. The labradorite variety of plagioclase feldspar constitutes 10 to 20 per cent of the black country rock. It forms irregular masses and subhedral crystals with prominent albite twinning lines. It is colorless and has a low relief and low birefringence. The individuals were generally 0.8 to 1.0 mm. in diameter. Common accessory minerals are magnetite, chlorite, quartz, actinolite and zircon. None of these minerals ever constitute over two per cent of the rock. Magnetite forms very irregular masses which are subrounded, tabular, or trellis-like. It is often slightly altered to hematite and limonite which are nearly opaque to transmitted light, but are reddish brown to ocher yellow in reflected light.

Many thin sections of the country rock contain a very fibrous or asbestiform mineral, which is probably an alteration of hypersthene to actinolite. The fibers are very coarse and irregular to wavy. Pleochroism is very strong, with a color variation from pale grayish brown to brownish black. The birefringence is high, but the colors are slightly obscured by the color of the mineral. Zircon is present in every thin section that was made of the country rock. It may be rounded, ellipsoidal, or rod-like with rounded ends. The extinction is parallel, the relief and birefringence are very high, and the color is gray to colorless.

The granite outcrops in the eastern third of the pre-Cambrian area. It is a medium to coarse-grained rock containing over 90 per cent pink feldspar with only a small amount of quartz and muscovite. Near the granite-schist contact the granite has a gneissic structure and a much greater percentage of muscovite and quartz. Joints extend from the granite into the schist without offset. The granite erodes into rounded knobs and hills of small relief. Granite also outcrops in Wind River Canyon (6) and near Birdseye.

Structure

The schist in this area has very distinct foliation and jointing. The strike and dip of the foliation of the schist varies considerably from one locality to another. The strike is "not more than 10° from east to west" in Wind River Canyon (6 p. 1419), but in the two sections that were mapped the strike varied from S. 40° W. to S. 83° W. with an average of S. 60° W.

The dip of the foliation in Wind River Canyon ranges from 30° to 60° S. with an average of 45° S. (6 p. 1419) while in the area that was mapped, the average dip was 66° S. with a maximum of 70° S. and a minimum of 58° S. The jointing in the schist dips against the foliation of the schist. The dip varies from 40° to 50° N. with an average of about 45° N. It is along these joints that many of the pegmatite dikes were intruded. The granite in the eastern part of the pre-Cambrian area, and many of the larger pegmatite dikes, also show distinct jointing.

History

A considerable controversy has taken place concerning the origin of hornblende schist and similar metamorphic rocks. Many conclusions have been based on the presence of quartz, the range of the plagioclase feldspars, and the physical properties of the zircon grains.

The zircons in some hornblende schists are smoothly rounded spheroids and ellipsoids, which closely resemble the rounded grains in sedimentary rocks. It has been inferred by some that this is sufficient proof of a sedimentary origin. Later investigators have pointed out that many of the zircon grains are oblong as well as rounded, and that rounded grains can be found in igneous rocks, such as diorite, dolerite and basalt (22). Zircon crystals from the Bridger mountain schists have length to width ratios as high as 8 to 1. Grains of such shape are probably not of sedimentary origin.

Carlson (3) believes feldspar and quartz are indicators of the former character of metamorphic rocks. A narrow range in the plagioclase feldspars is indicative of an igneous origin, for derivation from sedimentary rocks would result in a wide range in plagioclase feldspars, and also an excess of quartz.

The schists of the Bridger Range contain elongate grains of zircon, have a narrow range of plagioclase feldspars, and are almost devoid of quartz. These criteria point to an igneous origin, probably from a diorite or basalt.

The red, coarse-grained granite at the east end of the pre-Cambrian area was intruded after the formation of the black schist, for it shows very few signs of regional metamorphism. One jointing system passes through both schist and granite, which means that this granite is older than the nearby pegmatite dikes which were intruded along the jointing system in the schist.

Another area of red granite is exposed near Birdseye at the Gold Nugget mine. The pegmatite dikes in this locality have been intruded into the schist parallel to the near-vertical jointing system. These dikes also intrude the red granite which is probably the source of the later pegmatite dikes.

PEGMATITE DIKES

Distribution

The black schist in Wind River Canyon and in the pre-Cambrian area east of the canyon has been invaded by many granite pegmatite dikes. These dikes outcrop in all parts of the schist area and in the granite area near Birdseye, but none were found in the granite at the east end of the pre-Cambrian area.

The simple dikes (those which have not suffered later hydrothermal replacement) are evenly distributed throughout the area of black schist. Most of them strike and dip concordantly with the foliation of the schist, but a few in Wind River Canyon are parallel or subparallel to a joint system which dips against the foliation.

The complex dikes, all of which dip in a direction opposite to the dip of the foliation of the schist, are concentrated in a small area on the south side of the mountains in range 93 W. Most of them were included in the map of sections 17 and 28. Dike 86 is the only dike containing hydrothermal minerals that does not lie in either of these two sections. It outcrops in the southeast quarter of section 21.

Age

The pegmatite dikes are truncated by the Deadwood sandstone in Wind River Canyon. This indicates a pre-Cambrian age for the dikes. The relationships of the pegmatite dikes and the Paleozoic sediments are not readily observable along the south side of the Bridger Range because of the extensive overlap of the Wind River formation. The writer was unable to find any dikes that were intruded into sedimentary rocks.

