Geology of the High Climb Pegmatite, Custer County, South Dakota

By Douglas M. Sheridan

Trace Elements Investigations Report 231

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Geology and Mineralogy

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UNITED STATES DEPARTMENT OF THE INTERIOR

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By

Douglas M. Sheridan

December 1953

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*This report concerns work done partly on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

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GEOLOGY OF THE HIGH CLIMB PEGMATITE, CUSTER COUNTY, SOUTH DAKOTA

By Douglas M. Sheridan

ABSTRACT

The High Climb pegmatite, Custer County, S. Dak., belongs to the series of pegmatitic and granitic rocks that characterize the Harney Peak region of the southern Black Hills. It intrudes pre-Cambrian metamorphic rocks consisting chiefly of quartz-mica schist. The country rock has been altered to a tourmaline-rich schist along part of the pegmatite contact.

The structure of the pegmatite, in general, is concordant with the westward-dipping schistosity of the country rock, but locally the pegmatite is crosscutting. The main part of the pegmatite is an irregularly shaped pipe that plunges 45° N. 40° W., parallel to the average plunge of rolls in the footwall. A small northern extension of the pegmatite has a lenticular shape and crosscuts the schist at a low angle. Rolls in this part of the pegmatite have an average plunge of 28° N. 25° W. One large, north-trending crestal roll divides the outcrop of the northern segment of the pegmatite into two parts.

The pegmatite has a well-defined internal structure consisting of five zones. A fine-grained wall zone, consisting of albite-quartz pegmatite, and a medium-grained first intermediate zone, consisting of albite-quartz-muscovite pegmatite, form incomplete concentric shells. Perthite-quartz-albite pegmatite (second intermediate zone) forms a hood-shaped unit between the outer units and the third intermediate zone along the crest and hanging-wall of the pegmatite. A concentric shell of quartz-cleavelandite pegmatite (third intermediate zone) surrounds a lenticular core of quartz pegmatite that contains altered spodumene. In addition to the five zones, a fracture-filling unit of quartz-perthite-muscovite-albite pegmatite and a possible sixth zone (or replacement unit ?) of very fine-grained muscovite pegmatite were recognized.

The essential minerals of the pegmatite include microcline-perthite, quartz, albite, and muscovite. Accessory minerals include tourmaline, beryl, amblygonite (variety, montebrasite), apatite, columbite-tantalite, loellingite, altered spodumene, numerous unidentified dark-colored phosphate minerals, a manganese-bearing carbonate, garnet, and chalcopyrite.

An explanation of the origin of the pegmatite requires fractional crystallization and incomplete reaction in a restricted system. The concentric zonal structure and the general increase in grain size from the wall zone to the core suggest that the pegmatite units crystallized in order from the walls inward, without any true replacement stages.

Industrial minerals that have been produced at the High Climb pegmatite are beryl, amblygonite, potash feldspar, columbite-tantalite, scrap mica, and sheet mica.

INTRODUCTION

The High Climb pegmatite, Custer County, South Dakota, is a zoned pegmatite that has been the source of amblygonite, beryl, mica, feldspar, and columbite-tantalite. Geologic interest has been stimulated not only by the economic potentiality of the property as a producer of beryl and scrap mica, but also by the complex structure of the pegmatite and the unusually well-developed series of zones containing widely varied mineral assemblages.

Location and surface features

The High Climb pegmatite is on the boundary between the SE1/4, sec. 22 and the NE1/4, sec. 27, T. 2 S., R. 4 E., about 6 miles north of Custer, South Dakota (fig. 1). The pegmatite is just south of the boundary between Pennington and Custer Counties. A road log from Custer to the pegmatite is given below.

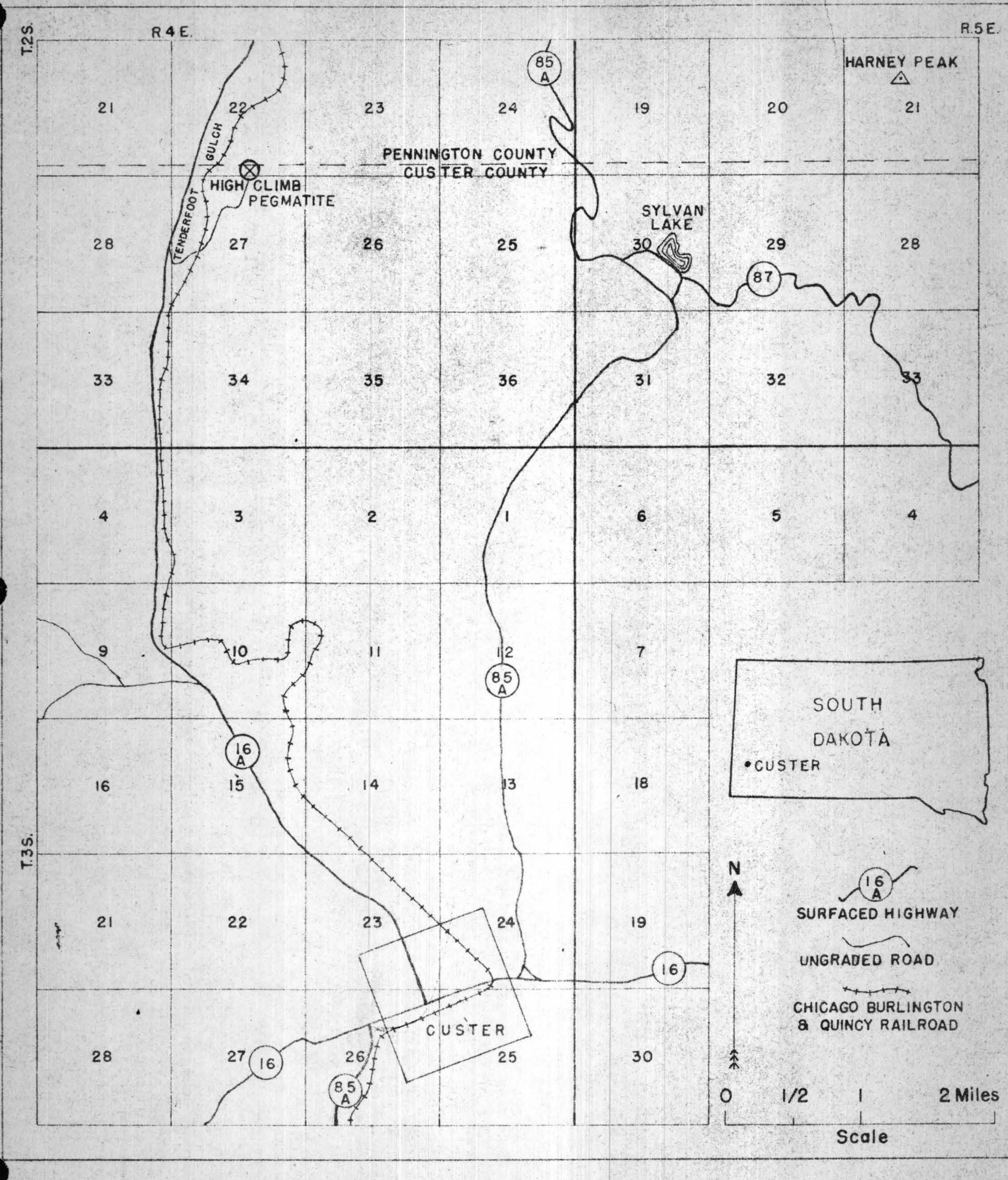

FIGURE I. MAP SHOWING LOCATION OF THE HIGH CLIMB PEGMATITE

Miles	
0.0	At Custer County Bank, Custer, S. Dak. Travel north on U. S. Highway 16-A (fig. 1).
6.3	Turn right to ungraded road.
6.5	Travel across small intermittent stream in Tenderfoot Gulch, under the Chicago, Burlington, and Quincy railroad trestle, and across small log-dirt bridge. Proceed north along Tenderfoot Gulch.
6.8	Road crosses small stream and winds northeastward up the slope on the east side of Tenderfoot Gulch.
7.0	Road turns sharply to the right at crest of ridge and winds across small valley.
7.3	High Climb pegmatite.

The High Climb pegmatite crops out between altitudes of 5,680 feet and 5,750 feet on the east side of Tenderfoot Gulch. It is on the west side of a northward-trending ridge, approximately 300 feet above the floor of the gulch. The relief is rugged, and the pine-covered slopes drop steeply to the valleys below.

Ownership and production

The High Climb pegmatite is on an unpatented claim owned by Mrs. Gladys Wells and Mr. Fred Heidepriem, both of Custer, S. Dak. The mine was first opened in 1932 and has been operated intermittently since then.

Minerals that have been produced from the High Climb pegmatite are amblygonite, beryl, columbite-tantalite, scrap mica, punch and plate mica, and feldspar. W. C. Stoll (unpublished report in files of U. S. Geological Survey, 1942) quotes Mrs. Wells for the following figures giving the approximate total production through 1940:

Amblygonite	Estimated 100-350 tons (no accurate figures available)
Beryl	60 tons
Scrap mica.	100 tons (including about 150 pounds of punch and sheet mica)
Feldspar	150-180 tons
Columbite	100 pounds

In 1944-45 the mine was worked intermittently for feldspar, but no production figures are available. In 1948 the mine was operated for beryl and scrap mica. Mrs. Wells and C. K. Koch, the mine operator, have provided the following figures for 1948:

Beryl	4,832 pounds shipped, and approximately 2,000 pounds mined but not cobbed
Scrap mica . . .	25,270 pounds

According to Mrs. Wells (oral communication, 1951), production since 1948 has been negligible, and no production figures are available.

Previous work

In 1941 Fisher (1942, p. 17-23) prepared a generalized map of the High Climb pegmatite and the mine workings; Fisher's report includes descriptions of the geology, mineralogy, and paragenetic relations, and also sections showing the mineralogic and textural relations on the walls of the main pit. Fisher (1945, p. 18-20, figs. 4-5) also illustrated and described a process of so-called "albitization of microcline", using examples from the High Climb pegmatite. In 1942, W. C. Stoll used Fisher's map as a base for preparing an unpublished memorandum on strategic minerals for the files of the U. S. Geological Survey. The results of Stoll's examinations were revised by J. W. Adams (Adams and Stoll, 1953, p. 131).

Present investigation

The purpose of the present investigation was to make a study of the internal structure and the lithologic units in the High Climb pegmatite, as a contribution to the Geological Survey's investigations of the pegmatites of the Black Hills. Although previous workers had prepared generalized maps and collected descriptive data, no detailed map or systematic study of the internal structure had been made.

The field work was carried out intermittently from July through December 1948. This work was done partly on behalf of the Division of Raw Materials of the Atomic Energy Commission. A detailed map (fig. 2) and geologic sections (fig. 3) at a scale of 1:240 were prepared, using plane table, alidade, and stadia rod. R. E. Roadifer, V. R. Wilmarth, J. J. Norton, and L. R. Page of the U. S. Geological Survey assisted the writer during the mapping. A. J. Lang and D. B. Stewart, also of the U. S. Geological Survey, measured beryl crystals on typical exposures.

Microscopic studies of grains and thin sections of pegmatite minerals were carried on at the University of Minnesota from January to June 1949.

The writer is indebted to Mrs. Gladys Wells, Mr. Fred Heidepriem, and Mr. C. K. Koch, for providing production figures and information regarding the mineralogical character of mined-out parts of the main pit. The writer appreciates the advice of Professor S. S. Goldich and other staff members of the Department of Geology and Mineralogy of the University of Minnesota during the laboratory investigations.

MINE WORKINGS

The High Climb pegmatite has been mined by two open cuts in the southern end of the body and three small open cuts to the north. The main pit extends 140 feet southeast across the southern part of the pegmatite (fig. 2); the pit is 50 feet wide and 42 feet deep. The main pit was originally operated from an opening in the southeast side of the pegmatite; a large dump made at that time extends 160 feet southeast from the pegmatite. More recently the lower part of the main pit has been mined through the narrow cut that opens to the northwest (fig. 2) at an altitude of 5,710 feet. A smaller open cut, 40 feet long, 30 feet wide, and 20 feet deep, is 30 feet northeast from the lower entrance to the main pit. The large dump, extending 170 feet to the northwest, consists of rock derived from operations in the lower part of the main pit and in the smaller open cut.

Three small cuts are in the northern extension of the pegmatite; the largest of these is only 10 feet deep. One small prospect trench to the northeast of the pegmatite was cut in schist.

GENERAL GEOLOGY

Regional setting

The Black Hills of South Dakota are a range of mountains eroded from a domal uplift, the long axis of which strikes north-northwest and is 125 miles long; the uplift is about 60 miles wide. The central part of the Black Hills consists of pre-Cambrian rocks that crop out in an area 60 miles long and 25 miles wide. On the flanks of the pre-Cambrian exposure are outcrops of Paleozoic and younger sedimentary rocks, which dip away on all sides from the pre-Cambrian area and form inward-facing scarps of hogback ridges.

