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STATE OF SOUTH DAKOTA

M. Q. SHARPE, GOVERNOR

STATE GEOLOGICAL SURVEY

E. P. ROTHROCK, STATE GEOLOGIST

REPORT OF INVESTIGATIONS

No. 50

PRELIMINARY REPORT

ON THE

MINERALOGY OF SOME PEGMATITES NEAR CUSTER

BY

D. JEROME FISHER

UNIVERSITY OF SOUTH DAKOTA
VERMILLION, SOUTH DAKOTA
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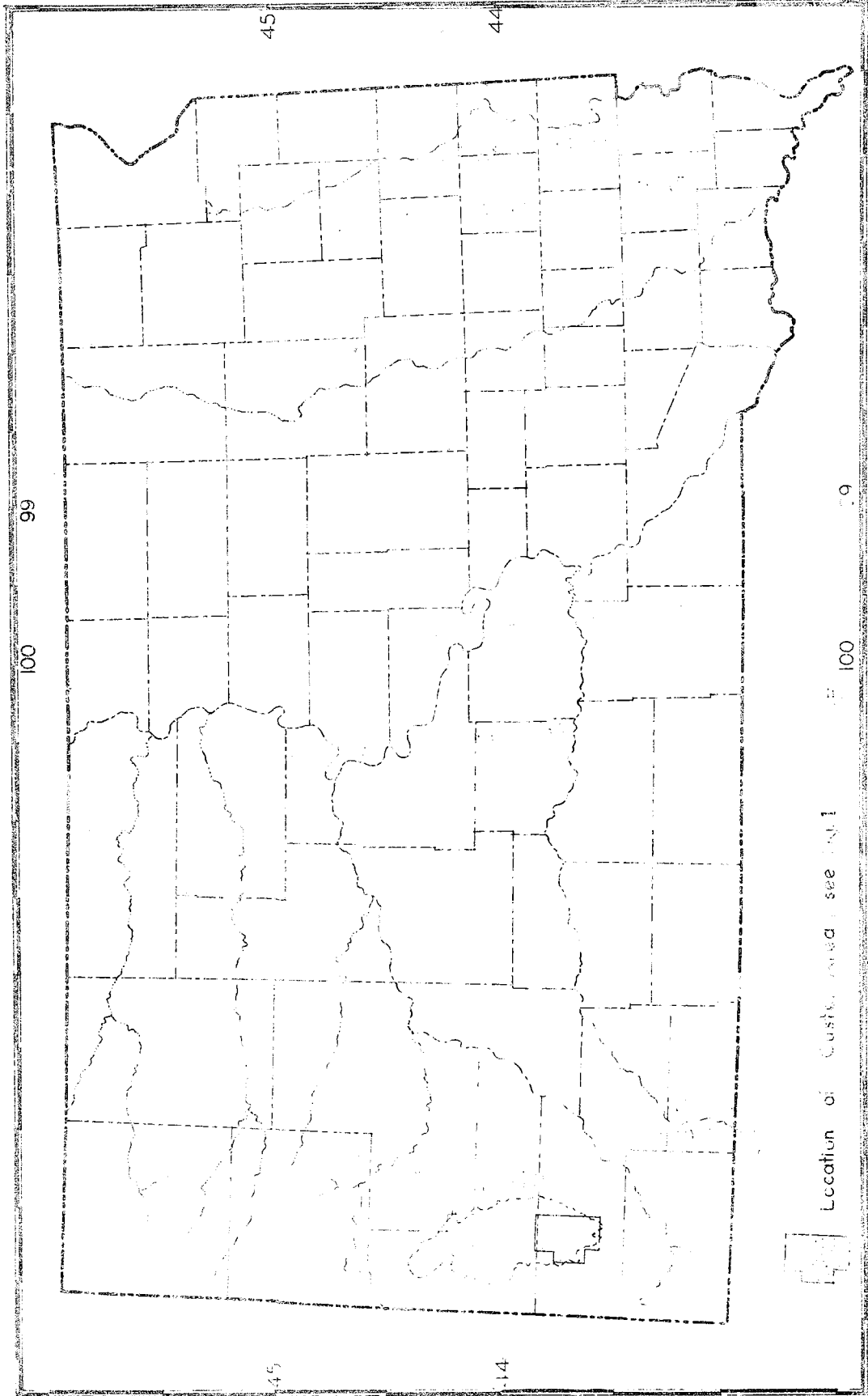
SOUTH DAKOTA

STATE GEOLOGICAL SURVEY

Preliminary Report

on the

MINERALOGY OF SOME PEGMATITES NEAR CUSTER

D. Jerome Fisher
Associate Professor Mineralogy
University of Chicago

MAP OF SOUTH DAKOTA

SHOWING COUNTY BOUNDARIES

45

44

99

100

9

100

14

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Location of Custer road see Vol 1

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NOTICE TO PROFESSIONAL GEOLOGISTS

The portions of this report likely to be found of most interest are pages 7-20, together with later places specifically referred to therein; also the description of the giant cleavelandite pipes, together with their associated beryls, possibly formed by "upward" enrichment, as is covered on pages 64-67. The paragenetic tables appear on pages 54, 71, and 88.

ERRATA

Page

9, line 37......."Pegmatite" should read "Pegmatites".

14, line 4 ...."expecially" in footnote 1 should read "especially".

18, line 1......."They" should read "they".

25, line 15......."nearly-associated" should read "nearby-associated".

30, line 1........should read "cleavelandite-quartz rock distinctly embays into the perthite,".

32, line 2........"NW" should read "NW".

39, line 28......."mpa" should read "map".

40, line 28.......insert "more" between "will" and "probably".

41, line 16......."xenoliths" should read "zenoliths".

59, line 2........"working" should read "workings"

60, line 3........the last word is "Green,".

62, line 31......."blobs" should read "blebs".
    line 32......."mearly" should read "nearly".

78, line 1........should read "Figure 17: Detailed views in the".

80, line 40......."ahead" should follow "discussed" in line 39.

83, line 1........the last word is "phosphates;"
    line 3........"tri hylite" should read "triphylite".

86, line 1........"E. J. Holden" in footnote 1 should read "F. F. Holden".

92, line 6........"Superhene" should read "Supergene".

Preliminary Report

on the

MINERALOGY OF SOME PEGMATITES NEAR CUSTER

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D. Jerome Fisher

INTRODUCTION

Scope of Report

The Black Hills are in the southwest corner of South Dakota,
in Custer, Pennington, Lawrence, and the southwest corner of Meade
Counties. They have a relief of about 4000 feet, extending up to
7244 feet. The latter elevation marks the top of Harney Peak,
the highest point east of the Rocky Mountains. Harney Peak is
shown near the north edge of Fig. 1.