Older Dikes

Description

The older dikes in this area are those which strike and dip parallel or subparallel to the strike and dip of the schist's foliation. Only 19 per cent of the dikes in sections 27 and 28 are of this type. Many of these dikes are small parallel bands intruded in a lit-par-lit manner. Others are large,

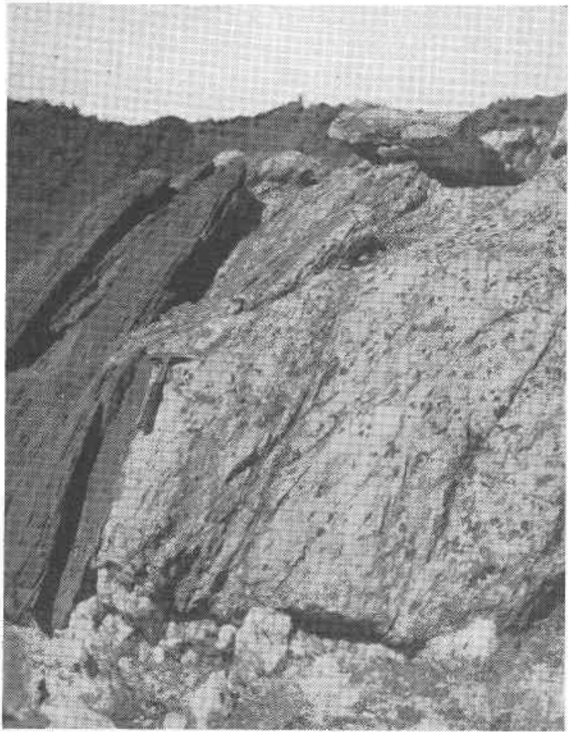


Fig. 2. Older dikes intruded parallel to the foliation of the schist.

coarsely-crystalline masses. Dike 38 is 50 meters wide and 170 meters long. The large area of altered schist adjacent to this dike indicates that if the dike were entirely exposed it would be nearly 350 meters long. Nearly 50 per cent of the older dikes are more than 35 meters in length and 90 per cent of them are 20 meters or more long.

The older dikes are all elongated bodies but where insufficient country rock has been eroded from the dike the outcrop area may be roughly circular. One can roughly determine the actual dimensions of the dike, however, by measuring the length and width of the zone of altered schist which invariably overlies the buried part of the dike. The length is always 5 to 10 times as great as the breadth.

Structural relationships

The average strike and dip of the dikes is S. 61° W. 65° S., which is almost identical to that of the foliation of the schist (S. 61° W. 66° S.). The strike of the dikes ranges from S. 40° W. to S. 80° W. The maximum dip of the dikes is 70° S. and the minimum dip is 58° S. The strike and dip of the dikes coincide much more closely with the strike and dip of the foliation in this area than they do in Wind River Canyon.

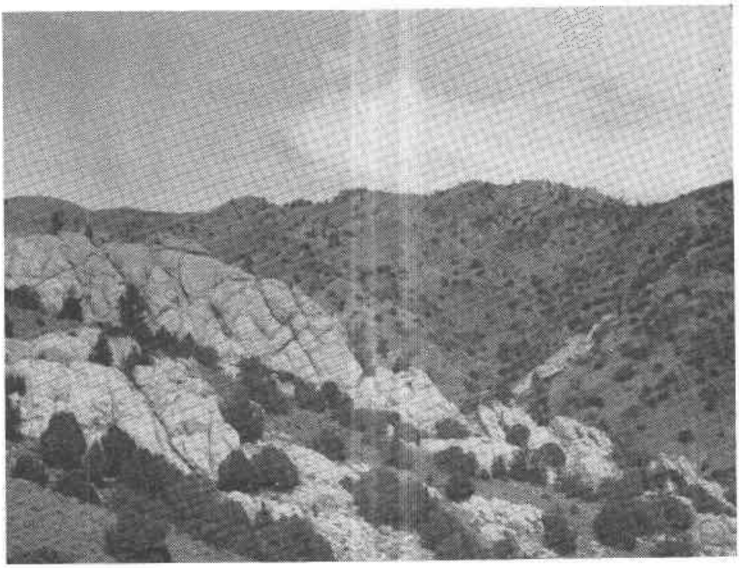


Fig. 3. Jointing in the older dikes.

Contact metamorphism

The intrusion of the older pegmatite dikes was accompanied by alteration of a large amount of country rock. The altered zone always lies above the dike and never extends more than one meter on either side of it. Silica-rich solutions, which travelled beyond the dike itself, followed the easiest passageway, which was parallel to the foliation of the schist. Thin sections of this altered country rock show considerable change from the original hornblende schist by the addition of a large amount of quartz and some muscovite. Hornblende and plagioclase, and the accessory minerals magnetite and zircon are present. The percentage of hornblende is greatly reduced and quartz is the predominant mineral.

Megascopically, the metamorphosed schist is brown to brownish green. It is more micaceous, softer, less brittle, and can be readily distinguished from the original black schist even at a considerable distance.

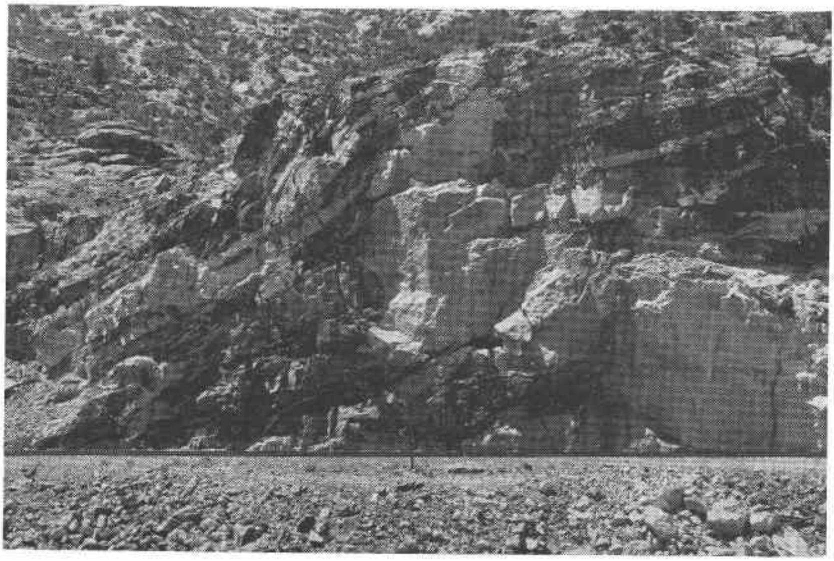


FIG. 4. Pegmatite dikes in the black schist in Wind River Canyon. (Photo by H. T. U. Smith)