The southern part of the pre-Cambrian core of the Black Hills contains many intrusives of pegmatitic and granitic rocks in a 250-square mile area surrounding Harney Peak. These intrusives range widely in character. At one extreme are those that consist almost entirely of granite. The other extreme is represented by well-zoned pegmatites like the High Climb. The High Climb is one of several such pegmatites that lie along the west side of the Harney Peak uplift.

Metamorphic rocks

The country rocks of the High Climb pegmatite consist of a series of metamorphosed pre-Cambrian sedimentary rocks, now mainly quartz-mica schists. The schistosity of these rocks in general strikes N. 20°-30° E. and dips from 40° to 85° NW. Bedding has approximately the same strike as the schistosity, but usually dips about 10 degrees less than the schistosity.

The country rock has been shown on the map as consisting entirely of quartz-mica schist, with the exception of one outcrop of graphitic schist cut by quartz stringers in the northwest corner of the area (fig. 2). Interbedded with the quartz-mica schist, however, are less abundant beds of lime silicate-quartz rock, micaceous quartzite, and porphyroblastic quartz-mica schist.

Quartz-mica schist

The brownish gray to silvery quartz-mica schist crops out in well-foliated beds that alternate with micaceous quartzite, lime silicate-quartz rock, and porphyroblastic quartz-mica schist. The beds range in thickness from less than an inch to over 12 inches. All gradations exist between schist and quartzite.

Thin-sections indicate that the quartz-mica schist contains quartz (40 to 50 percent), biotite (30 to 40 percent), muscovite (10 to 20 percent), zircon ($<$1 percent), magnetite (Tr.), garnet (Tr.), apatite (Tr.), microcline (Tr.), plagioclase (Tr.), and tourmaline (Tr.). Individual grains in the schist average about 0.01 inch or less in size. Some of the muscovite occurs in relatively coarse plates that cut across quartz grains.

Micaceous quartzite

All gradations exist between massive, blocky micaceous quartzite and more schistose rock. In thin-section the micaceous quartzite contains quartz (85 to 90 percent), biotite (10 percent), muscovite (1 percent), zircon ($<$1 percent), tourmaline ($<$1 percent), garnet (Tr.), apatite (Tr.), and magnetite (?) (Tr.). The quartz grains have a granoblastic texture, but the platy parallelism of the mica grains gives the rock a definite schistose appearance. Skeletal tourmaline crystals are present in amounts up to 4 percent in quartzite near small pegmatite stringers. The tourmaline has quartz inclusions and cuts across biotite flakes.

Porphyroblastic quartz-mica schist

Part of the quartz-mica schist contains 5 percent or more of porphyroblasts and augen-like lenses. These rocks include quartz-mica-garnet schist, quartz-mica-garnet-chlorite schist, and quartz-mica-garnet-sillimanite schist.

The quartz-mica-garnet schist contains 5 to 10 percent garnet, in reddish-brown to pink euhedral grains ranging from less than 0.05 inch to 0.15 inch in diameter. With the exception of garnet, the proportion of other minerals is the same as in normal quartz-mica schist. The foliation ordinarily bends around the garnet grains, but in some places it is cut by the garnet. Most of the garnet crystals are euhedral and contain numerous poikilitic inclusions of quartz, but some are very irregular and enclose both quartz and biotite. Zircon, apatite, and magnetite (?) are minor accessories. Some of the apatite is granulated. Minor amounts of tourmaline occur in some of the quartz-mica-garnet schist.

Quartz-mica-garnet-chlorite schist is similar to the quartz-mica-garnet schist, but characteristically is more crumpled and contains green-black metacrysts of chlorite, 0.2 inch to 0.5 inch in length. Megascopically, some of the dark-colored metacrysts have the shape of a cross, and thin-section studies indicated that some of these metacrysts may be retrograde staurolite. Most of the garnet grains exhibit euhedral or skeletal forms and appear quite fresh, but one grain observed in thin section has been altered to a fine-grained mass of chlorite. Pod-shaped aggregates of relatively coarse quartz and muscovite are irregularly distributed in the rock. The muscovite in these aggregates cuts across the elongated quartz grains.

Quartz-mica-garnet-sillimanite schist contains small grayish-white, augen-like lenses, 0.1 inch to 0.3 inch in length. Thin-section study of this schist indicates that the general composition is much like that of the quartz-mica-garnet schist, but the small lenses contain sericite and relicts of sillimanite. Sericite surrounds and apparently has replaced the sillimanite, and it cuts quartz grains around the margins of the lenses. The sericite is probably younger than the relatively coarse biotite and muscovite in the matrix of the schist.

Lime silicate-quartz lenses

In the northeastern part of the mapped area (fig. 2) lime silicate-quartz lenses, ranging from 1 foot to over 20 feet in length and from 1 inch to 12 inches in thickness, are interbedded with quartz-mica schist and quartzite. The lenses have a pale reddish-white to greenish-white central portion bounded on both sides by darker-colored marginal layers. The marginal layers characteristically have greenish-black grains of amphibole oriented parallel to the outer surfaces of the lenses.

The mineralogic composition of the light-colored central layer is quartz (50 percent), plagioclase (25 percent), garnet (10 percent), pyroxene (10 percent), zoisite and/or clinozoisite (5 percent), and sphene ($\ll$ 1 percent). The central parts of the lenses show no orientation of the minerals. The minimum index of refraction ($N\alpha'$) of cleavage fragments (001) of the plagioclase is 1.576 ± 0.001, indicating that the composition is about An_{90} (i.e., bytownite-anorthite). _/ Zoisite in irregular grains is intimately

_/ The plagioclase curves used for this report are those after Tsuboi, as diagrammed by Winchell (1951, fig. 173, p. 280).

associated with the plagioclase. Some of the grains have the slightly greenish-yellow interference color characteristic of clinozoisite rather than the anomalous blue color of zoisite. The pyroxene is mainly diopside, but several grains have extinction angles that suggest pigeonite.

The banded marginal layers of the lenses contain quartz (45 to 50 percent), amphibole (20 to 25 percent), plagioclase (15 to 20 percent), garnet (5 to 10 percent), zoisite and/or clinozoisite (5 percent), sphene ($<$ 1 percent), and rutile (Tr.). The amphibole is probably hornblende but was not identified specifically. The plagioclase is highly calcic, as in the central layer.

The occurrence of the lime silicate-quartz rock as conformable lenticular layers in the metamorphosed sedimentary series suggests that it was originally a calcareous sediment, probably a calcareous silt or a calcareous argillaceous sand. The reason for the pyroxene in the central layer and for the amphibole (and no pyroxene) in the well-banded marginal layers is not so apparent. Runner and Hamilton (1934, p. 51-64) have studied similar rocks in the southern Black Hills, but their article deals mainly with metamorphosed concretions that have similar characteristics. They suggest that there were two periods of metamorphism: an early period in which the lime silicate minerals and quartz were formed, and a later period in which outer layers were altered under stress to a banded amphibole-bearing rock.

Graphitic schist

Dark-colored graphitic schist crops out along the northwestern margin of the mapped area (fig. 2). The schist is cut in an intricate manner by abundant, irregular quartz veins. In thin-sections the graphitic material obscures the other minerals, but there are abundant minute crystals of tourmaline, in addition to graphite, quartz, biotite, and muscovite. The tourmaline may have been introduced at the time of veining by quartz.

Altered rocks adjacent to pegmatite

The country rock along the pegmatite contacts has been variously altered to tourmaline-rich schist, muscovite-rich schist, and a non-schistose rock consisting of tourmaline, quartz, and plagioclase. The altered rock does not form a complete shell around the pegmatite; along much of the contact no significant alteration was observed. The outcrops of altered rock have not been differentiated from "quartz-mica schist" on the map (fig. 2) because of their small size and irregular distribution. Thin stringers of pegmatite (< 0.25 inch thick) are common as lit-par-lit injections in the altered rock.

Tourmaline is the characteristic mineral of most of the altered rock; it forms as much as 75 percent of the rock near the pegmatite contact but decreases in abundance outward from the pegmatite. The thickness of the tourmaline-rich schist rarely exceeds 4 feet. Tourmaline crystals are euhedral and have irregular color zoning--from brown to grayish to light green. Quartz is included in the tourmaline. Quartz generally forms at least 25 percent of the tourmaline-rich schist, and muscovite is an essential constituent in the outer part of the altered zone. Accessory minerals are zircon, apatite, garnet, plagioclase, and microcline. In some places thin continuous layers of relatively coarse quartz are parallel to the schistosity.

A non-schistose rock, consisting mainly of tourmaline, quartz, and plagioclase, occurs along some of the discordant pegmatite contacts. This type of altered rock is usually less than 6 inches thick. Except that the platy minerals are not parallel this rock is very similar in character to the tourmaline-rich schist.

A less common type of altered rock is a schist containing as much as 80 percent muscovite that occurs as a 6-inch layer along part of the pegmatite contact. Clusters of tiny crystals of green apatite are abundant in this schist one-fourth to one-half inch from the pegmatite contact. The muscovite (average grain size, 0.05 inch) is generally coarser than in schist away from the contact.

Pegmatite

The High Climb pegmatite is a lenticular, well-zoned body containing quartz, albite, microcline-perthite, muscovite, tourmaline, beryl, amblygonite, apatite, columbite-tantalite, loellingite, spodumene, numerous dark-colored phosphate minerals, a manganese-bearing carbonate, garnet, and chalcopyrite. Fisher (1942, p. 22) also found a brown mineral resembling strueverite or tapiolite on the dump.

Numerous small pegmatite stringers intrude the metamorphic rocks of the area with both lit-par-lit and cross-cutting relationships. Most of the stringers are from less than one-half inch to 1 1/2 inches thick and commonly show "pinch-and-swell" structure. Some stringers are largely quartz with minor plagioclase; others contain differing proportions of microcline-perthite, quartz, plagioclase, muscovite, apatite, and tourmaline. The texture of the stringers is usually fine-grained. The thicker ones contain muscovite, quartz, and plagioclase in a fine-grained marginal zone, and potash feldspar in a coarser-grained central zone.

Quartz veins

Milky to colorless quartz veins, ranging from less than 6 inches to 3 feet in thickness, are abundant in the High Climb area. For the most part they are concordant, but some cut and distort the schistosity. No complete gradation could be traced from pegmatite to veins consisting solely of quartz, but some of the lit-par-lit pegmatite stringers consist mainly of quartz with only a small amount of plagioclase.

HIGH CLIMB PEGMATITE

Size, shape, and structure

On the surface, the High Climb pegmatite has a tadpole shape (fig. 2). The outcrop is 335 feet long (N. 10° E.) and is as much as 180 feet wide in the vicinity of the main pit; the maximum thickness is about 85 feet (fig. 3, section C-C'). The pegmatite dips to the west and, in general, is roughly concordant with the foliation of the schist. The strike of the foliation in the schist ranges from north to N. 55° E.; the dip is 38° to 84° W. Locally the pegmatite contact crosscuts the foliation.

The main part of the pegmatite has the structure of a pipe with an elliptical to thickly lenticular cross section (fig. 3, sections C-C', D-D', E-E'). The average plunge is about 45° N. 40° W. The shape of the pegmatite is complicated by large finger-like rolls, most of which are exposed on the eastern or footwall side of the intrusive. Perhaps the most conspicuous of the irregularities is at the east corner of the main pit (fig. 4), where a large arcuate offshoot from the pegmatite extends around the eastern side of a schist outcrop. The plunge of this structure is 57° N. 40° W.; but the angle of plunge apparently decreases with depth. Another prominent roll in the contact exposed in the southeast end of the main pit (fig. 2) plunges 45° N. 40° W. Other rolls in the south wall of the main pit plunge 30° to 40° N. 32° W. The position of the hanging wall contact is obscure, and consequently the shape of the pegmatite northwest of section C-C' (fig. 3) is not well known. Likewise, the structure of the extreme southern part of the body is imperfectly known; its shape in cross-section has been determined by projecting the inferred contacts down-plunge. Most of the footwall of the southern half of the pegmatite is concordant with the foliation in the schist, but locally along some of the sharp rolls and in the extreme southern part of the body the footwall contact crosscuts the foliation.

A small northern extension of the pegmatite is separated at the surface from the larger southern part by a small interval consisting mostly of overburden, schist, and a few small outcrops of pegmatite (fig. 2). There is no conclusive evidence that the two parts of the pegmatite are joined at the surface, as shown on the map (fig. 2), but a roll (fig. 5) plunging 46° S. 88° W. at the southern extremity of the northern part of the pegmatite suggests that the northern mass is connected, at least in depth, with the southern mass.