Important pegmatites are known in the southern part of the
Hills; also near Tinton in the northwestern portion. The former
are found in two main districts centered about Keystone (6 miles
east-northeast of Harney Peak) and Custer (8 miles south-southwest
of Harney Peak). In the Keystone District some of the pegmatites
have long attracted much attention; the Etta Mine in particular is
famous in the geological literature.

Descriptions of the geology of three of the pegmatites of
the Custer District appear in Report of Investigations No. 44 of
the South Dakota Geological Survey. This pamphlet by the present
writer, entitled "Preliminary Report on Some Pegmatites of the
Custer District," appeared in June, 1942; a slightly revised edi-
tion was distributed in December, 1942. The three pegmatites de-
scribed are shown as Nos. 2, 10, and 17 on Fig. 1 of the present
report. The reader is also referred to the earlier report for a
general bibliography.

The present preliminary report is in the main concerned with
the geology of five pegmatites near Custer; Nos. 3, 5, 8, 12, and
13 of Fig. 1. It is expected that further laboratory study will
cause modifications of some of the tentative conclusions here pre-
sented; this is especially true for the paragenetic sequence tables.

FIGURE 1

INDEX MAP
SHOWING
LOCATION OF PEGMATITES
EXAMINED

SCALE
0   1   2   3
MILES

LEGEND
Producing Mine ⚒
Non-producing Mine ✗
Prospect X
Mine Studied In Detail ⊗

N

SOUTH DAKOTA
GEOLOGICAL SURVEY
1941-42
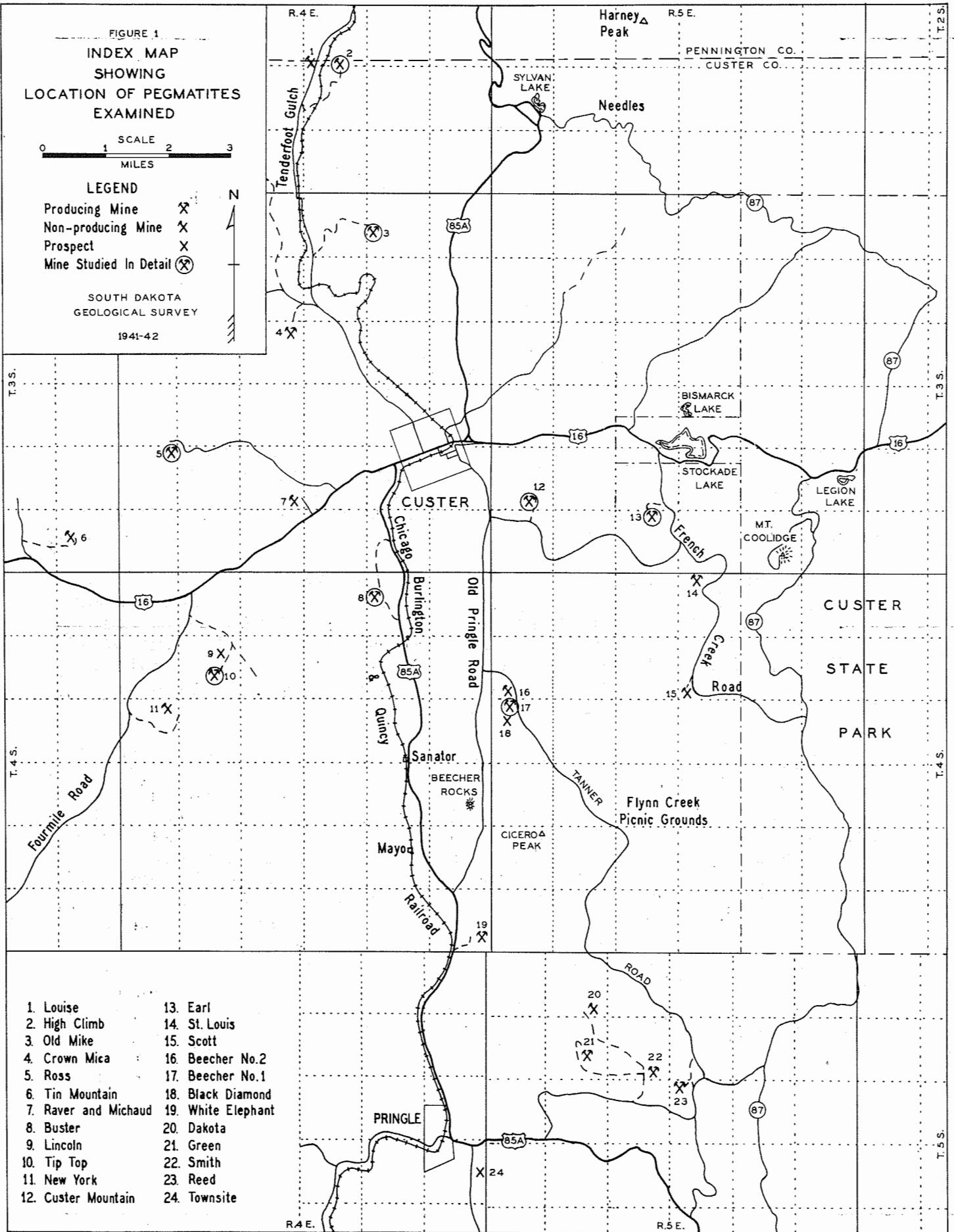
Harney Peak

R.4 E.   R.5 E.   T.2 S.

PENNINGTON CO.
CUSTER CO.

SYLVAN LAKE
Needles

Tenderfoot Gulch

85A

87

BISMARCK LAKE

T.3 S.

STOCKADE LAKE

LEGION LAKE

16

87

CUSTER

French Creek

MT. COOLIDGE

CUSTER

STATE

PARK

Chicago
Burlington
Quincy

Old Pringle Road

85A

Road

87

Fourmile Road

Sanator
BEECHER ROCKS
Mayo
CICERO PEAK

TANNER

Flynn Creek
Picnic Grounds

Railroad

T.4 S.

ROAD

PRINGLE

85A

87

T.5 S.

R.4 E.   R.5 E.

