PETROGRAPHY AND PEGMATITES OF THE FOURMILE AREA

CUSTER COUNTY, SOUTH DAKOTA

by

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Department____________________
Date________________________

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CUSTER COUNTY, SOUTH DAKOTA

by

Andrew J. Lang, Jr.

ABSTRACT

The Fourmile area is four miles west of Custer in the southern Black Hills, Custer County, South Dakota. The district is eight miles southwest of the granitic rocks of Harney Peak. The Fourmile area contains 7.8 square miles mapped by the author during the summers of 1948, 1949, and 1950.

The area is underlain by pre-Cambrian metamorphic and igneous rocks. The metamorphic rocks consist of quartz-mica schist, meta-conglomerate, amphibolites, and lime-silicate rocks that have been mapped as three formations, tentatively named, in ascending order, the Ruby Creek quartz-mica schist, the Raver formation, and the Ruddock schist.

The Ruby Creek quartz-mica schist consists mainly of quartz-muscovite biotite schist, biotite-muscovite-quartz schist, and biotite-quartz-garnet schist. These rock types are interbedded through the formation. Known exposures indicate that the thickness is at least 7,500 feet, and may be very much greater.

The Raver formation contains coarse and fine-grained amphibolite, microcline-biotite schist, cordierite-microcline-biotite schist, lime-silicate rock, and quartzite. The thickness of the formation ranges from 100 to 200 feet.

The Ruddock schist consists principally of quartz-mica-feldspar schist, staurolite-garnet schist, sillimanite-mica schist, lime-silicate rock, and meta-conglomerate. Known exposures in the mapped area indicate that the thickness is at least 10,000 feet, and may be very much greater.

Most of the area lies on the east limb of a southeast plunging syncline. The rocks are strongly folded probably isoclinally. The prevailing direction of the strike of schistosity is N. 40° W., and the prevailing direction of dip is 45° SW. Linear elements plunge about 32° S. 16° W. Many small diversly oriented faults are recognized, but can be observed only where they displace pegmatites. A lineament that is probably a vertical shear zone was observed in sections 20 and 29.

Approximately 450 granite pegmatites, consisting mostly of plagioclase, quartz, perthite, and muscovite were mapped in the Ruby Creek quartz-mica schist and Ruddock schist. Only a few thin unmapped pegmatites less than one foot thick occur in the Raver formation. The pegmatites range from 5 feet to 2,600 feet in length, and from one-fourth inch to 100 feet in thickness. The pegmatites are classified either as homogeneous or heterogeneous. The homogeneous pegmatites are essentially uniform in mineral composition and texture from wall to wall. The heterogeneous pegmatites are zoned and contain distinct textural and mineralogic units in the form of concentric shells about an innermost core.

All the homogeneous pegmatites contain potash feldspar and scrap mica, and a few contain sheet mica and beryl, but for the most part the sizes of the pegmatites are so small and the grade of the deposits is too low to be of commercial value at the present time. The heterogeneous pegmatites contain commercial deposits of potash feldspar, mica, and beryl.

Placer deposits containing gold are found in the valley of French Creek, Ruby Creek, and Fourmile Creek. Dredging operations have been carried on in the valley of French Creek. Lode deposits in quartz veins are found in all metamorphic rocks, particularly in the Haver formation. A small amount of gold has been recovered from both types of deposits.

INTRODUCTION

Location and accessibility

The Fourmile area is in the southern Black Hills, Custer County, South Dakota. The area described in this report (fig. 1) contains 7.8 square miles. The latitude is about 43° 45' N., and the longitude about 103° 39' W. The topographic and geologic map of the Harney Peak quadrangle, prepared by the U. S. Geological Survey[1], includes the Fourmile area. Custer, the principal city in the area, has a population of about 2,000, and is approximately 4 miles east of Fourmile.

The region is easily accessible. United States Highway No. 16 goes through Custer and passes through the southern part of the Fourmile area. Secondary gravelled roads branching from the Federal highway traverse the north and southwest parts of the area. Many small logging and mining roads cross all parts of the district.

Topography and drainage

The Fourmile area is a region of moderate relief with an average elevation of about 5,500 feet above sea level. The maximum relief is about 700 feet. The highest peak, about 6,200 feet above sea level, is in the northeast corner of the mapped area. The rock formations are predominantly schists that offer approximately equal resistance to erosion, and no formation causes persistant valleys or high ridges. The ridges and upland slopes are wooded by a thin pine forest. Between the ridges are basin areas of rolling topography covered by grass and sparsely covered by trees.

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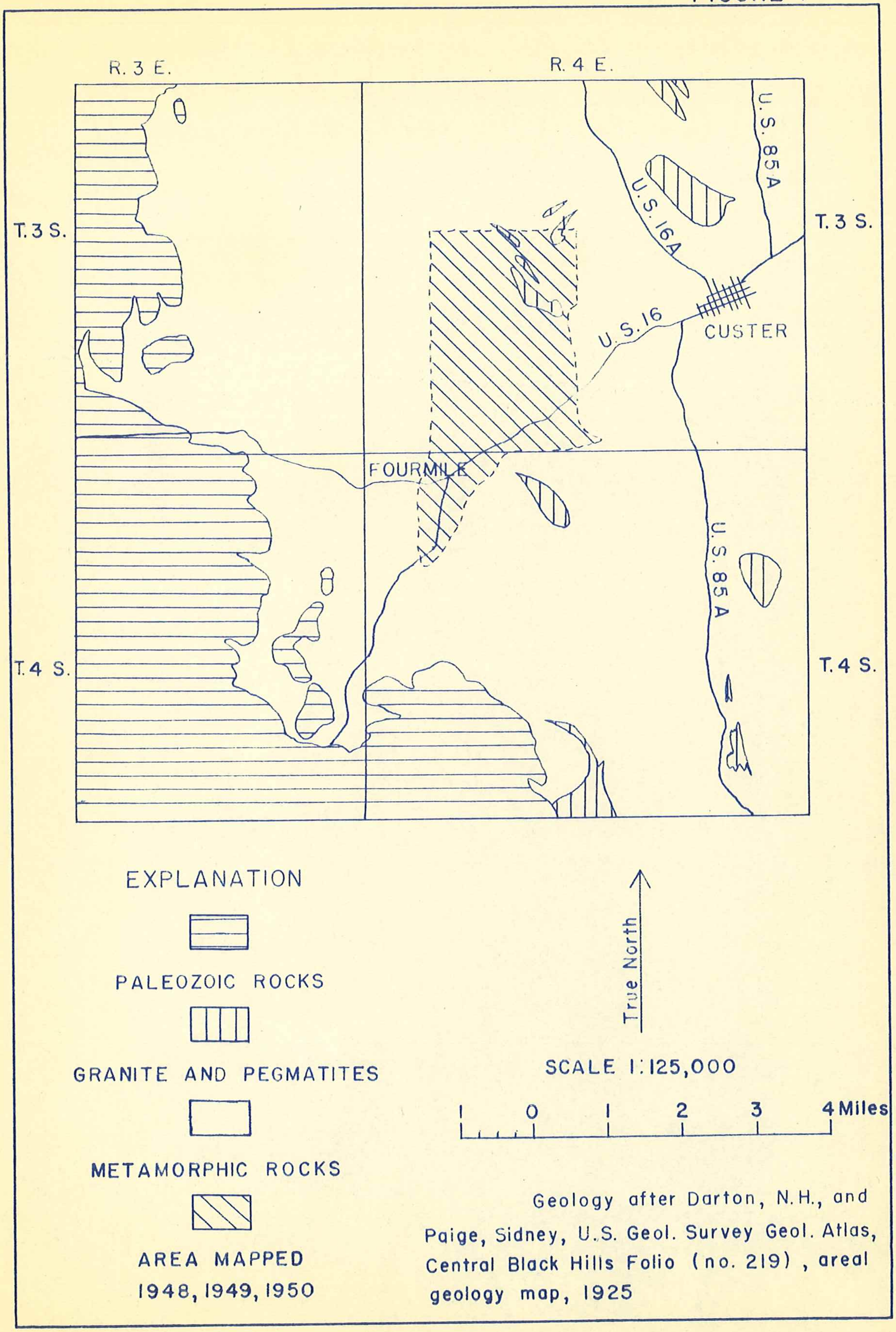
[1]Darton, N. H., and Paige, Sidney, U. S. Geological Survey Atlas, Centra Black Hills folio (no. 219), 1925.

FIGURE I



MAP OF THE SOUTHERN BLACK HILLS, SOUTH DAKOTA
SHOWING LOCATION OF FOURMILE AREA

The principal drainage in the north part of the Fourmile area is French Creek and its tributaries Ruby Creek and Crow Creek. The Valley of French Creek is essentially flat, and averages about 300 feet in width. It is locally cultivated. The southwest part of the area is drained by Fourmile Creek. Crow Creek, Ruby Creek, and Fourmile Creek are dry throughout the summer and autumn, but carry run-off after heavy precipitation. The drainage direction in the north part of the area is to the southeast, and in the southwest part of the area it is to the south.

Field work and acknowledgments

The field work for this report was done in seven months during the summers of 1948, 1949, and 1950. Mapping was done on aerial photographs enlarged to a scale of one inch to 1,000 feet (1:12,000). Pace-and-compass traverses were made of schist outcrops, contacts, and all pegmatites over one foot thick.

This work was done as a U. S. Geological Survey project in behalf of the Atomic Energy Commission. Petrographic studies were made under the supervision of Professor G. E. Goodspeed of the University of Washington.

Industries

The principal industries of the Fourmile area are mining, lumbering, and farming. Most of the mining has been of the pegmatites which have produced potash feldspar, sheet and scrap mica, and beryl. Gold-bearing quartz veins of small size are common in this area, particularly in the Mayer formation, but the amount of gold recovered is small. A deposit of gravel is found along the bottom of French Creek and has been dredged to recover gold.

Lumbering has been on a small scale, mostly by small operators and land owners. Locally the valleys of French Creek and Fourmile Creek have been cultivated for grain.

DESCRIPTIVE GEOLOGY

Metamorphic rocks

Three formations have been recognized in the Fourmile area. Names given to these formations are tentative because they have not been correlated with formations in other districts of the Black Hills. The lowest stratigraphic unit is named the Ruby Creek quartz-mica schist, the intermediate unit the Raver formation, and the highest stratigraphic unit is the Ruddock schist. The rocks were originally shale, siltstone, sandstone, conglomerate, impure magnesium limestone, and dolomitic shale and siltstone.

The metamorphism is high-grade. Minerals indicating high-grade metamorphism are sillimanite, cordierite, and diopside. These minerals are lacking over most of the area but their absence is due primarily to the original composition of the rocks and not temperature.

The exposed thickness of the three formations is at least 16,000 feet. The total thickness is unknown because the lower contact of the Ruby Creek quartz-mica schist and the upper contact of the Ruddock schist lie outside the mapped area.

Ruby Creek quartz-mica schist

The Ruby Creek quartz-mica schist occupies the north half of the mapped area. The formation was named after Ruby Creek which flows south across the formation in secs. 21 and 28. It is believed to be the oldest formation in the mapped area. The rocks are mostly quartz-muscovite-biotite schist, biotite-muscovite-quartz schist, and biotite-quartz-garnet schist. Modes are given in table 1. The rocks were derived from interbedded shales, siltstones, and sandstones.

Table 1.--Modes of the Ruby Creek quartz-mica schist, in percent

Number	1	2	3	4	5	6	7
Porphyroblasts							
Sillimanite	..	..	..	..	..	..	5
Garnet	3	7	..	..	6	2	..
Groundmass[1]							
Quartz	73	46	67	70	52	62	55
Plagioclase	7	..	10	12	15	10	15
Microcline	..	..	3	2	..	..	..
Biotite	15	35	15	10	15	12	15
Muscovite	tr	10	5	5	10	10	10
Zircon	tr	tr	tr	tr	tr	tr	tr
Tourmaline	..	..	..	..	tr	..	tr
Chlorite	..	..	..	1	..	..	..
Apatite	tr	tr	tr	tr	tr	tr	tr
Magnetite	2	1	tr	tr	2	1	tr
Size porphyroblasts in mm.	0.8	1.0	..	..	0.5	0.7	0.6
Size groundmass in mm.	0.5	0.4	0.6	0.4	0.3	0.3	0.2

[1]tr = less than 1 percent

Folding, lack of extensive outcrops, and possible repetition of beds make it almost impossible to calculate the true thickness of the formation. The base of the formation is not exposed but the known exposures indicate that the formation is at least 7,500 feet thick. The total amount of outcrop does not exceed 5 percent. The schist has a low resistance to erosion and single exposures of over 100 feet across the dip are not found. In the northeast corner of the area a resistant quartzite crops out and produces the highest elevation in the mapped area.

The Ruby Creek quartz-mica schist is light to dark grey and has an average grain size of about 0.5 millimeter. The rock contains abundant parallel laminae of mica which gives the rock a strong schistosity. The most abundant constituents are quartz, muscovite, and biotite. The rock is mostly even grained but occasionally shows crystals of micas, as much as 2 millimeters in length, transverse to the schistosity, and crystals of garnet, as much as 2 millimeters in diameter, in the more biotite-rich beds.

The lithologic uniformity of the formation is striking and bedding is poorly defined. In many places it is difficult to distinguish bedding from schistosity. The observed beds range from a fraction of an inch to several feet in thickness. Locally, alternating layers of micaceous quartzite, quartz-mica schist, and mica-quartz are found. Most of the foliation planes are parallel to the bedding planes although they may intersect each other at angles as much as 15 degrees. Parallel mica crystals and small scale crenulations in the plane of foliation form a linear pattern.

Thin sections of the Ruby Creek quartz-mica schist indicate the average composition is about 60 percent quartz, 15 percent biotite, 10 percent muscovite, 10 percent plagioclase, and 5 percent accessory garnet, magnetite, microcline, zircon, apatite, sillimanite, and tourmaline. The texture is crystalloblastic with occasional porphyroblasts of biotite, muscovite, garnet, and sillimanite. The structure of the schist is caused by a dimensional orientation of quartz, and parallelism of biotite and muscovite. The rock is unaltered except for rare shreds of penninite replacing biotite, and slight alteration of feldspars to kaolin and sericite.

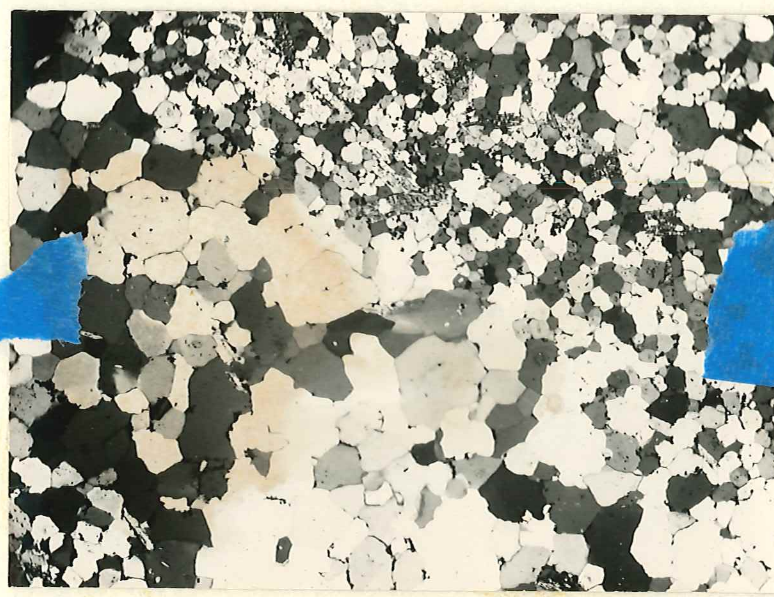
Quartz occurs as irregular to lenticular shaped grains averaging 0.5 millimeter in diameter. There is a tendency for many grains to be flattened in the plane of schistosity. The quartz shows smooth, rarely interlocking boundaries. (See pl. IA). The schist also contains many small segregation veinlets of quartz, with accessory micas and plagioclase, which are as much as one inch thick and 15 inches long. The texture is typically granoblastic.

Biotite occurs in laths parallel to the schistosity and as ragged porphyroblasts transverse to the schistosity. In some places biotite is concentrated into narrow bands up to 3 inches thick. These layers consist chiefly of biotite, quartz, and garnet, and others of biotite, plagioclase, and quartz. The biotite porphyroblasts enclose grains of quartz and more rarely plagioclase. Small grains of zircon, causing intense pleochroic halos, and magnetite are common in biotite.

Muscovite occurs in laths in the plane of schistosity and as porphyroblasts that are across the schistosity. The average grain size of the muscovite in the groundmass is 0.4 millimeter, and the porphyroblasts range from 0.8 to 2 millimeters in length. Muscovite occurs predominantly in the quartz-rich beds.

Plate I

A. Photomicrograph of Ruby Creek quartz-mica schist, showing textural bedding. The large irregular grains are quartz, the laths are biotite and muscovite, and the opaque grains are magnetite. Crossed nicols. X16.



B. Photomicrograph of Ruby Creek quartz-mica schist. Dark mineral is almandite with abundant opaque inclusions of magnetite and some quartz. Other minerals are quartz and mica. Plain light. X16.

Plagioclase occurs in the groundmass in grains of about the same size and shape as quartz. The average index of refraction (Np) is 1.533 ± .003, and indicates an oligoclase (An_{12}) in composition. Albite twinning is almost completely absent.

Garnet may form as much as 20 percent of the biotite-quartz-garnet schist, but in most rocks it is absent or present only in very small amounts. It invariably contains numerous inclusions, principally quartz and plagioclase, but also biotite and magnetite. (See pl. IB).

Microcline was found in two thin sections where it occurs as small grains associated with plagioclase and quartz.

Apatite and zircon, in euhedral to subhedral crystals, are evenly distributed accessory minerals and occur as inclusions in quartz, plagioclase, and micas. Magnetite is a plentiful accessory. Penninite is rare, and forms as an alteration product of biotite, probably formed during retrograde metamorphism. Sillimanite was found in three localities. It occurs as fine radiating fibers and groups of fibers oriented in the plane of schistosity.

Raver formation

The Raver formation goes east-southeast through the central part of the mapped area. It is named for the Raver ranch that covers a part of the formation in sec. 33. The formation contains amphibolite, microcline-biotite schist, cordierite-microcline-biotite schist, lime-silicate rocks, and quartzite. Modes of these units are given in table 2.

The true thickness of the formation is unknown, but probably ranges from 100 to 200 feet. The outcrop width ranges from 150 feet

Table 2.--Modes of the Raver formation, in percent

Number	1	2	3	4	5	6	7	8
Porphyroblasts								
Hornblende	65	50	70	60	..	..	..	15
Diopside	..	..	..	..	..	..	..	..
Microcline	..	..	..	..	..	..	..	..
Scapolite	..	..	..	..	..	..	..	..
Garnet	..	10	..	..	..	..	..	..
Groundmass[1]								
Quartz	12	20	7	18	7	8	28	20
Plagioclase	18	30	18	30	20	18	42	..
Microcline	..	..	..	..	..	..	..	30
Hornblende	5	10	..	..	70	70	30	..
Diopside	..	..	..	..	..	..	..	..
Biotite	..	..	tr	..	..	..	..	35
Calcite	..	..	tr	..	..	..	..	..
Muscovite	..	..	..	..	..	..	..	..
Epidote	..	..	..	..	..	..	..	..
Clinozoisite	..	..	tr	..	..	tr	..	..
Sphene	..	..	3	tr	2	3	..	..
Cordierite	..	..	..	..	..	..	..	..
Zircon	..	..	..	tr	..	..	..	..
Tourmaline	..	..	..	..	..	..	..	..
Chlorite	..	..	..	..	..	..	tr	..
Apatite	tr	tr	tr	tr	tr	tr	tr	tr
Magnetite	1	1	1	2	1	1	tr	tr
Structure[2]	G	G	G	G	S	S	G	S
Size porphyroblasts in mm.	1.3	0.8	1.6	1.0	..	..	..	1.0
Size groundmass in mm.	0.2	0.1	0.1	0.2	0.3	0.3	0.3	0.1

[1] tr = less than 1 percent
[2] G = granoblastic, S = schistose

1. Coarse-grained amphibolite
2. Coarse-grained amphibolite
3. Coarse-grained amphibolite
4. Coarse-grained amphibolite
5. Fine-grained amphibolite
6. Fine-grained amphibolite
7. Fine-grained amphibolite
8. Microcline-biotite schist

Table 2. Continued--Modes of the Rover formation, in percent

Number	9	10	11	12	13	14	15	16
Porphyroblasts								
Hornblende	..	..	..	..	..	..	..	..
Diopside	..	..	..	..	25	45	30	..
Microcline	..	..	3	..	..	..	..	..
Scapolite	..	..	..	..	..	..	..	10
Garnet	..	..	..	..	..	..	..	..
Groundmass[1]								
Quartz	40	38	3	5	10	10	17	20
Plagioclase	5	..	5	5	20	20	40	20
Microcline	30	45	15	20	15	2	10	5
Hornblende	..	..	..	..	15	5	tr	7
Diopside	..	..	..	..	..	..	..	15
Biotite	15	15	10	10	3	..	2	tr
Calcite	..	..	..	..	10	15	tr	15
Muscovite	..	tr	2	tr	..	..	tr	..
Epidote	..	..	..	..	tr	3	..	5
Clinozoisite	6	..	..	2	3	..	tr	tr
Sphene	1	tr	5	3	2	tr	1	2
Cordierite	..	..	52	55	..	..	..	..
Zircon	tr	tr	..	..	..	..	..	..
Tourmaline	..	..	..	..	..	..	..	tr
Chlorite	..	..	..	..	..	..	..	..
Apatite	tr	tr	tr	tr	tr	tr	tr	tr
Magnetite	tr	tr	tr	tr	tr	tr	tr	tr
Structure[2]	S	S	S	S	G	G	G	G
Size prophyroblasts in mm.	..	..	4.0	..	2.0	4.0	3.0	5.0
Size groundmass in mm.	0.1	0.2	0.5	0.4	0.4	0.3	0.3	0.1

[1]tr = less than 1 percent
[2]G = granoblastic, S = schistose

9. Microcline-biotite schist
10. Microcline-biotite schist
11. Cordierite-microcline-biotite schist
12. Cordierite-microcline-biotite schist
13. Lime-silicate rock
14. Lime-silicate rock
15. Lime-silicate rock
16. Lime-silicate rock

in sec. 32, to 1,500 feet in sec. 33. The variation in thickness is probably due to tectonic thickening and thinning, and to variations in thickness of the original sedimentary bed. The formation is not continuously exposed but is recognized in small widely scattered outcrops and as float.

Amphibolite.

Amphibolite is the most abundant rock of the Raver formation, and is best exposed in small outcrops and prospect pits in the SE¼ sec. 33 and SW¼ sec. 34. Exposures of amphibolite are rare in the west half of the area. The rock may be divided into coarse-grained and fine-grained amphibolites. The stratigraphic position of the amphibolites in the Raver formation varies from place to place. Outcrops are too widely scattered to determine the exact relationship between the two rock types, but the fine-grained rock is more common toward the upper and lower contacts of the formation, and the coarse-grained amphibolite is more common near the center of the formation.