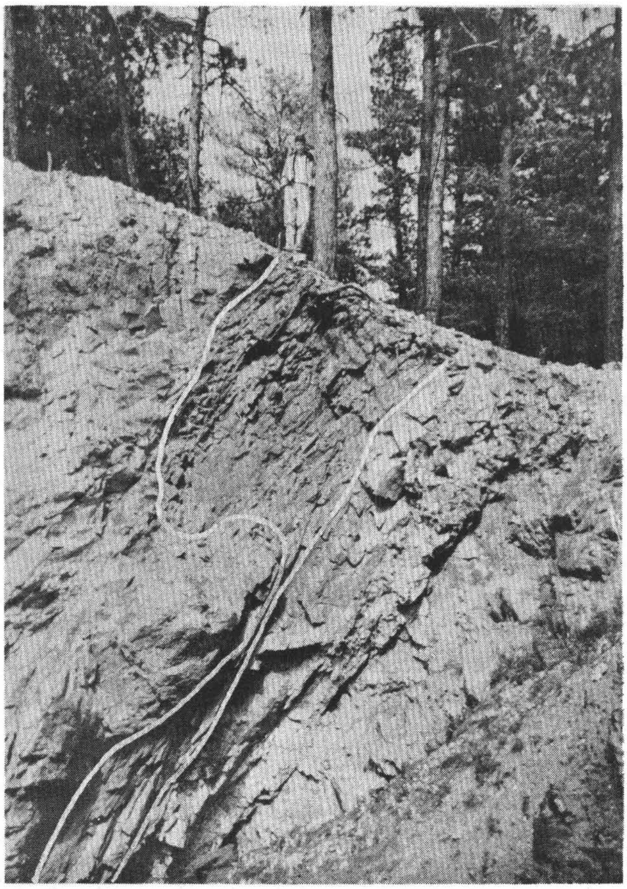

Figure 4.--Large outcrop of schist at east corner of main pit, High Climb pegmatite, Custer County, South Dakota. Schist inside the white line is bounded on both sides by pegmatite. This structure constitutes a major finger-like roll that plunges 57° N. 40° W.

Figure 5.--Roll in pegmatite contact, southern extremity of northern part of the High Climb pegmatite, Custer County, South Dakota. The axis of this roll (in line with handle of geologic pick) plunges 46° S. 88° W.

The northern part of the pegmatite is lenticular, but only the crest of this part of the pegmatite is exposed. The contacts are complicated by many rolls (fig. 2 and fig. 6). One large, north-trending crestal roll, in which schist cuts across the entire pegmatite outcrop, is nearly horizontal, but this roll may be a relatively shallow feature. Other rolls plunge 15° to 66° N. 12° W. to N. 40° W.; the average plunge is 28° N. 25° W. The footwall contact, on the northeast side of the outcrop, has an average dip of about 75° SW. Exposures of the hanging wall contact are not as numerous, but the dips range from 28° to 70° SW. The dike apparently widens slightly below the surface before pinching out in depth. Projections from the surface exposures suggest that the maximum thickness of the concealed part of the northern half of the pegmatite is probably not over 55 feet.

The High Climb pegmatite is cut by numerous fractures, most of which are small, very irregular, branching, and discontinuous. None of the fractures, with the exception of a single prominent joint in the southern part of the body, are shown on the map (fig. 2). One poorly exposed fracture in the north wall of the main pit may be a fault with a displacement of about 1 foot. Some of the fractures near phosphate-rich parts of the pegmatite are heavily stained by iron and manganese oxides.

Pegmatite units

In accordance with the classification of internal structural units in pegmatites defined by Cameron, Jahns, McNair, and Page (1949, p. 14), five zones have been mapped in the High Climb pegmatite: a wall zone, three intermediate zones, and a central zone or core. In addition to these units a possible sixth zone (or replacement unit ?) and a fracture-filling unit were recognized.

An albite-quartz wall zone forms a nearly complete shell around the pegmatite (fig. 3). In some outcrops a very thin discontinuous border zone rich in quartz and muscovite occurs along the pegmatite contact; because of the small volume of this unit it has been mapped and described together with the wall zone. Along some of the rolls the wall zone is locally absent and the first intermediate zone lies adjacent to the schist (e.g., fig. 3, section D-D', footwall of the pegmatite). The first intermediate zone, composed of albite-quartz-muscovite pegmatite, is discontinuous along the crest of the pegmatite, but it is rarely, if ever, absent on the footwall side of the pegmatite. The second intermediate zone is

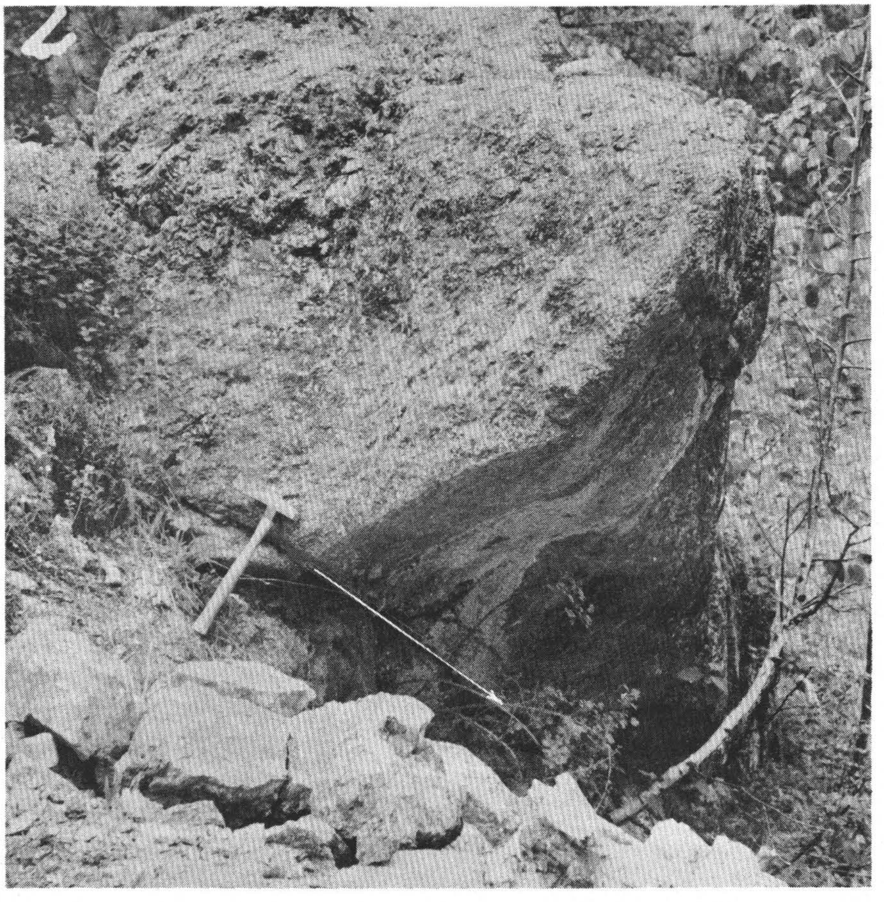

Figure 6.--Large roll in pegmatite contact, northeast side of High Climb pegmatite, Custer County, South Dakota. The axis of the roll (white arrow) plunges 32° N. 20° W.

an arcuate-shaped unit composed of perthite-quartz-albite pegmatite that is confined to the crest and hanging wall side of the pegmatite (fig. 3). This unit forms a hood above the quartz-cleavelandite pegmatite of the third intermediate zone. The core is quartz pegmatite.

The average mineralogic composition of each of the five zones in the High Climb pegmatite is given in table 1. The size classification for pegmatite textures in this report conforms to the system of Cameron, Jahns, McNair, and Page (1949, p. 16) as follows:

Term	General grain size
Fine	Less than 1 inch
Medium	1 to 4 inches
Coarse	4 to 12 inches
Very coarse	Greater than 12 inches

Small fracture-fillings of quartz-perthite-muscovite-albite pegmatite occur in the wall zone in the southern part of the pegmatite. Some of the waste rock on the dump southeast of the pegmatite suggests that a unit composed of very fine yellowish to grayish mica has been completely mined out. This may have been a discontinuous zone or a replacement body.

Albite-quartz pegmatite

The albite-quartz pegmatite or wall zone forms a shell around most of the High Climb pegmatite. Locally, however, the wall zone is absent, and the first intermediate zone is in contact with schist. The thickness of the wall zone is as much as 14 feet along the footwall of the pegmatite (fig. 3, section B-B'). The average thickness along the footwall in the southern segment of the pegmatite is about 4 feet, and in the northern segment between 6 inches and 1 foot. The overall average grain size of the wall zone is about 0.1 inch.

Along the crest of the northern part of the pegmatite the wall zone is thin and discontinuous. Albite-quartz pegmatite forms about 60 percent of the exposures mapped as wall zone in the northern area (fig. 2), and the remainder is albite-quartz-muscovite pegmatite (first intermediate zone) in patches too small to map.

Table 1.--Average mineralogic composition of zones in the High Climb pegmatite, based on visual estimates of all exposures.

Zone	Texture 1/	Average mineralogic compositions (percent): Plagioclase Percent	Plagioclase Variety	Quartz	Muscovite	Tourmaline	Perthite	Beryl	Amblygonite, var. montebrasite	Apatite	Unidentified phosphate 2/ minerals	Garnet	Loellingite	Mn-bearing carbonate	Chalcopyrite	Altered 3/ spodumene	Chlorite (?)	Columbite-4/ tantalite
Albite-quartz pegmatite, (wall zone).	Fine, (average grain size 0.1 inch)	63	Albite, 5/ An_{3-4}	26	4	3	3	<1	0	<1	<1	<1	0	0	0	0	0	0
Albite-quartz-muscovite pegmatite, (first intermediate zone.	Medium (average grain size 1.0 inch)	38	Albite, An_{3-4}	33	22	4	<1	1	<1	<1	1	0	<1	Trace	0	0	0	0
Perthite-quartz-albite pegmatite, (second intermediate zone).	Coarse, (average grain size 8.0 inches)	19	Albite, An_{3-4}	29	1	<1	50	0	Trace	<1	<1	0	Trace	Trace	0	0	0	0
Quartz-cleavelandite pegmatite, (third intermediate zone.	Medium, (average grain size 1 1/4 inches)	44	Cleavelandite, An_{3-4}	48	4	1.5	0	<1	<1	<1	1.5	0	<1	Trace	Trace	0	Trace	Trace(?)
Quartz pegmatite, (core).	Massive, (grain size not determined)	0	---	97	0	0	0	0	0	0	0	0	0	0	0	3	0	0

1/ The size classification follows Cameron, Jahns, McNair, and Page, 1949, p. 16.

2/ Unidentified phosphate minerals include dark brown, dark green, and purplish brown minerals, probably largely of the lithiophilite-triphylite group, but may also include heterosite (purpurite), triplite, and others.

3/ Altered spodumene is white to yellowish-white, very fine-grained micaceous material, some of which may be eucryptite (?); the largest remnant of an altered spodumene crystal is 3 feet long and 9 inches wide.

4/ C. K. Koch, mine operator, reported that columbite-tantalite had been found only in parts of the quartz-cleavelandite pegmatite in the northwest end of the main pit during mining operations prior to 1948. This mineral was not found by the writer in the present exposures.

5/ The plagioclase curves used for this report are those after Tsuboi, as diagrammed by Winchell(1951, fig. 173, p. 280).

The mineralogic composition and grain size of the wall zone differ from place to place (table 2). Three main types of wall zone have been mapped as a single structural unit on the basis of texture, because all are fine-grained (average grain size less than one inch) in contrast to the medium-grained intermediate zones. The three varieties all contain albite and quartz as the main essential minerals but the proportions of tourmaline, muscovite, and perthite are variable. Most of the wall zone in the northern segment of the pegmatite has an average grain size of 0.15 inch and contains albite (59 percent), quartz (34 percent), muscovite (5 percent), and accessory minerals. Along the footwall contacts in the southern part of the pegmatite the wall zone is sugary-textured (average grain size, 0.03 inch) and contains albite (71 percent), quartz (19 percent), tourmaline (8 percent), muscovite (1 percent), and accessory minerals. The remainder of the wall zone in the southern half of the pegmatite has an average grain size of 0.25 inch and contains albite (66 percent), quartz (20 percent), perthite (8 percent), muscovite (5 percent), and accessory minerals. Lack of exposures in critical areas prevented the study of possible "telescoping" (Cameron, Jahns, McNair, and Page, 1949, p. 19) of these varieties of wall zone.

In addition to the three main varieties of the wall zone, another subdivision could be made on some of the dip slopes and along some of the contacts where the outer 0.5 to 2 inches is relatively rich in quartz and muscovite. Because the total quantity of this "border zone" is negligible and because it is irregularly distributed, it was not mapped as a unit, and its mineralogic composition was not computed separately from the rest of the wall zone.