1. Louise
2. High Climb
3. Old Mike
4. Crown Mica
5. Ross
6. Tin Mountain
7. Raver and Michaud
8. Buster
9. Lincoln
10. Tip Top
11. New York
12. Custer Mountain
13. Earl
14. St. Louis
15. Scott
16. Beecher No.2
17. Beecher No.1
18. Black Diamond
19. White Elephant
20. Dakota
21. Green
22. Smith
23. Reed
24. Townsite

Object of Report

The primary object of this report is to assist in the devising of the most intelligent and economical plan for recovering the valuable minerals of the pegmatite deposits of the area. The demand is extremely variable; that is, in certain years feldspar is the chief product wanted; in other (especially war) years, mica (muscovite) along with the rarer minerals such as beryl, columbite, tantalite, and cassiterite may be desired. The lithium minerals such as amblygonite, spodumene, and lepidolite may also be in particular demand at certain times. The field work leading to this report has shown that few if any pegmatites are capable of being good (economical) producers of all these minerals; certain types of deposits are most suitable for certain minerals. That is, minerals tend to occur in certain suites or associations. By recognizing the presence or absence of certain members of a typical suite, the prospector is in a better position to know whether the prospect under examination is likely to "pan out" as a commercial producer of the material or materials he is particularly interested in. Moreover, as development proceeds and the story is more completely unfurled, the principles laid down in this report should be of equal or greater value if used along the lines just described.

No two pegmatites of the area are alike. Certain ones as the Tip Top or Ross are of the simpler type in the main. The Buster, Earl, and Old Mike are good examples of muscovite producers, although the Old Mike is more complex than the other two. The High Climb is a complex pegmatite that supplied much amblygonite. The Beecher is a spodumene- and amblygonite-rich deposit so complex and so badly altered that many conclusions regarding it are tentative. The Custer Mt. Lode is a rather minor dike of great mineralogical complexity that has much in common with the Beecher, but on a smaller scale.

This report is therefore devoted to a statement of the geologic features and principles involved and to a description of the five pegmatite deposits studied in detail. It is hoped that careful study of this manuscript may aid the prospector or geologist in deciphering the history of any pegmatite he may examine in the district, and thus lead to the most economical exploitation of the pegmatite mineral resources of the area in terms of any available minerals that may be needed at any particular time.

FIELD AND LABORATORY WORK; ACKNOWLEDGMENTS

The writer lived in Custer from August 2 to September 24, 1942. Mr. Robert G. Smalley faithfully assisted in the field work during this interval; under the writer's guidance he made the maps of the Buster, Custer Mt., and Old Mike lodes. Later he drafted these as well as the Ross map and copy for Fig. 1. The laboratory work involving microscopic study of numerous specimens including 50 thin-sections was prosecuted evenings and rainy days while in the field and in available hours since then when teaching and other duties at the University of Chicago would permit. Unfortunately, time for a thorough laboratory study has not been available prior to the date when this preliminary report must appear. Thanks are due William Schmidt for substantial aid in the laboratory photography.

The writer is under obligation to the State Geologist, Dr. E.P. Rothrock of Vermillion, who first suggested the problem and who cooperated in every way in pushing it along. Residents of Custer were very helpful. In particular, acknowledgments should be made to the operators (listed later) of the mines examined.

GEOLOGIC SETTING

Outline of Black Hills Geology

The Black Hills represent an earth bulge or blister in the Northern Great Plains which has broken (its top removed by erosion), leaving the normally-underlying material exposed in the central part. This portion is elliptical in shape, extending north-south 60 miles and east-west 25 miles; it is outlined on the state map facing page 3. Fringing this central core is a great series of later (Cambrian and younger) sediments, dipping away from it in all directions, which have accumulated during the last half billion years. See Fig. 2A. These would slightly resemble a giant shingled roof of elongate-domical shape if the central portion were left open and around this the shingles were placed in oval belts with the thick ends towards the top of the dome. Of course, this is the opposite from the proper way to lay shingles on a roof.

This report is concerned only with those rocks of the central core which were formed in pre-Cambrian times; that is, before any "shingles" were laid down on our imaginary roof. Compare Fig. 2A. According to Folio 219[1] these rocks are mainly metamorphosed sediments consisting of a kernel of coarser material (grit, graywacke, quartzite) surrounded by a heavy shell of finer material (slate and mica schist), except to the southeast where there is a large area of quartzitic schist. These rocks were metamorphosed by mountain-building action probably at least a billion and a half years ago.[2] Presumably important mountains were formed at this time, but by the ceaseless action of wind and water through a billion-year-long "Lipalian" interval, they were worn down to a plain more than a half billion years ago.

Intruded into these old sediments probably well along in the mountain-building epoch were minor amounts of basic (dark colored) igneous rock, diorite-gabbro. In part these suffered squeezing and so were changed into amphibolites, metamorphic rocks dominantly

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1. N.H. Darton and S. Paige, Central Black Hills Folio 219, U.S. Geological Survey, 1925.
2. According to the uranium-lead ratio determined by C.W. Davis on a sample of uraninite from the Ingersoll Mine, Keystone, South Dakota. See A. Holmes, "Radioactivity and Geologic Time," National Research Council Bulletin 80, Part IV, 1931, 334-38.

of hornblende or some other amphibole. These vary from fine-grained foliated rocks with quartz to massive faintly-banded crystallines carrying plagioclase.

Somewhat later, perhaps at the close of the mountain-building epoch, or shortly thereafter, a very large mass of granitic material known as a batholith was intruded into or formed within this older complex. How extensive this was is unknown, since erosion has gone far enough to expose it only in the southern part of the Hills, near Harney Peak and to the south, except for a minor patch 15 miles southeast of Deadwood along Little Elk Creek.

The main body of the Harney Peak granite appears on the map of Folio 219 as a roughly circular mass nearly 10 miles in diameter whose center lies near the northeast corner of Fig. 1. It consists of a variable-textured rock, mostly coarse or even pegmatitic, locally rich in inclusions of schist and other rocks. This portion may be regarded as something close to a cupola or giant bubble at the top of the batholith, intricately intruded by pegmatites.[1] The surface of the batholith dips off steeply to the north and northwest, judging by the relative rarity of pegmatites in this area. In other directions, however, and especially to the south and southeast, pegmatites are so thick in the pre-Cambrian core that one tends to feel he is never far above the top of the batholith. The assumption is the pegmatites are related to the attitude and altitude of the top of the batholith about like a series of oil pools might be to a gigantic domal structure.