Coarse-grained amphibolite.

The coarse-grained amphibolite is dark green, medium to coarse-grained, and consists mainly of green hornblende, plagioclase, and quartz. Garnet locally is an abundant constituent. Other accessory minerals are sphene, magnetite, apatite, clinozoisite, calcite, and biotite.

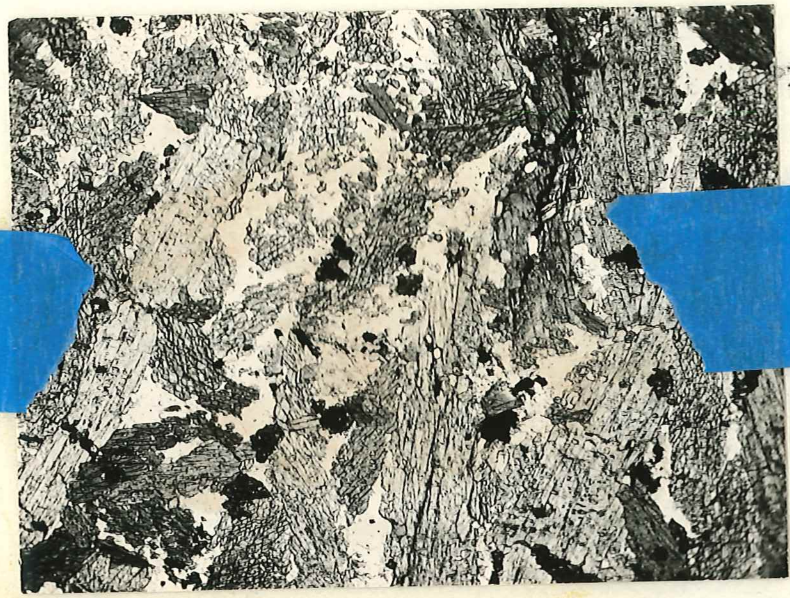
The rock shows more or less banded structure with alternating layers of hornblendic and feldspathic units, and intercalated lime-silicate bands of varying thickness. The bands range from less than one inch to several feet in thickness.

The texture of the plagioclase-quartz matrix is granoblastic, and the dominant texture of the hornblende is porphyroblastic. Subparallelism of hornblende can be recognized in many thin sections, but generally the rock is structureless. When biotite is present in quantity, it is commonly oriented showing a parallel arrangment. The grain size of the groundmass is fairly uniform and averages 0.2 millimeter. The hornblende crystals average about 1.5 millimeters in length.

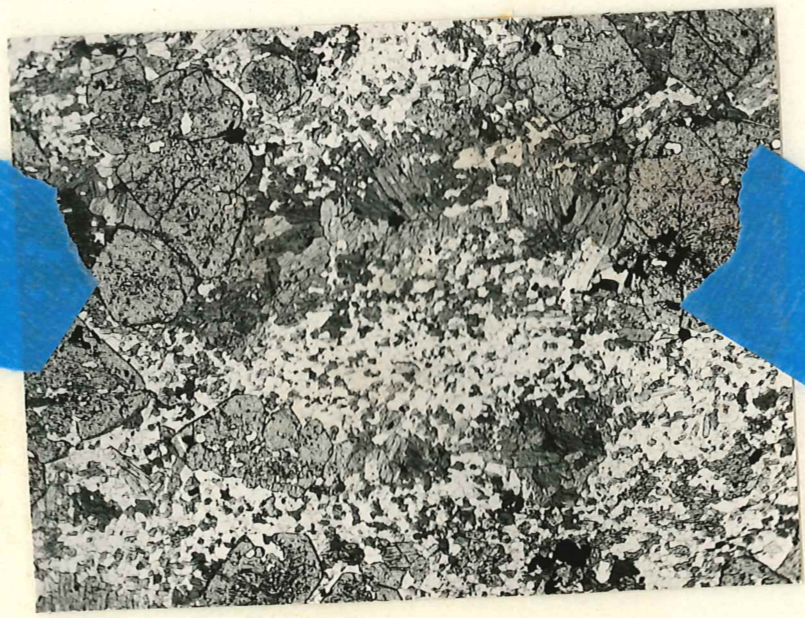
Hornblende is the dominant mineral and appears in thin section as acicular crystals, stout prisms, and anhedral plates sieved and embayed by plagioclase and quartz (See pl. IIA). Tiny euhedral prisms of hornblende are found in the groundmass and enclosed in hornblende porphyroblasts. Two kinds of amphibole are found. One type has optical properties as follows: biaxial negative, $2V=80^\circ$, $Z \wedge c=27^\circ$, pleochroism: X=straw yellow, Y=green, Z=greenish-blue, and intensity $X<Y<Z$. This amphibole is by far the commonest type of hornblende in the coarse-grained amphibolites. The second type of amphibole is slightly green to colorless and has the following optical properties: $2V=60^\circ$, $Z\ c=19^\circ$, $N_p=1.644$, $N_m=1.652$, $N_g=1.662$ (all $\pm$ .003). Optical properties indicate the mineral to be actinolite in composition. It occurs as slender prisms, as much as 1.5 millimeters in length, and as irregular blotches in and colorless rims around green hornblende crystals. The colorless blotches and rims are in homoaxial intergrowth with the green hornblende. The birefringence of the colorless amphibole is distinctly higher than the hornblende.

The groundmass consists of a fine mosaic of plagioclase and quartz. The plagioclase is in clear rounded grains that only rarely show albite twinning. Occasionally much larger plagioclase crystals, sieved by quartz granules, are found in the groundmass. The plagioclase is dominantly andesine, although the composition range is from oligoclase (An_{22}) to bytownite (An_{80}). Commonly the plagioclase grains have cores that are

Plate II



A. Photomocrograph of coarse-grained amphibolite, showing porphyroblasts of hornblende sieved by plagioclase and quartz. White areas are fine-grained plagioclase and quartz groundmass. Plain light. X16.



B. Photomicrograph of coarse-grained amphibolite. Coarse subhedral crystals are almandite, associated with biotite laths. Other minerals are hornblende (grey), plagioclase and quartz (white areas). Plain light. X16.

more sodic than the rims. This reverse zoning is recognisable in many grains, and is shown by an increase in extinction angle and refractive index toward the outer rims. Locally sericite is abundant in the plagioclase, rarely accompanied by clinozoisite, and probably represents retrograde metamorphism.

Quartz also occurs in small rounded grains and is similar in appearance to the plagioclase. It occurs in smaller quantities, and unlike plagioclase forms small segregations and veinlets.

Euhedral garnet porphyroblasts are from 0.4 millimeter to 1.2 centimeters in diameter (See pl. XIB). They contain inclusions of quartz and plagioclase, and rarely grains of hornblende, magnetite, and biotite. The inclusions tend to concentrate near the center of the porphyroblasts, and the rims are generally clear. The garnetiferous amphibolites contain a greater amount of plagioclase and quartz, and corresponding by lesser amount of hornblende than do the non-garnetiferous amphibolites.

Sphene is an uncommon accessory, but occasionally forms as much as 5 percent of the rock. It occurs in euhedral to rounded grains, singly or in aggregates. An opaque mineral, probably ilmenite, forms skeleton crystals in many grains of sphene. Magnetite is an abundant though minor accessory mineral. Apatite is present both as minute acicular prisms and as rounded grains of larger size. Calcite and biotite are very rare. The biotite is associated with hornblende and magnetite grains.

Fine-grained amphibolite.

The fine-grained amphibolite is typically fine- to medium-grained and light-to dark-green. The rock consists mainly of hornblende, which is generally the only mineral distinguishable in hand specimen, and plagioclase and quartz. The fine-grained amphibolite is more abundant than the coarse-grained amphibolite.

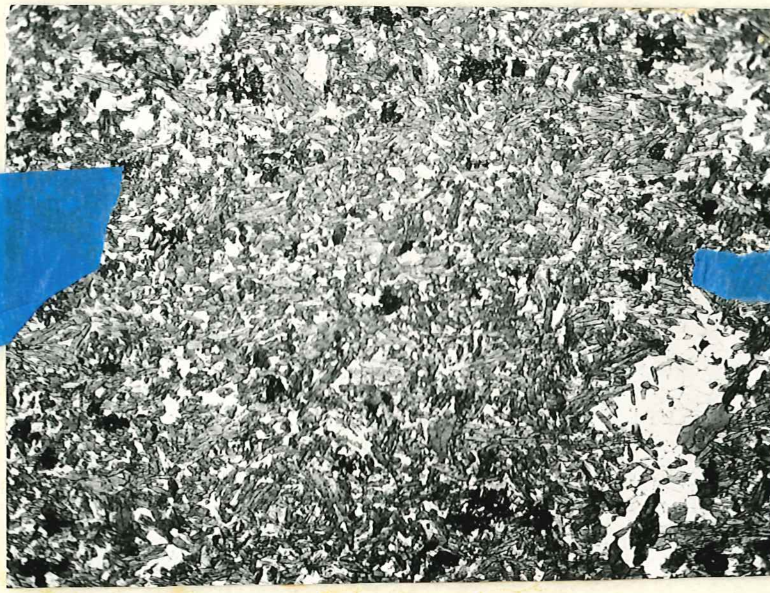
The optical properties of the hornblende in the two types of amphibolites is the same. The average grain size is about 0.5 millimeter in length. The crystals are evenly disseminated throughout the rock as poorly aligned prisms and ragged plates (See pl. III). The crystals are uniformly dark-green, and are rarely sieved by plagioclase and quartz, but may contain abundant grains of sphene. Between the crystals of hornblende are rounded grains of plagioclase and quartz that form the groundmass of the fine-grained amphibolites. The size of most grains fall within the range 0.1 to 0.4 millimeter. The plagioclase varies from An_{20} to An_{65} in composition, and, as in the coarse-grained amphibolites, there are probably all gradations between these extremes. Most of the plagioclase in the amphibolites is andesine. Albite twinning is rare, but reverse zoning, as seen in the coarse-grained amphibolites, is common. Most of the plagioclase and quartz is uniformly distributed throughout the rock, but occasionally are segregated into small pockets and lenses of coarser grains than the groundmass.

Sphene is present in a few sections and occurs in grains averaging about 0.1 millimeter in diameter, and in clusters. Apatite and magnetite are common accessories, and are present in all of the thin sections. Clinozoisite was noted in one section to replace plagioclase.

Microcline-biotite schist.

In the SE¼ sec. 33, and the SW¼ sec. 34, microcline-biotite schist crops out in an irregular belt near the middle of the formation. The schist is dark-brown, and fine-grained. Poorly defined beds range in

Plate III



Photomicrograph of fine-grained amphibolite. Grey mineral is fine needles of hornblende, and white areas are plagioclase and quartz. Plain light. X16.

thickness from one-half inch to several feet. The rock contains light-green bands and lenses, as much as one-half inch thick, that consist mostly of diopside, calcite, and feldspars. Schistosity, caused mainly by biotite, is fairly well formed. The maximum outcrop width of the schist member is 250 feet, but the average thickness is about 50 feet.

The microcline-biotite schist consists of microcline, biotite, plagioclase, muscovite, quartz, magnetite, hornblende, clinozoisite, sphene, apatite, and zircon. The texture is mainly crystalloblastic, modified by rare porphyroblasts of hornblende. (See pl. IV) The grain size ranges from 0.01 to 0.5 millimeter, and averages about 0.1 millimeter.

Microcline is the dominant constituent and averages about 40 percent of the rock. It occurs in irregular anhedral grains showing cross-hatch twinning. Plagioclase, rarely showing albite twinning, is present in smaller amount than the microcline, but locally forms as much as 50 percent of the rock. Its habit is similar to the microcline but commonly is finer grained. Abundant inclusions of apatite, biotite, magnetite, zircon, and rarely quartz and muscovite are found in both feldspars. The feldspars have a granoblastic texture.

Biotite constitutes about 25 percent of the rock, and occurs as small shreds, coarse irregular plates, and rarely as lense-shaped aggregates of small plates. Inclusions of sphene and magnetite are common, and pleochroic halos formed by zircon (?) are abundant in most sections. Muscovite, everywhere subordinate in amount to biotite, occurs in fine to coarse plates that are transverse to the bedding. It is probably later than most of the biotite.

Quartz in the schist is similar in habit to the feldspars, but generally forms less than 5 percent of the rock. Magnetite is abundant

Plate IV

Photomicrograph of microcline-biotite schist. Large porphyroblasts of hornblende are sieved by biotite and plagioclase. Groundmass is biotite (grey), and plagioclase and quartz (white). Plain light. X16.

in small grains included in all other minerals. Hornblende is a rare constituent of the rock but occurs abundantly in schists containing diopside-calcite bands. It forms large euhedral porphyroblasts, as much as 2 millimeters in length, sieved by biotite and feldspars. Clinozoisite is a rare accessory and was found in only one thin section. Sphene is an abundant accessory, occurring as small inclusions in biotite and feldspars, and as aggregates of grains as much as one millimeter in length. Apatite and zircon are also common accessories and are found as inclusions in biotite, feldspars, and quartz.

Cordierite-microcline-biotite schist.

A thin bed of cordierite-microcline-biotite schist associated with microcline-biotite schist occurs in the N½SE¼ sec. 33. There is probably a gradation between the two rock types. The thickness of this unit is probably less than 50 feet. The rock has a dark-brown groundmass which encloses grey grains of cordierite and a few coarse grains of microcline which on weathered surface appear as small knobs and lenses. The cordierite averages about one millimeter in diameter, and the microcline crystals as much as one centimeter in length.

The schistosity in most places is poorly formed. The rock has a layered structure parallel to the schistosity and consists of alternations of schist and light-green layers that consist mainly of diopside, calcite, and feldspars. (See pl. VA) The layers range from one-eighth inch to 6 inches in thickness.

In thin section the rock consists of cordierite, microcline, biotite, plagioclase, quartz, muscovite, sphene, magnetite, apatite, and zircon. The texture is crystalloblastic with a colorless base of mosaic cordierite, feldspars, and quartz. Small biotite and muscovite flakes are aligned

Plate V

A. Banded cordierite-microcline-biotite schist showing alternations consisting mainly of diopside, calcite, and feldspars.

B. Photomicrograph of cordierite-microcline-biotite schist. White and grey porphyroblasts are cordierite; groundmass is microcline, biotite, plagioclase, quartz, muscovite, and sphene. Crossed nicols. X16.

parallel to the schistosity. The grain size varies from less than 0.1 millimeter to 1 centimeter (microcline), and averages about 0.4 millimeter.

The principal constituent is cordierite which averages about 50 percent of the rock. It occurs in equidimensional grains, averaging one millimeter in diameter, some of which have penetration twins and polysynthetic twinning. (See pl. VB) The optical properties of the cordierite are as follows: biaxial negative, 2V ca. 65°, N_p-1.577, N_m-1.581, N_g-1.584 (all ± .003). Much of the cordierite is clouded with fine-grained inclusions consisting of euhedral prisms of apatite, occasional magnetite and zircon, and abundant muscovite and biotite which in some grains are oriented parallel to the schistosity. Cordierite is partly replaced by muscovite, or it may be entirely altered to a felted mass of sericite shreds.

Microcline is less plentiful than cordierite and generally forms about 20 percent of the rock. Its habit is similar to cordierite but tends to form larger grains. Microcline twinning is developed unevenly and in some grains it is lacking. Many of the large plates of microcline are made up of small plates, each with a different orientation. Included minerals are the same as in cordierite but are more abundant in microcline and in addition contain small blebs of quartz.

Biotite and muscovite are closely associated and together make up about 15 percent of the rock. They occur as small, poorly aligned shreds and flakes to coarse ragged plates. Both micas may form laminae, which in some places are relatively thick and continuous, alternating with layers of cordierite and feldspars. Mica flakes may curve around cordierite or abut sharply against them; both relationships are seen in a single slide. The coarse mica plates, sieved by feldspars and quartz, transect the schistosity and are probably of late origin.

The most plentiful of the minor constituents are plagioclase and quartz, which occur in small anhedral grains between cordierite and microcline. Plagioclase (An_{65}) is usually the more abundant. Few grains contain albite twinning. Much of the plagioclase is clouded with sericite, probably of retrograde origin. Sphene occurs as isolated anhedral grains and as abundant wedge-shaped aggregates of small grains. It is an unusually abundant, evenly distributed accessory mineral. Apatite, in small euhedral to subhedral prisms, and magnetite grains are common inclusions. Zircon is a rare accessory.

Lime-silicate rock.

In the Ravor formation are found a group of rocks consisting chiefly of lime-silicate minerals. The best exposures are found in the SE¼ sec. 33. The stratigraphic position of the rock varies from place to place, but is most common near the center and upper contact of the formation. The maximum thickness approximates 200 feet, but the average thickness is probably less than 50 feet. Considerable tectonic thickening and thinning has caused the member to vary greatly in thickness, and locally to pinch out along strike.

The rock has considerable variation in structure and color. It is characterized by the presence of numerous bands and lenses which are elongate in the direction of strike of bedding. This layering, at least in part, probably is bedding. Drag folding in the rock is common resulting in numerous small crenulations. The bands are as much as 12 inches in thickness and occur as alternations of brownish and greenish layers. The brown beds are chiefly feldspar with variable amounts of biotite and hornblende, and the green are composed mainly of diopside, feldspars, calcite, and epidote minerals.

The lime-silicate rock has a fine- to coarse-grained granular texture. The most diagnostic mineral is greenish diopside which may reach a size of one centimeter. In hand specimen the bands containing hornblende and biotite are oriented in planes showing a well-developed schistosity.

The rock consists of diopside, calcite, clinozoisite, epidote, microcline, plagioclase, scapolite, hornblende, biotite, quartz, sphene, and magnetite. The texture is typically granoblastic modified by the common occurrence of porphyroblasts of diopside and hornblende. The individual minerals differ considerably in size; those in the groundmass averaging from less than 0.1 millimeter to 3 millimeters, whereas the porphyroblasts are as much as one centimeter in length. The minerals in thin section contains no alteration products except for local retrograde metamorphic effects.

The diopside is colorless or pale-green. It forms small prisms or aggregates, amoeba-like incipient porphyroblasts, and large plates, most of which are intensely sieved and embayed by groundmass material. The porphyroblasts are characteristically spongy and commonly cover the entire field of view under the microscope. They consist of apparently disconnected blebs that are optically continuous. Diopside and pale-colored hornblende are sometimes found intergrown. The diopside may partially rim and embay hornblende as clear grains and is replacing the latter. For the most part the two minerals have crystallized at the same time. Diopside is abundantly and evenly scattered throughout the lime-silicate layers, but occurs sporadically and in minor quantity in the schist layers.

The contact between the feldspar-biotite-hornblende schist and lime-silicate rock is marked in some places by a very thin band containing sphene granules. On the schist side of the contact hornblende occurs to the exclusion of almost all diopside, but on the other side hornblende is unstable in the presence of excess calcite and abundant diopside has developed. On the lime-silicate side of the contact is found a thin layer of pale green hornblende crystals usually accompanied and being replaced by diopside.

The calcite is invariably present in the lime-silicate layers, and it is found in the accompanying schist only in very small quantity. The grains vary from small crystalloblasts to large irregular crystals enclosing quartz and feldspars, and occasionally diopside and hornblende. Clinozoisite is abundant in some sections, but epidote is subordinate. These minerals are in elongate crystals and rounded grains averaging 0.2 millimeter in diameter. Some clinozoisite and epidote apparently have formed as primary metamorphic minerals, but most of the clinozoisite is secondary. It is commonly found in patches in clouded lime-plagioclase and as rims enclosing remnants of plagioclase. It also occurs rimming diopside and along contacts between diopside and plagioclase. Clinozoisite invariably shows anomalous blue and yellow birefringence. Part of the epidote is slightly pleochroic, yellow to colorless; the center of the grains showing a higher birefringence than the rims.

Microcline and plagioclase occur in irregular grains; the former shows typical checkerboard twinning, and the latter twinning after the albite law. Some crystals of plagioclase are made up of small plates, each with a different orientation, and under crossed nicols show a checkerboard appearance. Part of the feldspar is untwinned. Generally the grains range from 0.1 to 1 millimeter in diameter, but crystals of microcline up to 6 millimeters have been observed (See pl. VIA). In the schist layers microcline forms up to about 50 percent of the rock, but in the lime-silicate layers the average amount is about 8 percent. Plagioclase occurs in somewhat greater amount than the microcline in the lime-silicate layers, and forms about 30 percent of the schist. The composition of plagioclase is labradorite (An_{55}) to calcic-bytownite (An_{85}). Inclusions of quartz grains, little prisms of sphene, and flakes of magnetite are common in feldspars. Throughout the rock feldspars are generally fresh, but locally plagioclases altered to sericite, clinozoisite, and rarely scapolite. Quartz is identical in appearance with the feldspars, but generally is finer grained and in smaller amounts.

Hornblende is a minor constituent in the lime-silicate rock but is one of the dominant constituents in the associated schist layers. It occurs in small irregular grains, needle-like prisms, and larger plates embayed and sieved by plagioclase, quartz, calcite, and microcline. The average grain size is about 0.3 millimeter in the lime-silicate rock, and 0.2 millimeter in the schist. The pleochroic scheme for the hornblende in the lime-silicate rock is X-colorless, Y-very light pale green, Z-pale green. The angle between Z and c is 19 degrees. Optical properties indicate the mineral to be actinolitic hornblende in composition. The hornblende of the schist is darker colored and has X-very light yellow-green, Y-light-green, Z-green. The angle between Z and c is 20 degrees. Biotite is associated with hornblende in the schist, but is rare in the lime-silicate rock. It forms small ragged flakes and shreds, dark-brown

Plate VI

A. Photomicrograph of lime-silicate rock. Large porphyroblast of microcline shows cross-hatch twinning. Other minerals are diopside, plagioclase, microcline, calcite, sphene, and quartz. Crossed nicols. X16.

B. Photomicrograph of lime-silicate rock. Large porphyroblasts of scapolite (white and grey, covering almost the entire field of view) intensely sieved by quartz, plagioclase, microcline, epidote, sphene, and calcite. Crossed nicols. X16.

to olive-green, and has a poor orientation. Where found in the lime-silicate rock, the biotite is coarser grained and has a distinct reddish tint.

Scapolite is found in at least two localities and forms plates to 5 millimeters in diameter (See pl. VIB). It is intensly sieved by quartz, plagioclase, microcline, epidote, sphene, and calcite grains. The birefringence is near middle second order and approaches meionite in composition. A second occurrence of scapolite was found replacing plagioclase.

Sphene occurs abundantly as minute wedge-shaped grains comprising as much as 15 percent of the schist. It occurs in less quantity in the lime-silicate rock but is much coarser grained and may form large spongy porphyroblasts up to 2 millimeters in diameter. Magnetite is invariably present as small flakes included in all other minerals.

Quartzite.

Quartzite occurs as thin discontinuous beds that are either near the upper or lower contact of the Raver formation. The beds range from 5 to 30 feet in thickness. Bedding within the quartzite is not everywhere visible but where found consists of bands one-eighth inch to several feet thick. Quartz veinlets cut the rock in many places. The quartzite locally shows evidence of shearing and is broken by closely spaced fractures.