MINERAL DESCRIPTIONS

Microcline. The most abundant mineral in the older dikes is microcline. It constitutes more than 70 per cent of the rock which is made up entirely of quartz and feldspar. The microcline is dominantly white but may also be various shades of gray, light blue and rarely pink. It is coarsely crystalline with some individuals more than a meter in diameter. No euhedral or subhedral crystals were observed. A perthitic intergrowth of albite and microcline was found in several dikes. The color of both the albite and microcline is white, making the perthite difficult to distinguish from the specimens of pure microcline. Quartz is the most common mineral associate of microcline but tourmaline may rarely be present where a younger dike transects an older one.

Quartz. Quartz is next in abundance and constitutes almost 30 per cent of the rock in the older dikes. It is always anhedral and its color is generally pale milky but locally is dull gray. The quartz is evenly dispersed throughout the dike and is seldom concentrated in lenses as it is in the younger dikes. It frequently forms veins, varying in width from 1 to 30 cm. which penetrate the country rock in a lit-par-lit manner. These veins often contain a small amount of microcline.

Tourmaline. Black tourmaline is found in an older dike (no. 28) where it is cut by a younger dike which dips in a direction opposite to that of the foliation of the schist. The tourmaline-bearing solutions obviously came from the same parent magmas as the younger dike. These solutions followed the sides of the younger dike and deposited tourmaline in small veins and clusters in both the older and the younger dikes. The tourmaline is found in subhedral crystals less than 2 cm. long. These elongated crystals cut both the quartz and the microcline.

Younger Dikes

Description

The younger dikes are those that dip north against the foliation of the schist. Eighty-one per cent of the dikes that were mapped in sections 27 and 28 are of this type. These dikes outcrop only in a small area on the

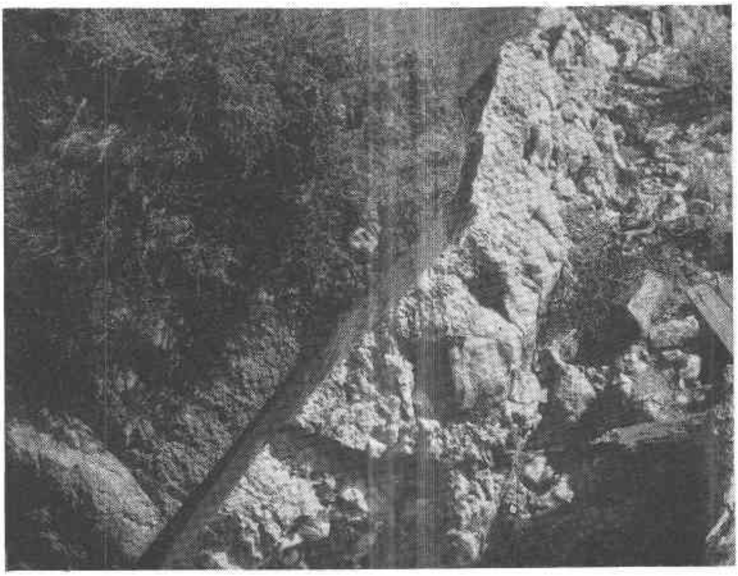


Fig. 5. Sharp contact of a younger dike with the country rock.

south side of the Bridger Mountains near the contact of the black schist and the alluvium. Most of the younger dikes are elongated, tabular masses with a length 5 to 20 times as great as the thickness. The average thickness of the dikes in sections 27 and 28 is 5 meters and the average length is 84 meters. The mean ratio of length to thickness is 16 to 1. The feldspar in the dikes is white, gray, or pale blue and gives the dike a decidedly white color which is amplified by the background of black schist. This contrast of color makes the dikes visible for a great distance.

The younger dikes do not weather to any characteristic forms. There is no distinct jointing, but the dikes fracture easily causing them to erode as rapidly as the schist. The rate at which they erode is controlled by the rate of weathering of the schist.

Structural Relationships

One of the outstanding features of this area is the almost perfect control on the position of the dikes exercised by the structure of the country rock. All of the older dikes strike and dip parallel to the foliation of the schist. Variations in strike and dip of these dikes is caused by variations in the strike and dip of the foliation. All of the younger dikes have been intruded parallel to the jointing in the country rock. The directions of jointing are more uniform than the foliation of the schist, therefore, the strike and dip of the younger dikes is more uniform than that of the older ones.

The maximum dip measured in sections 27 and 28 is 62° N. and the minimum is 30° N. The average of all the dips measured is 45.5° N. Eighty-five per cent of the dikes dip to the north at an angle within 40° and 50°, and 50 per cent of the dikes dip north at an angle within 3° of the mean (45.5°). The average strike of the dikes is S. 43° W. which is nearly the same as that of the foliation of the schist.

Contact Metamorphism

Metamorphic effects of igneous intrusion were noted in all but two of the younger dikes. The otherwise hard, black hornblende schist has been altered to a dark bluish-green, friable material which megascopically looks very different from the original material. The contact of the altered schist with the unaltered material is always a joint plane. The metamorphosed rocks are coated at the surface by brown iron oxides. This has probably been caused by oxidation of the iron in the schist to limonite, followed by incomplete dehydration to hematite and perhaps turgite.