Fig. 2B, taken from a vertical air photograph[2] by the Department of Agriculture, shows how thickly these pegmatite dikes are concentrated in certain areas. This view covers a district about one mile square immediately west of Mayo (south center of Fig. 1),

1. Compare J.J. Runner, "Structure and Origin of Black Hills pre-Cambrian Granite Domes," _Journal of Geology_, 51 (7), 1943, 431-57.
2. Symbol BNW, roll No. 176, exposure No. 16, October 12, 1938, abbreviated BNW 176-16. See Custer County Index Sheets Nos. 1 & 2. Prints may be obtained in time of peace from the Agricultural Adjustment Administration. Where locations on such photographs are described in terms of coordinates in this report, these are given in inches and tenths, measured right (east) and then up(north) from the lower left (southwest) corner of the 9-inch square photo trimmed along its black collimation arrows.
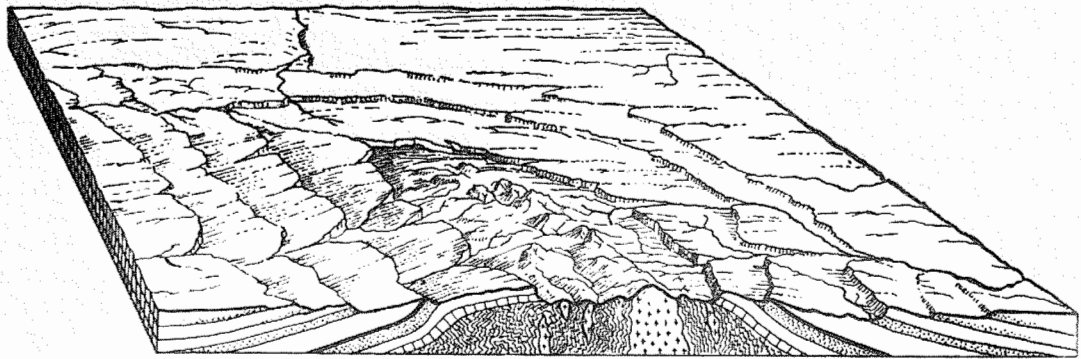
2A. East-west cross-section of the Black Hills. (From
The U. S. Geol. Survey and P. G. Worcester: Geomor-
phology, 1939. D. van Nostrand Co.)

2B. Vertical Aerial view of pegmatites near
Mayo, S. D. (U. S. Dept. of Agriculture)

2C.   Pegmatite wall near Mayo

which appears near the left (east) side of the picture.[1] The numerous dikes here stand up as sloping walls striking N. 25° W. and dipping about 65° to the west. The white line through the lower left portion is the concrete strip of U.S. 85A. The side road leads westerly from this across the railroad in a valley at Mayo and then winds upwards between these pegmatite walls, which appear as a series of short parallel offset white lines. The relatively soft mica schist which controlled the attitude of the pegmatites has eroded away much faster than the latter. The parallelism of these many dikes, as well as their concordance with the enclosing schists, is strong evidence that the development of the schistosity preceded the intrusion of the dikes. Fig. 2C is an ordinary (terrestrial) photograph taken of one of these dikes, looking in a general northwesterly direction.

Pegmatites

The pegmatites of the Custer area are more or less altered plutonic (deep seated) igneous rocks of modified granitic composition which show crystals of varying sizes, but some of them are quite large, thus see Fig. 3A showing black tourmaline crystals two feet long in the Smith Mine (No. 22, Fig. 1). Many of the smaller pegmatites are tabular-shaped bodies, but the larger ones (25 to 150 feet thick and 200 to 1000 or more feet in length) are more commonly bulging, so as to resemble an irregular biconvex lens. With one or two exceptions all those examined have been intruded into foliated metamorphic rocks. They have been pushed in like the water in a blister, causing the schist layers to spread apart. The schist bends out and around the pegmatite, and only very rarely is a cross-cutting relationship observed, such as at the small dike near the northwest end of the Tip Top Lode (No. 10 of Fig. 1) claim.[2] In the third dimension (along the dip of the schistosity) all but the smaller pegmatites also tend to be shaped like a biconvex lens. There is definite field evidence that these bodies are not shaped like a pane of glass, thus extending down to some mass of parent igneous rock with only minor changes in thickness. Rather they seem to be more or less isolated masses suspended at bulges in the schist. They are thus not dikes or sills in the ordinary elementary textbook sense of the word. Runner[3] suggests that these pegmatites may have been portions of continuous masses

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L. The locations of these dikes are shown on the map by R. Lawton; see Fig. 1 of Rep. of Inv. No. 48, 1944.
2. Similar cross-cutting is observed at the Old Mike Mine, (See p. 59).
3. Op. cit., 445. Of course, the writer never considered that these blisters advanced through the schist as such; in attributing this idea to him, Runner misunderstood his position.

which were subsequently pinched off. Had this occurred after solidification, they should show pronounced evidence of stress metamorphism, which they generally lack. The alternative picture would be to have a pod- or tabular-shaped intrusion followed (prior to solidification) by a local squeezing-in of the schist walls, isolating the pegmatite into two or more blisters. Since the active force was that which sent the pegmatite liquid into the schist, it would seem more logical to assume that this penetrated along surfaces of weakness like lit-par-lit injection until it came to a location where the schist could be bulged out easier than it could be pried apart ahead along the surface of penetration. Once any bulging was initiated, this would tend to be rapidly enlarged, and might even lead to a blunt-ended blister such as occurs at the Buster Lode, south end (see page 23). A blister of such shape would hardly form by being pinched off. Of course, this implies some rock flowage in the schist at the time of the intrusion.

If it can be shown that in a number of instances[1] a given series of such pegmatite blisters lines up along a single surface of rock foliation, something like beads on a string, it then might be concluded that the alternative hypothesis has some validity, though it would be extremely difficult to show that these did not form as isolated blisters in the first place. In any case the theories are not mutually exclusive. It is true that in places the pegmatites are so thick that apparently disconnected bodies may be or may once have been part of one single mass which has extremely pronounced pinch-and-swell structure; these may represent truly disconnected bodies (either isolated intrusions, or a single one pinched at several places to zero thickness) or they may still be connected below the present surface, or they may once have been connected above the present surface.