Quartz constitutes about 95 percent of the rock, the average grain size which is about 0.3 millimeter in diameter. The texture is typically granoblastic. The grains are sharply outlined with curved boundaries. Sutured or interlocking boundaries are entirely absent. Undulatory extinction is lacking except where the rock is cut by shear zones.

The minor constituents are magnetite, graphite, sericite, tourmaline, calcite, apatite, microcline, and rutile. Magnetite and graphite are locally present in sufficient quantities to produce a banded structure. Individual bands and pockets may contain as much as 60 percent graphite. Sericite appears as minute scales between quartz grains, and as an alteration product of microcline. Black tourmaline has been locally introduced and forms as much as 50 percent of the rock. It occurs as small euhedral to subhedral crystals up to one centimeter in length. Calcite is commonly found in the tourmaline-rich quartzites. A few microcline grains were noted in one thin section. Apatite is present both as fine acicular needles and as rounded grains of larger size.

Ruddock schist

The Ruddock schist extends throughout the southwest part of the mapped area. This formation is the uppermost stratigraphic unit in the mapped area.

The Ruddock schist consists for the most part of quartz-mica-feldspar schist. Outcrops are not abundant and form less than 5 percent of the area. No attempt was made to calculate the total thickness of the formation because the top of the formation was not found. Intense folding and shearing, and probably repetition of beds would prohibit an accurate calculation. The known exposures in the area indicate that the formation is at least 10,000 feet thick.

The Ruddock formation consists of (1) quartz-mica-feldspar schist, (2) staurolite-garnet schist, (3) sillimanite-mica schist, (4) lime-silicate rock, (5) meta-conglomerate. Modes estimated from thin sections of these rocks are given in table 3.

Quartz-mica-feldspar schist.

Quartz-mica-feldspar schist is the most abundant rock in the Ruddock schist. The schist is light to dark grey, and fine- to coarse-grained. The rock generally has a good schistosity produced by the parallelism of muscovite and biotite, and the dimensional orientation of quartz and feldspars. Bedding is poorly defined throughout most of the formation, and where observed the bed range from one-eighth inch to several feet in thickness. Quartz-mica-feldspar schist and quartz-mica schist are interbedded at many places.

Thin sections show the rock to consist of about 60 percent quartz, 20 percent feldspars, 12 percent biotite, 7 percent muscovite, and 1 percent garnet, apatite, magnetite, zircon, and tourmaline. The texture of the rock is predominately crystalloblastic. The grain size ranges from 0.3 to 1 millimeter, and averages about 0.7 millimeter. A few large grains of quartz, plagioclase, and microcline, as much as 5 millimeters in diameter, are found in the coarse-grained arkosic beds.

Quartz is the most abundant mineral and occurs in anhedral grains and lenticular aggregates. (See pl VIIA) The smaller quartz grains, together with feldspars and micas, make up the groundmass of the schist. Larger quartz grains and aggregates probably represent original recrystallized grains and sheared and stretched pebbles. (See pl. VIIB)

Table 3.--Modes of the Ruddock formation, in percent

Number	1	2	3	4	5	6
Porphyroblasts						
Sillimanite	..	..	..	..	..	..
Garnet	..	..	..	..	..	2
Staurolite	..	..	..	..	..	7
Hornblende	..	..	..	..	..	..
Diopside	..	..	..	..	..	..
Groundmass[1]						
Quartz	55	62	61	60	65	24
Plagioclase	14	15	12	10	10	7
Microcline	10	6	4	12	8	..
Diopside	..	..	..	..	..	..
Biotite	15	12	15	10	10	54
Calcite	..	..	..	..	..	..
Muscovite	6	5	7	8	7	5
Epidote	..	..	..	..	..	..
Clinozoisite	..	..	..	..	..	..
Sillimanite	..	..	..	..	..	tr
Sphene	..	..	..	..	..	..
Garnet	..	..	1	..	..	..
Orthoclase	..	..	..	..	..	..
Zircon	tr	tr	tr	tr	tr	..
Tourmaline	..	..	tr	..	tr	1
Chlorite	..	..	..	..	..	tr
Apatite	tr	tr	tr	tr	tr	tr
Magnetite	tr	tr	tr	tr	tr	tr
Structure[2]	S	S	S	S	S	S
Size prophyroblasts in mm.	..	..	..	..	..	4.0
Size groundmass in mm.	0.5	0.4	0.4	0.3	0.8	0.5

[1]tr = less than 1 percent
[2]S = schistose, G = granoblastic

1. Quartz-mica-feldspar schist
2. Quartz-mica-feldspar schist
3. Quartz-mica-feldspar schist
4. Quartz-mica-feldspar schist
5. Quartz-mica-feldspar schist
6. Staurolite-biotite schist

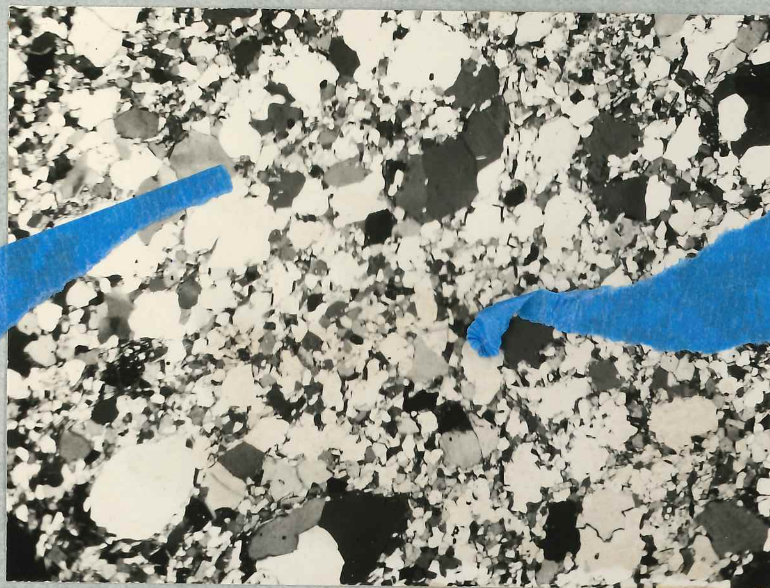
Table 3. Continued--Modes of the Ruddock formation, in percent

Number	7	8	9	10	11
Porphyroblasts					
Sillimanite	10	15	15	..	..
Garnet	..	1	1	5	5
Staurolite	..	..	..	..	..
Hornblende	..	..	..	10	17
Diopside	..	..	..	20	..
Groundmass[1]					
Quartz	52	40	53	15	35
Plagioclase	12	12	10	5	20
Microcline	..	..	..	20	5
Diopside	..	..	..	..	10
Biotite	15	25	12	..	..
Calcite	..	..	..	20	..
Muscovite	10	7	8	..	..
Epidote	..	..	..	2	..
Clinozoisite	..	tr	tr	2	7
Sillimanite	..	..	..	..	..
Sphene	..	..	..	1	1
Garnet	..	..	..	..	..
Orthoclase	1	..	..	..	..
Zircon	tr	tr	tr	tr	tr
Tourmaline	tr	tr	tr	tr	..
Chlorite	tr	tr	1	..	..
Apatite	tr	tr	tr	tr	tr
Magnetite	tr	tr	tr	..	tr
Structure[2]	S	S	S	G	G
Size porphyroblasts in mm.	1.9	2.2	2.6	1.0	1.5
Size groundmass in mm.	0.5	0.7	0.6	0.1	0.2

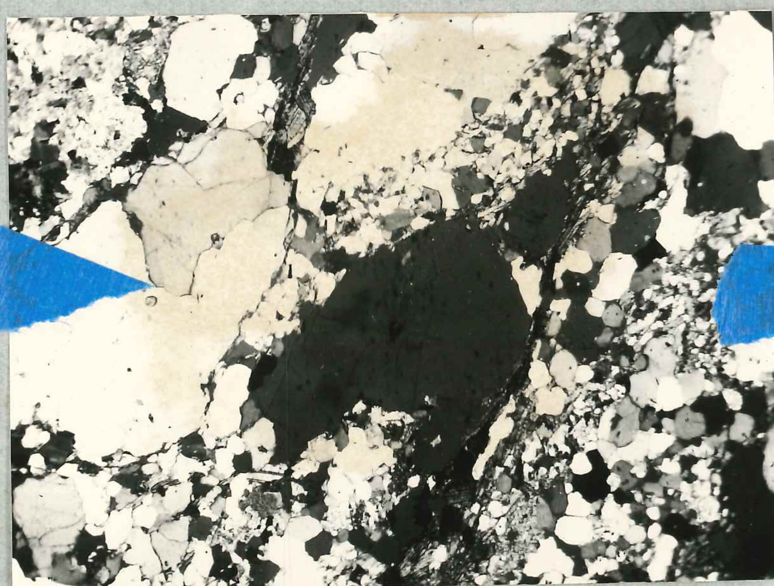
[1]tr = less than 1 percent
[2]S = schistose, G = granoblastic

7. Sillimanite-mica schist
8. Sillimanite-mica schist
9. Sillimanite-mica schist
10. Lime-silicate rock
11. Lime-silicate rock

Plate VII



A. Photomicrograph of quartz-mica-feldspar schist from the Ruddock formation. Coarse grains are quartz in a finer grained groundmass of quartz, feldspars, and micas. Crossed nicols. X16.



B. Photomicrograph of quartz-mica-feldspar schist from the Ruddock formation. Large lenticular grains are quartz in a groundmass of quartz, micas, and feldspars. Crossed nicols. X16.

The dominant feldspar is plagioclase, which ranges in composition from sodic oligoclase (An_{12}) to sodic andesine (An_{32}). The average length of the grains is about 0.5 millimeter. Plagioclase is present in variable amounts and in places it is sufficiently concentrated to call the rock an arkose. It may occur in very small amounts in which case the relative proportion of micas increase and the bed is quartz-mica schist. Microcline is almost always less abundant than plagioclase. Like the plagioclase it occurs in small grains in the goundmass and occasionally as coarse grains as much as 5 millimeters in diameter. Both feldspars may occur as sporadic porphyroblasts.

Biotite occurs as flakes, laths, and lense-shaped aggregates of small flakes. The aggregates are as much as one millimeter in length, but the average of the flakes is about 0.2 millimeter. Muscovite is less abundant than biotite. It occurs as flakes in the goundmass, generally coarser grained than the biotite, and as spongy porphyroblasts enclosing grains of quartz and feldspars. The porphyroblasts of muscovite cut across the schistosity and are considered to be of late origin.

Garnet is a rare accessory mineral in the quartz-mica-feldspar schist and was observed as small grains,averaging about 0.5 millimeter, in only one section. Apatite, magnetite, and zircon are common and evenly distributed accessory minerals. Small euhedral crystals of tourmaline were noted in two thin sections.

Sillimanite-mica schist.

Sillimanite-mica schist in the Ruddock formation is well-exposed in two localities: (1) in the NE¼ and SE¼ sec. 6, and (2) in the SW¼ sec. 34. In sec. 6 the sillimanite-mica schist crops out in a bed that is about 400 feet thick. In sec. 32 a lenticular bed of schist 2,200 feet long and at least 300 feet thick lies along the lower contact of the Ruddock formation. The schist is characterized by swirls and lenticular aggregates of coarse sillimanite which givesthe rock a spotted appearance. The matrix is light- to dark-grey and fine- to medium-grained. Biotite and muscovite, in flakes as much as 1.2 millimeter in length, give the rock a strong and coarse foliation. Occasionally porphyroblasts of garnet are found. The distribution of the quartz and feldspar is patchy among the biotite-muscovite areas.

Thin sections of the sillimanite-mica schist contain on the average 50 percent quartz, 15 percent biotite, 15 percent sillimanite, 10 percent plagioclase, 8 percent muscovite, and 2 percent accessory garnet, orthoclase, tourmaline, zircon, magnetite, apatite, clinozoisite, and chlorite. The texture is crystalloblastic modified by the granoblastic mica-poor quartz and feldspar patches. The grain size averages about 0.2 millimeter for the micas, and about 2 millimeters for the sillimanite porphyroblasts.

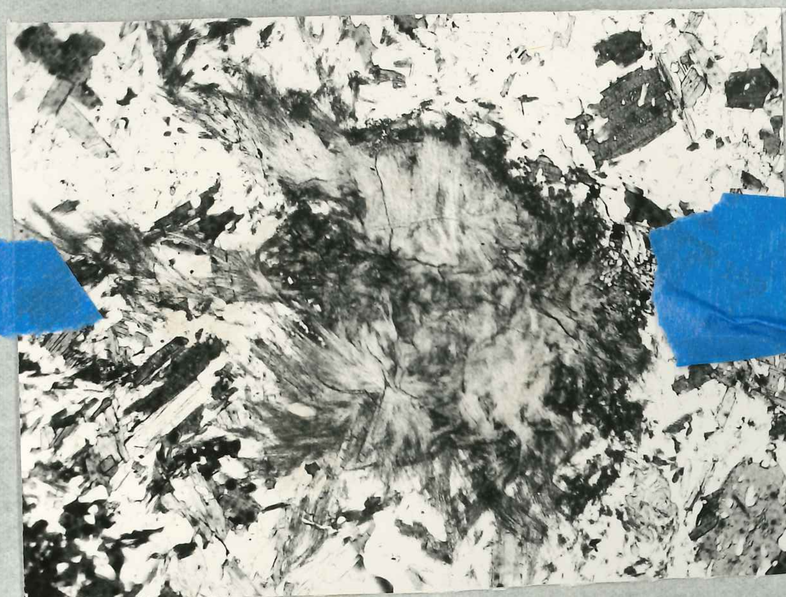
The quartz and feldspars have a uniformity of shape and size throughout the rock. They occur as irregular grains with smooth and interlocking boundaries. Quartz generally contains a few apatite, magnetite, and tourmaline grains and locally abundant sillimanite prisms. The plagioclase is clear, rarely twinned, and occasionally includes a few small quartz grains. Potash feldspar, if at all present, is limited to a few small grains of orthoclase. It is difficult to determine the relative amounts of quartz and plagioclase because of their small grain size, similarity of indices, and lack of twinning and cleavage.

In thin section the sillimanite shows a varied habit. It is most abundant as dense felted knots of sillimanite prisms often concentrated in aggregates that are brown and translucent. (See pl. VIII) The prisms are haphazardly oriented and in patches of parallel needles. Irregular cracks or possibly a poorly developed cleavage system is found in the center of the mats. Surrounding the core of the mats is a sheath of needle-like euhedral crystals radiating outward in swirls or tufts into the surrounding minerals. In a second type, linear swarms of sillimanite prisms oriented roughly with the schistosity stream through the biotite flakes and quartz. Sillimanite is present also as tiny clusters of needles in biotite, which has apparently replaced it, and as individual prisms scattered haphazardly in quartz.

Of the micas, biotite is the more common and occurs as small flakes of the groundmass and as large flakes with well-developed basal faces and ragged ends. Dark-brown halos are very common, especially in the coarser biotite, and appear to form around grains of zircon. Quartz is a common inclusion in biotite. Biotite has locally altered to chlorite and magnetite, and probably is the result of retrograde metamorphism. Muscovite has a habit similar to biotite but tends to concentrate into patches.

A few hand specimens contain small garnets averaging about one millimeter in diameter. Green tourmaline, zircon, magnetite, and apatite are common and evenly distributed accessory minerals. Clinozoisite was noted in two thin sections where it occurs as light yellow, slightly pleochroic grains included in muscovite and with quartz and plagioclase in the groundmass.

Plate VIII



Photomicrograph of sillimanite-mica schist from Ruddock formation showing felted knots of sillimanite. Plates are biotite and some muscovite, and white areas are plagioclase and quartz, Plain light. X16.

Staurolite-biotite-garnet schist.

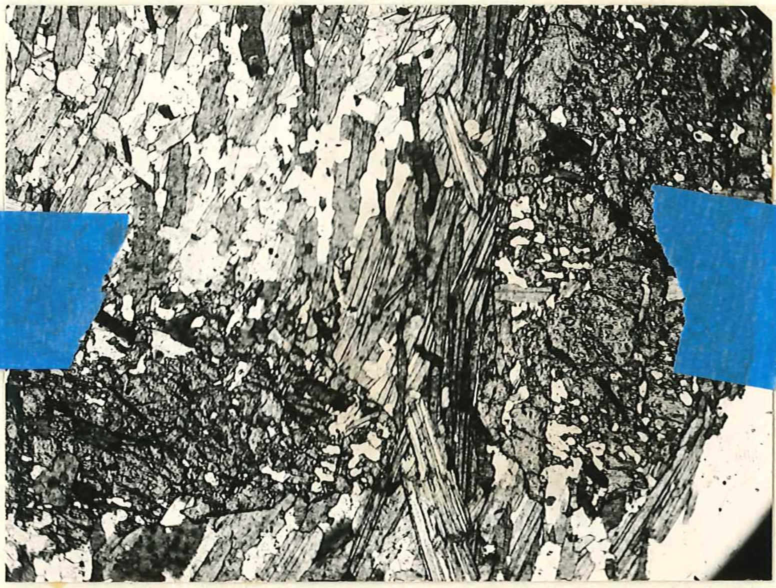
Staurolite-biotite-garnet schist is exposed in the SW¼ sec. 5, in three small outcrops less than three feet in diameter. The length and thickness of the unit could not be determined. Euhedral staurolite crystals, 2 to 10 millimeters in length, and subhedral garnets, averaging 1.2 millimeters, are set in a finer-grained nearly black groundmass. Rarely the staurolite has cruciform twins.

In thin section the staurolite encloses quartz, plagioclase, and biotite of the groundmass, and clearly replaces them. (See pl. IX) The pleochroic formula of the tourmaline is $X<Y<Z$ with X-very pale brownish yellow, Y-light-yellow, and Z-golden yellow. The groundmass of the schist is composed of coarse parallel biotite laths, and finer-grained quartz and plagioclase. Muscovite up to 2 millimeters in length is found cutting across the schistosity and is of late origin. Sillimanite is a very minor constituent of the schist, and occurs as aggregates of needles in biotite.

Lime-silicate rock.

Lime-silicate rocks are exposed in the Ruddock schist and consist chiefly of quartz, feldspars, hornblende, and diopside. These rocks probably represent marly beds within the formation. The rock crops out in two horizons in the SW¼ and SE¼ sec. 32, T. 3 S., R. 4 E., and in the NE¼ sec. 5, T. 4 S., R. 4 E. The beds range from 6 to 40 feet in thickness. The distance between adjacent beds varies from 150 feet in the SW¼ sec. 32, to as much as 800 feet in the NE¼ sec. 5. The beds cannot be traced continuously along strike and in places are covered by alluvium. The rock is not resistant to weathering and does not form conspicuous outcrops.

Plate IX



Photomicrograph of staurolite-biotite-garnet schist from Ruddock formation. Large porphyroblasts are staurolite, surrounded by plates of biotite. White areas are fine-grained plagioclase and quartz. Plain light. X16.

The lime-silicate rock is fine- to medium-grained, ranging from grey to green, and generally lacks schistosity. Hornblende, quartz, and occasionally diopside may be recognized in hand specimen. The hornblende crystals are 2 millimeters or less in length and are dark green. In some specimens the hornblende crystals are oriented to give the rock a distinct lineation, but in others the crystals have a random orientation. Pink garnet is unevenly scattered throughout the rock in crystals up to 1.5 millimeters in diameter. Light-green diopside occurs rarely. Finer-grained quartz, feldspar, clinozoisite, epidote, and calcite make up most of the groundmass. A layered structure parallel to the bedding is apparent in many places and is the result of interbedded quartz-mica-feldspar schist and lime-silicate rock. The interbedded schist layers contain hornblende and garnet in addition to their normal constituents.

In thin section the rock consists mainly of quartz, plagioclase, hornblende, and diopside, with accessory microcline, clinozoisite, epidote, garnet, calcite, sphene, magnetite, apatite, and zircon. The grain size of the groundmass ranges from 0.2 to 0.7 millimeter in diameter. The matrix of the rock is dominantly granoblastic, containing porphyroblasts of hornblende, garnet, and diopside.

Green hornblende is the most diagnostic mineral and forms as much as 20 percent of the rock. The grain size ranged from 0.3 millimeter to 2 millimeters and averages about 0.8 millimeter. The optical properties have been determined as follows: biaxial negative, $Z \wedge c$=20°, pleochroism X<Y<Z, X-yellowish-green, Y-green, and Z-dark-green. The hornblende encloses portions of the groundmass, especially quartz and plagioclase.

Quartz and plagioclase make up most of the groundmass. They occur as subrounded to lenticular grains with an average grain size of about 0.5 millimeter. The plagioclase commonly shows albite twinning and has an average composition of An_{60}.

Diopside was found in most of the sections, and occurs chiefly as porphyroblasts enclosing quartz, feldspars, and hornblende. The crystals are from 0.5 to 1 millimeter in diameter. Clinozoisite, in subhedral to euhedral crystals, appears to be retrogressive replacing plagioclase. Epidote is a fairly rare mineral which occurs in euhedral grains and is probably contemporaneous with diopside and hornblende. Garnet is found as porphyroblasts enclosing quartz and feldspar. Calcite occurs rarely as irregular grains intergrown with quartz and feldspars of the groundmass. Sphene occurs as minute crystals as much as 0.1 millimeter in diameter. It is an early formed mineral that is included in hornblende, diopside, and plagioclase. Magnetite, apatite, and zircon are common accessory minerals, and occur as small inclusions in all other minerals.

<u>Meta-conglomerate.</u>

The Ruddock schist contains a thin conglomeratic unit approximately 4,200 feet above the lower contact. It extends northwest-southeast across secs. 5 and 6, T. 4 S., R. 4 E., and sec. 31, T. 3 S., R. 4 E. The thickness of the conglomerate differs considerably from place to place and ranges from 6 to 20 feet. The unit is conglomeratic quartz-mica-feldspar schist containing flattened pebbles up to 2 inches in length. The pebbles are subrounded to lenticular in shape and lie with their intermediate and long axes in the plane of the schistosity. (See pl. X)

Plate X

Meta-conglomerate from the Ruddock formation, showing large flattened pebbles of quartz.

Graded bedding by pebble size distribution indicates that the bed is upright. The conglomerate is more resistant to weathering than the surrounding schist and forms a prominent outcrop.

Three kinds of pebbles are found: (1) subrounded grains of quartz with an average grain size of 0.5 millimeter, (2) coarse-grained quartz with an average grain size up to 5 millimeters in diameter, and (3) quartz and feldspar with a grain size averaging about one millimeter. Biotite and muscovite are common accessory minerals in the pebbles.

The groundmass consists of fine-grained quartz, biotite, muscovite, plagioclase, and microcline. Accessory minerals include magnetite, apatite, tourmaline, sericite, and penninite. Biotite, locally altered to penninite, and muscovite wrap around the pebbles.