The overall average composition of the wall zone is albite (63 percent), quartz (26 percent), muscovite (4 percent), tourmaline (3 percent), perthite (3 percent), apatite ($<$ 1 percent), garnet ($<$ 1 percent), unidentified phosphate minerals ($<$ 1 percent), and beryl ($<$ 1 percent). This average composition was obtained by weighting the percentage figures for the minerals of each variety (table 2) against the estimated volume of each variety of wall zone.

Optical data for albite, tourmaline, and apatite from the wall zone are included in table 3. Thin-sections of the sugary-grained facies show that tourmaline crystals have inclusions of quartz and albite, and show color zoning from blue at the edge to yellow-brown near the center. Microcline perthite

Table 2.--Variations in mineralogic composition and grain size of albite-quartz pegmatite (wall zone), High Climb pegmatite.

Location	Average grain size 1/ (inches)	Mineralogic composition (percent)								
		Plagioclase, var. albite	Quartz	Muscovite	Tourmaline	Perthite	Apatite	Garnet	Unidentified phosphate minerals	Beryl
Along footwall in main pit (southern part of pegmatite) and in several irregular outcrops in the northern part of the pegmatite	0.03	71	19	1	8	0	<1	0	<1	0
Wall zone in remainder of southern part of the pegmatite	0.25	66	20	5	<1	8	<1	<1	0	<1
Most of the wall zone in northern part of the pegmatite	0.15	59	34	5	<1	0	<1	1	0	<1
Average mineralogic composition -- compiled from visual estimates at numerous exposures of the zone; the percentage for each of the three varieties were weighted against the estimated volume of each variety.	0.1	63	26	4	3	3	<1	<1	<1	<1

1/ Average grain size means the average maximum dimension of the grains.

Table 3.--Mineralogy of albite-quartz pegmatite (wall zone), High Climb pegmatite.

Mineral	Average composition of zone (percent)	Size of mineral (inches) Range	Average 1/	Occurrence	Color	Optical data	Remarks
Plagioclase, var. albite	63	0.01-0.5	See remarks.	Blocky to subplaty grains	White	$N\alpha'$ = 1.529 to 1.530 (± 0.001) 2/ (composition, An_3 to An_4)	Average size in sugary type of wall zone is 0.02 inch; average size in remainder of wall zone is about 0.1 inch.
Quartz	26	0.01-0.6	See remarks.	Irregular grains and masses intimately intergrown with plagioclase	Colorless to slightly milky	-------------------	Average size in sugary type of wall zone is 0.1 inch; average size in remainder of wall zone is about 0.2 inch.
Muscovite	4	0.01-0.75	0.2	Tabular flakes	Yellowish to silvery	-------------------	--------------------------
Tourmaline	3	0.02-0.75	0.2	Euhedral grains	Black to bluish-black	Bluish-black: N_ω = 1.659 to 1.669 (zoned crystals).	Optical data are for tourmaline from the sugary-grained variety of wall zone.
Perthite	3	0.3-4.0	1.75	Blocky grains	Buff-white to flesh	-------------------	--------------------------
Apatite	<1	------	<0.1	Rounded grains	Greenish-blue to green	One greenish-blue grain:- N_ω = 1.642, N_ϵ' = 1.637 (probably a hydroxl-apatite)	--------------------------
Garnet	<1	0.01-0.2	0.1	Rounded grains	Reddish-brown	-------------------	Irregularly distributed.
Unidentified phosphate minerals	< 1	0.1-3.5	0.75	Irregular grains	Brownish to gray-black	-------------------	Irregularly distributed along inner edge of wall zone near phosphate-rich parts of first intermediate zone; probably minerals of lithiophilite-triphylite group, but may also include heterosite (purpurite), triplite, and others.
Beryl	<1	0.5-2.5	1.0	Euhedral grains	White	(Optical data are included in table 4.)	Occurs only along gradational contacts of wall zone and albite-rich parts of first intermediate zone.

1/ The "average" size means the average maximum dimension of the grains of each mineral.

2/ $N\alpha'$ is the minimum index of refraction, as determined on cleavage fragments (001).

The plagioclase curves used for this report are those after Tsuboi, as diagrammed by Winchell (1951, fig. 173, p. 280).

occurs as blocky grains in part of the wall zone in the southern half of the pegmatite _/. Iron and

_/ Note:-All of the perthite in the High Climb pegmatite is microcline-perthite.

manganese oxides, resulting from the alteration of phosphate minerals, cause irregular staining of much of the sugary-grained footwall part of the albite-quartz pegmatite. Beryl occurs only along gradational contacts with the first intermediate zone. It commonly is much less than 0.5 percent of the wall zone, whereas it generally constitutes 1 percent of the first intermediate zone. Optical properties of the beryl are the same as properties of the beryl in the first intermediate zone.

Albite-quartz-muscovite pegmatite

Albite-quartz-muscovite pegmatite forms the first intermediate zone in the High Climb pegmatite. On some of the rolls and in places along the footwall of the southern half of the pegmatite, the wall zone is absent and the first intermediate zone is in direct contact with the schist. The first intermediate zone borders the third intermediate zone in the keelward and footwall parts of the pegmatite and borders the second intermediate zone along the hangingwall side and the crest (fig. 3). The first intermediate zone is as much as 5 feet thick; the average thickness is about 2.5 feet. The zone is thickest along the complex rolls on the footwall of the southern part of the pegmatite. The average size of individual grains is about 1 inch, but the grain size ranges widely.

The average mineralogic composition of the first intermediate zone, as compiled from visual estimates at numerous exposures, is albite (38 percent), quartz (33 percent), muscovite (22 percent), tourmaline (4 percent), beryl (1 percent), unidentified phosphate minerals (1 percent), amblygonite (variety, montebrasite) (< 1 percent), apatite (< 1 percent), perthite (< 1 percent), loellingite (< 1 percent), and a manganese-bearing carbonate (Tr.). The relative proportions of albite and muscovite range widely. In most of the exposures of the zone, muscovite forms at least 20 percent and in a few it constitutes as much as 50 percent of the zone. In the northern segment of the pegmatite, fine-grained (average 0.5 inch) albite-rich areas are irregularly distributed in the zone. These contain albite (55 percent), quartz (25 to 30 percent), muscovite (10 percent), tourmaline (3 percent), beryl (as much as 3 percent) amblygonite (variety, montebrasite) (1 percent), and accessory apatite and dark-colored phosphate minerals.

Optical data and descriptions of the minerals of the first intermediate zone are included in table 4. In most of the zone the albite is platy (variety, cleavelandite), but in the relatively fine-grained mica-poor parts of the zone, it is blocky to subplaty. Most of the muscovite has varying proportions of "A" and herringbone structures, and some contains mineral inclusions (tourmaline, cleavelandite, and quartz) and hair cracks. The muscovite occurs in flakes and books that range in diameter from 0.1 inch to 10 inches. Beryl occurs as white to greenish-white euhedral grains that generally are stained in part by brown to reddish-brown iron oxides. They range in length from less than 0.5 inch to 12 inches; the average crystal is about 3.5 inches in length and 1.5 inches in diameter. The maximum index of refraction (N_{ω}) of the beryl ranges from 1.5794 to 1.5865 ($\pm$ 0.0005). According to an unpublished curve by W. T. Schaller of the U. S. Geological Survey, the BeO content of this beryl ranges from 13.10 percent for the grains of lowest index to 12.35 percent for grains of the highest index. Unidentified dark-colored phosphate minerals intimately intergrown with other minerals of the zone are commonly concentrated in irregular, heavily-stained pods, 1 foot to 6 feet in length, along the inner edge of the zone; the pods contain as much as 10 percent phosphate minerals. Some of these minerals are probably members of the lithiophilite-triphylite group. Fisher (1942, p. 19) has reported heterosite and triplite in the phosphate-bearing rocks of the High Climb pegmatite. Silvery prismatic crystals of loellingite, averaging about 0.1 inch in diameter and 0.5 inch in length, and traces of a pinkish-buff manganese-bearing carbonate occur in the phosphate-rich pods. Rounded grains of amblygonite (variety, montebrasite), 0.5 inch to 3 inches in diameter, commonly occur in the albite-rich parts of the zone. The maximum index of refraction (N_{γ}') of the montebrasite ranges from 1.634 to 1.638 ($\pm$ 0.002), which, according to Winchell's curves (1951, p. 224, fig. 121) places the mineral at the extreme montebrasite end of the amblygonite-montebrasite series. A partial analysis of

Table 4.--Mineralogy of albite-quartz-muscovite pegmatite (first intermediate zone), High Climb pegmatite.

Mineral	Average composition of zone (percent)	Size of mineral (inches) Range	Average 1/	Occurrence	Color	Optical data	Remarks
Plagioclase, var. albite	38	0.1-2.5	0.75	Mostly platy (var. cleavelandite). Blocky to subplaty in the relatively fine-grained, mica-poor parts of the zone	White to grayish-white	$N\alpha'$ = 1.529 to 1.530 (±0.001). 2/ (Composition, An_3 to An_4)	Aggregates of platy albite are as large as 5 inches in diameter.
Quartz	33	0.1-5.0	1.25	Irregular grains and masses	Colorless to milky	---------------	------------------------------
Muscovite	22	0.1-10.0	3.0	Tabular flakes and books	Silvery, yellowish-silvery, pale ruby, and pale greenish-brown	---------------	Some of the muscovite contains mineral inclusions (tourmaline, cleavelandite, and quartz) and hair cracks; most of the muscovite has varying proportions of "A" and herringbone structures.
Tourmaline	4	0.75-12.0	2.5	Subhedral to euhedral grains	Black to greenish-black	---------------	Anhedral bluish-black tourmaline forms intimate intergrowths with other minerals in phosphate-rich parts of the zone.
Beryl	1	0.5-10.0 (length)	3.5 (length) 1.5 (diameter)	Euhedral grains	White to greenish-white, generally stained in part by reddish-brown iron oxides	N_ω=1.5794 to 1.5865 (±0.0005). Most of beryl grains are complexly zoned; very small chips from various parts of the crystals have a range in index (N_ω) of as much as 0.0030. Nearly all of the crystals have higher indices in outer parts of grains than in centers of grains, but in one grain the higher index is in the center.	Thin-sections indicate that many beryl crystals are veined by muscovite and quartz. At the edges of some grains, beryl and albite are intergrown, with evidences of each replacing the other. The prism faces of beryl grains are commonly grooved when they are in contact with muscovite books. A thin coating of very fine muscovite generally occurs along the contacts of beryl with quartz and albite. The beryl commonly carries a network of fine dusty alteration (clay minerals ?), associated with varying quantities of iron stain. Liquid and gas inclusions are common.

1/ See end of table, p. 30.
2/ See end of table, p 30.

Table 4. --Mineralogy of albite-quartz-muscovite pegmatite (first intermediate zone), High Climb pegmatite--Continued

Mineral	Average composition of zone (percent)	Size of mineral (inches)		Occurrence	Color	Optical data	Remarks
		Range	Average 1/				
Unidentified phosphate minerals	1	0.1-3.5	0.75	Irregular grains	Brown, gray-black, dark green, and purplish-brown	----------------	Some of these minerals are probably members of the lithiophilite-triphylite group, but some may be heterosite and triplite. Alteration products of the phosphate minerals, including vari-colored iron and manganese oxides, occur as heavy stains on other minerals of the zone in the immediate vicinity of phosphate mineral concentrations.
Amblygonite, var. montebrasite	<1	0.5-3.0	1.25	Rounded grains	Grayish-white	$N\gamma'$ = 1.634 to 1.638 ($\pm$ 0.002). Usually it is coated with a white dusty alteration product, the identity of which is unknown.	Montebrasite is chiefly in the albite-rich parts of the first intermediate zone. In the phosphate-rich pods, montebrasite is commonly veined by the dark-colored phosphate minerals and is intimately intergrown with anhedral blue-black tourmaline.
Apatite	<1	-----	$<$ 0.1	Rounded grains	Bluish-green to green	----------------	A few anhedral grains, intimately intergrown with albite, are as large as 1 inch.
Perthite	<1	4 - 18	10	Blocky grains	Flesh to buff-white	----------------	Distributed irregularly along contacts with second intermediate zone.
Loellingite	<1	0.1-1.5 (length) 0.05-0.3 (diameter)	0.5 (length) 0.1 (diameter)	Euhedral grains, generally prismatic and elongate	Silvery	----------------	Occur in phosphate-rich pods.
Mn-bearing carbonate	Trace	----	----	Fine-grained intergrowth in phosphate-rich pods	Pinkish-buff	----------------	Qualitative chemical tests indicated the presence of considerable manganese in the carbonate, which is probably between rhodochrosite and siderite in composition.