Microscopic examinations of thin sections of the metamorphosed material have revealed very little mineralogical change from the original unaltered schist. It contains over 70 per cent of hornblende, 5 to 15 per cent of quartz, and lesser amounts of magnetite, actinolite, and zircon.

Mineral Descriptions

Microcline. Microcline is the most abundant mineral in the younger dikes as well as in the older ones, but the percentage is much smaller in the younger dikes. The microcline in these complex dikes is white to pale blue and gray. It is coarsely crystalline, some individuals being over 2 meters in diameter.

The dikes originally were intruded as liquid masses of microcline and quartz with the quartz concentrated in irregular lenses at the center of the dikes and microcline along both walls of the dikes. Later invasion and replacement at the center and along the walls left only small zones of microcline about one-third of the way in from each wall. Microcline is almost always found in these zones; and in a few dikes where there is no quartz lens, it may be found at the center of the dike.

Microcline is relatively soluble and has been attacked by hydrothermal solutions and partially replaced by later minerals. Some individuals have been almost entirely replaced by cleavelandite and muscovite. Perthitic intergrowths of white albite and white to gray microcline were found in dike 25. They occur in a narrow zone near the top wall of the dike.

Quartz. Quartz is found in three places within the complex dikes: (1) in lenses near the center of the dikes, (2) in a small zone near the walls of the dike, and (3) rather evenly disseminated throughout the rest of the dike.

The quartz is white, milky, dull gray or, in a few instances, rose. It is always anhedral. Dikes 79 and 82 are made up almost entirely of feldspar, but grade into pure white quartz dikes or veins which stand above the rest of the rock because of greater resistance to erosion. Conchoidal fracture is most common, but a few specimens display a poor cleavage. The luster is vitreous, except for the gray quartz which has a dull luster.

Lepidolite. The lithium minerals are not very abundant. They were found in dikes 7, 11, and 86. The lepidolite was deposited in irregular zones at the center of the dikes where

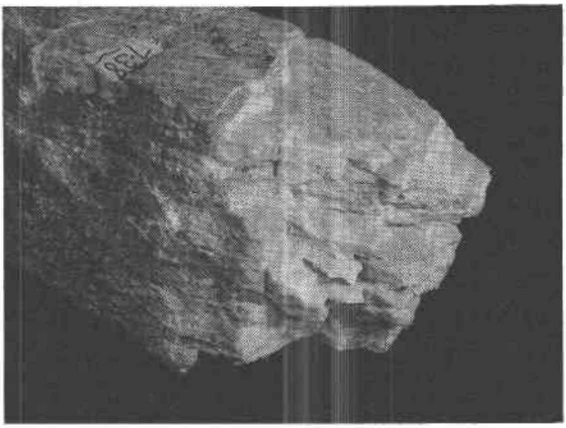


FIG. 6. Pseudomorph of albite after petalite. One-half natural size.

it is commonly associated with quartz, sericite and some cleavelandite. The mineral occurs as small plates or thin books less than 6 mm. in diameter which are rather evenly disseminated through the central part of the dikes. The plates are pale lilac in color, irregular in outline, and slightly fractured.

Petalite. Dike 86 is the only one where petalite was collected. However, pseudomorphs of albite after petalite are rather abundant in dike 7. A lens of milky quartz lies at the center of 86 and is overlain by a zone containing cleavelandite and a pseudomorph of albite after petalite. The pseudomorph, however, is absent from the zone of cleavelandite which lies immediately below the quartz lens. Number 7 has no lens of quartz at the center, but there is instead a belt of lepidolite, cleavelandite, and some sericite and quartz. This central area is both overlain and underlain by a pseudomorph of albite after petalite.

The petalite individuals are as much as 20 cm. long. They are extremely brittle and therefore highly fractured. The cleavage is good both on *c*(001) and *o*(201). The basal cleavage is not perfect as many textbooks describe it. The color and diaphaneity closely resemble that of pale milky quartz except along the basal fracture or cleavage planes where it is white and less translucent.

The replaced petalite resembles to some extent the original mineral. The basal cleavage lines are very distinct (Fig. 6), but traces of cleavage along *o*(201) are poor or absent. The cleavage plates are 1 to 3 mm. thick and are always normal to the dike walls. The zones of replaced petalite lie immediately above and below the central area of lepidolite in dike 7. These zones are very irregular and are at no place more than 1.5 meters thick. Apparently the replacement was complete for no specimens of residual petalite could be found. Specimens collected from the Bridger Range closely resemble those from Londonderry in Western Australia except that the former contain more sericite and have preserved the original structures somewhat better.

Amblygonite. Although no amblygonite was collected from any of the dikes, it has been reported by Mr. Maghee to be present in dike 7.

Cleavelandite. Cleavelandite is the most abundant hydrothermal mineral present in the younger dikes. It is white to cream colored, but may be stained black by manganese oxide. The cleavelandite is subhedral with individuals varying greatly in size. The specimens having a sugary texture contain crystals as small as 1 mm. Several crystalline aggregates taken from dike 7 were more than 15 cm. wide. They consist of radiating tabular crystals of cleavelandite elongated parallel to the side pinacoid. Albite twinning is noticeable.

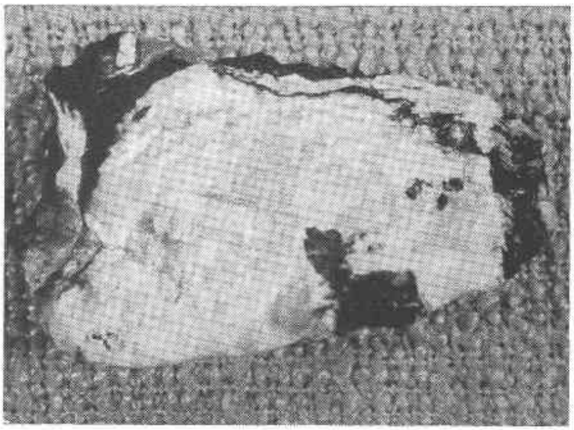


FIG. 7. Black tourmaline transecting cleavelandite. Three-fourths natural size.