There is no doubt that the Custer pegmatites came into rocks which were already schists. They show very sharp-wall contacts with the schist, and in general the wall rock is relatively unaffected, even though blocks of it may be engulfed in the pegmatite as shown in Fig. 3B (Smith Mine No. 22, Fig. 1). Exomorphic changes (those in the wall rocks formed as a result of the pegmatite intrusion) are limited to a narrow range, and consist mainly in the development of tourmaline and mica (both muscovite and biotite). An extreme case appears to be represented by the Crown Mine (No. 4 on Fig. 1), where so much muscovite has been developed locally in the schist above the pegmatite that the contact cannot be located exactly. At the north end of the Beecher No. 1 Lode the

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1. One such case near Hill City is cited by F.L. Hess in U.S. Geo. Sur. *Bull.* 380, 1909, 136.
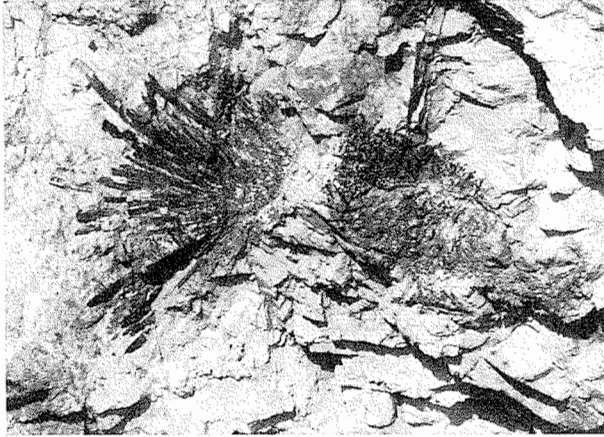
3A. Tourmaline nest
at the Smith Mine

3B. Schist inclusion
at the Smith Mine
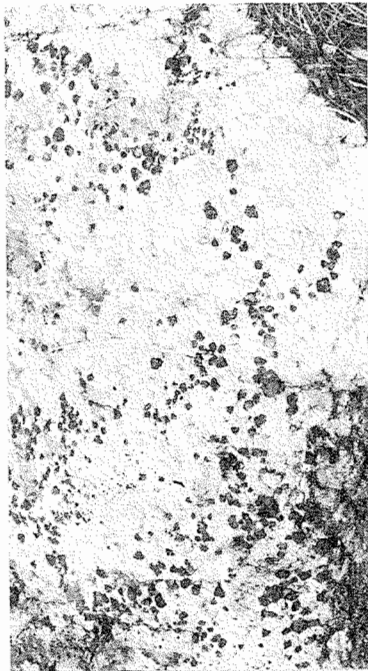
3D. Looking down at a
block showing the foot-
wall surface, Gray Rocks
Lode. Tourmalines appear
in cross section normal
to their c-axes.

3C. Face normal to the footwall
Gray Rocks Lode, showing black
tourmaline sections parallel
their c-axes. Note the house
key, nearly 3 inches long.
Schist in lower left half.

schist is locally impregnated with tiny lilac spodumene crystals. The most obvious endomorphic changes (those in the pegmatite near its contact with the wall rock) are those which result in the concentration of certain minerals as muscovite or tourmaline in the pegmatite near its contact walls. Fig.3C shows black tourmalines two or three inches long growing into the Gray Rocks pegmatite (one mile north of No. 8 on Fig. 1) normal to its contact wall; Fig. 3D depicts the surface of this pegmatite wall with the cross-sections of the tourmaline prisms appearing as dark splotches.

Fig. 18D brings out some of the characteristic features of granitic pegmatites. It may be taken either as a vertical cross-section or a horizontal plan (a map). Two pegmatites are shown; one cuts both granite and neighboring schist; the other is an isolated blister in the schist, so far as can be seen from a single cross-section. Because of space limitations the pinch-and-swell structure of the left pegmatite is greatly exaggerated. The features brought out by this figure may be summarized under eight headings, as follows: the first four represent external relationships; the remainder cover internal characteristics.

1. Pegmatites show great variability in shape, though they are commonly thought of as being crudely tabular (dikes or sills). Where intruded into foliated or bedded rocks they may be more lens-shaped or blister-shaped and are generally concordant with the structure. They may be sub-spherical, as is the Etta deposit near Keystone, according to the description of G.M. Schwartz[1]. They are also reported as cylindrical or pipe-like. Pinch-and-swell structure may considerably modify the shape of a single deposit. Where intruded into massive rocks (as granite, or quartzite, or even some gneisses), the shape is generally highly irregular. Under these conditions the contacts may be gradational and difficult to establish. This is particularly true if the intruded rock is the parent granite (one considered to have crystallized from the same mass that supplied the pegmatitic solutions); the Sky Lode[2] is a good example; the Custer Mt. Lode (see page 40) is much less typical. Pegmatites found in the parent granite, although they may be numerous, are generally small.

2. Pegmatite have extreme variability in size. While ordinarily they are under one mile in greatest exposed dimension, they

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1. Econ. Geol 20, 1925, 651 and Fig. 2. This deposit is sub-circular in cross-section (200 by 250 feet), and 250 to 300 feet long in the direction of dip of the enclosing schist. If a feeder is still present, the shape of this pegmatite may be likened to that of a tadpole.
2. Rep. of Inv. No. 44; No. 4 on Fig. 1, 1942.

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may reach several (4?) miles, with a thickness of several hundred feet. Contrasting with these are small pegmatites near the Ross Lode which are less than an inch thick, and so appear in complete cross-section on a single ordinary-size thin-section.

3. Pegmatites may appear to be (and may be in fact, like blisters in schist) entirely isolated from the parent igneous rock. On the other hand they may grade into rather typical quartz veins, though these (like the pegmatites themselves, except for columbite-tantalite) rarely if ever carry metallic-lustered minerals in important amount.[1] A possible example is the wolframite-bearing quartz veins near Hill City.[2]

4. Pegmatites are more common in soft rock, as schist, than in hard rock, as quartzite. They are generally thought to be more important near the upper surface of a batholithic mass, especially if they show a varied suite of minerals, but this can hardly be regarded as a demonstrated fact.

5. Except for single pegmatites consisting almost solely of potash feldspar (microcline, commonly perthitized) and quartz, with very minor muscovite (potash mica) or other accessory minerals, these deposits often show a great variability of composition as well as of distribution of mineral components. Some have a central quartz mass (Old Mike, New York, Scott, possibly the Ross); others may show a crude zoning (compare Figs. 3C, D) or banding (Ross, High Climb). Muscovite may be concentrated near the walls of a

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1. Some pegmatites carry later hydrothermal deposits containing metallic-lustered minerals, though these also are rarely if ever in amounts sufficient to be economically important. The High Climb Lode (Rept. of Invest. No. 44, page 23) as well as the Custer Mt., Earl, and others, carry loellingite. The Kiam prospect of Llano Co., Texas, has bismuth, bismuthinite, and molybdenite in minor amounts. See Stenzel and Barnes, University of Texas Bull. 3945, 1939, page 911. Magnetite is not uncommonly present in pegmatites, though it has not been found in such deposits in the Black Hills. Cassiterite is present at Tin Mountain, Custer Mt., and Beecher No. 1, as well as near Keystone and Tinton. Uraninite and other metallic-lustered minerals are exceedingly rare or found only in occasional pegmatites.
2. ,L. Hess, "Ore Deposits of the Western States," American Institute of Mining and Metallurgical Engineers, 1933, 535; also U.S. Geological Survey Bulletin 380, 1909, 149.

pegmatite (Crown Mica, New York[1]). The growth inward from the walls of successive layers of crystals (right pegmatite of Fig. 18D) has not been observed near Custer. This dike also shows a vug or cave lined with euhedral to subhedral[2] crystals. Such cavities are very rare in the Black Hills, but were noted at the Tip Top and High Climb Lodes.[3] Since the gem minerals of pegmatites usually occur in such vugs, they are almost unknown from the Hills. An exception is rose quartz, very rare except as anhedral masses, and so not a typical vug mineral; the Southern Hills and especially the Scott mine are world famous for this semi-precious stone.