Approximately 75 measurements were made on 5 specimens of conglomerate to determine the amount of deformation of the pebbles. In all cases a and b lie in the plane of the schistosity, and c is perpendicular to both a and b. Axis a is approximately parallel to the biotite lineation and small-scale crenulations in the plane of the schistosity in the surrounding schist. The axial ratios a:b:c are fairly constant over the area but the ratios differ in different kinds of pebbles. The axial ratios of the coarse quartz pebbles range from 6:4:1 to 2:1.5:1 and average 3:2:1. The fine-grained quartz pebbles range from 20:14:1 to 9:5:1 and average 10:7:1.

Amphibolite dikes

Massive amphibolite of probable igneous origin occurs in the southwest part of the mapped area throughout the Ruddock schist.

The amphibolite bodies range from 2 to 150 feet in thickness and 90 to 1,100 feet in length. Most of them are less than 15 feet thick. The shape is generally thinly lenticular or tabular although a large mass which measures 150 feet across crops out in a nearly circular outline. The rock weathers easily and does not form conspicuous features of the topography. The long dimension of the amphibolite bodies parallels the regional trend of the schistosity, and locally reflects the structure of minor folds in the surrounding rock. The structural relation of the amphibolite bodies to the bedding in the country rock is uncertain. Vertical exposures and contacts with the enclosing schist are absent.

The amphibolite is dark-green and fine- to medium-grained. The main constituents are hornblende and plagioclase. Foliation is very poor to absent throughout most of the bodies, but there is some orientation of hornblende along the borders of the dikes. The thin amphibolite bodies show a somewhat better schistosity than the larger bodies. A layered structure parallelling the schistosity is conspicuous in a few places. The layers are light-colored, in contrast to the dark-green amphibolite, and are composed mostly of plagioclase, quartz, and some hornblende. The overall appearance of the massive rock closely resembles a fine-grained diorite. The mineral composition of the amphibolite dikes are the same.

Thin sections of the amphibolite consist of hornblende in a finer-grained granulitic groundmass of plagioclase and quartz. Accessory minerals include sphene, ilmenite (?), biotite, chlorite, and apatite. Modes estimated from thin sections are given in table 4. The grain size of the groundmass varies from 0.1 to 0.5 millimeter, and averages about 0.3 millimeter.

Table 4.--Modes of the Amphibolite Dikes, in percent

Number	1	2	3	4	5
Porphyroblasts					
Hornblende	40	55	80	70	65
Groundmass[1]					
Quartz	15	10	6	5	10
Plagioclase	40	35	12	25	23
Biotite	2	..	..	..	..
Sphene	3	..	..	tr	tr
Zircon	tr	tr	..	tr	tr
Apatite	tr	tr	tr	tr	tr
Ilmenite	tr	tr	2	tr	2
Structure[2]	G	G	G	G	G
Size porphyroblasts in mm.	0.8	1.0	0.7	1.0	0.7
Size groundmass in mm.	0.1	0.2	0.1	0.3	0.3

[1]tr = less than 1 percent
[2]G = granoblastic

Hornblende is the most abundant constituent and averages about 60 percent of the rock. It varies considerably in grain size but commonly occurs as small crystals, irregularly shaped ragged grains, and porphyroblasts. The crystals occasionally occur in clusters and more rarely in radial aggregates. Small idioblastic crystals having well-developed amphibole cleavage are common. The grain size of the hornblende ranges from 0.1 to 1 millimeter, but averages about 0.5 millimeter. Small poikiloblastic grains of plagioclase and quartz of the groundmass are commonly included in the hornblende. The hornblende is a common green variety with the following optical properties: 2V-80°, Z∧c-20°, X-yellow, Y-dark green, Z-green.

Plagioclase and quartz form the groundmass surrounding the larger hornblende crystals. The plagioclase occurs in anhedral grains which characteristically have reverse zoning. It is dominantly andesine (An_{35}) in composition though the range noted lies between An_{22} and An_{54}. Quartz is less abundant than plagioclase.

Sphene is a common accessory, occurring as aggregates of crystals with skeleton crystals of ilmenite (?). Biotite and chlorite both occur with hornblende and have apparently replaced it. Apatite needles are included in plagioclase and quartz.

Lime-silicate ellipsoids

Ellipsoidal masses of quartz-plagioclase-hornblende-garnet composition are widely distributed in the schists of the Fourmile Area and surrounding districts of the southern Black Hills. Runner and Hamilton[1]

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[1] Runner, J. J., and Hamilton, R. G., Metamorphosed calcareous concretions and their genetic and structural significance: Am. Jour. Sci., 5th ser., vol. 28, pp. 51-64, 1934.

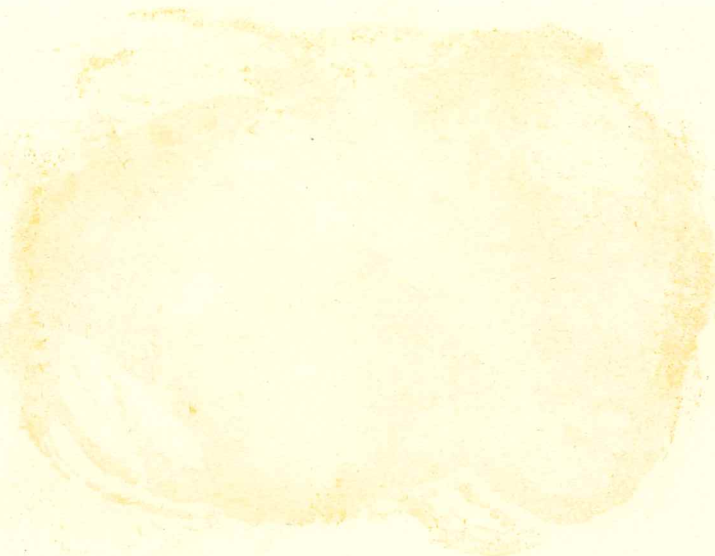
have described these rocks as metamorphosed calcareous concretions. They are abundant in the Ruby Creek quartz-mica schist and Ruddock formation. The distribution of the ellipsoids, although widespread, is very irregular. In some areas they are abundant and in others, apparently as favorably located both structurally and mineralogically, are found in small quantity or are entirely lacking. Although ellipsoids have been found throughout the schists, a tendency for them to be concentrated at certain horizons can be recognized.

These lime-silicate masses have the shape of a triaxial ellipsoid with a short axis ranging from one-half inch to 6 inches, an intermediate axis ranging from 4 to 20 inches, and a long axis ranging from 12 to 60 inches. The intermediate and long axes lie in the plane of the schistosity of the schist. The average ratio of the short to intermediate axes is 1 to 3, and that of the short to long axes is 1 to 12.

A concentric zoning about the center is present in all but the smallest ellipsoids. The zones have a variable thickness and may or may not be continuous. (See pl. XI) Commonly only two zones are present, but as many as four can be recognized in some ellipsoids. The central core is generally finer grained than the surrounding layers. The outer layers are slightly foliated and contain an abundance of coarse-grained hornblende, biotite, and garnet. A thin light-colored layer, one-half inch thick or less, and commonly discontinuous, may be found on the outside of some ellipsoids.

The ellipsoids are usually more resistant to weathering than the rocks in which they occur and project from it by weathering of the outcrops. Fragments of the ellipsoids are common in stream gravels.

Plate XI



Polished cross section of lime-silicate
ellipsoid, showing concentric zonal
structure.

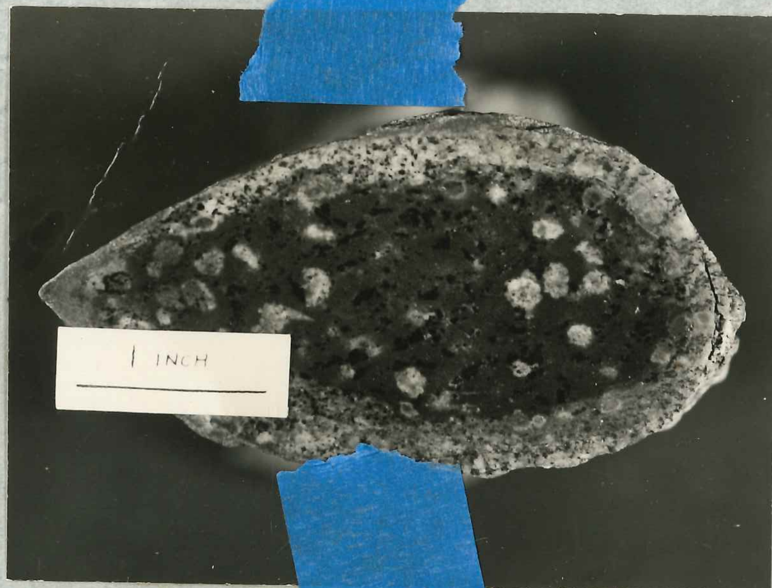
The microscope shows the following minerals, named in order of abundance: quartz, plagioclase, hornblende, biotite, garnet, clinozoisite, diopside, calcite, sphene, muscovite, magnetite, apatite, and zircon. Modes estimated from thin sections of the ellipsoids are given in table 5. Quartz and plagioclase are the dominant minerals of the matrix and show a granoblastic texture. Poikiloblastic crystals of hornblende and garnet are common. The ellipsoids, except occasionally the outer shell, do not exhibit a distinct foliation as in the enclosing schists. Hornblende and biotite show a subparallel arrangment that gives the rock a poor parting parallel to the intermediate and long axes of the ellipsoids.

Quartz occurs in anhedral grains which average about 0.2 millimeter and make up from 35 to 50 percent of the ellipsoids. The quartz shows a tendency to be somewhat flattened parallel to the long dimension of the ellipsoids. The grains contain a small amount of inclusions of plagioclase, apatite, zircon, and magnetite.

The plagioclase occurs in smaller grains than the quartz and comprises from 20 to 40 percent of the rock. It occurs between quartz grains producing a pseudo-morter texture, and as rounded grains in biotite and hornblende. The plagioclase is recognized in section by its high relief. It is invariably untwinned. Most of the plagioclase is bytownite but the composition range is from about An_{60} to An_{90}.

Hornblende forms 5 to 15 percent of the ellipsoids that range in size from small grains to poikiloblastic crystals 0.2 to 3 millimeters in length. The crystals contain inclusions of quartz and plagioclase, and a few small grains of magnetite, sphene, biotite, and chlorite. The hornblende also contains very small inclusions that produce an intense

Plate XI



Polished cross section of lime-silicate ellipsoid, showing concentric zonal structure.

Table 5.--Modes of the lime-silicate ellipsoids, in percent

Number	1	2	3	4	5	6	7	8
Porphyroblasts								
Biotite	..	5	..	..	..	..	15	2
Hornblende	5	..	15	..	..	10	..	..
Diopside	..	..	..	..	5	..	..	..
Garnet	6	5	5	7	7	5	12	8
Groundmass[1]								
Quartz	45	45	35	48	40	44	42	40
Plagioclase	20	36	40	31	26	35	36	32
Hornblende	5	..	..	..	1	..	..	..
Biotite	7	7	tr	8	..	tr	..	4
Calcite	..	..	..	..	8	..	..	..
Muscovite	..	..	..	5	..	..	..	4
Clinozoisite	..	..	..	..	10	2	..	2
Sphene	tr	..	1	..	2	..	..	1
Garnet	6	..	..	..	..	..	..	..
Zircon	tr	tr	tr	tr	tr	tr	tr	tr
Chlorite	..	tr	5	2	..	3	..	6
Magnetite	2	2	1	1	1	1	1	1
Apatite	tr	tr	tr	tr	tr	tr	tr	tr
Structure[2]	G	G	G	G	G	G	G	G
Size porphyroblasts in mm.	2.0	1.2	1.6	1.5	1.5	1.2	1.0	1.2
Size groundmass in mm.	0.1	0.1	0.1	0.2	0.2	0.3	0.2	0.2

[1]tr = less than 1 percent
[2]G = granoblastic

pleochroic halo and radiating cracks. The optical properties are similar to those described by Runner and Hamilton[1], who believe them to be allanite. The optical properties of the hornblende are as follows: biaxial negative, $Z \wedge c$-20°, pleochroism X-greenish-yellow, Y-green, and Z-bluish-green.

Biotite occurs as small grains to large porphyroblasts 0.1 to 1 millimeter in diameter, and makes up from 1 to 15 percent of the ellipsoids. Biotite is most abundant in the outer portion of the ellipsoids. It appears in some places to take the place of hornblende.

Light-pink garnet forms about 7 percent of the ellipsoids and occurs in crystals as much as 6 millimeters in diameter. The garnets have a poikiloblastic texture enclosing grains that are mostly quartz. Clinozoisite occurs as small anhedral grains are lath-shaped prisms less than 0.1 millimeter in length. It is an uncommon accessory mineral associated with quartz and plagioclase, and is abundant in rocks containing calcite and diopside. Sphene occurs in the ellipsoids as small anhedral grains in amounts up to 2 percent. The other accessory minerals are muscovite, which sometimes occurs in the outer shells of the ellipsoids, and minute grains of magnetite, apatite, and zircon which are found as inclusions in almost all other minerals of the rock.

Pegmatites

The pegmatites in the mapped area are granite pegmatites consisting mainly of plagioclase, quartz, perthite, and muscovite. The mapped pegmatites (fig. 2) are greater than one foot in thickness and all

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[1]Runner, J. J., and Hamilton, R. G., op. cit., p. 59.

occur in the Ruby Creek quartz-mica schist and Ruddock schist. Only a few thin unmapped pegmatites less than one foot thick were observed in the Raver formation. Approximately 450 pegmatites were mapped in the Four mile Area.

The pegmatites may be classed into two types: those essentially uniform in texture and mineralogy from wall to wall, and those that contain distinct textural and mineralogic units. This classification is analogous to that proposed by Johnston[1] for the pegmatites of northeastern Brazil. The former are called homogeneous pegmatites and the latter are called heterogeneous pegmatites.

The characteristics of the southern Black Hills pegmatites has been thoroughly discussed by Page[2], and the origin of the zonal structure in heterogeneous granitic pegmatites has been described by Cameron, et. al.[3]

Homogeneous pegmatites

The homogeneous pegmatites are similar in mineralogy and texture to the pegmatitic phases of the granitic rocks around Harney Peak, 8 miles northeast of the Fourmile Area. They are generally medium- to coarse-grained, and consist mostly of plagioclase, quartz, perthite, and muscovite.

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[1]Johnston, W. D., Jr., Beryl-tantalite pegmatites of northeastern Brazil: Geol. Soc. America Bull., vol. 56, pp. 1024-1025, 1945.

[2]Page, L. R., in Page, L. R., et. al., Pegmatite investigations 1942-1945, Black Hills, South Dakota: U. S. Geol. Survey Prof. Paper, 247.

[3]Cameron, E. N., Johns, R. H., McNair, A. H., and Page, L. R., Internal structure of granitic pegmatites: Econ. Geology Monograph 2, pp. 97-106, 1949.

The presence of distinct textural and mineralogic units in the homogeneous pegmatites is generally limited to a fine-grained selvage at the pegmatite contact. The grain size of the selvage ranges from one-sixteenth to one-half inch, but the average size is about one-eighth inch. The thickness ranges from one-fourth inch to 3 inches. The rest of the pegmatite is coarser grained, and is fairly uniform in mineral composition and texture although there is some increase in grain size toward the center of the pegmatite.

Mineralogy.

The essential mineral constituents of the homogeneous pegmatites are plagioclase, quartz, perthite, and muscovite. Accessory minerals include tourmaline, garnet, apatite, beryl, biotite, and lollingite. The mineral variations in the pegmatite groups are shown in table 6.

Plagioclase, ranging from An_4 to An_{15}, is generally the most abundant constituent and forms from 15 to 50 percent of the homogeneous pegmatites. Most of the plagioclase is white, but pink and grey tints are not uncommon. The grain size ranges from less than one-fourth inch to phenocrysts 2 feet in length, but the average grain size is about three-fourths inch. The plagioclase is intergrown with quartz, muscovite, and accessory minerals. The plagioclase content in a pegmatite is not uniform and the amount may vary as much as 20 percent in different places. In general the plagioclase content tends to decrease toward the center of the pegmatite.

Quartz is second to plagioclase in abundance and forms from 15 to 45 percent of the rock. The quartz is white or colorless, and occurs as anhedral grains averaging one-half inch in diameter. Quartz is usually the dominant mineral in the fine-grained selvage at the pegmatite contact. Within the pegmatite body the quartz content is either essentially uniform or tends to increase inward. Coarse masses of grey and rose quartz as much as 3 feet thick have been found near the center of the pegmatites. Occasionally tabular units of massive white to rose quartz, as much as 15 inches thick, cut the pegmatites bodies at various angles. These dike-like units were not observed to extend into the schist country rock but are confined to the pegmatite bodies.

Potash feldspar in the homogeneous pegmatites occurs as perthite and graphic granite that together make up from 10 to 50 percent of the pegmatite. The perthite is evenly distributed in the pegmatites and occurs either as fine-grained anhedral crystals intergrown with plagioclase and quartz, or as coarse crystals, as much as 5 feet in length, in a plagioclase-quartz matrix. Graphic granite was observed in all homogeneous pegmatites except in pegmatites 43, 61, and 63 and occurs as coarse phenocrysts as much as 5 feet in length. Graphic granite is more common near the center of the pegmatite bodies. The perthite ranges from white to dark red, but white to light-pink colors are most characteristic. Dark-red perthite and graphic granite occur in pegmatites in the southwest part of the mapped area.

Muscovite occurs in all homogeneous pegmatites in amounts ranging from 1 to 15 percent. It may form as much as 50 percent of the fine-grained selvage along the contact. In this selvage the muscovite occurs in small flakes and books oriented approximately perpendicular to the pegmatite contact. The mica is commonly associated with plagioclase and quartz. The grain size averages one-fourth inch near the pegmatite contact and about three-fourths inch in the pegmatite centers.

The mica may be colorless, light-green, ruby-colored, or rarely yellow. It also occurs as radial aggregates, as much as 2 inches in diameter, consisting of small colorless flakes, and as narrow blades sometimes intergrown with biotite. Books of muscovite, as much as 6 inches in diameter and two inches thick, are associated with massive quartz.

Tourmaline, the most abundant accessory mineral, forms from 1 to 5 percent of the pegmatite, and averages about 2 percent. It is invariably black. It occurs in euhedral to subhedral crystals with an average grain size of one-half inch. Individual crystals may reach 6 inches in length and 2 inches in diameter in the outer parts of the pegmatite. Tourmaline crystals near the wall tend to be perpendicular to the contact. Tourmaline also occurs graphically or subgraphically intergrown with quartz, and in crystal rosettes in perthite and massive quartz.

Garnet, averaging less than one percent of the rock, occurs in many homogeneous pegmatites. It is dark red-brown and occurs in euhedral to subhedral crystals which average about one-sixteenth inch in diameter. It is evenly distributed throughout the rock as individual crystals or as inclusions in quartz and feldspars.

Apatite is an abundant although minor accessory mineral that constitutes less than one percent of the homogeneous pegmatites. It occurs as euhedral to subhedral crystals, averaging less than one-sixteenth inch in length. The color varies from light-green to greenish-blue. Apatite is most common as microscopic inclusions in quartz although crystals as much as one-fourth inch in diameter are found.

Beryl was observed in pegmatite groups 13, 19, and 25. It constitutes less than one percent of the rock and is commonly less than one inch in diameter. The largest crystal observed measured 11 inches long and 5 inches in diameter. Beryl occurs in yellow to green, euhedral to subhedral crystals in a matrix containing plagioclase, quartz, perthite, and muscovite. The index of refraction of the ordinary ray of the beryl in the three pegmatite groups range from 1.572 to 1.580. Beryl is believed to occur in many other homogeneous pegmatites, and probably could be found by very thorough search.

Biotite is in only about one-third of the homogeneous pegmatites, and most of these are in sec. 21. It constitutes less than one percent of the rock. Biotite occurs as small flakes and books and also intergrown with muscovite in narrow strips. The average grain size is about one-eighth inch. The largest crystal observed was 2 feet in diameter and 3 inches thick.

Lollingite was observed only in pegmatite 15. It occurs in subhedral crystals, as much as 1.5 inches in length, associated with quartz and plagioclase. The crystals tend to occur a few inches in from the fine-grained selvage.

Texture.

In all homogeneous pegmatites in the mapped area the grain size generally increases from the walls to the center of the pegmatite. Minerals that occur in greater concentration near the walls, however, such as tourmaline and sometimes muscovite, tend to be finer-grained near the center of the body. The following grain size classification is used for pegmatite textures: average grain size of one inch or less is called fine-grained, average grain size more than one inch to 4 inches is called medium-grained, average grain size more than 4 inches to 12 inches is called coarse-grained, and average grain size more than 12 inches is called very coarse-grained.

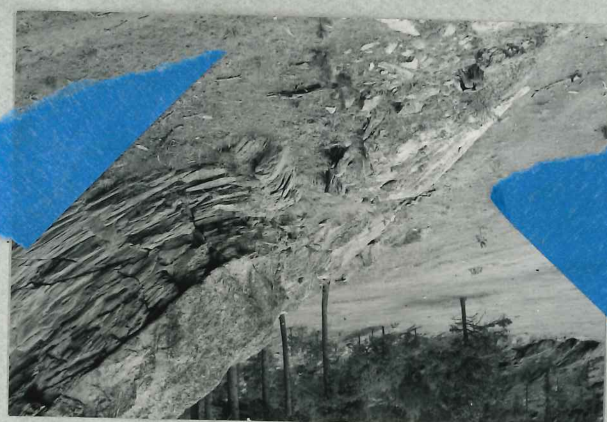
The estimated average grain size of the minerals in the homogeneous pegmatites is given in table 6. The grain size of the minerals is not uniform within any pegmatite. The thin selvage at the pegmatite contact is invariably fine-grained with an average grain size of about one-eighth inch. The grain size of this selvage is generally uniform. Inside the selvage, the pegmatite texture varies from fine- to very coarse-grained. It is more nearly porphyritic than equigranular. The grain size of the matrix averages about three-quarters inch but may be fine-grained in a part of a pegmatite and medium-grained in another part. The matrix may be entirely fine-grained or entirely medium-grained. Coarse and very coarse phenocrysts of perthite and graphic granite are common.

Size and shape.

The majority of the homogeneous pegmatites occur in the form of tabular or thinly lenticular bodies with fairly constant dip and strike. The pegmatites range from 5 feet to 2,600 feet in length and from one-fourth inch to 100 feet in thickness. Of 439 homogeneous pegmatites mapped, 403 are concordant, narrow, sill-like bodies, and 36 are markedly discordant. Almost all large pegmatites are locally discordant but in general concordant. The concordant relationship between pegmatite and schist country rock is shown in plate XIIA (pegmatite group 24), and plate XIIB (pegmatite group 54.) Most of the concordant pegmatites have a uniform thickness and are less than 20 feet thick. The largest concordant pegmatite occurs in pegmatite group 20 and has a length of 2,550 feet and an average thickness of 100 feet. Pinch and swell

Plate XII

A. Pegmatite group 24, showing concordant relationship between pegmatite and schist country rock.



B. Pegmatite group 54, showing concordant relationship between pegmatite and schist country rock.

C. Pegmatite 15, showing pegmatite outcrop along a dip slope structures occur in a few pegmatites less than 2 feet thick. Many of the large homogeneous pegmatites crop out in the form of a dip slope as shown in plate XIIC. In general the pegmatites were intruded along the pre-existing schistosity of the metamorphic rocks.