The cleavelandite occurs in irregular zones near the walls of the dike. These zones are very indefinite. A wide variety of minerals is associated with cleavelandite, including microcline, quartz, muscovite, garnet, beryl, columbite and tantalite.

Tourmaline. The ordinary black variety is the only type of tourmaline found in these dikes. It commonly occurs as elongated and striated crystals which were deposited in small veins and lenses within the dike. The tourmaline bearing solutions rose along the contact of the dikes and precipitated tourmaline crystals both in the dikes and in the schist. The mineral is subhedral and very brittle and is found replacing or cutting into quartz, microcline, cleavelandite, and schist.

Braunite. The mineral braunite always occurs in very irregular nodules surrounded by coarsely crystalline blades of greenish muscovite. The nodules in dike 85 were all found at or near the base of a large lens or band of muscovite and cleavelandite. The mineral is dark brown to nearly black and is submetallic to earthy. The submetallic part of a specimen generally shows good cleavage in one direction, probably parallel to $p(111)$. The earthy part is browner and breaks with an uneven, slightly conchoidal fracture. Single nodules are as wide as 12 cm. but the average is about 5 cm.

Muscovite. The muscovite found in these dikes is pale green and highly fractured. Hydrothermal solutions have deposited this mineral in three distinct zones within the dikes: (1) at the contact of the dike with the country rock, (2) in lenses between the quartz lode at the center of the dike and the upper contact with the schist, and (3) in small books and flakes associated with the cleavelandite.

Muscovite is comparatively resistant to attack and is only replaced by one mineral, sericite. Small books of muscovite may be replaced along their borders, and a few specimens show small veinlets of sericite cutting entirely across books of muscovite.

Apatite. Several small aggregates of anhedral grains were identified by oil immersion methods as apatite. Such aggregates were never over 1 cm. wide, and individual grains were less than 1 mm. in diameter. These sub-rounded grains were all found in specimens collected from dike 25. However, much larger individuals are reported by Mr. Maghee to have been found in dike 86.

The mineral is dark bluish-green, translucent, and shows a sub-vitreous luster. In every specimen that contained apatite, the small grains were imbedded in a mass of white saccharoidal cleavelandite with fine flakes of muscovite and a small amount of residual pale milky quartz.

Beryl. Cleavelandite and muscovite are always associated with beryl. The beryl may occur as light green to pale blue elongated euhedral prisms imbedded in the cleavelandite zones near the center of the dike, or as aggregates of small blue green anhedral blebs in the bands of sugary cleavelandite found in the banded dikes. Some of the euhedral crystals of beryl are aquamarine and of gem quality.

The individuals vary in size from small rounded masses less than 1 mm. wide, to euhedral prisms 20 cm. in diameter. The beryl crystals cut through masses of sugary clevelandite, but are unaltered by any of the hydrothermal solutions.

Columbite-tantalite. Both the nearly pure niobate and the nearly pure tantalate often are found in the dikes in this area. This mineral is found associated with sugary cleavelandite in a zone just above the center of the dike. The zone varies greatly both in thickness and in concentration of columbite-tantalite. Only dikes 85 and 86 contain it in considerable quantities. Specimens belonging at both ends of the isomorphous series occur in these two dikes.

Columbite is almost entirely confined to dike 85, but a few crystals were collected from 86. It crystallizes in very thin tabular crystals elongated parallel to $a(100)$. The crystals are generally less than 1 mm. thick, about 1.5 cm. wide, and 5 to 10 cm. long. The most common forms present are two prisms, brachypinacoid and macropinacoid. The mineral is also commonly in anhedral masses with quartz and cleavelandite. Chemical analyses by the Fansteel Metallurgical Corporation show that the columbite is very low in tantalum, and that one specimen from dike 86 was almost pure columbite. It is always black and displays a metallic luster. The specific gravity is 6.21, which is high for a mineral of this series so low in tantalum.

Tantalite is much more abundant than columbite, but is almost entirely limited to dike 86. A few euhedral crystals, which closely resemble those found in dike 86, were found in dike 7. Tantalite is in most cases euhedral, although a few individuals are subhedral or anhedral. Crystals of this mineral are equidimensional and may be as large as 5 cm. in diameter, but have an average width of 2 to 3 cm.

The luster is metallic and the color is generally black, but may be a medium grayish brown when weathered. The specific gravity is 7.82, which indicates a high per cent of tantalum. It has been shown (10) that in the columbite-tantalite series the specific gravity varies roughly with the amount of Ta_2O_5.

Garnet. All of the dikes from which mineral specimens were collected contained at least a small amount of garnet. This mineral occurs as irregular, reddish brown anhedral, subhedral, or euhedral individuals with a vitreous luster. Specific gravity measurements and chemical tests indicate that the variety is spessartite.

Anhedral garnets with a dull luster were found in dike 7 where they occur in 2 to 10 cm. masses imbedded in cleavelandite. The small red and amber crystals are most commonly associated with cleavelandite, but may be found with microcline. The euhedral crystals contain both the trapezohedron and the dodecahedron. They are found cutting into microcline, evenly disseminated throughout the zones of cleavelandite, or concentrated into bands less than 2 cm. wide which dip parallel to the dip of the dike. The anhedral garnets are roughly spheroidal blebs most of which are smaller than a pin head. The garnet is very resistant to replacement and is not altered or cut by any of the other hydrothermal minerals in the specimens collected.