6. There is great variability in texture even within short distances in a single pegmatite, but these rocks are characterized by the presence of some relatively large crystals. A beryl 19 feet long and up to 5 feet through, and a spodumene 47 feet long and 3 to 6 feet through, have been found at Keystone. Spodumenes and potash feldspars over 10 feet long are present at Beecher No. 1 and the Tip Top Lode, respectively. Such large crystals may be against small ones, even of the same species. Fine-granular rocks (soda aplites) may be closely associated (High Climb, Custer Mt.); see Fig. 10D. The giant crystals tend to be concentrated near the central portion[4] of the pegmatite, but if the process which produces them continues long enough, they may extend throughout the whole body (Etta Mine near Keystone).

7. Graphic granite[5], an intergrowth of rod-like masses of quartz in potash feldspar, as well as perthite, an oriented intergrowth of soda spar in potash feldspar (See Fig. 12B) are very common constituents of pegmatites, but they (at least the former) are not universally present. The detailed compositions of certain pegmatites and also their sequences of crystallization are discussed later.

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1. The New York mine is described on pp. 745-48 of Mineral Resources of the U.S., 1908; also see D.B. Sterret, U.S. Geo. Sur. Bull. 740, 1923, 292-95. The Crown Mica Mine is covered on pp. 297-99 of the latter.
2. A crystal bounded by its own faces (relatively plane growth surfaces) is known as a euhedron; one bounded by irregular surfaces is an anhedron; crystals of intermediate character in this respect are subhedra.
3. Rep. of Inv. No. 44, 1942, 12, 22.
4. See the cross-section of the Beecher No. 1 Lode facing p. 26 in Rep. of Inv. No. 44, 1942.
5. See E.E. Wahlstrom, Amer. Mineral., 24, 1939, 681-98; and N.M. Uspensky, Ibid., 28, 1943, 437-46.
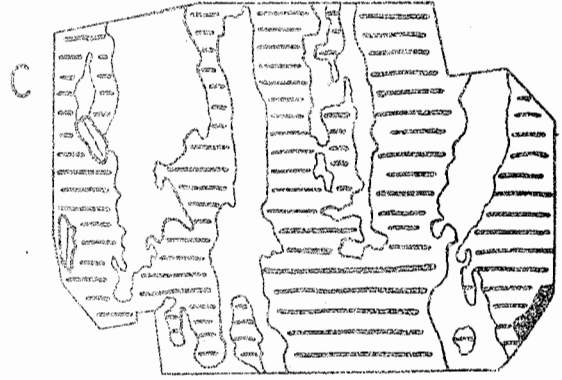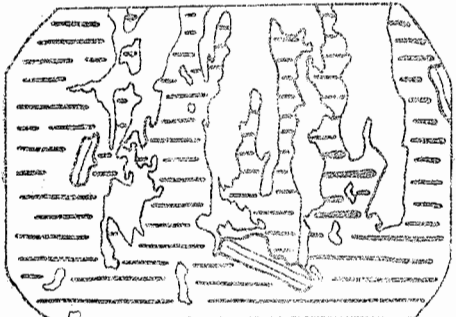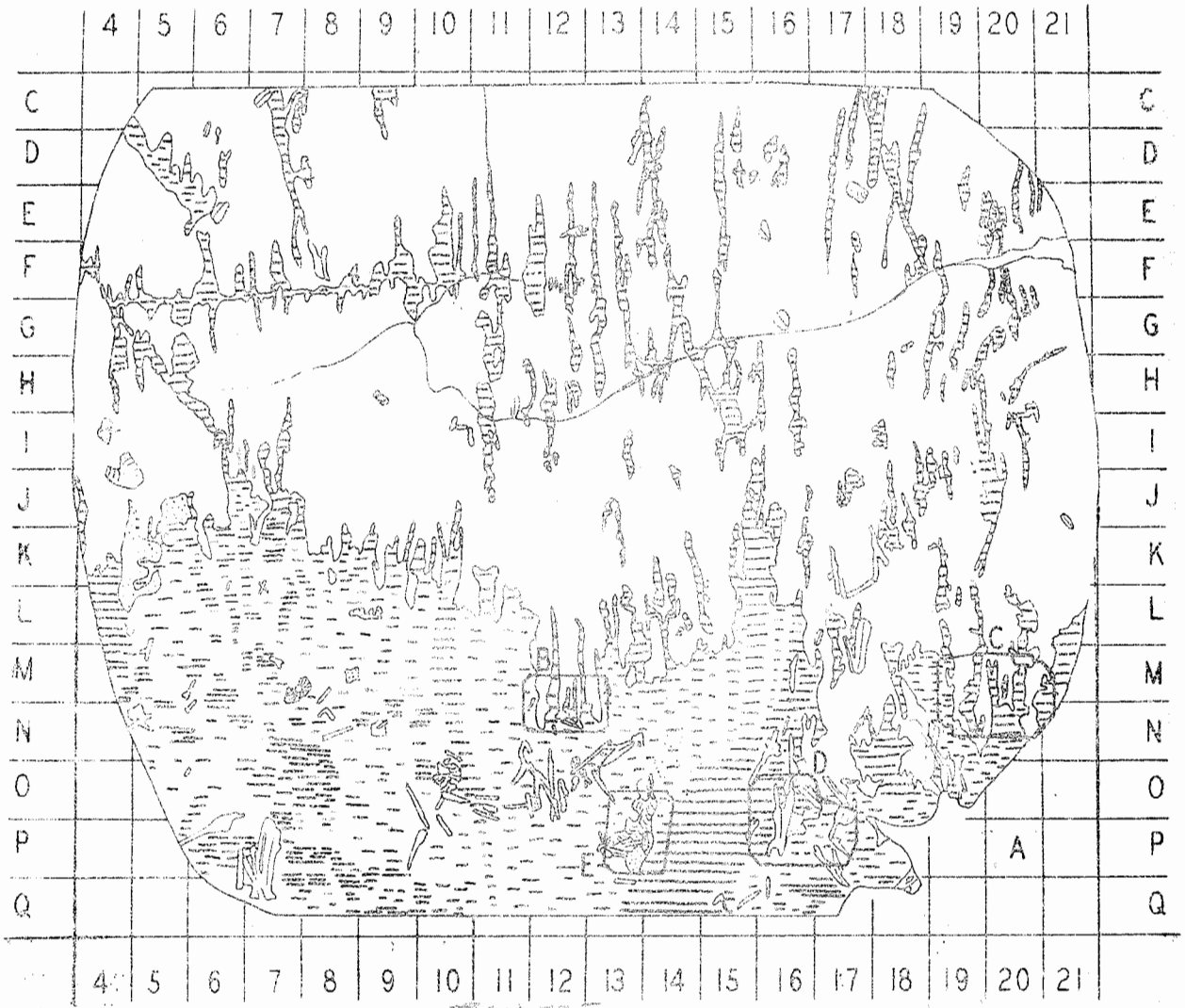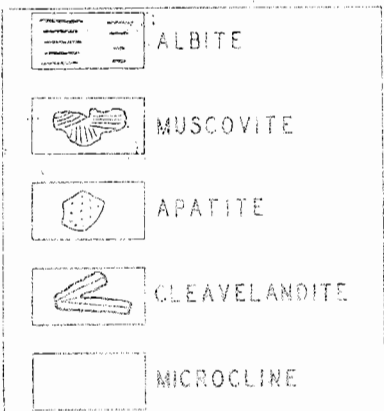
FIGURE 4