The discordant pegmatites are tabular, branching, or hook-shaped. Pegmatites that are discordant are abundant in the southwest part of the mapped area in pegmatite groups 70, 71, 72, 73, 75, and 80, and in pegmatite group 35, in the SE¼ sec. 28. Most of these pegmatites trend approximately north-south in a direction subparallel to the strike of the major structures of the area. Some discordant pegmatites when traced along strike branch into two or more pegmatites some of which trend parallel with the schistosity in the country rock. These pegmatites do not conform to any joint pattern observed in the schist.

Heterogeneous pegmatites

The Fourmile Area contains eleven pegmatites that may be considered heterogeneous. These pegmatites contain lithologic units distinct from one another on the basis of mineralogy and texture, and may be called zones and fracture fillings. Zones, as defined by Cameron, et. al.[1], are successive shells, complete or incomplete, that reflect to varying degrees the shape or structure of the pegmatite body. Where ideally developed they are concentric about an innermost core or zone. They also define fracture fillings as units, generally tabular, that fill fractures in previously consolidated pegmatite.

[1]Cameron, et. al., op. cit., p. 14.

The zones in the heterogeneous pegmatites are characterized by a specific mineral assemblage, and according to Cameron, et. al.[1], are called border zone, wall zone, intermediate zone, and core. The sequence of assemblages of essential minerals in the zones from the walls inward in the heterogeneous pegmatites are quartz, plagioclase, muscovite; plagioclase, quartz, perthite; and quartz and perthite. The estimated mineral composition of the zones is given in table 7.

Zones are not necessarily uniform in mineral composition or texture. A given zone may consist of portions rich in beryl, muscovite, and sometimes perthite. The grain size of these minerals vary considerably in different parts of a zone. Muscovite, for example, tends to concentrate in larger books and in mineable quantity in the wall zone on the hanging wall side of the pegmatite. Pegmatite 56 shows a localization of beryl in a part of the wall and intermediate zones and although it is found in other parts of these zones, it occurs in smaller quantities and is much finer-grained.

Internal units.

In a general way none of the pegmatites in the mapped area are unzoned. The homogeneous pegmatites invariably contain a fine-grained selvage or border zone at the pegmatite contact. Apart from this zone these pegmatites are considered homogeneous even though there appears to be a slight differentiation in grain size and texture. Whether or not a pegmatite appears to be zoned depends in large part on the degree of

[1] Cameron, et. al., op. cit., p. 20.

exposure of the pegmatite. If only the outer portion of the pegmatite is exposed it will appear unzoned. Since the amount of pegmatite exposed is generally small some pegmatites designated homogeneous may in fact be heterogeneous.

The border zone occurs at the contact of the pegmatite and wall rock. It is fine-grained, and ranges from one-fourth inch to 2 inches in thickness. The dominant minerals are quartz, plagioclase, and muscovite. The accessory minerals include tourmaline, perthite, garnet, and apatite. The order of abundance of the essential minerals is not the same in each pegmatite. In pegmatites 14, 53, 64, and 66, the border zone consists of quartz-plagioclase-muscovite pegmatite. In pegmatite 52 and 56, the border zone consists of plagioclase-quartz-muscovite pegmatite. In pegmatite 23, perthite takes the place of muscovite as an essential mineral and the zone consists of plagioclase-quartz-perthite pegmatite. Pegmatites 12b and 101 are in a wall zone of homogeneous pegmatite and do not possess a border zone.

The wall zone occurs as a relatively thin continuous unit separating the border zone from the intermediate zone or core. It is coarser grained and thicker than the border zone. The contact between the zones is gradational both in texture and mineralogy. The minerals in the wall zone average one-half inch in diameter. The zone ranges in thickness from 6 inches in pegmatite 64 to 8 feet in pegmatite 100. The essential minerals are plagioclase, quartz, and perthite, and the accessory minerals are muscovite, tourmaline, garnet, apatite, beryl, and biotite. In pegmatites 14, 23, 52, 53, and 56, the wall zone consists of plagioclase-quartz-perthite pegmatite. Pegmatites 66, 100, and 101 contain a wall zone of plagioclase-quartz-muscovite pegmatite. In pegmatite 64 the wall zone consists of plagioclase-quartz-perthite pegmatite, and in pegmatite 12b the zone consists of plagioclase-quartz-tourmaline pegmatite.

The intermediate zone of a pegmatite includes any zone between the wall zone and core. Five of the heterogeneous pegmatites contain an intermediate zone. The zone is medium- to coarse-grained, and has an average thickness ranging from 8 feet in pegmatites 64 and 66 to 18 feet in pegmatite 56. The thickness of the zone is dependent on the size and shape of the pegmatite body. The essential minerals are quartz, plagioclase, and perthite, and the accessory minerals are muscovite, tourmaline, beryl, garnet, and apatite. Pegmatites 52 and 64 contain an intermediate zone of quartz-plagioclase-perthite pegmatite; pegmatites 56 and 66 contain perthite-quartz-plagioclase pegmatite; and pegmatite 12b contains plagioclase-quartz-perthite pegmatite. These zones are composed of medium- to very coarse-grained perthite and graphic granite crystals enclosed in a quartz and plagioclase matrix which averages about one inch. The pegmatites have not been mined out sufficiently to give accurate data concerning the size and shape of the intermediate zone. In pegmatites 12b, 56, and 66, the intermediate zone is thickest at the crest and thins along the hanging wall and footwall sides of the body. In pegmatite 12b, the intermediate zone is thickest on the hanging wall side of the pegmatite, but in pegmatite 66, the zone is thickest on the footwall side. In the exposed part of the pegmatites the intermediate zones are continuous.

The core is the innermost zone of a pegmatite. In general the texture of the cores are coarser than those of the outer zones. The core in these pegmatites may be represented by a tabular unit whose average thickness ranges from 6 feet in pegmatite 23, to 20 feet in pegmatite 12b. The cores of pegmatite 52, 56, and 64 are a series of small disconnected pods. The essential mineral composition of the cores are quartz and perthite, or quartz, perthite, and plagioclase. The accessory minerals are muscovite, tourmaline, beryl, garnet, apatite, biotite, arsenopyrite, and phosphate minerals (lithiophillite-triphylite). In pegmatites 12b, 52, 56, and 66, the core consists of massive quartz-perthite pegmatite, and in pegmatites 100 and 101, perthite-quartz pegmatite. In pegmatites 14, 23, and 53, the core contains medium-grained quartz, perthite, and plagioclase. In pegmatite 67 (Highland Lode, John Ross Mine) the core is divided into two units as perthite-quartz-plagioclase pegmatite, and perthite-quartz pegmatite. In the pegmatites containing no intermediate zone the visible cores consist of medium-grained quartz and plagioclase, and coarse- to very coarse-grained perthite and graphic granite. The texture and composition is identical to the intermediate zones in those pegmatites containing massive quartz and perthite cores. This may indicate that the units designated as cores in pegmatites 14, 23, and 53, are really intermediate zones with massive quartz and perthite cores unexposed.

The core of pegmatite 66 (Dorothy Lode Mine) and the intermediate zone of pegmatite 52 contain several small pods of mica-rich aggregates or "bull" mica units. These pods average about 3 feet long and 2 feet wide. They are fine-grained and contain 70 percent muscovite, 20 percent quartz, and 10 percent plagioclase. The origin of these deposits is not known but may be attributed to a primary segregation or a replacement of preexisting pegmatite.

A few of the homogeneous pegmatites contain small fracture filling units which may be classified as heterogeneous pegmatite. They are rudely zoned but because of their small size are classified with the homogeneous pegmatites.

Quartz veins

Quartz veins are abundant throughout the area and range from one-fourth inch to 6 feet in thickness, and a few inches to 300 feet in length. Quartz veins less than one foot thick are most common and can be found in almost every schist outcrop. Generally the larger veins are concordant with the structure of the country rock while many of the small veins are discordant or even ptygmatic.

Quartz constitutes from 60 to 99 percent of the veins. The accessory minerals are microcline, plagioclase, muscovite, biotite, tourmaline, apatite, and garnet. The quartz is mostly white, but may be grey, colorless, or light-pink. It is fine-grained in the thin veins, and coarse-grained and massive in the thicker veins. The thick veins contain a trace of microscopic muscovite, feldspars, tourmaline, and apatite. The thin veins may contain as much as 40 percent accessory minerals, the most common being microcline and plagioclase. These veins are somewhat similar in composition and texture to the thin homogeneous pegmatites. Pegmatites and quartz veins were never found grading into one another.

Many quartz veins, both large and small, contain concentrations of dark minerals along the vein walls. These layers range from one-fourth inch to one inch in thickness and consist of biotite and garnet, with small amounts of penninite, feldspars, muscovite, tourmaline, and quartz. Biotite and garnet are common minerals in the schist but are in far greater concentration near the rims than in the normal schist.

Sedimentary rocks

Deadwood formation (Cambrian)

A small outcrop of Cambrian Deadwood formation about 5 feet in diameter occurs in the SW¼SE¼ sec. 33, T. 3 S., R. 4 E. The rock is light to dark brown, hard, and consists of rounded fragments of white and grey vein quartz, quartzite, and schist in a matrix of quartzite. The pebbles are poorly sorted into layers and together with alternations with iron staining probably represent original bedding. The attitude of the bedding is approximately horizontal. The thickness of the conglomerate cannot be determined.

The pebbles range from one-eighth inch to one inch in diameter, and average about three-eighths inch. The average grain size of the quartzite matrix is about 0.5 millimeter. Clastic grains are cemented together by quartz and hematite. Accessory minerals that include sericite, biotite, tourmaline, apatite and zircon make up less than one percent of the rock.

The Cambrian Deadwood formation crops out as a cuesta about 5 miles west of the Fourmile Area. It overlies the unconformity at the top of the pre-Cambrian metamorphic rocks. The Deadwood formation in the Fourmile Area may have reached its present position by down-faulting, since the plane of the unconformity by projection should lie several hundred feet above the Fourmile Area, as float, or it may be approximately in place if the surfact of unconformity had considerable relief. The latter is probably more nearly correct and thus would explain the beveled pegmatites in the vicinity of the Deadwood outcrop.

Alluvium

Thin surficial deposits of alluvium cover the bottom of the valleys of French Creek, Ruby Creek, and Fourmile Creek. The thickness of the deposits is unknown but is probably less than 20 feet in most places. The aluvium is poorly sorted and is mostly fine sand, but all gradations to boulders up to 6 feet in diameter are found. The pebbles and boulders consist mostly of pegmatite, quartz-mica schist, quartzite, vein-quartz, and amphibolite. All but the schist fragments are rounded.

STRUCTURAL GEOLOGY

Folds

Most of the area mapped lies on the east limb of a southeast plunging syncline which is probably overturned. The prevailing direction of strike of the schistosity is N. 40° W., and the average dip is 45° SW. The bedding trends N. 30°-60° W. and dips 25°-60° SW. The beds are folded, probably isoclinally, and the folds are overturned to the northeast. In outcrops where bedding is visible the schistosity is parallel to the bedding or may differ as much as 15°.

Sufficient data are lacking over most of the area to determine the structure precisely. The Ruby Creek quartz-mica schist contains a few thin quartzite layers but they cannot be traced more than a few feet. The Ruddock formation contains a thin conglomeratic member and two lime-silicate rock units but they are not continuous. The Raver formation is most useful for deciphering structure.

The basic structural unit is an overturned syncline whose axis lies somewhere west of the mapped area. This structure is inferred from minor folds and from a large anticline visible in the N½ sec. 21, and to the north and east of the mapped area. The general strike of the axial plane of the syncline is approximately S. 55° E. The plunge of the synclinal axis is probably 30° S. 10° E. as indicated by the plunge of minor folds. The bedding continues to strike northwest and dip southwest over a distance of three miles west of the mapped area. Graded bedding in the conglomeratic member and arkosic layers in the Ruddock formation indicate that the beds in the syncline are upright.

The relative position of schistosity and bedding also indicates that the beds are upright.

Small folds range from 5 to 1,000 feet across. Because of the parallel or near parallel attitude of the bedding and schistosity small folds could be detected only by observing the crest and these are rarely exposed because of deep weathering. Most of the folds tend to be isoclinal, but a few are relatively open. The plunge of the minor folds varies from 26° S. 44° E. to 42° S. 28° W., and average 30° S. 10° E. A thin bed of quartzite near the base of the Raver formation in sec. 33, has the open type structure in a fold measuring 150 feet across. Along the upper and lower contact of the Raver formation numerous drag folds occur that range from 10 to 200 feet across. The prevailing direction of the axial plans of these folds is comparatively constant in a northwest-southeast direction. Drag folds in quartz-mica schist have amplitudes ranging from one-half inch to 2 inches. In the SE¼ sec. 21, two large folds occur and are of the broad open type. The axial planes trend NNW and are overturned to the northeast. Bedding is obscure in this area but the fold structure is outlined by tabular pegmatites parallel to the schistosity.

Schistosity

The rocks of the Fourmile Area are characterized by well-developed schistosity of two types: a primary schistosity parallel to bedding, which is by far the most common, and a secondary schistosity or shear cleavage. In most places where bedding is recognizable, schistosity is essentially parallel to the bedding. Bedding plane schistosity may, in some places, represent axial plane foliation in tight isoclinal folds.

However in broad open type folds, schistosity parallels bedding throughout the length of the fold, even on the crest.

A secondary schistosity is shear cleavage. It is represented only locally and consists of a parallel orientation of micas in a plane inclined to the bedding. It has been observed to cut the bedding in angles of as much as 20 degrees in the Ruby Creek quartz-mica schist. In most of the outcrops containing shear cleavage a bedding plane schistosity is also present.

Lineation

Various types of linear elements are well-developed in nearly all the metamorphic rocks. Lineations are found as (1) an alignment of streaks of platy minerals, such as muscovite and biotite, (2) parallel elongate minerals, such as hornblende, (3) elongate pebbles whose intermediate and long axes lie in the plane of schistosity, and (4) small crenulations with an amplitude of less than an inch. These linear structures are essentially parallel to one another in an outcrop or over a series of outcrops, and presumably were developed by the same force.

The linear structures show a systematic orientation over the area. The plunge of the linear elements varies from southeast to southwest but averages 32° S. 16° W. The lineations plunge in a direction 10° to 35° west of the plunge direction of the minor folds. The average strike direction of the long axes of 20 lime-silicate ellipsoids is S. 15° W. The apparent deviation from the lineation and ellipsoid plunge direction and that of the minor folds is probably due to a change in stress direction after the main period of folding.

Faults and lineaments

The metamorphic rocks are cut by many small and diversely oriented faults. Those that have been found are shown in figure 2, but this probably represents only a small portion of them actually present. The recognition of faults is difficult because of a scarcity of the outcrops and the rarity of marker beds. Faults of large displacement are probably absent in the mapped area.

Small faults are recognizable only when they displace pegmatite. Most of the faults strike about N. 50° E. The dip of the fault planes is difficult to determine, but in most places is approximately vertical. Horizontal displacement ranges from a few inches to 30 feet. Vertical displacement is almost impossible to determine, but where it can be calculated it is less than 5 feet.

A lineament, probably a shear zone, trends N. 38° E. is in the west part of secs. 20 and 29 (fig. 2). This structure can be recognized as a line on aerial photographs but cannot be recognized readily in the field. It is marked on aerial photographs by a narrow valley over most of its length. The lineament can be traced over a distance of 4,500 feet in the mapped area but continues southwest for a distance of about 9 miles where it disappears under Paleozoic sediments. Only a small amount of horizontal and vertical movement is indicated by displacement of pegmatites. Plate XIII shows the lineament cutting pegmatite 51. The structure transects the Rever formation outside the mapped area in sec. 30, but the contacts of the formation here cannot be located accurately enough to determine the displacement. The horizontal displacement is probably less than 100 feet, and the vertical displacement, if any, is very small.

Plate XIII

The lineament cutting pegmatite 51. The pegmatite, where the lineament has cut it, has been removed by erosion.

Joints

Joints are well developed in the Ruby Creek quartz-mica schist and Ruddock formation, and poorly developed in the Raver formation. Of about 80 measurements made on the direction of joints planes, 34 percent lie between N. 20° W. and N. 50° W., averaging N. 30° W.; 31 percent lie between N. 50° E. and N. 80° E., averaging N. 64° E.; and 15 percent between N. 20° W. and N. 20° E., with the remainder outside these ranges. These observations indicate the presence of two distinct directions almost at right angles; one direction N. 30° W., and the other N. 64° E. The average dip of the joint planes of the former is 65° NE, and the latter 80° NW.

METAMORPHISM

The original sedimentary rocks and basic dikes of the area were regionally metamorphosed contemporaneously with folding. Most of the metamorphic rocks in the area mapped have attained the high-grade zone of regional metamorphism. The schistsare sporadically sillimanite-bearing and using the Grubenmann-Niggli[1] scheme of classification the rocks lie in the kata-zone. Similarly the rocks lie in the sillimanite zone of Harker.[2] The index minerals in the lime-silicate rocks are diopside and cordierite, and since they are overlain and underlain by sillimanite-bearing schist, they are apparently high-grade. There is no orderly change of index minerals, either in the aluminous or non-aluminous rocks, that would indicate a distinct metamorphic zoning. Retrograde changes resulting in a decrease in the degree of regional metamorphism by decline of temperature are local.

Ruby Creek quartz-mica schist

The composition of the Ruby Creek quartz-mica schist indicates that the rocks were derived from shales, argillaceous siltstones, and sandstones. Most of the variations in mineral composition and texture are probably the result of differences in the original sedimentary rock, and are not due to local variations in temperature and pressure conditions.

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[1]Grubenmann, U., and Niggli, P., Die Gesteinsmetamorphose, Borntraeger, Berlin, 1924.

[2]Harker, A., Metamorphism, 2nd ed., pp. 227-229, Methuen & Co., London, 1939.

The Ruby Creek quartz-mica schist consists mostly of quartz-muscovite-biotite schist, biotite-muscovite-quartz schist, and biotite-quartz-garnet schist. The rocks are composed of such minerals as quartz, muscovite, biotite, garnet plagioclase, microcline, and sillimanite. Sillimanite, however, was observed in only three localities. The rocks are almost everywhere medium-grained with no orderly increase in grain size anywhere. It appears that these rocks were metamorphosed under conditions indicative of high-grade metamorphism although equilibrium conditions generally were not obtained.

Sillimanite is the diagnostic mineral. The three localities where it occurs are widely separated but the presence of the mineral would indicate a high degree of metamorphism attained for the unit. There are probably several reasons why the mineral is not more widespread. Sillimanite should be confined to the highly aluminous sediments and its general absence may have been due to a lack of sufficient aluminum over and above that required to bind potash and soda in the aluminosilicates. In addition there may have been some physical condition prohibiting a breakdown of muscovite to form sillimanite and potash-feldspar. In one thin section of sillimanite-bearing schist the sillimanite locally shows a retrograde conversion to muscovite but there is no evidence, except for this one instance, to indicate a widespread breakdown of sillimanite to muscovite or staurolite. According to Harker[1] after metamorphism has reached the greatest intensity, and while stress declines, muscovite may dissociate into potash feldspar releasing some free alumina to form sillimanite. In the Ruby Creek

[1] Harker, A., op. cit., p. 228.

quartz-mica schist sillimanite is rare and potash feldspar is almost entirely absent.

Garnet occurs almost everywhere in the biotite rich units throughout the Ruby Creek quartz-mica schist. Garnet is mostly a late mineral replacing biotite and some muscovite. Most of the biotite and muscovite are probably contemporaneous because both show the same amount of deformation. Locally, biotite and muscovite form large porphyroblasts in a quartz-mica matrix and lie across the schistosity. Apparently deformation had ceased and while temperature was still high, part of the biotite and muscovite recrystallized.

Raver formation

The rocks of the Raver formation are chiefly amphibolites, lime-silicate rock, microcline-biotite schist, and cordierite-biotite schist. Modes and field relations indicate the amphibolites were originally dolomitic shales and siltstones, the lime-silicate rocks were originally arenaceous and argillaceous dolomites, and the microcline-biotite and cordierite-biotite schists were originally iron and magnesium-rich clays. The Raver formation carries no index minerals except diopside and cordierite that would definitely distinguish between middle-grade and high-grade metamorphism. In as much as the formation is overlain and underlain by sillimanite-bearing schists, it probably has reached the high-grade zone.

Hornblende is the dominant mineral in the amphibolites. Greenish-blue hornblende is the common type and optical data indicate that it is relatively uniform throughout the area mapped. Hornblende is associated with plagioclase and quartz in the amphibolites and although hornblende is not an index mineral of high-grade metamorphism it appears stable under these conditions in this area. Hornblende is also associated with calcite and lime-silicate minerals in the lime-silicate rock. It is partially unstable in this association and, although the hornblende sometimes occurs as independent crystals, it is often rimmed and replaced by diopside. An amphibole whose optical properties indicate it to be actinolite was observed in two thin sections of coarse-grained amphibolite. It occurs as thin light-green bands composed of actinolite, plagioclase, and quartz. Adjacent to these bands hornblende has been converted to actinolite surrounding hornblende.

Diopside is common in the lime-silicate rocks and can be considered a high-temperature mineral of the impure dolomites. Diopside occurs in two ways. Most commonly it has resulted directly from the reaction of dolomite and quartz. It has also formed as a replacement of hornblende. The presence of hornblende rimmed with diopside throughout the lime-silicate rock indicates a lack of equilibrium. With sufficient temperature and also the addition of calcium and magnesium, hornblende will be converted to diopside. Apparently temperature was not high enough to cause a complete transformation.

Cordierite is confined to a thin schist member near the upper part of the Raver formation. The associated minerals are microcline, biotite, plagioclase, quartz, and muscovite. Generally, cordierite is considered a high-grade mineral and is placed in the sillimanite zone of Harker.[1]

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[1]Harker, A., op. cit, p. 229.

Cordierite is considered by Harker as an antistress mineral and its presence indicates that crystallization outlasted deformation. Its post-orogenic origin is indicated in thin section by an alignment of inclusions in cordierite inherited from the schistose matrix. Cordierite has been partly replaced by muscovite and felted masses of sericite shreds. This is the result of retrograde conditions during decline of temperature.

Scapolite is present in very small amounts in the lime-silicate rocks. The mineral occurs in at least two different ways: as a replacement of Ca-rich plagioclase, and as a primary metamorphic mineral. The scapolite has high birefringence and therefore approaches meionite in composition. Partial conversion of plagioclase to scapolite was noted in a few sections. The replacement takes the form of partial rims and irregular penetrations into plagioclase. Evidence of entire replacement was not observed. The $CaCO_3$ necessary for the formation of scapolite was available in the form of calcite, and this, with Ca-plagioclase, produced the scapolite. In nearly all thin sections of lime-silicate rocks the association of plagioclase and calcite with no accompanying scapolite is common. Certainly, then, the local occurrence of scapolite formed in this way indicates disequilibrium.