Chalcopyrite. A 50 cm. vein of quartz and 35 cm. zone of microcline lie at the center of dike 49. Many small irregular anhedral masses of chalcopyrite were found in this part of the dike. This mineral has in many specimens been oxidized to malachite, forming a green stain on microcline, quartz, and cleavelandite.

Supergene quartz. Cavities are very rare both in the simple and in the complex dikes. One small cavity, which was less than 3 cm. in diameter, was found in a specimen collected from dike 3. It is lined with subhedral crystals of quartz. The crystals are very poorly developed, but show a prism and rhombohedral forms. This quartz is undoubtedly supergene, having been formed after the deposition of the hydrothermal minerals.

Sericite. Sericite is commonly associated with the zones in which lepidolite, cleavelandite, columbite and tantalite are found. It was found in specimens collected from dikes 7, 85, and 86. It has been deposited along the cleavage or fracture planes of the pseudomorph of albite after petalite, in scattered flakes and grains dispersed throughout the zones of lepidolite, and in small veins cutting into and across books of muscovite. In some specimens the muscovite has been so severely attacked by sericite that only a small part of the original book remains.

Malachite. The oxidation of chalcopyrite has produced a green stain of malachite throughout dike 49, although the primary sulphide is confined to the center of the dike. A few specimens show an accumulation of malachite about 1 mm. thick.

Limonite. Limonite occurs only as small earthy masses, closely associated with chalcopyrite. It varies in color from light yellowish brown to very dark brown. The dark brown variety commonly coats chalcopyrite.

ZONING

The younger pegmatites show various degrees of hydrothermal mineralization ranging from unaltered to completely replaced dikes. The later minerals have been deposited in some dikes in distinct zones. Many of the dikes show several but no dike was found which contained all of the zones. A classification of replacement deposits follows:

1. Unreplaced dikes.
2. Cleavelandite and mica replacement (all degrees).
3. Lithium phase.

4. Columbite-tantalite and beryl phase.
5. Tourmaline phase.
6. Banded garnet phase.

UNREPLACED DIKE. No younger dikes were found which did not show at least a slight replacement along the walls by cleavelandite and muscovite. This later mineralization, however, was so negligible in several dikes that they can be considered as unreplaced. These dikes consist dominantly of white microcline and perthite with lesser amounts of pale milky quartz. The quartz is either rather evenly distributed throughout the dikes or it is concentrated in lenses and bands at the center of the dike or near the walls. The larger lenses, which may be as much as 2 meters thick, are invariably near the center. The lenses and bands near the walls are never more than 0.5 meter in thickness.

CLEAVELANDITE AND MICA REPLACEMENT. The addition of muscovite and cleavelandite may vary from a few scales and plates along the walls to an almost complete replacement of the entire dike. Mineralization obviously began along the dike walls, where microcline is replaced by white cleavelandite and coarsely crystalline muscovite. Toward the center of the replaced dike the muscovite is less abundant and more finely crystalline.

Microcline is more easily replaced by cleavelandite than is quartz, therefore, the lenses of quartz at the center and near the walls are the last parts of the original dike to disappear. Even in those dikes which are almost completely replaced, residual quartz occurs with the cleavelandite and mica near the center of the dike.

LITHIUM PHASE. Lithium minerals, including petalite, lepidolite and amblygonite, were deposited in zones at the centers of several dikes. Lepidolite is found at the center of the lithium zone, with petalite lying immediately above or below it. Where later hydrothermal mineralization has failed to replace the lens of quartz at the center of the dike, the lithium minerals were deposited directly above.

COLUMBITE-TANTALITE AND BERYL PHASE. The quartz lenses in the central part of the dikes are generally only slightly replaced. The zones between these lenses and the dike walls consist of cleavelandite and mica in many cases. It is in these zones that columbite, tantalite and beryl were deposited, mainly between the quartz lens and the hanging wall of the dike. Beryl is evenly distributed through this zone, but columbite and tantalite are found in aggregates or "pockets."

TOURMALINE PHASE. The boron-bearing solutions rose along the footwall contact of the dike and deposited black tourmaline in the schist, along the dike wall, and in small veins and "pockets" toward the center of the dike. Tourmaline groups within the dikes are connected with the footwall of the dike by fractures along which the solutions passed.

BANDED GARNET PHASE. Distinct zones of banding are found in several of the dikes (Fig. 8). These bands consist chiefly of small blebs and crystals of garnet with fine flakes of mica, sugary cleavelandite, and, more rarely, splotches of greenish blue beryl. Residual pale milky quartz

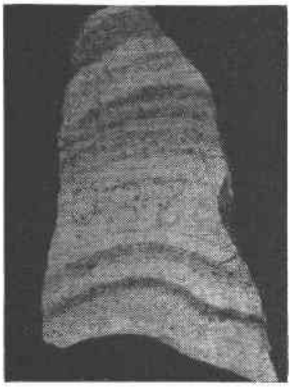


FIG. 8. Specimen from younger dike showing banding. One-fourth natural size.

is also present. The zones of banding may occur in any part of the dike, but the larger ones are commonly near the footwall.

BANDING

A distinct banding of the minerals was noted in at least six of the dikes, and is especially prominent in dikes 4, 8, and 25. The bands are parallel to each other, but unequal in their thickness, which ranges from 1 mm. to 15 cm. The thickness of a single band is very uniform for several meters. Many bands are wavy, especially in a direction parallel to the strike of the dike. The dip roughly conforms to that of the dike. The zones of banding may be in any part of the dike, but are near the center in most cases. There may be as many as three of these zones separated by areas of coarsely crystalline microcline, quartz and muscovite. The banded zones do not extend throughout the entire length of every dike.