Legend:
- ALBITE
- MUSCOVITE
- APATITE
- CLEAVELANDITE
- MICROCLINE
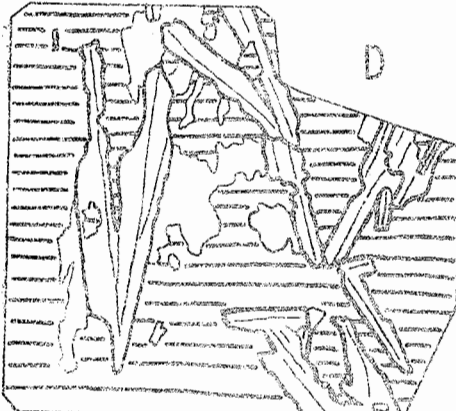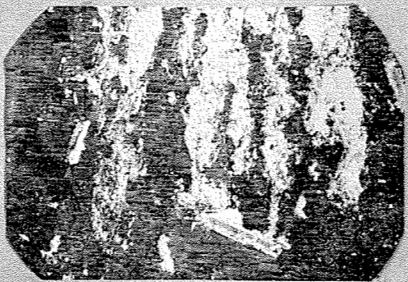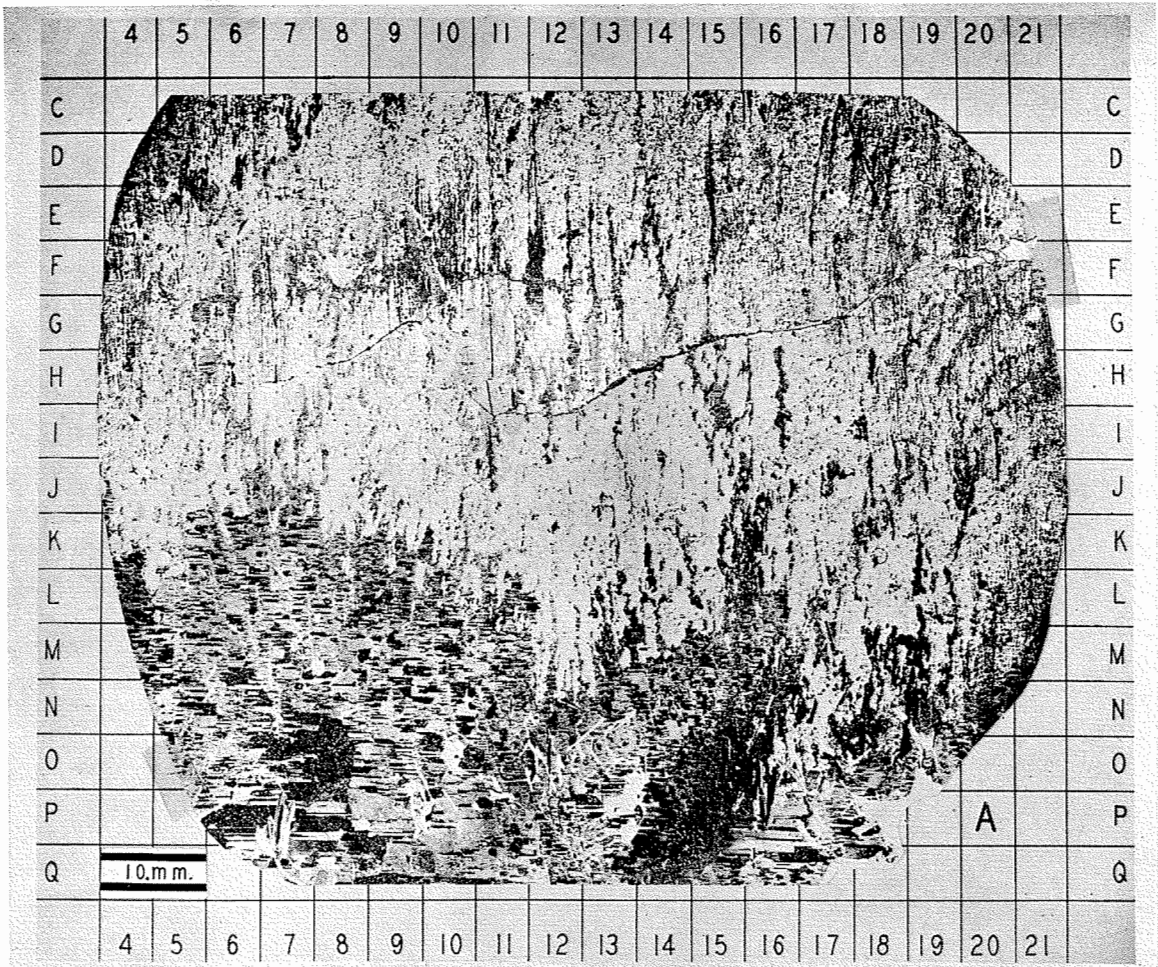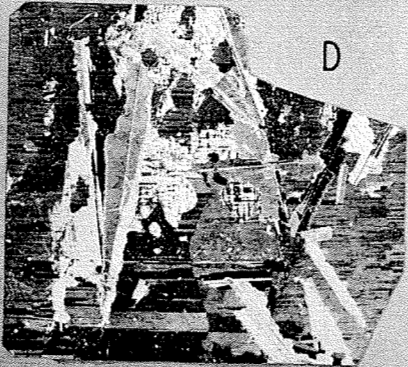
FIGURE 5

ALBITIZATION

OF MICROCLINE.