The most common occurrence of scapolite is as large porphyroblasts, sieved by and replacing quartz, microcline, plagioclase, epidote minerals, diopside, and hornblende. Field evidence is lacking for the formation of scapolite by introduction of solutions. The necessary constituents for the primary crystallization are present in the rock. Additional evidence for the primary origin lies in the composition of the scapolite itself. Turner[1] indicates pneumatolytic scapolite (marialite) is sodic, and that meionite is generally formed by normal metamorphism.

Clinozoisite and epidote are common accessory minerals and either or both can be found in every thin section of the lime-silicate rock. Evidence in thin section indicates the two minerals to be of different origin. Clinozoisite, generally more abundant than epidote, has formed by replacement of plagioclase and rarely diopside. The upper stability range of clinozoisite is imperfectly known but it is generally considered to form mostly in the low and middle grades of metamorphism and not in the high-grade zone. Clinozoisite is here considered as retrogressive. Epidote, on the other hand, occurs mostly as a primary mineral. It takes the form of spongy porphyroblasts of various size enclosing feldspars, quartz, and calcite. The association of diopside with epidote, both appearing stable, would indicate that epidote was stable at least in the low temperature portion of the high-grade zone. Weiss[2] has reported epidote being stable in the sillimanite zone.

Ruddock Schist

The Ruddock schist consists chiefly of quartz-mica-feldspar schist, staurolite-biotite-garnet schist, sillimanite-mica schist, and lime-silicate rock. The index minerals staurolite and sillimanite are absent

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[1] Turner, F. J., Evolution of the metamorphic rocks, Geol. Soc. Am., Mem. 30, p. 128, 1948.

[2] Weiss, J., Wissahickon schist at Philadelphia, Pennsylvania: Geol. Soc. America, Bull., vol. 60, p. 1725, 1949.

throughout most of the formation and are restricted to narrow units at three horizons. The lime-silicate of this formation consist mainly of quartz, plagioclase, hornblende, and diopside, and are similar in mineralogy to the lime-silicate rocks of the Rover formation.

Sillimanite is the index mineral of the high-grade zone and is present in two localities: in sec. 6 as a bed approximately 400 feet thick, and in sec. 32 as a lense-shaped bed at least 300 feet wide and 2,200 feet long, at the lower contact of the Ruddock formation. Sillimanite is not confined to the highly argillaceous sediments because the formation consists mostly of quartz-mica-feldspar schist which contains a sufficient amount of potential aluminum for the formation of sillimanite. However, in the quartz-mica-feldspar schist the quantity of mica and feldspar is generally greater than in the sillimanite-bearing schists. Thus the quartz-mica-feldspar schist had a sufficient quantity of sodium and potassium to bind all aluminum, whereas in the sillimanite-bearing schist there must have been an insufficient amount of alkalies to use all available aluminum. Harker suggests that a decline of stress under high-grade conditions may cause the dissociation of muscovite, thus forming potash-feldspar and releasing free alumina to form sillimanite. Potash-feldspar is not a constituent of the sillimanite-bearing schists, which indicates that in this area at least muscovite was unable to dissociate. The sillimanite takes the form of coarse felted aggregates growing for the most part indiscrimantly across the foliation and thus may be considered essentially post-orogenic.

Staurolite-biotite-garnet schist is in a relatively thin bed in the SW¼ sec. 5. The staurolite occurs as euhedral porphyroblasts, 2 to 10 millimeters in length, and are diversly oriented. The porphyroblasts are spongy and contain abundant quartz, plagioclase, and biotite. The diverse orientation of the porphyroblasts indicate that they must have formed subsequent to the main stress. The presence of staurolite within a few hundred feet of sillimanite-bearing schists is extraordinary and cannot be explained on the basis that both crystallize under similar temperature conditions. The staurolite is found, however, in the zone of high-grade metamorphism, but must be a retrogressive mineral formed during the decline of temperature. The suhedral boundaries and orientation of staurolite indicate it to be post-orogenic which is compatible with a retrograde origin.

Garnet is almost entirely restricted to the sillimanite-mica schist and staurolite-biotite-garnet schist and it occurs in very small amounts especially in the sillimanite-bearing schist. The mineral occurs in subhedral to euhedral porphyroblasts, 0.5 millimeter to 2 millimeters in diameter, and may show well-formed dodecahedrons. Spongy porphyroblasts with abundant inclusions of quartz and feldspar are common. Garnet apparently is a late mineral and replaces the earlier quartz, feldspar, and mica groundmass. Garnet is almost universally absent throughout the Ruddock quartz-mica-feldspar schist and its absence is probably due to the high potash content of the rocks. Its place is apparently taken by biotite.

ECONOMIC GEOLOGY

Homogeneous pegmatites

All the homogeneous pegmatites contain potash feldspar and scrap mica, and a few contain sheet mica and beryl, but the grade of these deposits is too low to be of commercial value at the present time. Potash feldspar occurs in crystals as much as 5 feet in length and constitutes from 10 to 50 percent of the pegmatites. About 50 percent of the potash feldspar is intergrown with quartz and is not saleable. Scrap mica is an abundant accessory to mineral, averaging from 5 to 10 percent of the pegmatite, and occurs in small flakes and books less than one inch in diameter. The grade of these deposits is much too low for recovery under present mining methods.

Beryl was observed in pegmatite groups 13, 15, and 25, but it is probably more abundant than this would indicate. The pegmatite exposures are generally poor permitting only an examination of the outer parts of the pegmatite and this is usually limited to the hanging wall. Internal structures and mineralogy are therefore uncertain. Beryl was observed in crystals which average less than one inch in length and are mostly too small to be recovered by hand cobbing. The grade of the beryl deposits is too low to be of economic value under present conditions.

Heterogeneous pegmatites

The industrial minerals of the heterogeneous pegmatites include potash feldspar, sheet and scrap mica, and beryl. There are 11 heterogeneous pegmatites in the mapped area, but pegmatite 74b (Pleasant Valley Mine) is the only one being mined at the time of the mapping.

Pegmatites 23 and 76b have not been operated, but have been prospected, and pegmatite 64 has never been prospected.

Beryl

Pegmatites 12b, 14, 52, 53, 56, 64, 66, 67, 74b, and 76b (see section on mines and prospects) contain beryl. The beryl occurs in three types of deposits: wall zone, intermediate zone, and core. Tables 7 and 8 show the distribution of beryl in the heterogeneous pegmatites. In the wall zone the beryl occurs in euhedral to subhedral crystals, averaging about one inch in length, and is associated with plagioclase and quartz. This type of deposit is relatively less important than the other deposits because of the small size of the zone and most of the beryl could be recovered only by milling. The intermediate zone deposit contains euhedral to subhedral crystals which average about 2 inches in length and three-fourths inch in diameter. The matrix of the crystals is plagioclase-quartz-perthite pegmatite. Almost all the beryl observed in this zone in pegmatites 12b, 52, 56, and 74b could be recovered by hand sorting, while the beryl in pegmatite 64 could be recovered by milling methods. The intermediate zone deposits contain the largest beryl reserves. The core zone beryl deposits are of two types. One type contains coarse euhedral crystals which are light green and have a glassy luster. The crystals are associated with coarse quartz-perthite pegmatite and are embedded in the quartz along the outer edge of the zone. The crystals are as much as 13 inches long and 6 inches in diameter. Examples of this type of deposit are pegmatites 56 and 64. In the second type of deposit beryl occurs in yellow to light-green subhedral crystals with an average length of 2 inches. The

Table 8.[1]

Distribution of Economic Minerals in the Heterogeneous Pegmatites.

Pegmatite	12b	14	23	52	53	56	64	66	67	74b	76b
Beryl[2]											
Wall zone		B				B	B		B	B	B
Intermediate zone	B	M	M	B	M	B	B		M	B	M
Core zone					B	B	B	B	B		
Mica[3]											
Wall zone	C	C	SC	C	SC	SC	C	SC	SC	C	SC
Intermediate zone	SC	M	M	SC	M	C	C	C	M	C	M
Core zone	C	C	C	C	C	C	C	C	SC		
Potash feldspar[4]											
Wall zone		P	P	P	P	P	P		P		P
Intermediate zone	PG	M	M	PG	M	PG	P	P	M	P	M
Core zone	G	PG	PG	P	PG	PG	P	P	PG		P

1M-zone not present
2B-beryl
3S-sheet mica; C-scrap mica
4P-perthite; G-graphic granite

matrix of these crystals is fine-grained quartz and plagioclase which occurs either as patches in coarse quartz-perthite pegmatite (pegmatite 66), or as a groundmass with coarse perthite masses (pegmatite 53). All beryl in the core deposits could be recovered by hand sorting.

Mica

All heterogeneous pegmatites contain scrap mica, and pegmatites 12b, 23, 52, 53, 56, 66, 67, and 76b contain a small quantity of sheet mica (see tables 7 and 8). All zones in the pegmatites examined contain scrap mica. It occurs as small flakes and books averaging less than one inch in diameter. The mica is commonly intergrown with plagioclase and quartz in amounts less than 5 percent. The mica is too fine-grained to recover by hand methods, although it could be recovered as a by-product by milling. Pegmatites 52 and 66 contain mica-rich aggregates or "bull" mica units consisting of about 70 percent muscovite in books about one-half inch in diameter. These units may provide a source of scrap mica, but they are too small to be of much importance. Pegmatites 14, 52, 64, and 76b contain large mica books, some of which would yield sheet mica but many of which have defects and would yield only scrap mica.

Sheet mica occurs mostly in the wall zone and less frequently in the intermediate and core zones (see section on mines and prospects, and table 7). In the wall zone muscovite occurs as books averaging from 1.5 to 3 inches in diameter. The mica is commonly free of inclusions and is light-ruby to colorless. The books may contain so many defects, such as ruling, wedging, and "A" structure, that no sheet mica could be recovered. Pegmatites 12b and 52 contain a small quantity of sheet mica in the intermediate zone. In pegmatite 12b (Big Spar No. 1 Mine) sheet mica occurs in books as much as 6 inches in diameter. This mine has produced 150 pounds of sheet mica of No. 2 grade from 1,500 tons of mined pegmatite. In the intermediate zone of pegmatite 52 most of the mica contains defects and would yield only a small quantity of punch or sheet mica. In pegmatite 67 (Highland Lode, John Ross Mine) book mica occurs in the wall zone and core. A small quantity is present and is slightly air-stained, flat, and hard. The pegmatite has produced about 52 pounds of sheet mica and 150 pounds of punch mica from 1938 to 1944. About 20 percent of the sheet mica sold was No. 1 quality, 65 percent No. 2, and the remainder No. 2 inferior.

Potash feldspar

Potash feldspar occurs in three types of deposits: wall zone, intermediate zone, and core. Tables 7 and 8 show the distribution of potash feldspar in the heterogeneous pegmatites. In the wall zone the potash feldspar occurs as perthite crystals averaging about 2 inches in diameter in a matrix of plagioclase and quartz. The crystals are too small to recover by hand methods but could be recovered by milling. The narrowness of the wall zone would permit only a small recovery of feldspar. Potash feldspar occurs in the intermediate zone as perthite and graphic granite in pegmatites 12b, 52, and 56, and as perthite in pegmatites 64, 66, and 74b. Both perthite and graphic granite occur in coarse crystals averaging about 2 feet in length. Most of this potash feldspar could be recovered by hand sorting. The cores contain perthite alone or perthite and graphic granite crystals associated with massive quartz or medium-grained plagioclase and quartz. The crystals average from 1 to 3 feet in diameter in the different pegmatites. Pegmatites 12b (Big Spar No. 1 Mine), 66 (Dorothy Mine), and 67 (Highland Lode, John Ross Mine) have produced a large quantity of potash feldspar. Pegmatites 52 and 56 (Silver Top Lode Mine) have been mined principally for potash feldspar. Pegmatites 23, 53, and 64 are probably too small to be worked for potash feldspar alone.

Gold

Placer deposits

Placer deposits are found along French Creek, Ruby Creek, and Fourmile Creek. Dredging operations have been carried on in the valley of French Creek in secs. 20, 28, and 29, T. 3 S., R. 4 E., in a narrow belt along the present channel. Records of the date of operation and amount of gold recovered are not available. A small amount of assessment work was done in the placer deposits along Fourmile Creek in sec. 5, T. 4 S., R. 4 E., which included the straightening of the stream channel for a distance of about one-half mile. It is believed that the placer gold in this area was derived from the quartz veins.

Lode deposits

Many quartz veins containing a small amount of gold occur throughout the area, particularly in the Raver formation. Prospect pits and shafts are located along most of the larger veins. A part of the Raver formation in secs. 29 and 32, T. 3 S., R. 4 E., is heavily iron-stained and contains abundant quartz veins with tourmaline and some pyrite. A great deal of prospecting has been done along this zone, apparently for gold, and although the values obtained are not known, the result of the prospecting was evidently not encouraging.

In this district four mines have been operated in the past: the Minnie May, Oneonta, Bebington, and Ruberta. Their locations are shown in figure 2, and the published information on them is summarized below.

Minnie May mine:

The Minnie May group consists of 10 patented claims which covers 185 acres. The mine workings consist of a vertical 50-foot shaft, now full of water, which cuts a 4-foot quartz vein at a depth of about 40 feet. Analysis of various samples from the mine range from $2.70 to $5.90 in gold per ton, apparently based on gold at $20.67 an ounce. About 100 tons of rock was run through the 10-stamp mill on the property, and $1.50 in gold per ton was saved.

Oneonta mine:

The Oneonta mine, formerly the Mineral Hill mine, is owned by Mrs. W. A. Nevin of Custer, South Dakota, and others. The deposit is a quartz fissure vein, 3 to 4 feet wide, in schist. The mine workings consist of a 65-foot shaft, a 40-foot shaft, a 60-foot adit, and several cuts and trenches, all on the quartz vein. Sampling from a dump consisting of oxidized wall rock assayed $1.40 in gold per ton. Samples from the vein range from $1.05 to $5.25 in gold per ton and averages $2.85 per ton (gold as $35 per ounce).

Bebington mine:

The Bebington group spans the Custer-Newcastle Highway 2½ miles southwest of Custer. A 2 inch wide quartz stringer in schist south of the highway assayed $2.80 in gold per ton (gold at $35 an ounce). North of the highway a quartz fissure vein, exposed in an open-cut, assayed $10.50 in gold per ton.

Ruberta mine:

The Ruberta mine workings consist of an open-cut 100 feet long, 6 to 20 feet deep, and an average of 15 feet wide. At the south end of the cut an inclined shaft 180 feet deep, now inaccessible, was sunk.

MINES AND PROSPECTS

Pegmatite 12b (Big Spar No. 1)

The Big Spar No. 1 Mine is in the SW¼ sec. 21, T. 3 S., R. 4 E. (fig. 2). It is owned by the consolidated Feldspar Company of Trenton, New Jersey, which operated the mine for feldspar intermittently from 1943 to 1948. The mine workings consist of a single large open cut, 85 feet long, 25 feet wide, and averaging 30 feet deep.

This pegmatite was described in a Geological Survey report by J. W. Adams[1] who visited the property in June 1945. This report includes a brief description of the mine workings and geology of the pegmatite.

The Big Spar No. 1 is a well-zoned, lenticular pegmatite which forms a segregated body in the southwest part of a large homogeneous pegmatite. It measures 140 feet long and 45 feet thick, and strikes N. 10° W. Its apparent plunge is to the southwest. The homogeneous pegmatite measures 300 feet long and averages 50 feet thick. It is exposed as a dip slope that strikes N. 60° W., and dips 50° SW. The approximate plunge is 45° S. 30° W.

The Big Spar No. 1 contains a wall zone of fine-grained plagioclase-quartz-tourmaline pegmatite, an intermediate zone of plagioclase-quartz-perthite pegmatite, and a core of quartz-perthite-plagioclase pegmatite. No border zone occurs in this pegmatite body. The contact between the zoned pegmatite and homogeneous body is distinctly marked by a tourmaline-rich wall zone.

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[1] Adams, J. W., Big Spar No. 1 mine, in Page, L. R., et. al., Pegmatite Investigations 1942-1945, Black Hills, South Dakota: U. S. Geol. Survey Prof. Paper 247.

Plagioclase-quartz-tourmaline pegmatite (wall zone). The wall zone has a maximum thickness of 4 feet and an average thickness of one foot. It is composed of an estimated 50 percent plagioclase, 30 percent quartz, 10 percent tourmaline, 5 percent muscovite, and a small amount of apatite and garnet. The average grain size of quartz and plagioclase is three-fourths inch. Plagioclase forms anhedral crystals with a composition indicated by the index of refraction as about Ab_8. Black tourmaline crystals as much as 12 inches in length and 4 inches in diameter are locally concentrated to form as much as 30 percent of the rock. The wall zone is exposed on the east wall about 20 feet above the floor of the open cut. It has been mined out on the north and west side of the pegmatite.

Plagioclase-quartz-perthite pegmatite (intermediate zone). The intermediate zone averages 15 feet thick but varies from 5 to 30 feet in thickness. It consists of an estimated 45 percent plagioclase, 30 percent quartz, 20 percent perthite, 5 percent muscovite, and accessory beryl, tourmaline, apatite, and garnet. Individual masses of perthite, some graphically intergrown with quartz, are as much as 8 feet long and 5 feet wide, but the average size is about 3 feet by one foot. The perthite and graphic granite occur as isolated masses in a plagioclase-quartz matrix. Plagioclase and quartz average about one inch in diameter. The plagioclase is albite and has a composition near Ab_5. Muscovite occurs typically as aggregates of flakes three-fourths inch in diameter that are intergrown with plagioclase and quartz. A few large books of muscovite as much as 6 inches in diameter were observed in the southeast wall of the open cut. Light green beryl crystals intergrown with plagioclase and quartz average [illegible] inches in length and occur in the outer part of the intermediate zone.

Quartz-perthite-plagioclase pegmatite (core). The core of the pegmatite measures 30 feet long and 20 feet wide. It is composed of an estimated 40 percent quartz, 40 percent perthite and graphic granite, 15 percent plagioclase, and accessory tourmaline, apatite, and garnet. The core is composed of massive white to pink quartz with subhedral masses of cream colored perthite and graphic granite. The individual masses of perthite are as much as 5 feet long and 2 feet wide. The core also contains isolated pockets of fine-grained quartz, plagioclase, and muscovite which average one inch in grain size.

Mineral Deposits. Most of the mica produced from the Big Spar No. 1 mine is of scrap quality. It occurs mostly in the intermediate zone. Wedge-shaped and ruled sheet mica books obtainable from the intermediate zone have an average length of 3 inches, but some books 6 inches in diameter were seen. About 150 pounds of sheet mica of No. 2 grade were recovered in 1943 from the intermediate zone. Mica can be recovered profitably only as a part of the feldspar mining.

Beryl occurs in the intermediate zone as light-green crystals. The largest crystal measured was 8 inches in length but the average grain size is about 2 inches in length. N_o is 1.577 ± .003, which indicates a BeO content of 13.3 percent. A measured area of 160 square feet contained 0.12 percent beryl. A small quantity of beryl was recovered during feldspar mining.

Considerable potash feldspar occurs in the intermediate zone in crystals as much as 8 feet long, 5 feet wide, and 3 feet high. The crystals average about 3 feet in length. Most of the potash feldspar occurs as graphic granite which contains inclusions of tourmaline and garnet. Feldspar from the core occurs mostly as graphic granite and is not acceptable for milling at the present time.

Pegmatite 14 (Big Spar No. 2)

The Big Spar No. 2 mine is in the SW¼ sec. 21, T. 3 S., R. 4 E. (fig. 2). It is owned at the present time by William Wiederholt and Lena Boyum of Custer, South Dakota, who relocated the property June 21, 1950. The owner of the mine prior to this time is not known. The mine workings include two open cuts: a large cut measuring 45 feet long, 10 feet wide, and 8 feet deep, and a smaller one 15 feet long, 6 feet wide, and 3 feet deep.

The pegmatite is a tabular body which measures 450 feet long and averages 30 feet thick. It is exposed on a dip slope which strikes N. 55° W., and dips 45° SW. The approximate plunge of the pegmatite is 45° S. 40° W.

The pegmatite is rudely zoned, containing a border zone of fine-grained quartz-plagioclase-muscovite pegmatite, a wall zone of plagioclase-quartz-perthite pegmatite, and a core of perthite-plagioclase-quartz pegmatite.

Quartz-plagioclase-muscovite pegmatite (border zone). The quartz-plagioclase-muscovite pegmatite of the border zone is discontinuous. On the hanging wall of the pegmatite most of it has been removed by erosion. Footwall exposures show the zone to range from one-fourth inch to $1\frac{1}{2}$ inches in thickness, and average about one inch thick. The average grain size is about one-eighth inch.

Plagioclase-quartz-perthite pegmatite (wall zone). The wall zone, averaging 5 feet in thickness, consists of 60 percent plagioclase, 30 percent quartz, 5 percent perthite, 3 percent muscovite, and less than 2 percent tourmaline, beryl, garnet, biotite, and apatite. The average grain size of the zone is one inch. Muscovite books, which average one inch in diameter, occur throughout the wall zone. Beryl occurs as yellowish-green euhedral crystals in the wall zone in the upper open cut. The crystals may be as much as one inch in diameter and 2 inches long, but the average size is about one-fourth by three-fourths inch.

Perthite-plagioclase-quartz pegmatite (core). The core averages 420 feet in length and 15 feet in thickness and consists of 40 percent perthite, 35 percent plagioclase, 20 percent quartz, 2 percent muscovite, and 3 percent tourmaline, arsenopyrite, biotite, garnet, and apatite. The average grain size of the core is larger than that of the wall zone. Large perthite crystals up to 4 feet in length are surrounded by finer-grained plagioclase and quartz, the average grain size of which is $1\frac{1}{2}$ inches. Much of the perthite is graphically intergrown with quartz. Other perthite crystals contain inclusions of garnet and radial aggregates of black tourmaline crystals. Large tourmaline crystals, which are associated with massive quartz, measure up to 2 feet in length and 4 inches in diameter. Muscovite books are very subordinate throughout the core and have an average diameter of less than one inch. Small crystals of arsenopyrite up to one inch in length are sometimes found associated with the massive quartz.

Mineral Deposits. A small quantity of scrap mica occurs in the wall zone and core of the pegmatite. A few large books as much as 3 inches in diameter were observed in the wall zone but are wedged, ruled, have "A" structure, and would not yield mica of sheet quality.

Beryl crystals in the wall zone average one-fourth inch in diameter and three-fourths inch in length. Measurements over an area of 27 square feet indicated 0.1 percent beryl. The refractive index of the ordinary ray was determined to be 1.575 ± .003, indicating that the beryl has a BeO content of 13.5 percent. Most of the beryl is too fine-grained to recovered by hand cobbing.

The core contains potash feldspar and graphic granite masses as much as 6 feet long and 5 feet wide. Small quantities of garnet and tourmaline occur in the potash feldspar. These considerably lower the quality of feldspar from this pegmatite.