1/ Except where specific dimensions are noted, the "average" size means the average maximum dimension of the grains of each mineral.

2/ $N\alpha'$ is the minimum index of refraction, as determined on cleavage fragments (001). The anorthite content of the albite is based on the curves after Tsuboi, as diagrammed by Winchell (1951, fig. 173, p. 280).

the montebrasite, made by C. M. Warshaw and W. W. Brannock of the U. S. Geological Survey, gave the following:

	Percent
Al_2O_3	33.15
Li_2O a/	9.51
H_2O b/	4.88
F	.59

a/ Determined with flame photometer by W. W. Brannock.

b/ Averages of three determinations of total H_2O.

In the phosphate-rich parts of the zone, the montebrasite is intimately intergrown with anhedral blue-black tourmaline and commonly is veined by the dark-colored phosphate minerals.

Perthite-quartz-albite-pegmatite

Perthite-quartz-albite pegmatite forms the second intermediate zone in the High Climb pegmatite. In the southern half of the pegmatite this zone is arcuate in cross-section (fig. 3, sections C-C', D-D', and E-E') and occurs as a hood above the inner zones. The maximum thickness of the unmined parts of the zone is 26 feet (fig. 3, section A-A'). The zone thins away from the crest of the pegmatite, and on the footwall side it pinches out completely. Only the upper parts of the second intermediate zone are exposed in the northern half of the pegmatite, and its full extent is not known. The overall, average size of individual grains in the zone is about 8 inches, but the size of grains varies widely. Relatively large perthite crystals are enclosed in a matrix of relatively fine-grained quartz and albite.

The average composition of the second intermediate zone is estimated to be: perthite (50 percent), quartz (29 percent), albite (19 percent), muscovite (1 percent), tourmaline ($<$ 1 percent), unidentified dark-colored phosphate minerals ($<$ 1 percent), apatite, ($<$ 1 percent), amblygonite (variety, montebrasite) (Tr.), loellingite (Tr.), and Mn-bearing carbonate (Tr.). Variations in the mineralogical composition of the zone are chiefly in the proportion of perthite. The upper parts, near the crest of the pegmatite, contain as much as 75 percent perthite; the percentage of perthite decreases downward and the lower parts of the zone contain as little as 25 percent perthite. In the northern part of the pegmatite, perthite grains averaging 1 foot in size constitute 60 percent of the visible exposures, and the quartz is probably more abundant in the matrix than in the southern part of the pegmatite.

Optical data and descriptions of the minerals of the second intermediate zone are given in table 5. Individual crystals and masses of perthite range from 1 foot to 5 feet in maximum dimension. Some of the perthite grains are rounded and embayed by the matrix of quartz and albite. The texture of this matrix is very similar to the texture of the third intermediate zone. Some thin-sections contain evidence that the albite of the matrix replaces microcline-perthite, but others contain evidence that microcline replaces and veins the albite. Unidentified dark-colored phosphate minerals are associated with amblygonite (variety, montebrasite), loellingite, Mn-bearing carbonate, and bluish-black anhedral tourmaline. These are distributed in heavily stained aggregates along the zonal contacts with the first and third intermediate zones.

Quartz-cleavelandite pegmatite

Quartz-cleavelandite pegmatite of the third intermediate zone underlies the hood-shaped second intermediate zone. In the lower parts of the pegmatite the third intermediate zone is in contact with the first intermediate zone (fig. 3). Quartz-cleavelandite pegmatite forms a shell around the quartz core. The thickness ranges from 2 feet to 30 feet; the average is about 14 feet. The average size of individual grains is about 1.25 inches, but the average size of aggregates of grains is about 3 inches.

The average mineralogic composition of the third intermediate zone is estimated to be: quartz (48 percent), cleavelandite (44 percent), muscovite (4 percent), tourmaline (1.5 percent), unidentified phosphate minerals (1.5 percent), amblygonite (variety, montebrasite) (<1 percent), beryl (<1 percent), apatite (<1 percent), loellingite (<1 percent), Mn-bearing carbonate (Tr.), chalcopyrite (Tr.), chlorite (?) (Tr.), and columbite-tantalite (Tr. ?). In several exposures the inner 1 to 2 feet of the zone, marginal to the quartz core, contain as much as 70 percent cleavelandite and 10 percent montebrasite. In other exposures quartz forms 60 percent of the zone, cleavelandite is only 35 percent and montebrasite is absent.

Table 5.--Mineralogy of perthite-quartz-albite pegmatite (second intermediate zone), High Climb pegmatite.

Mineral	Average composition of zone (percent)	Size of mineral (inches) Range	Average 1/	Occurrence	Color	Optical data	Remarks
Perthite	50	6-60	15	Blocky grains	Flesh-white to buff creamy white	Most of the thin-sections 2/ of perthite grains show albite intergrown with microcline as "vein" and "patch" perthite. For this albite in the perthite, $N\alpha' = 1.5300$ ($\pm$ 0.0005), composition An_4.	The perthite grains are set in a matrix of quartz and albite; the texture of the matrix is very similar to the texture of the third intermediate zone. Some of the perthite grains are rounded and embayed by the matrix. The perthite and albite of the enclosing matrix are mutually intergrown; in some thin-sections, albite of the matrix appears to replace microcline in the perthite, but in others microcline veins and replaces albite.
Quartz	29	0.2-4	1.5	Irregular grains and masses	Colorless to milky	------------	------------------------
Plagioclase, var. albite	19	0.1-3	0.75	Mostly platy grains; minor amounts as blocky to subplaty grains	White	$N\alpha'$ = 1.529 to 1.530 2/ ($\pm$ 0.001) (composition An_3 to An_4).	Aggregates of platy albite as large as 4 inches in size generally occur as irregular intergrowths with quartz.
Muscovite	1	0.05-3	0.75	Tabular flakes and books	Silvery to yellowish silvery	------------	Sparsely distributed in the quartz-albite matrix.
Tourmaline	<1	0.5-5	1.5	Subhedral to euhedral grains	Black to greenish-black	Apparently zoned greenish-black tourmaline: $N\omega$ = 1.653 to 1.656 ($\pm$ 0.002).	Anhedral bluish-black tourmaline occurs in the heavily stained aggregates of phosphate minerals.
Apatite	<1	----	<0.1	Rounded grains	Bluish-green to green	------------	------------------------
Unidentified phosphate minerals	<1	0.1-3.5	0.75	Irregular grains	Brown, gray-black, dark green, and purplish-brown	------------	Some of these minerals are probably members of the lithiophilite-triphylite group, but some may be heterosite and triplite.
Amblygonite var. montebrasite	Trace	0.5-3.0	1.25	Rounded grains	Grayish-white	$N\gamma'$ = 1.634 to 1.638 ($\pm$ 0.002).	Montebrasite occurs in the phosphate-rich aggregates; commonly it is veined by the dark-colored phosphate minerals and is intimately intergrown with anhedral blue-black tourmaline.

1/ Except where specific dimensions are noted, the "average" size means the average maximum dimension of the grains of each mineral.

2/ $N\alpha'$ is the minimum index of refraction, as determined on cleavage fragments (001). The anorthite content of the albite is based on the curves after Tsuboi, as diagrammed by Winchell (1951, fig. 173, p. 280).

Table 5.--Mineralogy of perthite-quartz-albite pegmatite (second intermediate zone), High Climb pegmatite--Continued

Mineral	Average composition of zone (percent)	Size of mineral (inches)		Occurrence	Color	Optical data	Remarks
		Range	Average 1/				
Loellingite	Trace	0.1-1.5 (length) 0.05-0.3 (diameter)	0.5 (length) 0.1 (diameter)	Euhedral grains, generally prismatic and elongate	Silvery	---------------------	Occurs in the phosphate-rich aggregates.
Mn-bearing carbonate	Trace	-----	-----	Fine-grained intergrowth in phosphate-rich aggregates	Pinkish-buff	---------------------	Qualitative chemical tests indicated the presence of considerable manganese in the carbonate, which is probably between rhodochrosite and siderite in composition.

Descriptive data for individual minerals of the third intermediate zone are listed in table 6. All of the plagioclase in this zone is the platy variety, cleavelandite. Most of the montebrasite is in the core-margin parts of the zone, but a few grains are scattered irregularly through the rest of the zone. In thin-sections the montebrasite shows multiple lamellar twinning and is cut by quartz veins 0.03 inch thick. Estimation of the actual quantity of montebrasite in this zone is difficult because of its irregular distribution and the inadequacy of exposures. Visual estimates, however, indicate and average content of 0.25 to 0.5 percent. White to greenish-white crystals of beryl, as much as 12 inches in length, occur only at the extreme outer edge of the zone, where it is in contact with the first intermediate zone; optical properties of the beryl are the same in both zones. Elongate, heavily-stained pods, rich in dark-colored phosphate minerals, are as much as 10 feet in length. These are most common near zonal contacts with the other intermediate zones. One polished section of a sample of this phosphate-rich rock contained tiny grains of chalcopyrite associated with crystals of loellingite. One thin-section contained traces of a green micaceous mineral with optical characteristics of chlorite that is intimately intergrown with dark phosphate minerals and the manganese-bearing carbonate. Columbite-tantalite is reported (C. K. Koch, oral communication, 1948) to have occurred in parts of the third intermediate zone that were mined from the northwestern end of the main pit. Fisher (1942, p. 21) also reports "columbite (?)" as occurring in unstained areas in the phosphate rock. No columbite-tantalite was found by the writer.

Quartz pegmatite

The quartz core is entirely enclosed by the third intermediate zone. In cross-section (fig. 3) the shape of the core is thinly to thickly lenticular. The texture is massive.

The core is composed of colorless quartz (97 percent) and altered spodumene (3 percent) (table 7). Remnants of altered spodumene crystals, as much as 3 feet in length, are diversely oriented in a matrix of massive quartz in the north wall at the northwest end of the main pit (fig. 2). The alteration products of the spodumene are chiefly white to yellowish-white, fine micaceous material, some of which may be eucryptite.

Table 6.--Mineralogy of quartz-cleavelandite pegmatite (third intermediate zone), High Climb pegmatite.

Mineral	Average composition of zone (percent)	Size of mineral (inches)		Occurrence	Color	Optical data	Remarks
		Range	Average 1/				
Quartz	48	0.2-12	1.5	Irregular grains and masses	Colorless to milky	----------------------	------------------------------
Plagioclase, var. cleavelandite	44	0.5-3.5	0.75	Platy grains	White to grayish-white	Nα' = 1.529 to 1.530 (± 0.001) 2/ (composition An_3 to An_4)	Aggregates and radiating rosettes of cleavelandite are as much as 12 inches in diameter.
Muscovite	4	0.05-6	1.75	Tabular books and flakes	Yellowish-silvery to pale greenish-silvery	----------------------	------------------------------
Tourmaline	1.5	0.5-12	4	Subhedral to euhedral. Anhedral	Greenish-black to black. Bluish-black	----------------------	Anhedral grains of bluish-black tourmaline are intergrown with other minerals in the phosphate-rich parts of the zone. Elsewhere in the zone tourmaline is subhedral to euhedral and greenish-black to black.
Unidentified phosphate minerals	1.5	0.1-3.5	0.75	Irregular grains	Brown, gray-black, dark green, and purplish-brown	----------------------	Some of these minerals are probably members of the lithiophilite-triphylite group, but some may be heterosite and triplite. The phosphate-rich parts of the third intermediate zone are generally in elongate heavily-stained pods, as much as 10 feet in length, and are most common near the zonal contacts with the other intermediate zones. Alteration products of the phosphate minerals, including vari-colored iron and manganese oxides, occur as heavy stains on the other minerals of the zone in the immediate vicinity of the phosphate-rich pods.
Amblygonite var. montebrasite	<1 (See remarks)	0.5-8	3.5	Rounded grains	White to grayish-white	Biaxial (+) Nγ' = 1.634 to 1.638 (± 0.002) Nβ' = 1.620 to 1.629 (± 0.002) Nα' = 1.608 to 1.609 (± 0.002) Birefringence of some grains is as much as 0.026.	Most of the montebrasite is in the core-margin parts of the zone, but a few grains are scattered irregularly through the rest of the zone. Visual estimates indicate an average content of 0.25 to 0.5 percent. The specific gravity of one sample was found to be 2.94.

1/ Except where specific dimensions are noted, the "average" size means the average maximum dimension of the grains of each mineral.

2/ Nα' is the minimum index of refraction, as determined on cleavage fragments (001). The anorthite content of the cleavelandite is based on the curves after Tsuboi, as diagrammed by Winchell (1951, fig. 173, p. 280).