The minerals in the banded zones are very fine grained, giving the rock a saccharoidal texture. The most common minerals in the bands are cleavelandite, quartz, garnet, muscovite, and lesser amounts of tourmaline, apatite and beryl. The contact between the various bands is not sharp, but gradational. The red bands are caused by a concentration of garnets, but many garnets are also found scattered throughout the white zones of cleavelandite.

Banding in igneous rocks has been explained as due to either gravity separation or rhythmic precipitation. Gravity separation could not have been the cause in these dikes for the minerals are not banded according to specific gravity. Bands of any type can be found in any part of a dike.

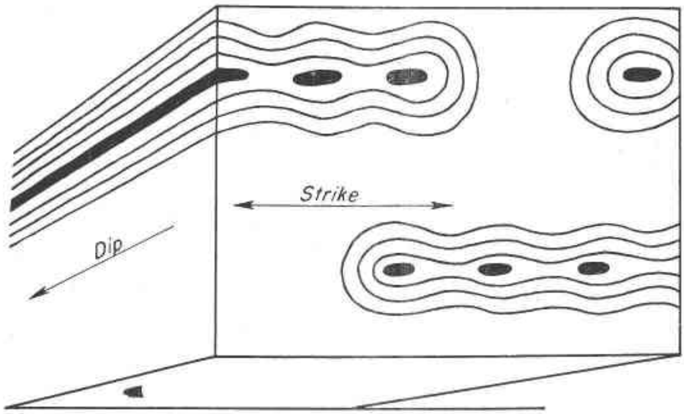


FIG. 9. Block diagram showing formation of bands concentric about finger-like openings.

The remarkable paralellism of the bands, the waviness of the bands in a direction parallel to the strike of the dike, and the less wavy character in a direction parallel to the dip of the dike indicate the development of the bands by a "rhythmic precipitation" similar to Liesegang rings (17). Hydrothermal solutions, rising along tubular or finger-like fractures elongated parallel to the dip of the dike, precipitated material in parallel bands concentric about these elongate fractures or openings. Because these openings were almost infinitely longer than wide, the bands are straight in a direction normal to the strike and irregular in a direction parallel to the strike of the dike. This view is also supported by the fact that the bands are persistent along the dip of the dike but not along its strike.

The sharpness of the bands would depend upon the physical character of the dike rock and the chemical composition of the ascending solutions. The high temperatures and pressures associated with such mineralization would also affect the physical condition of the resulting bands.

Paragenesis

The paragenetic relationships could not be determined for all of the minerals. Not all of the minerals were found in any single dike, so the time relationships between some minerals could not be checked. The mineralization can be roughly divided into seven stages:

1. Magmatic stage. Quartz and microcline, and perhaps a small amount of muscovite, were precipitated from the primary pegmatite magma. Because the dikes which have been subjected to hydrothermal alteration contain much more muscovite than do the unaltered dikes, the muscovite must be dominantly hydrothermal. The microcline and quartz were precipitated almost simultaneously, for every specimen shows mutual boundaries between these minerals. The muscovite is later than either the microcline or quartz.

2. Muscovitization. Intrusion of the magma was followed by replacement of part of the microcline and quartz by muscovite. Blades of muscovite transect both the microcline and quartz.

3. Lithium phase. The lithium phase is generally a late hydrothermal stage, but in these dikes the petalite is completely replaced by cleavelandite, so the lithium phase must be pre-albite in age. The minerals, lepidolite, petalite and amblygonite were deposited in a few dikes at this time.

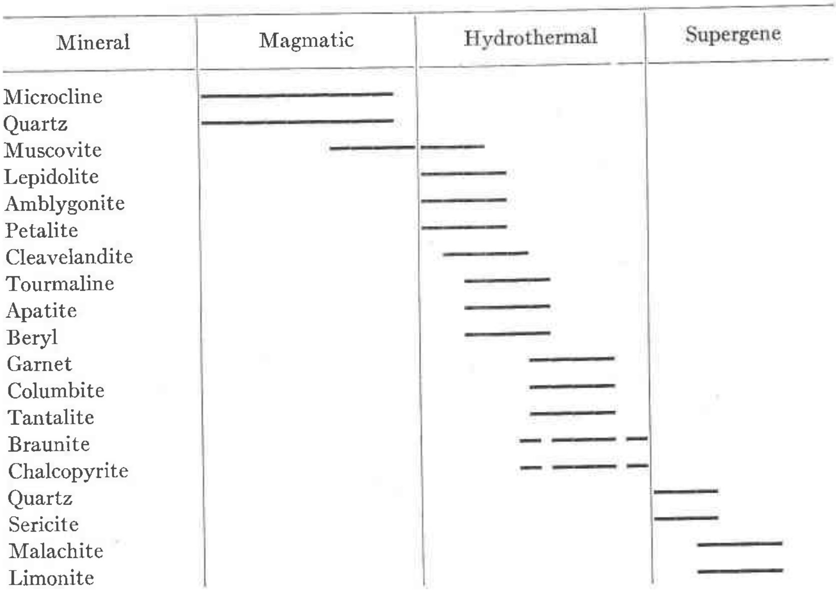
4. Albitization. Almost every dike was partly or entirely replaced by cleavelandite. Crystals of this mineral transect microcline, quartz and muscovite, and replace large masses of petalite.

5. Other hydrothermal minerals. Because of lack of association, many minerals could not be arranged in a definite order based on time of formation. Some of these minerals were probably precipitated simultaneously and all of them transect blades of cleavelandite. They include tourmaline, apatite, beryl, garnet, columbite, tantalite and braunite.

6. Primary sulphides. Chalcopyrite is found in a vein of quartz in one dike. Because quartz is the only other mineral present, the age of the chalcopyrite cannot be determined.