Pegmatite 23

Pegmatite 23 is in the SW¼ sec. 21, T. 3 S., R. 4 E. (fig. 2). The only opening is a shallow pit about 6 feet in diameter near the southeast end of the dike.

The pegmatite is a tabular body that strikes N. 45° W. and dips 44° SW. The approximate plunge is 36° S. 24° E. The pegmatite measures 270 feet in length and has an average thickness of 10 feet. The structure indicates that the thickness of the pegmatite increases with depth.

Three zones have been recognized in this pegmatite: a border zone of fine-grained quartz-plagioclase-muscovite pegmatite, a wall zone of plagioclase-quartz-perthite pegmatite, and a core of quartz-perthite-plagioclase pegmatite.

Quartz-plagioclase-muscovite pegmatite (border zone). The border zone, ranging from one-fourth inch to 2 inches in thickness, consists of 45 percent quartz, 30 percent plagioclase, 15 percent perthite, 5 percent muscovite, and 5 percent tourmaline, garnet, and apatite. The average grain size is one-eighth inch, but the inner part of the zone contains muscovite books as much as one inch in diameter.

Plagioclase-quartz-perthite pegmatite (wall zone). The wall zone averages one foot thick and consists of an estimated 50 percent plagioclase, 30 percent quartz, 10 percent perthite, 5 percent muscovite, and less than 3 percent tourmaline, apatite, and garnet. The average grain size is one-half inch, although muscovite books up to 4 inches in diameter and tourmaline crystals up to 5 inches in length are present. Coarse-grained, cream-colored perthite crystals average about 3 inches in diameter.

Quartz-perthite-plagioclase pegmatite (core). The core constitutes most of the visible pegmatite. It measures 260 feet in length and averages 6 feet in thickness. The estimated mineral composition is 40 percent quartz, 30 percent perthite, 25 percent plagioclase, 3 percent muscovite, 2 percent tourmaline, apatite, and garnet. The average grain size is about 2 inches. The plagioclase occurs in anhedral grains with an average size of $1\frac{1}{2}$ inches. The index of refraction was determined to be 1.529 ± .003, which indicates a composition of An_9. Small muscovite books averaging one inch in diameter occur with fine-grained quartz and plagioclase. Blocky perthite crystals up to 3 feet in diameter are in a fine-grained matrix consisting of all the other minerals of the zone. The perthite crystals average one foot in diameter. Much of the perthite is graphically intergrown with quartz.

Mineral Deposits. Scrap mica, which averages one inch in diameter, occurs in both the wall zone and the core. The wall zone on the hanging wall side of the pegmatite contains ruby-colored sheet mica. The sheet mica is usually wedged, and locally ruled and slightly stained, although many of the books are clear. Books as much as 4 inches in diameter were seen.

Potash feldspar of the wall zone is mostly too fine-grained to be recovered by hand cobbing. Some feldspar, however, could be mined from the core, but because the crystals are small the recovery would be low. About one-third of the potash feldspar of the core occurs as graphic granite and is not acceptable at the present time.

Pegmatite 52

Pegmatite 52 is in the NE¼ sec. 29, T. 3 S., R. 4 E. (fig. 2). The name of the mine and owner of the property is not known. The mine workings consist of a single open cut which measured 54 feet long, 20 feet wide, and averages 6 feet deep.

The pegmatite is a tabular body with a strike length of 200 feet and an average thickness of 15 feet. It is exposed as a dip slope which strikes N. 30° W. and dips 40° SW. The approximate plunge is 35° S. 27° W.

The pegmatite contains a border zone of plagioclase-quartz-muscovite pegmatite, a wall zone of plagioclase-quartz-perthite pegmatite, an intermediate zone of plagioclase-quartz-perthite pegmatite, and a discontinuous core of quartz-perthite pegmatite.

Plagioclase-quartz-muscovite pegmatite (border zone). The plagioclase-quartz-muscovite pegmatite forms a thin discontinuous zone at the contact between pegmatite and wall rock. The zone ranges from one-half inch to 2 inches in thickness, but averages about one inch thick. The average grain size is one-fourth inch.

Plagioclase-quartz-perthite pegmatite (wall zone). The wall zone, which averages one foot thick, consists of 40 percent plagioclase, 30 percent quartz, 20 percent perthite, 5 percent muscovite, and 5 percent tourmaline, garnet, and apatite. The average grain size is one-half inch. Muscovite occurs in aggregates of ruby colored sheets and books as much as 2 inches in diameter, but the average size is three-fourths inch. The plagioclase in this zone has an N_p-1.531 ± .003 and is therefore near An_9 in composition. Perthite crystals up to 2 inches in diameter and tourmaline crystals up to 6 inches in length occur along the inner margin of the wall zone.

Quartz-plagioclase-perthite pegmatite (intermediate zone). An intermediate zone, averaging 12 feet thick, makes up the bulk of the pegmatite. It consists of 35 percent quartz, 30 percent plagioclase, 30 percent perthite, 5 percent muscovite, and accessory tourmaline, garnet, apatite, and beryl. The average grain size of the entire zone is about 2 inches. Perthite occurs as light-pink crystals as much as 4 feet long and 2 feet thick. The average length is about 2 feet. Graphic granite masses are found in this zone, occur mostly in the outer part.

Quartz and plagioclase are fine-grained, averaging three-fourths inch in diameter. The plagioclase occurs in anhedral crystals slightly larger than the quartz. The index of refraction was determined to be 1.531 ± .003, which indicates a composition near An_7. Most of the muscovite occurs as aggregates of small, light yellow-green books. The muscovite is mainly of scrap quality although a few books are present up to 5 inches in diameter. Pale-yellow crystals of beryl, averaging 2 inches in diameter, are unevenly distributed throughout the zone.

This zone also contains several pod-shaped mica-rich aggregates which measure up to 3 feet long and 2 feet wide. These aggregates contain an estimated 70 percent muscovite, 20 percent quartz, and 10 percent plagioclase. The aggregates are fine-grained, averaging about three-fourths inch.

Quartz-perthite pegmatite (core).

The core of this pegmatite is a series of disconnected, irregular shaped pods which average about 4 feet in length and 2 feet in thickness. The pods contain an average of 60 percent massive quartz and 40 percent perthite. Muscovite books, averaging one-half inch in diameter, constitute about 2 percent of the zone. The perthite occurs as light-pink crystals averaging 1½ feet in diameter.

Mineral Deposits. Scrap mica occurs in the three inner zones of the pegmatite. The wall zone contains mica books as much as 2 inches in diameter, but mostly of scrap quality. The intermediate zone contains mica books which average about 2½ inches in diameter. This mica occurs in wedge-shaped books, is ruled, and shows "A" structure. It is mostly unsuitable for punch or sheet mica.

Beryl occurs as euhedral crystals as much as 9 inches long and 5 inches in diameter near the inner portion of the intermediate zone. The refractive index of the beryl was determined to be N_o=1.575 ± .003, indicating that the beryl has a BeO content of 13.5 percent. Measurements showed that beryl crystals cover 0.1 percent of a 200 square foot area. Most of the beryl is large enough to be recoverable by hand cobbing.

The core and intermediate zones contain small reserves of recoverable potash feldspar. The potash feldspar in the wall zone is too fine-grained for recovery by hand. In the intermediate zone 80 percent of the potash feldspar occurs as graphic granite and this is not acceptable for milling at the present time.

Pegmatite 55

Pegmatite 55 is in the SW¼ sec. 20, T. 5 S., R. 4 E. (Fig 2). The mine workings consist of a small open cut measuring 10 feet long, 8 feet wide, and 5 feet deep.

The pegmatite is a tabular body 110 feet long and 10 feet thick, which strikes N. 45° W., and dips 46° SW. (See pl. XIV) The approximate plunge is 42° S. 20° W. A shear zone, recognizable as a part of a lineament on aerial photographs, strikes N. 49° E. and offsets the pegmatite at two points. The horizontal displacement is less than 5 feet.

The pegmatite contains three zones: a fine-grained border zone of quartz-plagioclase-muscovite pegmatite, a wall zone of plagioclase-quartz-perthite pegmatite, and a core of quartz-perthite-plagioclase pegmatite.

Plate XIV

Pegmatite 53 in foreground

Quartz-plagioclase-muscovite pegmatite (border zone). The border zone is about three-eighths inch thick but is only discontinuously exposed along the pegmatite contact. It is composed of 50 percent quartz, 35 percent plagioclase, 10 percent muscovite, and 5 percent tourmaline, apatite, and garnet. Muscovite occurs as pale-yellow books which average about one-eighth inch in diameter. The plagioclase and quartz have an average grain size approximately the same as muscovite. The plagioclase in this zone has an N_p-1.533 ± .003 and is therefore near An_{12} in composition.

Plagioclase-quartz-perthite pegmatite (wall zone). The wall zone has an average thickness of one foot. It consists of 40 percent plagioclase, 35 percent quartz, 15 percent perthite, 5 percent muscovite, and less than 4 percent tourmaline, apatite, and garnet. The average grain size is about one-half inch. A small amount of muscovite occurs in books as much as 1½ inches in diameter. The plagioclase has an N_p-1.531 ± .003 which indicates a composition near An_9. Cream-colored perthite crystals are as much as one foot in length but the average is about 2 inches.

Quartz-perthite-plagioclase pegmatite (core). A core, averaging 8 feet thick, consists of 35 percent quartz, 30 percent perthite, 25 percent plagioclase, 10 percent muscovite, and 5 percent tourmaline, garnet, beryl, and apatite. The core is much coarser in texture than the outer zones. It contains large pink perthite crystals, averaging 2 feet in length, which are surrounded by finer grained quartz and plagioclase, the average grain size of which is about one inch. About half the perthite is graphically intergrown with quartz. The N_p of plagioclase is 1.531 ± .003 and has a composition near An_9. Tourmaline crystals, averaging 6 inches in length and 1½ inches in diameter, and muscovite books, averaging one inch in diameter, occur in the outer part of this zone. Beryl crystals are in the fine-grained quartz-plagioclase matrix. The crystals are yellowish-green and range from one inch to 5 inches in length, and one-half inch to 3 inches in diameter.

Mineral Deposits. All the mica in the pegmatite is of scrap quality. A small quantity of the beryl in the core zone is in large enough crystals to be recovered by hand cobbing. However, most of the beryl is not recoverable at present. The refractive index of the ordinary ray of the beryl was determined to be N_o-1.577 ± .003 indicating that the beryl has a BeO content of 13.3 percent. The amount of beryl in the core was estimated as 0.85 percent on the basis of a mineral count over an area of 45 square feet.

Recoverable potash feldspar occurs in the core zone. However, the percent of potash feldspar is low and about one-half occurs as graphic granite. Also the size of the core zone, as exposed, is too small to permit appreciable feldspar production.

Pegmatite 56 (Silver Top Lode)

Pegmatite 56 (Silver Top Lode Mine) is in the SW¼ sec. 20, T. 3 S., R. 4 E. (fig. 2). The property is owned by R. A. Schull of Custer, South Dakota. The mine workings consist of two open cuts along the west side of the pegmatite: one measures 50 feet long, 30 feet wide, and 15 feet deep, and the other 30 feet long, 20 feet wide, and 5 feet deep.

The pegmatite is a tabular body 150 feet in length and averaging 25 feet in thickness. It is exposed as a dip slope which strikes N.

46° W. and dips 50° SW. The plunge of the pegmatite is 40° S. 26° W.

The pegmatite contains four zones: a border zone of plagioclase-quartz-muscovite pegmatite, a wall zone of plagioclase-quartz-perthite pegmatite, an intermediate zone of perthite-quartz-plagioclase pegmatite, and a core zone of quartz-perthite pegmatite.

Plagioclase-quartz-muscovite pegmatite (border zone). The border zone, ranging from one-fourth inch to 1½ inches in thickness, consists of 45 percent plagioclase, 35 percent quartz, 15 percent muscovite, and 5 percent tourmaline, biotite, garnet, and apatite. The average grain size is about one-eighth inch.

Plagioclase-quartz-perthite pegmatite (wall zone). The wall zone, averaging 2 feet in thickness, has a grain size of about one inch. It is composed of 40 percent plagioclase, 30 percent quartz, 20 percent perthite, and 5 percent muscovite. Accessory tourmaline, garnet, biotite, apatite, and beryl constitute less than 5 percent of the zone. Muscovite is in books averaging about 3 inches in diameter. The plagioclase is albite with an average composition of An_{10}. Pale-yellow to green beryl occurs in euhedral crystals in the inner part of the wall zone. The crystals average less than one inch long, although a few are as much as 3 inches long. Most of the beryl is fractured and altered to a clay-like material.

Perthite-quartz-plagioclase pegmatite (intermediate zone). An intermediate zone, averaging 18 feet thick, consists of 45 percent perthite, 30 percent quartz, 20 percent plagioclase, and 3 percent muscovite. Accessory tourmaline, apatite, garnet, and beryl constitute about 2 percent of the zone. The average grain size of the rock appears to be about 5 inches. Coarse-grained perthite and graphic granite crystals, averaging 2 feet in diameter, are enclosed in a finer grained matrix of quartz and plagioclase. The plagioclase has a composition of about An_9. The muscovite books average about three-fourths inch in diameter, and some books as much as 2 inches in width and 1½ inches in length are present. Beryl is most abundant in the outer portion of the intermediate zone, although it is unevenly distributed throughout the zone. It is less altered than the beryl in the wall zone. The largest crystal measured was 11 inches long and 2 inches in diameter.

Quartz-perthite pegmatite (core). The core is several disconnected lenticular pods, averaging 6 feet in length, which are concentrated near the center of the intermediate zone. The pods consist of 55 percent quartz, 40 percent perthite, and 5 percent muscovite. Accessory tourmaline, apatite, and beryl constitute less than 3 percent of the pods. The core contains massive white to pink quartz with subhedral crystals of pink perthite and graphic granite. The perthite crystals average about 2 feet in length. The muscovite is fine-grained, averaging one-half inch in diameter. Beryl crystals occur in two of the pods and are light green and glassy. The largest crystal was 15 inches long and 6 inches in diameter.

Mineral Deposits. Most of the mica is of scrap quality. Mica in the wall zone occurs in books as much as 5 inches in diameter and 1½ inches thick and would yield a small quantity of punch and sheet mica. The intermediate zone contains a few books that would yield some punch mica.

Beryl occurs in all inner zones of the pegmatite. In general, beryl of the wall and intermediate zones is altered, and beryl of the core is fresh. Most of the beryl in the wall zone is too fine-grained to recover by hand cobbing. Most of the beryl could be recovered from the intermediate and core zones. Optical data show that the BeO content of the beryl in the intermediate zone is 13.5 percent, and the BeO content in the core zone is 13.0 percent. The grade of beryl was estimated at 0.15 percent on the basis of measurment of beryl crystals over 1,500 square feet.

Potash feldspar occurs in all inner zones of the pegmatite, but could be recovered only from the intermediate and core zones by hand cobbing. The intermediate zone contains masses as much as 10 feet long, 7 feet wide, and 4 feet high. About one-third of the perthite occurs as graphic granite. Potash feldspar could be mined from the core zone but the small size of the pods restrict recovery.

Pegmatite 64

Pegmatite 64 is in the NW¼ sec. 20, T. 3 S., R. 4 E. (fig. 2). No prospecting work has been carried out.

The pegmatite contains at least four zones: a thin border zone of quartz-plagioclase-muscovite pegmatite, a wall zone of quartz-plagioclase-perthite-muscovite pegmatite, an intermediate zone of quartz-plagioclase-perthite pegmatite, and a core consisting of disconnected pods of quartz-perthite pegmatite.

Quartz-plagioclase-muscovite pegmatite (border zone). A thin border zone, averaging one inch in thickness, occurs at the pegmatite contact. It consists of fine-grained quartz, plagioclase, and muscovite which average less than one-fourth inch in grain size.

Quartz-plagioclase-perthite-muscovite pegmatite (wall zone). The wall zone averages 0.5 feet thick. It contains an estimated 40 percent quartz, 35 percent plagioclase, 10 percent perthite, 10 percent muscovite, and less than 5 percent tourmaline, beryl, and apatite. The average grain size of the wall zone is about one-half inch. Perthite crystals, averaging 2 inches in diameter, are enclosed in a finer grained matrix of the other minerals of the zone. The average grain size of the muscovite is about one-fourth inch. Fine-grained, light-green beryl crystals are intergrown with quartz and plagioclase.

Quartz-plagioclase-perthite pegmatite (intermediate zone). This zone is exposed for 175 feet along strike and has an average width of 8 feet. It contains an estimated 40 percent quartz, 35 percent plagioclase, 20 percent perthite, 5 percent muscovite, and accessory tourmaline, beryl, and apatite. Cream to light-pink perthite occurs in crystals averaging one foot in diameter. The coarse perthite is enclosed in the finer grained quartz and plagioclase. Pale yellowish-green muscovite books and light-green beryl crystals have an average diameter of three-fourths inch.

Quartz-perthite pegmatite (core). The apparent core is a series of disconnected pods that are a few feet thick and consist of an estimated 50 percent quartz, 40 percent perthite, 10 percent muscovite, and accessory beryl. It cannot be determined whether or not the pods coalesce into a single core at depth. Perthite crystals are light pink and average one foot in diameter. Muscovite is concentrated along the periphery of the quartz-perthite core in books which average about 3 inches in diameter. Beryl crystals average about 3 inches in length.

Mineral Deposits. Mica in the wall, intermediate, and core zones is mostly of scrap quality. Some mica books of sheet quality occur along the periphery of the core. An estimated 0.1 percent of beryl occurs in these same three zones. However, the average grain size of the beryl is one inch, which is too small for present hand methods of recovery. The larger crystals in the core zone are recoverable by hand cobbing.

Potash feldspar could be mined from the core and intermediate zones, but the small thickness of the zones restrict the total recovery.

Pegmatite 66 (Dorothy Lode Mine)

Pegmatite 66 (Dorothy Lode Mine) is in the SW¼ sec. 27, T. 3 S., R. 4 E. (fig. 2). It is owned by Consolidated Feldspar Corporation of Trenton, New Jersey. The mine workings consist of an open cut which is 100 feet long, 20 feet wide, and has an average depth of 30 feet. (See pl. XVA) This pegmatite was described in a Geological Survey report by W. E. Hall[1] who visited the property October 31, 1942. His report includes a brief description of the pegmatite, the muscovite bearing units, and the feldspar and mica production from September and October, 1942.

The pegmatite forms a narrow ridge which is surrounded by quartz-mica schist. It is a tabular body which strikes N. 70° E. and dips 40° SE. The probable plunge of the pegmatite is about 35° S. 25° E. The pegmatite as exposed has a length of about 150 feet, an average width of 25 feet, and a maximum width of 45 feet.

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[1]Hall, W. E., Dorothy Lode Prospect, in Page, L. R., et. al., Pegmatite Investigations 1942-1945, Black Hills, South Dakota: U. S. Geol. Survey Prof. Paper 247.

Plate XV

A. Open-cut of pegmatite 66

B. ... of massi... and blocky perthite.

The pegmatite contains four zones: a border zone of quartz-plagioclase-muscovite pegmatite, a wall zone of plagioclase-quartz-muscovite pegmatite, an intermediate zone of perthite-quartz-plagioclase pegmatite, and a core of perthite-quartz-plagioclase pegmatite.

Quartz-plagioclase-muscovite pegmatite (border zone). The border zone is about three-fourths inch thick and consists of about 45 percent quartz, 35 percent plagioclase, 15 percent muscovite, and 5 percent tourmaline, garnet, and apatite. The average grain size is about one-fourth inch.

Plagioclase-quartz-muscovite pegmatite (wall zone). The wall zone has an average thickness of 2 feet. Its composition is estimated at 55 percent plagioclase, 35 percent quartz, and 5 percent muscovite. Accessory tourmaline, apatite, and garnet constitute less than 5 percent of the zone. Muscovite commonly occurs in wedge shaped books as much as 9 inches in diameter but the average size is about 3 inches.

Perthite-quartz-plagioclase pegmatite (intermediate zone). An 8 foot thick intermediate zone is composed of an estimated 80 percent perthite, 10 percent quartz, and 7 percent plagioclase. Muscovite, tourmaline, and apatite are accessory. White perthite occurs in crystals as large as 5 feet in diameter. These are surrounded by a fine-grained matrix of quartz and plagioclase, averaging three-fourths inch in diameter. The plagioclase has an N_p of 1.529 ± .005 which indicates albite with a composition near An_6. Locally, either quartz or plagioclase may predominate in the finer grained matrix. Tourmaline occurs as inclusions in the perthite.

Perthite-quartz-plagioclase pegmatite (core). The core has an estimated average composition of 40 percent perthite, 40 percent quartz, 15 percent plagioclase, and accessory muscovite, beryl, phosphate minerals (lithiophillite-triphylite). The perthite and most of the quartz is coarse-grained. Perthite occurs in euhedral crystals which average about 5 feet in length and 2 feet in width. Pale-yellow beryl crystals associated with plagioclase average three-fourths inch in length. A lesser amount of fine-grained quartz and plagioclase forms a matrix to the coarse-grained perthite and quartz. They occur in anhedral crystals with an average size of three-fourths inch. The plagioclase has a composition near An_8. Lithiophillite-triphylite occurs in dark-brown masses as much as 5 inches in diameter associated with plagioclase and quartz.

The contact of these finer grained masses with the coarse-grained perthite and quartz indicate that some of the finer material replaces the coarser so that they may be replacement pods within the core.

The core also contains mica-rich aggregates or "bull" mica units. (See pl. XVB) These average 2 feet in diameter and contains about 60 percent muscovite, averaging one-half inch in diameter. The remaining minerals are plagioclase and quartz.

Mineral Deposits. Most of the mica in the pegmatite is of scrap quality. Books of sheet mica, averaging 3 inches in diameter, were mined from the wall zone. The mica is commonly light-ruby colored and is clear and hard. Ruled and "A" structure are minor defects in the mica. Beryl occurs in the core in crystals too small to recover by hand cobbing. It has an index of refraction N_o=1.515 ± .003 which indicates a BeO content of 13.5 percent. Tantalite is reported from the mine, but none was found in this investigation.

Potash feldspar occurs in the intermediate and core zones in crystals of large size. Considerable potash feldspar was mined from the intermediate zone. A lesser quantity of feldspar was mined from the core. The potash feldspar contains a very small amount of mineral impurities.

Pegmatite 67 (Highland Lode or John Ross Mine)

Pegmatite 67 (Highland Lode, John Ross Mine) is a well-zoned pegmatite in the NE¼ sec. 30, T. 3 S., R. 4 E. (fig. 2). The mine has produced more feldspar and beryl than any of the pegmatites in the mapped area. The pegmatite has been described in detail by Page and Stoll.[1]

Pegmatite 74b (Pleasant Valley)

Pegmatite 74 b (Pleasant Valley) is in the NE¼ sec. 7, T. 4 S., R. 4 E. (fig. 2). The property is owned by Charles A. Parker, Jr., of Custer, South Dakota, and has been operated intermittently by George Bland, Jr. since 1945.