Table 6.--Mineralogy of quartz-cleavelandite pegmatite (third intermediate zone), High Climb pegmatite--Continued

Mineral	Average composition of zone (percent)	Size of mineral (inches)		Occurrence	Color	Optical data	Remarks
		Range	Average 1/				
Beryl	<1	0.5-12 (length)	3.5 (length) 1.5 (diameter)	Euhedral grains	White to greenish-white	(Optical data are included in table 4).	Beryl occurs only at the extreme outer edge of the zone along contacts with the first intermediate zone.
Apatite	<1	---------- As much as 1.5	< 0.1 --------	Subhedral grains Anhedral masses intergrown with cleavelandite	Green to bluish-green	-------------------	--------------------
Loellingite	<1	0.1-1.5 (length) 0.05-0.3 (diameter)	0.5 (length) 0.1 (diameter)	Euhedral grains, generally prismatic and elongate	Silvery	-------------------	Occurs in the phosphate-rich pods.
Mn-bearing carbonate	Trace	----------	--------	Fine-grained intergrowth in the phosphate-rich pods	Pinkish-buff	-------------------	Qualitative chemical tests indicated the presence of considerable manganese in the carbonate, which is probably between rhodochrosite and siderite in composition.
Chalcopyrite	Trace	----------	--------	(See remarks)	---------------	-------------------	One polished section of a sample of the phosphate-rich rock contained tiny grains of chalcopyrite associated with loellingite crystals.
Chlorite (?)	Trace	----------	--------	(See remarks)	---------------	-------------------	One thin section of phosphate-rich rock contained traces of a green micaceous mineral with optical characteristics of chlorite, intergrown with dark phosphate minerals and the Mn-bearing carbonate.
Columbite-tantalite	Trace (?)	---------	--------	(See remarks)	---------------	-------------------	Columbite-tantalite was reported in the High Climb pegmatite by Fisher (1942, p. 21) and by Koch 3/, but no specimens were found by the author.

3/ Koch, C. K., (oral communication, 1948) said that Columbite-tantalite occurred in parts of the third intermediate zone that were mined from the northwestern end of the pit.

Table 7. --Mineralogy of quartz pegmatite (core), High Climb pegmatite.

Mineral	Average composition of zone (percent)	Range in size mineral (inches)	Occurrence	Color	Remarks
Quartz	97	----------	Massive with no apparent individual grains	Milky to colorless	------------------------
Altered spodumene	3	1 x 10 to 12 x 48	Altered remnants of spodumene crystals are diversely oriented in matrix of massive quartz	White to yellowish-white	The alteration products of the spodumene are chiefly white to yellowish-white micaceous material, some of which may be eucryptite. A thin-section of part of one spodumene relict shows an aggregate of very fine-grained pale yellowish micaceous material intergrown with small quantities of fine-grained, quartz and albite.

Quartz-perthite-muscovite-albite pegmatite

Fracture-filling units of quartz-perthite-muscovite-albite pegmatite cut the wall zone south of the main pit. The largest fracture-fillings are only 2 feet long and 6 inches wide, and cannot be shown on the map. The average grain size is about 3 inches.

The fracture-fillings are estimated to contain quartz (45 percent), perthite (35 percent), muscovite (10 percent), and albite (10 percent). Colorless to milky quartz and flesh-colored perthite grains are 2 to 8 inches in maximum size. Subplaty to platy albite is intergrown with quartz. Yellowish-silvery muscovite books, averaging about 0.75 inch in size, commonly occur at the margins of the fracture-fillings.

Muscovite pegmatite

Blocks of very fine-grained muscovite pegmatite were found on the large dump southeast of the main pit, but similar rock was not found in place. The rock is composed almost entirely of yellowish to grayish muscovite flakes, less than 0.2 inch in size, intergrown with a little platy albite and quartz. Some of the muscovite-rich material is associated with coarse perthite blocks that are apparently corroded and embayed by the mica. This fine-grained muscovite pegmatite may have been derived from a discontinuous zone adjacent to the second intermediate zone or from a replacement unit of unknown shape and position. The color of the material suggests that it may be a lithium-bearing mica, but Fisher (1942, p. 22) reports that this mineral is muscovite and not lepidolite.

Origin

The High Climb pegmatite has many of the characteristics that led Page and others (1953, p. 17-24) to believe that zoned pegmatites of the Black Hills were formed by the intrusion of a viscous fluid followed by fractional crystallization to produce the various units of the pegmatite. Other authors, however, have not arrived at this conclusion, and for this reason a brief statement of the evidence from the High Climb pegmatite and a discussion of what the evidence means are presented herewith.

Geologists generally agree that pegmatites are formed by fluids derived from differentiating granite magma. The principal dissent from this opinion with regard to Black Hills pegmatites has been presented by Higazy (1949, p. 555-581), who believed that the pegmatites were formed by metasomatism of schist. Many of Higazy's arguments rest on the fallacious assumption that Black Hills pegmatites consist chiefly of perthite, whereas actually perthite is less abundant than quartz and plagioclase. The predominance of soda feldspar over potash feldspar in the bulk composition of many of the well-zoned pegmatites in the Black Hills and the presence of notable quantities of lithium, beryllium, and phosphate minerals are not adequately explained by a granitization theory that relies heavily on the movement of potassium ions. Furthermore, Higazy failed to describe such features as island-mainland structure, gradational phases between schist and the various kinds of pegmatite, or changes in pegmatite composition correlated with changes in composition of the country rock, all of which are to be expected under his theory. The High Climb pegmatite has sharp contacts with the country rock, and evidence for a gradational change from one to the other cannot be recognized.

The close areal proximity of the High Climb pegmatite to the granite of Harney Peak and the similarities in mineralogy and composition strongly suggest that the pegmatite and the granite are genetically related. Both have microcline-perthite, sodic plagioclase, quartz, tourmaline, and muscovite as the dominant constituents. Whether the Harney Peak mass was the actual source of the material for the High Climb pegmatite and other pegmatites in the southern Black Hills or whether the granite and the pegmatites have a common deep-seated batholithic source is not known.

The composition of the fluid or "magma" which formed the High Climb pegmatite is indicated in a general way by its mineralogy. Quartz, albite, perthite, and muscovite are the major minerals, indicating that the pegmatite fluid was rich in Si, Na, K, and water. Significant amounts of beryl, phosphate minerals, tourmaline, and amblygonite also indicate that the pegmatite fluid contained Li, Be, B, and P. This assemblage of elements together with significant amounts of water suggests that the pegmatite fluid was a late stage product resulting from the differentiation of a granitic magma.

The overall general concordance of the High Climb pegmatite with the foliation in the country rock suggests that the emplacement of the pegmatite was controlled mainly by the regional foliation. Locally the pegmatite contact cross-cuts the foliation, suggesting that the viscosity of the pegmatite fluid and the force of its movement were sufficient to breach the country rock. A noteworthy example of this breaching occurs along the footwall of the southern part of the pegmatite (fig. 2, and fig. 3, section E-E'), where a large finger-like extension of the pegmatite cuts across the schist and then extends parallel to the main contact.

Speculation about the history of crystallization of pegmatites after emplacement has brought forth the greatest diversity of opinion among geologists. Many geologists, including Schaller (1925, p. 269-279), Landes (1925, p. 355-411), and Hess (1925, p. 289-298), believed that complex pegmatites are formed in two or more phases: an initial intrusion and crystallization of a magma, simple in composition, followed by one or more hydrothermal phases, during which the original material was partly or completely replaced by hydrothermal minerals. Quirke and Kremers (1943, p. 571-580) supported the idea that pegmatites were formed by crystallization of solutions moving through open systems. Many recent publications (Cameron, Jahns, McNair, and Page, 1949, p. 104; Page and others, 1953, p. 20-24; Hanley, Heinrich, and Page, 1950, p. 8; Jahns, Griffitts, and Heinrich, 1952, p. 45) have shown that the internal structure of pegmatites supports the concept that pegmatite zones developed by fractional crystallization and incomplete reaction in a restricted system. Stockwell (1933, p. 38-39) had earlier expressed essentially this same viewpoint for Manitoba pegmatites, which, he believes, show a definite order of solidification progressing from the walls inward.

Fisher (1942, p. 23) has postulated a three-fold sequence for the genesis of the High Climb pegmatite: first, the pegmatite was formed as a small mass consisting of the "soda aplite" (the sugary-grained facies of the wall zone); subsequently the "quartz-microcline microperthite aggregate" was introduced; most of the "later" components were formed by replacement from solutions that continued to penetrate already solidified pegmatite. In another report Fisher (1945, p. 14-20, fig. 4, fig. 5) used textural studies showing "albitization" of microcline at the High Climb pegmatite as evidence for replacement to support a general genetic theory consisting of several stages. In Fisher's "igneous" stage, a light fluid portion of a deeply buried magma was forced up into the schist and yielded the bulk of the pegmatite material (mainly potash feldspar, quartz, and minor muscovite and black tourmaline). Fisher postulated that during later "hydrothermal" stages residual water-rich portions of increasingly fluid nature were forced out of the magma at depth, and they moved upward to replace some of the earlier-formed pegmatite. He further postulated that a final stage of alteration was effected in some pegmatites by meteoric waters, after a period of considerable erosion.

The textural phenomena cited by Fisher are of value in determining the detailed paragenetic sequence of minerals within an individual zone. In the present investigation, for example, detailed thin-section studies of material from the second intermediate zone show that the albite of the matrix appears to "replace" microcline-perthite in some specimens, and in others the microcline veins and "replaces" the albite of the matrix and poikilitically includes crystals of cleavelandite. Textural studies alone, however, do not determine which process caused the embaying, veining, and corrosion; the overall structural and mineralogic relations in the pegmatite must also be considered. The so-called "replacement" textures can be caused by several processes, including hydrothermal replacement, pneumatolytic action, and the incomplete reaction between rest liquids and crystals during fractional crystallization.

The well-developed zonal structure, the general increase in grain size inward, the concentration of mineral assemblages in definite zonal positions, and the similarity of the zonal sequence with that of other pegmatites constitutes evidence in favor of fractional crystallization in situ. The internal structure of the High Climb pegmatite strongly indicates that the so-called "replacement" textures were actually formed by incomplete reaction between already-formed crystals and a progressively crystallizing rest liquid, and that the process operated in an essentially closed system with no addition of "hydrothermal" fluids from the outside after the original emplacement.

The concentric zonal arrangement could not have been formed in successive stages by "open system" crystallization of through-going solutions, as in the process suggested by Quirke and Kremers (1943, p. 571-580), because the combination of wall zone and first intermediate zone completely encloses the other zones in the High Climb pegmatite at all exposures except where mining or erosion has cut through the outer shells. The concentric zonal arrangement and the concentration of certain mineral assemblages in definite zonal positions suggest that processes of differentiation, fractional crystallization, and segregation were operating throughout the history of the solidification of the High Climb pegmatite. The internal structure and zonal sequence in the High Climb pegmatite are compatible with the internal structure and zonal sequence in many other pegmatites in the United States (Cameron, Jahns, McNair, and Page, 1949, p. 59-70) and are best explained by fractional crystallization. It seems very improbable that either the through-going "open-system" solutions of Quirke and Kremers (1943, p. 571-580) or the successive stages of hydrothermal replacement of pre-existing pegmatite, as proposed by Landes (1925, p. 355-411), could cause such a uniformity of sequence of the dominant mineral assemblages in concentric lithologic zones in so many districts. Consequently, it seems most probable that the solidification of the pegmatite magma was an orderly process involving differentiation and fractional crystallization in a system which was essentially closed. Crystallization started at the walls and progressed inward, forming concentric zones differing in mineralogic composition and texture. The entire process of fractional crystallization was accompanied by incomplete reaction between the rest liquid and the newly-formed crystals.

An outer zone of fine-grained albite-quartz pegmatite formed at the contact and is separated from the schist by a very thin, discontinuous chilled margin, or border zone, rich in quartz and muscovite. Along the footwall of the southern part of the body, rapid loss of volatiles probably was the cause of the formation of the sugary-grained facies of the wall zone. The escape of volatiles is indicated by alteration of the adjacent schist. Probably most of the volatiles, however, streamed inward and upward along the major structural rolls in the footwall and by slowing the rate of crystallization at these sites caused the crystallization of medium-grained albite-quartz-muscovite pegmatite adjacent to schist. The crystallization of this medium-grained first intermediate zone was partly simultaneous with and partly subsequent to the formation of fine-grained albite-quartz pegmatite elsewhere along the contact (e.g., fig. 3, section E-E').

It is possible that the sugary-grained facies of the wall zone may actually be a replacement body formed by solutions rich in sodium aluminum silicate escaping from the rest liquid at the time the first intermediate zone was crystallizing. If so, these escaping solutions should have replaced a pre-existing wall zone or schist to form the sugary-grained unit. However, because no consistent cross-cutting relations and no pseudomorphic textures either of schist or of a pre-existing wall zone were recognized, the sugary-grained rock is best considered to be a facies of the wall zone.