7. Supergene minerals. Quartz, sericite, malachite and limonite were deposited by later supergene mineralization.

The minerals are listed in the following table as nearly as possible in the order of their formation.



REPLACED SCHIST

North of section 27 in Hoodoo Canyon and in adjacent regions are several large areas of replaced schist. The country rock has been partly or completely replaced by later hydrothermal mineralization. The altered schist varies in color from gray to almost snow white. The areas are generally 12 to 16 meters wide, and all are less than 200 meters in length. The altered schist strikes and dips in the same direction as the original black schist. The change from completely replaced schist to unaltered material is quite abrupt, the entire transition taking place within a distance of 3 meters. The areas are bounded on all sides by unaltered hornblende schist.

Microscopic studies of thin sections of these rocks show almost complete replacement by quartz, sericite and muscovite. Several specimens contained more than 95 per cent quartz, and another showed at least 90 per cent sericite. Only slight indications of the original character of the rock were found. Almost every thin section contained grains of zircon similar to those found in the hornblende schist. Quartz is the dominant mineral in the specimens taken from the areas of replaced schist. It constitutes from 10 to 98 per cent of the rock. Sericite and quartz together in most cases make up 98 per cent of the entire rock specimen.

Because of the great extent of the replaced area in a direction parallel to the strike of the schist compared with the very limited extent normal to the strike, and the existence of similar alteration of the country rock above and adjacent to the older dikes in sections 27 and 28, it is logical to conclude that this replacement is due to the activity of silica-rich solutions which followed the intrusion of dikes parallel to the foliation of the schist. Solutions could travel great distances in the plane of the foliation, but would be unable to penetrate the impervious layers in a direction normal to the plane of the foliation of the schist.

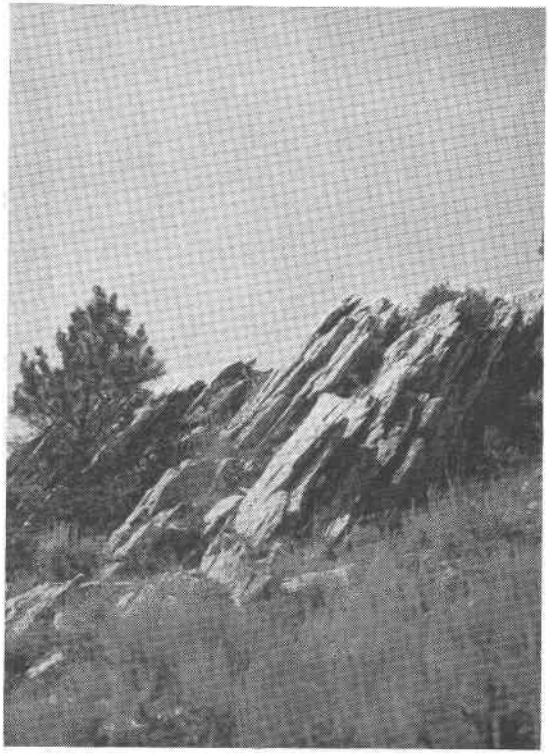


FIG. 10. Steeply dipping replaced schist.

The gently dipping joint system which strikes normal to the schistosity, and along which the younger dikes were intruded, is also present in the replaced schist. These joints were obviously formed after the replacement of the schist had taken place, for, if they had been present, the solutions would have traveled a greater distance in a direction normal to the strike of the schist. The replacement is probably closely associated with the intrusion of the older dikes which parallels the foliation of the schist.

HISTORY OF MINERALIZATION

The history of mineralization of this area may be summarized as follows:

1. Intrusion or extrusion of a mafic igneous magma into or upon the country rock. Microscopic examinations of thin sections of the black schist indicate a derivation from an igneous rock chemically and mineralogically similar to a diorite, or possibly a basalt. The fact that the black schist is fine grained leads one to conclude that the original igneous rock was also fine grained or perhaps aphanitic.

2. Regional metamorphism of the igneous rocks. Great pressures applied to these rocks caused a transformation of the diorite, or basalt, into a fine grained hornblende schist.

3. Intrusion of red granite. The granite is very coarsely crystalline and was probably intruded at great depth.

4. Development of the vertical jointing system. These nearly vertical joints are parallel to the foliation of the schist and extend from the schist out into the red granite and were, therefore, developed after the intrusion of the granite.

5. Intrusion of older pegmatite dikes along the vertical jointing system. The older dikes were intruded into the black schist and into the adjacent masses of coarse grained red granite. The magma soaked and forced its way through the black schist; in several places the contact between dike and schist is gradational. Considerable force also accompanied the intrusion, for in several places the foliae of the schist have been bent by the forceful intrusion of the dikes.

6. Replacement of the schist adjacent to the dikes by highly attenuated silica- and potash-rich hydrothermal solutions which deposited quartz and sericite. These solutions traveled along the vertical joints and foliation of the schist and replaced the schist rather than the minerals in the dikes.

7. Development of the second and nearly horizontal joint-set. Because the schist is replaced for a great distance in a direction parallel to the strike of the schist and for only a very short distance normal to the schist's foliation, it is apparent that these joints were developed after the replacement of the schist.

8. Intrusion of younger dikes took place along the second set of joints. The magma must have been more viscous than that which formed the older dikes because there was no soaking up of the schist by the younger dikes, and the crystals are not quite as large.

9. Hydrothermal replacement of the younger dikes. Later hydrothermal solutions replaced parts of the dikes and, in a few places, the adjacent schist.

10. Removal of the overlying country rock by erosion.

11. Supergene mineralization. This is represented by the deposition of later sericite, the oxidation of chalcopyrite to malachite and limonite, and the incipient kaolinization of feldspar.

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