The pegmatite is a well-zoned fracture filling in a large homogeneous pegmatite consisting mainly of albite, quartz, and perthite. The fracture filling has been mined to recover potash feldspar and beryl. The pegmatite has been described by Adams and Stoll[2].

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[1] Page, L. R., and Stoll, W. C., Highland Lode (John Ross Mine), in Page, L. R., et. al., Pegmatite Investigations 1942-1945, Black Hills, South Dakota: U. S. Geol. Survey Prof. Paper 247.

[2] Adams, J. A., and Stoll, W. C., Pleasant Valley Pegmatite, in Page, L. R., et. al., Pegmatite investigations 1942-1945, Black Hills, South Dakota: U. S. Geol. Survey Prof. Paper 247.

Pegmatite 76b

Pegmatite 76b is in the NE¼ sec. 7, T. 4 S., R. 4 E. (fig. 2). The owner of the property is not known.

The pegmatite is a tabular body which strikes N. 16° E. and dips 75° SE. The pegmatite measures 350 feet long and 15 feet thick, and consists of 40 percent plagioclase, 30 percent quartz, 25 percent perthite, and 5 percent muscovite, tourmaline, and apatite. A cross-cutting, zoned, vertical fracture filling 10 feet thick, occurs near the south end of the pegmatite.

Two zones have been recognized in the fracture filling: a wall zone of plagioclase-quartz-muscovite pegmatite, and a core of perthite-quartz-pegmatite.

Plagioclase-quartz-muscovite pegmatite (wall zone). The wall zone averages 6 inches thick and consists of an estimated 40 percent plagioclase, 30 percent quartz, 15 percent muscovite, 10 percent perthite, and 5 percent accessory phosphate minerals (lithiophillite-triphylite), beryl, and apatite. The average grain size is 1½ inches. Muscovite is present in light-ruby colored aggregates of books ranging from one-half inch to 5 inches in diameter. Yellow-green crystals of beryl, averaging one inch in length, are associated with muscovite and perthite. Pink perthite crystals average about 2 inches in length. The lithiophillite-triphylite is unevenly scattered throughout the zone and occurs in dark-brown masses one inch to 5 inches in diameter.

Perthite-quartz pegmatite (core). The core averages 9 feet thick and consists of about 60 percent perthite and 40 percent quartz. The perthite occurs in light-pink subhedral masses as much as 3 feet long and 2 feet wide. The quartz is mainly massive and white to light-pink in color.

Mineral Deposits. Mica occurs only in the wall zone and is mostly of scrap quality. The books average about 3 inches in diameter and are wedged, ruled, show "A" structure, and contain abundant inclusions. An estimated 0.5 percent beryl occurs in the wall zone. The refractive index of the beryl was determined to be N_o-1.580 ± .003, indicating a BeO content of 13.0 percent. The crystals range from one-half inch to 3 inches in length and for the most part can be recovered by hand cobbing.

Recoverable potash feldspar occurs in the core, but because of the small thickness of the zone, the total recovery would be small.

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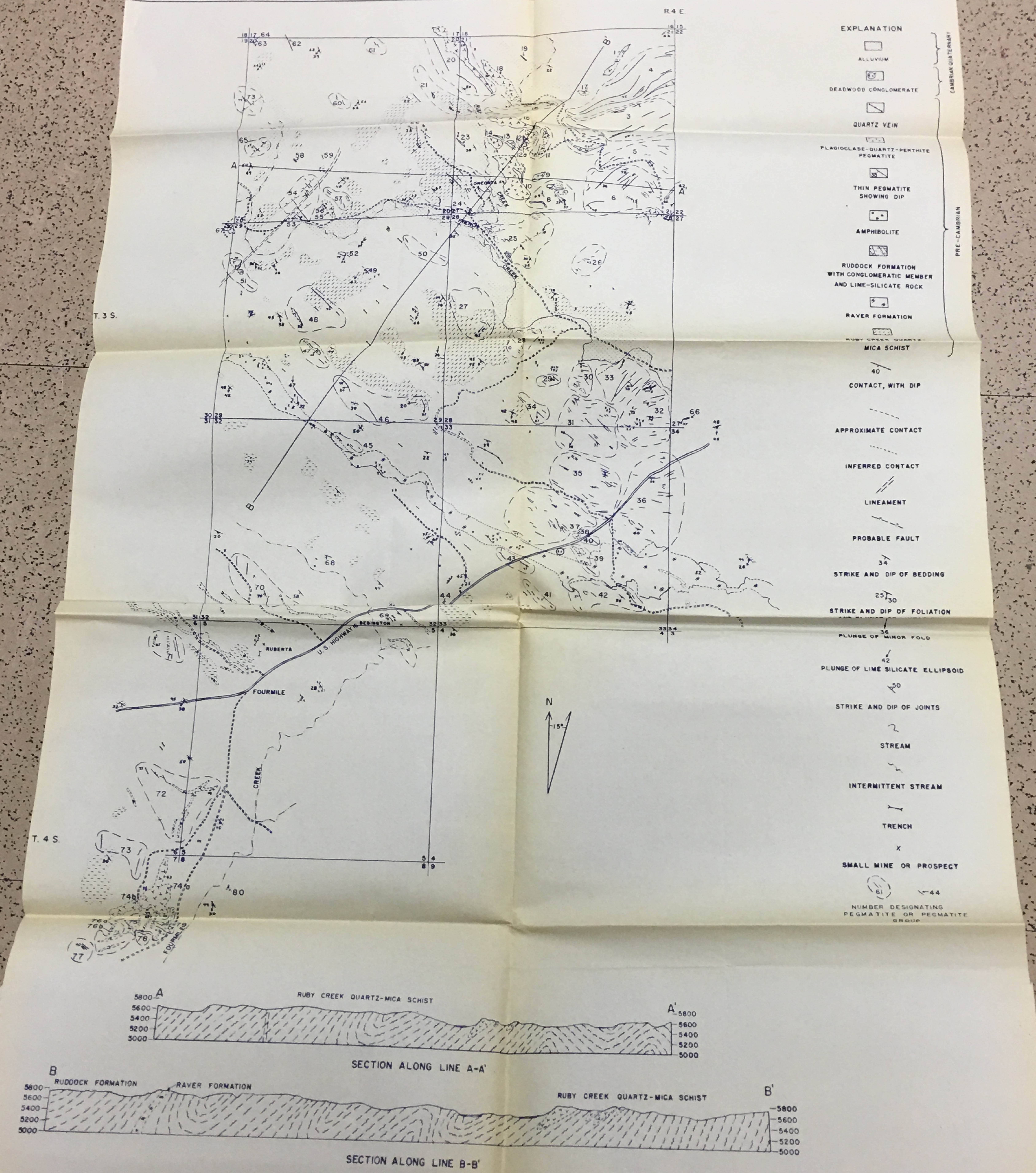
FIGURE 3



GEOLOGY MAPPED IN 1948, 1949, 1950

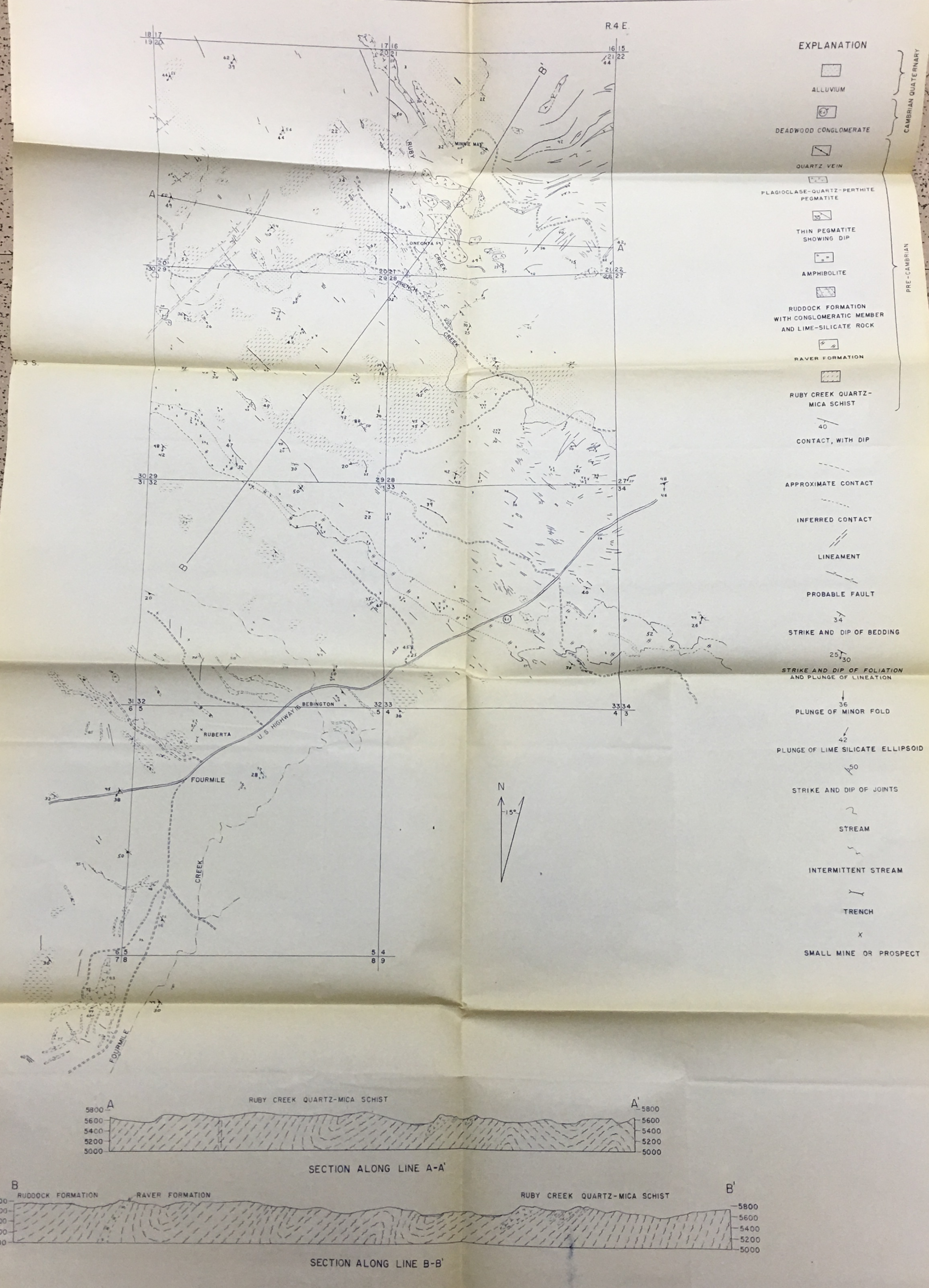
GEOLOGIC MAP AND SECTIONS OF THE FOURMILE AREA, CUSTER COUNTY, SOUTH DAKOTA

GEOLOGY BY ANDREW J. LANG JR.

SCALE 1:12,000

0 500 1000 2000 3000 F

FIGURE 2



GEOLOGY MAPPED IN 1948, 1949, 1950

GEOLOGIC MAP AND SECTIONS OF THE FOURMILE AREA, CUSTER COUNTY, SOUTH DAKOTA

GEOLOGY BY ANDREW J. LANG JR.

SCALE 1:12,000

0 500 1000 2000 3000

Table 7.--Mineralogy of Heterogeneous Pegmatites

Number and name of pegmatite	Zone	Plagioclase		Perthite		Graphic granite		Quartz		Muscovite		Tourmaline		Garnet		Other minerals		
		%	Size[1]	%	Size[1]	%	Size[1]	%	Size[1]	%	Size[1]	%	Size[1]	%	Size[1]	Min.[2]	%	Size[1]
12b. Big Spar No.1 Mine	Wall	50	1/4					30	1/4	5	1/4	10	3	1	1/8	A	1	F
	Inter	45	1	15	12	5	12	30	1	5	1	1	F			A	1	F
																Br	1	2
	Core	15	1			40	24	40	2	5	F	1	F	1	1/8	A	1	F
14 Big Spar No. 2 Mine	Wall	60	1	5	1			30	1	3	F	2	F	1	1/16	B	1	1/8
																Br	1	3/4
	Core	35	1	10	18	30	24	20	1	2	F	1	F	1	1/8	Ar	1	1/4
																B	1	1/8
23	Wall	50	1/2	10	3			30	1/2	5	1/2	2	1/2			A	1	1/16
	Core	25	1	20	12	10	14	40	1	3	1/2	1	1/4	1	1/16	A	1	1/16
52	Wall	40	1/2	20	1			30	1/2	5	1/4	2	F	1	1/16	A	1	1/16
	Inter	30	1	5	24	25	24	35	1	5	3/4	1	F	1	1/16	A	1	1/16
																Br	1	2
	Core			40	18			60	C	2	F					A	1	1/16
																Br	1	1
	Bull-mica	10	1/2					20	1/2	70	1							
53	Wall	40	1/2	15	2			35	1/2	5	1/4	3	1/2	1	1/8	A	1	1/16
	Core	25	1	15	24	15	24	35	1	10	3/4	2	1	1	1/8	A	1	1/16
																Br	1	1
56 Silver Top Lode Mine	Wall	40	3/4	20	2			30	3/4	5	1/2	3	F	1	1/8	Br	1	1
	Inter	20	1	35	24	10	24	30	1	3	1/2	2	F	1	1/8	Br	1	2
	Core			30	24	10	24	55	C	5	1/2							
64	Wall	35	1/2	10	2			40	1/2	10	1/2	1	F			A	1	1/16
																Br	1	1/2
	Inter	35	3/4	20	12			40	3/4	5	3/4	1	F			A	1	1/16
	Core			40	12			50	C	10	1							
66 Dorothy Lode Mine	Wall	55	3/4					35	3/4	5	1/2	1	F			A	1	1/16
	Inter	7	1	80	36			10	1	2	3/4	1	F			A	1	1/16
	Core	15	3/4	40	36			40	C	5	1/2					A	1	1/16
																Br	1	1
																LT	1	?
76b	Wall	40	3/4	10	2			30	3/4	15	3					LT	1	2
																A	1	1/16
																Br	1	1
	Core			60	24			40	C									

1. Size given in inches, or F-less than 1 inch, M-1 inch to 4 inches, C-4 inches to 12 inches, VC-over 12 inches
2. A-apatite, B-biotite, Br-beryl, Ar-arsenopyrite, LT-lithiophylite-triphylite.

Table 6.--Mineralogy of Homogeneous Pegmatites--Continued.

Number of pegmatite[1]	Plagioclase		Perthite		Graphic granite		Quartz		Muscovite		Tourmaline		Garnet		Other minerals		
	%	Size[2]	%	Size[2]	%	Size[2]	%	Size[2]	%	Size[2]	%	Size[2]	%	Size[2]	Min.[3]	%	Size[2]
41(13)	30	1/4	20	2	5	4	40	1/4	5	1/2	3	1/2	1	1/16	A	1	F
42(3)	30	1/2	25	6			35	1/2	10	1/2	2	1/2			A	1	F
43	25	1/2	30	M	20	M	15	1/2	5	1/2	5	1/2			A	1	F
44	35	F	30	M	10	M	20	F	3	1/2	2	1/4			A	1	F
45(5)	35	1/2	20	8	5	8	30	1/2	5	1/2	3	1/4	1	1/16	A	1	F
46(3)	40	1/4	15	12	5	12	30	1/4	5	1/4	3	1/4			A	1	F
47(2)	35	1/2	10	10	10	10	30	1/2	10	1/4	2	1/4	1	1/16	A	1	F
48(4)	30	1/2	10	10	20	14	25	1/2	10	1/4	2	1/4			A	1	F
49	35	F	10	6	20	10	25	F	5	1/4	2	1/4	1	1/16	A	1	F
50(2)	35	1/2	10	8	20	12	25	1/2	5	1/4	2	1/4	1	1/16	A	1	F
51(2)	25	3/4	5	10	25	14	35	1/2	5	1/2	3	1/4	1	1/16	A	1	F
54(9)	35	1/2	5	8	20	12	30	1/2	5	1/2	2	1/4			A	1	F
55	35	1/2	5	8	20	14	30	1/2	5	1/2	2	1/4	1	1/16	A	1	F
57(5)	30	1/4	5	8	15	12	40	1/4	5	1/8	2	1/4			A	1	F
58(2)	25	3/4	5	4	25	6	30	3/4	10	1	2	1/2			A	1	F
59	30	1/4	20	M	5	C	35	1/4	5	1/4	3	1/4			A	1	F
60(3)	20	1/2	15	C	25	C	30	1/2	5	1/2	3	1/2			A	1	F
61(2)	35	F	15	C			40	F	5	F	2	F			A	1	F
62(2)	30	F	15	C	5	C	40	F	5	1/4	2	F			A	1	F
63	30	1/2	15	M			40	1/2	15	1/4	1	1/4			A	1	F
65	25	1/2	10	4	20	6	30	1/2	10	1/2	2	1/2	1	1/4	A	1	F
68	30	1/4	10	C	20	C	30	1/4	5	1/4	2	1/8			A	1	F
69	35	1/4	5	C	20	C	30	1/4	5	1/4	3	1/4			A	1	F
70	35	1/4	20	C	5	C	30	1/4	5	1/4	2	1/8			A	1	F
71	35	1/4	20	M	5	M	30	1/4	5	1/8	2	1/8			A	1	F
72	40	1/2	15	5	5	5	30	1/2	8	1/4	1	1/9			A	1	F
73	40	1/2	15	4	5	4	30	1/2	5	1/4	2	1/4			A	1	F
74a	35	3/4	15	15	10	20	30	3/4	5	1/2	2	1/4			A	1	F
75	35	1/2	15	10	10	10	30	1/2	5	1/4	2	1/4			A	1	F
76a	35	1/2	20	10	5	10	30	1/2	5	1/2	2	1/4			A	1	F
77	45	1/2	15	4	5	4	30	1/2	5	1/4	1	1/4			A	1	F
78	40	1/2	20	5	5	5	30	1/2	5	1/4	1	1/4			A	1	F
79	40	1/2	15	5	10	5	30	1/2	5	1/4	1	1/4			A	1	F
80	35	1/2	15	5	10	5	30	1/2	5	1/4	2	1/4			A	1	F

1. Number of pegmatites in a group in parenthesis
2. Size given in inches, or F-less than 1 inch, M-1 inch to 4 inches, C-4 inches to 12 inches, VC-over 12 inches.
3. A-apatite, B-biotite, Br-beryl, L-lollingite.

Table 6.--Mineralogy of Homogeneous Pegmatites

Number of pegmatite[1]	Plagioclase		Perthite		Graphic granite		Quartz		Muscovite		Tourmaline		Garnet		Other minerals		
	%	Size[2]	%	Size[2]	%	Size[2]	%	Size[2]	%	Size[2]	%	Size[2]	%	Size[2]	Min.[3]	%	Size[2]
1	45	F	15	C	5	C	30	F	3	1/2	1	1	1	F	A	1	F
2(11)	50	1/2	15	6	5	6	25	1/2	3	1/2	2	1	1	F	A B	1 1	F F
3(21)	40	1/2	20	5	5	5	30	1/2	3	1/2	2	1	1	F	A B	1 1	F F
4(12)	40	1/2	15	5	5	5	35	1/2	3	1/2	2	1	1	F	A B	1 1	F F
5(12)	40	1/2	20	5	5	5	30	1/2	3	1/2	2	1	1	F	A B	1 1	F F
6(24)	30	F	15	4	5	4	40	F	5	3/4	3	1	1	F	A B	1 1	F F
7	35	F	20	C	5	C	30	F	5	1/2	3	3/4	1	F	A B	1 1	F F
8(5)	40	F	15	C	5	C	35	F	3	1/2	2	1/2	1	F	A	1	F
9	30	3/4	20	12	20	12	5	3/4	3	3/4	2	1	1	F	A B	1 1	F F
10	50	1/2	5	C	5	C	30	1/2	3	1/4	2	1/4	1	F	A B	1 1	F F
11(2)	35	1/2	20	C	10	C	25	1/2	5	3/4	2	1/2	1	F	A	1	F
12a(2)	45	1	20	12	10	12	15	1	5	3/4	3	1	2	F	A	1	F
13(2)	40	3/4	20	12	10	12	25	3/4	1	1/2	2	3/4			Br A	1 1	F F
15	30	3/4	25	12	10	12	25	3/4	3	3/4	3	1	1	F	Br A B L	1 1 1 1	F F F F
16(5)	35	F	20	C	10	C	30	F	2	1/2	2	3/4			A	1	F
17	40	3/4	15	6	5	6	35	3/4	3	1/2	2	1/2	1	F	A B	1 1	F F
18	40	F	20	C	10	C	25	F	3	1/2	2	1	1	F	A B	1 1	F F
19	45	F	15	C	5	C	30	F	2	1/2	3	1/2			A	1	F
20(4)	30	3/4	10	6	20	12	25	3/4	5	1/2	3	1/2	1	F	A B	1 1	F F
21(8)	35	F	20	C	10	C	30	F	2	F	2	F			A B	1 1	F F
22	35	1	10	8	15	12	30	3/4	5	1/2	2	1	1	F	A	1	F
24(20)	45	3/4	5	5	15	8	30	3/4	3	1/2	2	1/2	1	F	A B	1 1	F F
25(8)	30	3/4	10	C	20	C	30	3/4	5	1/2	3	1/2			A Br	1 1	F F
26(5)	45	2	10	C	5	C	25	1/2	10	3/4	2	1			A	1	F
27(4)	35	3/4	10	6	10	10	30	1/2	10	3/4	3	3/4	1	F	A	1	F
28(8)	35	1	10	12	5	12	35	1/2	10	3/4	4	1			A	1	F
29(2)	30	1/2	10	4	30	5	25	3/4	5	1/2	3	1	1	F	A	1	F
30(14)	30	1/2	30	6	5	4	25	1/2	5	1/2	2	1	1	F	A B	1 1	F F
31(25)	30	1	25	5	5	M	30	1/2	5	1/2	2	1/2	1	F	A B	1 1	F F
32(30)	20	3/4	20	4	25	6	25	1/2	5	3/4	2	1/2	1	F	A	1	F
33(7)	35	1/4	10	M	20	M	25	1/4	5	1/8	2	1/4	1	F	A	1	F
34(2)	35	1/2	5	4	10	6	35	1/2	10	1	3	1	1	F	A	1	F
35(31)	25	1/2	10	4	20	6	35	1/2	5	1	3	1			A	1	F
36(18)	25	3/4	15	6	15	6	35	1/2	5	3/4	3	3/4			A	1	F
37(27)	35	1/2	20	C	10	C	25	1/2	5	1/2	2	1/2	1	F	A	1	F
38	25	1/2	20	8	10	12	35	1/2	5	1/2	3	1/2			A	1	F
39(2)	35	1/2	10	12	25	12	20	1/2	5	1/2	4	1/2			A	1	F
40	45	3/4	5	M	15	M	20	1/2	10	1/2	2	1/2			A	1	F

1. Number of pegmatites in a group in parenthesis.
2. Size given in inches, or F-less than 1 inch, M-1 inch to 4 inches, C-4 inches to 12 inches, VC-over 12 inches.
[illegible] B-biotite, Br-beryl, L-lollingite.