As crystallization proceeded, the distinctive mineral assemblages of the first, second, and third intermediate zones were deposited as quasi-concentric shells. The distribution of minerals in these units suggests a certain degree of segregation in the liquid prior to crystallization or during crystallization. The best development of the mica- and beryl-rich first intermediate zone was in the lower part of the body, while a fraction rich in potash and poor in water segregated near the crest to form the hood-shaped second intermediate zone. Fractures formed after crystallization of the wall zone in the southern part of the pegmatite were filled by liquid that crystallized and formed some of the essential minerals of both the first and second intermediate zones. Phosphate-rich materials, containing some lithium, arsenic, copper, and carbonate, were segregated along the inner edge of the first intermediate zone, where it is in contact with the second and third intermediate zones, and also along the contact between the second and third intermediate zones. Other fractions of fluid rich in water reacted elsewhere along the underside of the perthite-rich second intermediate zone to form a discontinuous unit of fine-grained muscovite rock. It is possible that some of these segregations may be replacement units, but no evidence of relict pegmatite was found.

As the end of crystallization approached, the residual material became sufficiently concentrated in lithium to form a meshwork of spodumene. The spodumene, however, was subsequently altered almost completely to fine micaceous material. The alteration was not the result of late weathering processes as indicated by the fact that other silicate minerals in the pegmatite exhibit very little alteration. The alteration of the spodumene could not have been caused by through-going hydrothermal solutions subsequent to the crystallization of the pegmatite because there is no evidence to indicate that such solutions passed through other units of the pegmatite. It seems very likely that the alteration of the spodumene crystals occurred simply as a reaction with the rest liquid. The reasons for this reaction, however, are not entirely clear. It is not readily apparent why this rest liquid, so soon after depositing spodumene, should change in composition sufficiently to replace the spodumene pseudomorphically. A possible explanation is that the crystallization of the spodumene may have occurred prior to the completion of crystallization of the third intermediate zone. Then, reaction between the progressively crystallizing inner part of the third intermediate zone and the rest liquid may have changed the composition of the rest liquid enough to cause it, in turn, to react with and to alter the spodumene.

If the alteration of the spodumene was accomplished by simple reaction between the crystals and the rest liquid, as the field evidence seems to indicate, there still remains the problem of the disposal of the lithium. It is important to note that the actual exposure of the quartz core is rather small and that the altered spodumene crystals were observed only near the upper and outer edge of this exposure. Altered or "rotten" spodumene crystals have also been reported at the Edison and Etta pegmatites in Pennington County, S. Dak. (Page and others, 1953, p. 112 and p. 118); in these pegmatites the altered crystals generally occur in outer spodumene-bearing units or in the outer parts of central units, whereas fresh spodumene generally occurs in the inner parts of the pegmatites. According to Page (oral communication, 1953), the lithium from the altered crystals at the Edison and Etta pegmatites probably went to form the fresh crystals of the relatively younger, inner parts of these pegmatites. If fresh spodumene occurs in the unexposed inner part of the core of the High Climb pegmatite, Page's explanation would also apply in the genetic sequence there. If, however, all of the spodumene in the core of the High Climb pegmatite is altered, a possible explanation may be that the lithium is now disseminated in the molecules of the micas and the quartz that make up the core. The altered spodumene forms only 3 percent of the exposure of the core. If this percentage can be applied safely to the entire core, then the total quantity of lithium present in the original crystals was rather small, and dissemination of this small quantity to the entire volume of the core does not seem unreasonable.

The final product of crystallization at the High Climb pegmatite was a silica-rich fluid that crystallized as a quartz core, enclosing the meshwork of altered spodumene logs. There is no evidence that at any time during the entire process of crystallization, from the formation of the outermost zones through the crystallization of the core, was material added to the pegmatite by through-going hydrothermal solutions. The crystallization operated in a system which was essentially closed, except for the minor escape of some volatiles which altered the adjacent schist.

The pegmatite fluid in its late stages may well have been more nearly hydrothermal than magmatic. The boundary between processes which have been termed "magmatic", or "igneous", and processes which have been called "hydrothermal" has long been a controversial problem. It is true that many minerals, such as beryl and muscovite, occur not only in pegmatites but also in quartz veins. Adams (1953, p. 98-100), for example, has reported beryl both in pegmatites and in quartz veins of the Mount Antero region, Colorado. The fact that some minerals occur in hydrothermal quartz veins does not necessarily mean that the occurrence of these same minerals in pegmatites should demand a separate stage in the genetic sequence, as postulated by Landes (1925, p. 355-411) and Schaller (1933, p. 144-151). Landes (1933, p. 55) later recognized the possibility that the hydrothermal solutions may be "residua" of the crystallization of pegmatite magma in the larger pegmatites. The process of fractional crystallization of a pegmatite magma in an essentially closed system, as postulated by Cameron, Jahns, McNair, and Page (1949, p. 97-106), is entirely compatible with the so-called "hydrothermal" character of some of the younger minerals in pegmatites. During the process of fractional crystallization the proportion of mineralizers in the rest liquid tends to increase, and the solution may change from a viscous liquid essentially magmatic in character to one that is essentially hydrothermal. The exact nature of the change from magmatic to hydrothermal conditions has been difficult to study in the laboratory because extreme difficulties are encountered in working with concentrations of mineralizers under combined heat and pressure. However, the change in character of the solution during fractional crystallization is strongly suggested in many pegmatites by the increase in grain size from the walls to the center of the pegmatite, by the increase in abundance of "reaction replacement" textures inwards in the pegmatite, and by the presence, in some pegmatites, of true replacement bodies which extend outward from inner zones and replace parts of older zones.

The High Climb pegmatite contains no evidence that there have been any significant changes since the original crystallization of the pegmatite, although there has been minor alteration of the phosphate minerals. Certainly there is no evidence of carbonate veins cutting the pegmatite. The carbon in the manganese-bearing carbonate in the phosphate-rich assemblage of minerals could easily have been a primary constituent of the source magma or could have been derived by partial assimilation of carbonaceous metasediments as the pegmatite fluid moved through the schists to its present site.

Mineral deposits

The industrial minerals that have been produced at the High Climb pegmatite are amblygonite, beryl, columbite-tantalite, potash feldspar, scrap mica, and punch and sheet mica. In 1948 the pegmatite had significant quantities of all of these minerals except columbite-tantalite.

Amblygonite

The amblygonite in the High Climb pegmatite is the high hydroxyl and low fluorine variety, montebrasite. It is mainly in the third intermediate zone (quartz-cleavelandite pegmatite), especially in a 2-foot thickness of cleavelandite-rich rock marginal to the core. It occurs as rounded nodules that average about 3.5 inches and range from 0.5 inch to 8 inches in size. Smaller quantities occur in the phosphate-rich pods in the first, second, and third intermediate zones and in the albite-rich parts of the first intermediate zone.

The percentage of montebrasite in the third intermediate zone is estimated to be between 0.25 percent and 0.5 percent. The distribution, however, is very spotty. The montebrasite content of the other zones is negligible.

Beryl

Beryl is confined almost entirely to the first intermediate zone of albite-quartz-muscovite pegmatite; this zone is also the main mica deposit in the High Climb pegmatite. Minor quantities of beryl occur in the innermost part of the wall zone and in the extreme outer part of the third intermediate zone, where these zones are adjacent to albite-quartz-muscovite pegmatite.

The beryl in the High Climb pegmatite is white to greenish-white but generally carries considerable reddish-brown iron stain. Beryl from areas rich in phosphate minerals is stained brown to gray-black by alteration products of the phosphate minerals. The length of crystals ranges from 0.5 inch to 12 inches; the average crystal is about 3.5 inches long and 1.5 inches in diameter. Most of the beryl is in euhedral crystals, but some is in subhedral intergrowths with albite and muscovite. The maximum index of refraction (N_ω) of the beryl ranges from 1.5794 to 1.5865 ($\pm$ 0.0005). According to an unpublished curve by W. T. Schaller of the U. S. Geological Survey, this indicates that the BeO content of the beryl ranges from 12.35 to 13.10 percent.

The average beryl content of the albite-quartz-muscovite pegmatite (first intermediate zone) is estimated to be about 1 percent. This estimate was obtained by measuring the area of beryl on three rich faces and estimating the beryl content of numerous other exposures of the zone. On the north wall of the main pit 17.5 square feet of albite-quartz-muscovite pegmatite was found to contain 31 crystals of beryl totaling 0.88 square feet in area, for a grade of 5.03 percent beryl; the exposed area of individual crystals in this rich face ranges from 0.0025 square foot to 0.1 square foot. Measurements of beryl crystals were made by Lang and Stewart (1948) on two exposures of the first intermediate zone in the northern half of the pegmatite. An area of 21 square feet of this zone in the south wall of the northernmost pit (fig. 2) contained 2.3 percent beryl in 22 beryl crystals with a total area of 0.48 square feet. In the south wall of the southern cut (fig. 2) in the northern half of the pegmatite a grade of 0.8 percent beryl was indicated in an area of 40 square feet that had 50 crystals of beryl having a total area of 0.31 square foot. Visual estimates of several other exposures of the zone indicate beryl contents of less than 0.5 percent.

The beryl content of those parts of the wall zone and the third intermediate zone immediately adjacent to the main beryl deposit (first intermediate zone) is less than 1 percent, and beryl has not been found elsewhere in the pegmatite. The beryl from both the wall zone and the third intermediate zone can be mined at the same time as the beryl is mined from the main unit.

The percentage of beryl that can be hand-cobbed from the albite-quartz-muscovite pegmatite differs from place to place. Lang and Stewart (1948) estimated 96 percent and 41 percent in the two exposures they measured. Probably the average percentage of cobbable beryl in the entire zone is in the order of 40 to 50 percent. The remainder of the beryl would have to be recovered by some other method.

Columbite-tantalite

Columbite-tantalite was not observed by the writer in the present workings, but according to descriptions by C. K. Koch, mine operator, the 100 pounds that has been mined was mainly from quartz-cleavelandite pegmatite (third intermediate zone).

Potash feldspar

The only minable deposit of potash feldspar in the High Climb pegmatite is the second intermediate zone. Only very small quantities of this mineral occur in other zones.

The potash feldspar is flesh white to buff creamy-white microcline-perthite which for the most part is clean and free from excessive iron stain except near irregular fractures. The size of individual crystals of the perthite in the second intermediate zone ranges from less than 1 foot to 5 feet but the average is probably about 1.5 feet in the southern part of the pegmatite and 1 foot in the northern part.

The average perthite content of the second intermediate zone in the southern half of the pegmatite is about 50 percent. The grade in the uppermost parts of the zone is as high as 75 percent, and in the lower parts of the zone, as low as 25 percent. In the northern half of the pegmatite the average grade of the exposures of the zone is about 60 percent perthite.

Mica

Muscovite occurs in all the units of the High Climb pegmatite, but it is most abundant in the first intermediate zone (albite-quartz-muscovite pegmatite), which is also the main beryl deposit in the High Climb pegmatite. The muscovite in this zone is silvery, yellowish-silvery, pale ruby, and pale greenish-brown in color. Books range in size from less than 0.25 to 10 inches; the average size is about 3 inches. Most of the mica contains varying amounts of A-structure and herringbone structure, and some contains mineral-inclusions and hair cracks. In parts of the zone near phosphate-rich pods, the mica is badly stained. Muscovite from elsewhere in the zone is sold as white scrap mica.

The average muscovite content of the first intermediate zone is estimated to be about 22 percent. The amount of sheet mica in present exposures is negligible. Adams and Stoll (1953, p. 131) estimated that about 10 percent of the small quantity of sheet mica recovered was on No. 1 and 2 qualities.

Muscovite also occurs in the wall zone, in the second and third intermediate zones, and in fracture-fillings of quartz-perthite-muscovite-albite pegmatite, but the grade in these units is too low for economic recovery of scrap mica by hand sorting. Furthermore, the small quantity of other economic minerals in these units decreases the chances that the mica will be extracted even as a byproduct.

Reserves

Amblygonite

Reserves of amblygonite (montebrasite) are in the same order of magnitude as total past production, which as been estimated at between 100 and 350 tons. The main deposit is in the third intermediate zone, which is estimated to contain between 0.25 and 0.5 percent amblygonite. The average thickness of the third intermediate zone in the southern part of the pegmatite is about 14 feet, but most of the exposed montebrasite is in the inner 2 feet of the zone. The length of the third intermediate zone, measured normal to the plunge, is about 125 feet; the depth of the zone, measured down the plunge (fig. 3, sections A-A', B-B'), is at least 110 feet and may be as much as 250 feet. This zone is not exposed in the northern part of the High Climb pegmatite.

Beryl and mica

The principal reserves of both beryl and mica are in the first intermediate zone, which is estimated to contain 1 percent beryl and 22 percent mica. Past production has been small. Reserves of beryl are probably somewhat less than 100 tons. However, if the southern part of the pegmatite continues down-plunge for a considerable distance and if the northern part of the body does not taper too sharply in depth, the total reserves of beryl may be considerably more than 100 tons. Reserves of mica are estimated to be a few thousand tons. Not more than about half of the beryl and less than half of the mica can be recovered by handcobbing.

The average thickness of the first intermediate zone is about 2.5 feet in the southern half of the High Climb pegmatite, but the zone is as much as 5 feet thick; the thickest exposures occur along the footwall. The depth of the deposit, inferred down the plunge along the footwall (fig. 3, sections A-A' and B-B'), is at least 105 feet but may be as much as 250 feet. The total length of exposures of the first intermediate zone in the southern half of the pegmatite is about 200 feet, but the shape is very irregular, reflecting the many rolls in the pegmatite contact.

In the dike-like northern half of the pegmatite the first intermediate zone is exposed for a total of 60 feet along the strike of the pegmatite and averages about 2 feet in thickness. The depth of this beryl deposit is not known but is probably at least 50 feet.

Potash feldspar

Reserves of potash feldspar are in the second intermediate zone. The grade ranges from 25 to 75 percent; the average is about 50 percent. Total reserves are a few thousand tons.

In the southern part of the pegmatite, the maximum thickness of the perthite-quartz-albite pegmatite is about 26 feet. The zone pinches out on the footwall side and thins down-dip on the hanging wall side. The maximum depth, measured down the plunge (fig. 3, section A-A'), is 190 feet and the length, measured normal to the plunge, is about 110 feet.

In the northern part of the pegmatite, the second intermediate zone is exposed for a total of 75 feet along the strike of the dike. Exposures are too poor to allow accurate determination of the thickness and depth in this part of the pegmatite.

The low grade, small size, and erratic distribution of perthite in the wall zone, in the first intermediate zone, and in the fracture-filling unit are unfavorable to mining of these units for potash feldspar.

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CONTENTS

TABLE

ABSTRACT

The High Climb pegmatite, Custer County, S. Dak. is a zoned pegmatite containing three zones that are economically significant: albite-quartz-muscovite pegmatite (first intermediate zone), perthite-quartz-albite pegmatite (second intermediate zone), and quartz-cleavelandite pegmatite (third intermediate zone). These three zones are estimated to contain a total of 45,000 short tons of pegmatite for an average distance of 120 feet down the plunge.

The main mica and beryl deposit, the first intermediate zone, is estimated to contain 9,000 tons of albite-quartz-muscovite pegmatite with an average grade of 22 percent muscovite and 1 percent beryl. Total inferred reserves in this deposit are 90 tons of beryl and 2,000 tons of muscovite. It is estimated that about 45 percent of the beryl, or about 40 tons, is recoverable by hand-cobbing methods. An additional 10 to 15 tons of beryl might be cobbed from the parts of the wall zone (albite-quartz pegmatite) and third intermediate zone immediately adjacent to the first intermediate zone.

In the southern half of the High Climb pegmatite the main potash feldspar deposit, the second intermediate zone, is estimated to contain 7,000 tons of perthite-quartz-albite pegmatite with an average grade of 50 percent perthite; the inferred reserves of perthite are 3,500 tons. Exposures of the second intermediate zone in the northern half of the pegmatite are insufficient to indicate its thickness and depth.

In the southern half of the High Climb pegmatite, the third intermediate zone is estimated to contain 29,000 tons of quartz-cleavelandite pegmatite with an average grade of 0.25 percent to 0.5 percent amblygonite; the inferred reserves of amblygonite are 70 to 145 tons. The third intermediate zone is not exposed in the northern half of the pegmatite.

About 100 pounds of columbite-tantalite has been produced from the High Climb pegmatite, but none of this mineral was observed in the present exposures.

INTRODUCTION

The High Climb pegmatite, Custer County, S. Dak. is a zoned pegmatite that has produced beryl, potash feldspar, mica, amblygonite, and columbite-tantalite. Part I of this report contains detailed descriptions of the internal structural units, the individual minerals, and the mineral deposits, together with data on the size, shape, structure, origin, and past production of the High Climb pegmatite.

METHOD OF CALCULATION OF RESERVES

Southern half of the High Climb pegmatite

The reserves of beryl, perthite, muscovite, and amblygonite in the southern half of the High Climb pegmatite (Part I, fig. 2), have been calculated according to the following procedure:

(1) The areas of the first intermediate zone (albite-quartz-muscovite pegmatite), second intermediate zone (perthite-quartz-albite pegmatite), and third intermediate zone (quartz-cleavelandite pegmatite) on sections C-C', D-D', and E-E' (Part I, fig. 3) were determined with a planimeter. Likewise, the areas of these zones northwest of section C-C' were planimetered on sections A-A' and B-B' (Part I, fig. 3).

(2) The volume of rock in each of these zones was then calculated between the cross-sections and to the limits of the pegmatite south and east of the sections. The volume of each of the zones was also calculated to an arbitrary distance of 40 feet northeast of section A-A'.

(3) The volume of rock in each zone was converted to short tons at the ratio of 11.75 cubic feet per ton of pegmatite.

(4) The reserves (table 8) were calculated by applying average grades to the calculated total tonnage of each zone. The muscovite content of the second and third intermediate zones is only 1 percent and 4 percent, respectively, and was not used in calculating reserves of mica.

Table 8.--Inferred reserves of beryl, muscovite, perthite, and amblygonite in the High Climb pegmatite, Custer County, South Dakota

	Zone	Thickness of zone (feet)		Total calculated tonnage of zone (short tons)	Economic mineral	Average size (inches)	Average grade 1/ (percent)	Reserves (short tons)
		Range	Average					
Southern half of High Climb pegmatite	Albite-quartz-muscovite pegmatite (first intermediate zone)	0.5-5	2.5	6,000	Beryl	1.5 x 3.5	1	60
					Muscovite	3	22	1,300
	Perthite-quartz-albite pegmatite (second intermediate zone)	26 (maximum)	--- ---	7,000	Perthite	18	50	3,500
	Quartz-cleavelandite pegmatite (third intermediate zone)	2-30	14	29,000	Amblygonite (variety, montebrasite)	3.5	0.25 to 0.5	70 to 145 2/
Northern half of High Climb pegmatite	Albite-quartz-muscovite pegmatite (first intermediate zone)	0.5-4	2	3,000	Beryl	1.5 x 3.5	1	30
					Muscovite	3	22	700
	Perthite-quartz-albite pegmatite (second intermediate zone)	----------	---	-----	Perthite	12	60	?
	Quartz-cleavelandite pegmatite (third intermediate zone)	Not exposed		-----	Amblygonite (variety, montebrasite)	---------	-----------	?
TOTALS FOR ENTIRE HIGH CLIMB PEGMATITE:	Albite-quartz-muscovite pegmatite (first intermediate zone)	----------	---	9,000	Beryl	---------	-----------	90 3/
					Muscovite			2,000
	Perthite-quartz-albite pegmatite (second intermediate zone)	----------	---	7,000	Perthite	---------	-----------	3,500 4/
	Quartz-cleavelandite pegmatite (third intermediate zone)	----------	---	29,000	Amblygonite (variety, montebrasite)	---------	-----------	70 to 145

1/ Average grade of beryl was determined by measuring beryl crystals on rich faces and by making visual estimates of other exposures. Average grades of other minerals were determined by visual estimates.

2/ Exposures are insufficient to indicate whether the grade of amblygonite is constant but the 145 tons probably is the maximum possible reserve.

3/ About 45 percent of the beryl (i.e., about 40 tons) is recoverable by hand-cobbing. Possibly an additional 10 to 15 tons of beryl may be cobbed from parts of the wall zone (albite-quartz pegmatite) and the third intermediate zone, where these zones are adjacent to the first intermediate zone.

4/ Data are for the southern half of the High Climb pegmatite only; exposures of the second intermediate zone in the northern half of the body are insufficient to indicate its thickness and depth.

The calculations were made for that amount of pegmatite which lies above an altitude of 5,640 feet (Part I, fig. 3); the structure of the pegmatite down-plunge to the northwest below that altitude is not known accurately, and the position of the hangingwall is uncertain. If the pegmatite continues down-plunge for a considerable distance without tapering sharply, the reserves of mica and beryl would be much greater than have been calculated using presently available data.

Northern half of the High Climb pegmatite

The exposures of zones in the northern half of the High Climb pegmatite (Part I, fig. 2) are insufficient to warrant extensive calculations of reserves. Preliminary rough calculations indicate that the maximum thickness of this part of the pegmatite is about 55 feet, and the outcrop length is 170 feet. The thickness of the first intermediate zone is about 2 feet. If it be assumed that this zone extends the entire length of the outcrop along both the hangingwall and footwall to a depth of 50 feet, the total volume of the zone is found to be 34,000 cubic feet or about 3,000 tons of rock. Assuming an average grade of 22 percent muscovite and 1 percent beryl, the inferred reserves are: mica, 700 tons; beryl, 30 tons. Exposures of the second intermediate zone are insufficient to indicate its thickness and depth, and the third intermediate zone is not known to exist in this part of the pegmatite.

RESERVES

Three zones in the High Climb pegmatite are of significant economic importance: albite-quartz-muscovite pegmatite (first intermediate zone), perthite-quartz-albite pegmatite (second intermediate zone), and quartz-cleavelandite pegmatite (third intermediate zone). The principal industrial minerals are beryl, muscovite, perthite, and amblygonite, but a small quantity of columbite-tantalite has also been produced.

Beryl

The first intermediate zone is the main mica and beryl deposit in the High Climb pegmatite. This zone is estimated to contain 9,000 tons of rock to a depth of 70 feet below the floor of the main cut (i.e., to an altitude of 5,640 feet) in the southern half of the pegmatite, and to a depth of 50 feet below the surface in the northern half of the pegmatite (table 8). The average grade is 1 percent beryl. Thus, the total inferred reserves of beryl in the first intermediate zone are 90 tons (table 8). It is estimated that approximately 45 percent of this beryl, or about 40 tons, is recoverable by hand-cobbing methods. If the southern part of the pegmatite continues down-plunge for a considerable distance below an altitude of 5,640 feet (Part I, fig. 3) and if the northern part of the pegmatite does not taper sharply in depth, the reserves of beryl in the first intermediate zone may be as much as twice the inferred totals.

Minor quantities of beryl occur in the innermost part of the wall zone (albite-quartz pegmatite) and in the extreme outer part of the third intermediate zone (quartz-cleavelandite pegmatite), where these zones are adjacent to the first intermediate zone. The beryl content was not determined accurately, but visual estimates suggest that it is considerably less than 0.5 percent. Possibly 10 to 15 tons of beryl might be cobbed from the parts of the wall zone and third intermediate zone adjacent to the main beryl deposit.

Optical data (Part I) indicate that the BeO content of the beryl in the High Climb pegmatite ranges from 12.35 percent to 13.10 percent.

Muscovite

The first intermediate zone not only is the main beryl deposit,but it also is the main mica deposit in the High Climb pegmatite. The 9,000 tons of rock estimated to be available has an average grade of 22 percent muscovite; the inferred reserves of muscovite are 2,000 tons (table 8). The mica reserves, like the beryl reserves, may be as much as twice the inferred totals.

Reserves of muscovite were not calculated for the second and third intermediate zones because these contain only 1 percent and 4 percent muscovite, respectively.

Most of the muscovite in the first intermediate zone contains A-structure and herringbone structure, and some contains mineral inclusions and hair cracks. The muscovite, therefore, has been sold largely as scrap mica, and the amount of plate mica visible in exposures is negligible.

Perthite

The second intermediate zone in the southern half of the High Climb pegmatite is estimated to contain 7,000 tons of perthite-quartz-albite pegmatite with an average perthite content of 50 percent; the total inferred reserves of perthite is 3,500 tons (table 8). Reserves of perthite were not calculated for the northern part of the body because the exposures of the second intermediate zone are insufficient to indicate its thickness and depth. Only very minor quantities of perthite occur in other internal units in the High Climb pegmatite.

Amblygonite

The amblygonite in the High Climb pegmatite is the high-hydroxyl, low-fluorine variety, montebrasite. The main amblygonite deposit is in the third intermediate zone. In the southern half of the pegmatite the third intermediate zone is estimated to contain 29,000 tons of quartz-cleavelandite pegmatite, with an average amblygonite content of about 0.25 percent to 0.5 percent; the inferred reserves of amblygonite are 70 to 145 tons (table 8). Small amounts of amblygonite also occur in the first and second intermediate zones, but the distribution is irregular and an accurate grade for these zones is not available.

Columbite-tantalite

Although no columbite-tantalite was observed in the present mine workings, it is possible that a small quantity may be mined from unexposed parts of the third intermediate zone. The distribution is probably very irregular.