HIGH CLIMB LODE

CUSTER, S.D.

8. Most granitic pegmatites that carry important amounts of minerals other than potash feldspar and quartz, have probably suffered partial replacement. This complex process as it occurred in the potash feldspar at the High Climb Lode is described in detail a few pages ahead. Corroded crystals of potash feldspar are common in Black Hills pegmatites. The cylinders and crudely globular masses of cleavelandite (platy soda spar[1]) with mammillary surfaces that are found at the Old Mike Lode (see Fig. 15) are described later; they also formed by replacement. They are shown diagrammatically at the base of the quartz mass in the left pegmatite of Fig. 18D.

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1. About two-thirds of the "skin" of the solid portion of the earth (lithosphere) consists of feldspar, the name of a group of minerals composed of aluminum silicates of potassium (K), sodium (Na), and calcium (Ca). The potassium feldspar ("potash spar") found in granite pegmatites is generally the triclinic form Microcline, locally called "spar." In these rocks the soda-lime (plagioclase) feldspar is often remarkably pure soda-spar, albite, with very little of the lime (calcium oxide) component; when over 10 percent of this latter is present, the plagioclase is oligoclase (soda-lime feldspars with more than 30 percent of the lime component are known and are not called oligoclase, but they are not found in granite pegmatites). There are three varieties of albite common in the Custer pegmatites; these are: 1) ordinary massive, cleavable albite; 2) lamellar albite called cleavelandite, which occurs in platy crystals (often corroded), tabular parallel (010), generally with Carlsbad (as well as albite) twinning; and 3) perthitic albite, or the albite occurring in the microcline as blebs which may have very irregular boundaries (Fig. 12B) but which have twinning parallel to that of the microcline. There are a number of types of perthitic albite, but the vein type where the blebs are crudely tabular and often not far from parallel to (100), and the more irregular patch type are very common, the latter often showing chess-board texture (Fig. 5). There are also at least two types of cleavelandite. The more abundant is the more typical coarse cleavelandite such as is shown in Fig. 15 A-C; photomicrographs of similar cleavelandite appear in Fig. 12A, C, D, E. Much rarer are the tiny platy albites that are found in small veins or often as isolated individuals (see Figs. 5B, D, E; 12B, F; and 14B). The latter are referred to as poikilitic cleavelandites, since they most typically occur as scattered inclusions of random orientation in the large microclines, sometimes giving the latter a faintly speckled or mottled appearance.

Order of Crystallization

The pinch-and swell structure exhibited by many pegmatites of the Custer area is good evidence that fairly high pressures prevailed. It is thus clear that the pegmatites were formed at some considerable depth, well below the surface then in existence. Their dense spacing over a wide area indicates a fairly large parent source below this district. They did not form by the simple intrusion of dikes or blobs of molten lava-like material, called _magma_ when thus deeply buried. A better concept is that this hot buried magma mass would have been like a boiling cauldron of slag, except for the high pressures which prevailed. Under these conditions certain lighter and more fluid portions of the late-stage magma forced their way into the present pegmatite zone, shoving the schist layers apart, and yielding the bulk of the original pegmatite material consisting of potash feldspar in considerable part perthitic, along with quartz and minor muscovite and black tourmaline (schorl).

Later, after a considerable portion of the magma had crystallized at depth, residual increasingly fluid portions were forced out and upward, in the main following the paths of the original larger pegmatitic injections. These solutions were relatively rich in water, and thus the minerals formed from them are referred to as "hydrothermal deposits." In part they dissolved out some of the earlier-formed material, replacing it with other minerals.

As millennia rolled by, these solutions became more tenuous and less hot, and the tendency was to get more or less irregular replacement veins cutting through the pegmatite roughly up-dip and containing still later minerals which formed at lower temperatures. Eventually as erosion following uplift brought the pegmatite locale close to the surface, alterations due to cool, downward-seeping ground waters (called meteoric waters) were brought about in certain cases.

The pegmatites of the area may thus consist of material formed at several stages, which in order of time may be distinguished as the pyrogenic (or igneous), hydrothermal, and supergene (formed from meteoric water). Hydrothermal stages may be divided into hypothermal (high temperature)[1], mesothermal (intermediate tempera-

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1. Some of the high-temperature hydrothermal minerals of this report may have been deposited from gaseous solutions; these could more strictly be classed as pneumatolytic. Cassiterite and columbite-tantalite expecially may be in this catagory.

-14-

ture), and epithermal (fairly low temperature). It should be emphasized that this classification is one of convenience for ease in explanation and interpretation. No two pegmatites studied were similar in all respects. In some the first stage is greatly dominant; in others the various hydrothermal stages have been of very great importance. It is also true that many more stages may be recognized. Thus we may speak of early, middle, and late hypothermal substages. For any one pegmatite containing 20 or 30 minerals it may be possible to determine a sequence of crystallization that may involve at least a dozen stages. It should also be emphasized that a given mineral may not be limited to any single stage; it may continue through several stages (e.g., quartz), or may occur in more than one stage with intermediate stages in which it did not form.

Pegmatites are thus rock units which in most instances in the Custer area are far from genetic units. In some cases the actual genetic units composing a given pegmatite are sufficiently clear-cut or isolated bodies (rock types) so that they can be shown (at least in part) on maps or cross-sections (High Climb, Old Mike, Ross). In others and possibly the majority of cases the various genetic units pervade each other in such complex fashion that it may be difficult to show the boundary lines in a photograph or even a thin section. In the former type of deposit, mining for a given component or combination of components may often be given intelligent guidance by the competent specialist, whether he be a scientifically-trained geologist or a keen observer in the school of practical mining experience. In the latter type the problem is far more difficult, and conclusions drawn in advance of mining in the absence of drilling can in general be relied upon with less certainty.

After a preliminary study involving detailed examination of eight pegmatites (1941, 1942) in the Custer area, it seems quite certain that there is no general uniform sequence of crystallization of the various post-pyrogenic minerals.[1] Moreover there is no apparent regular distribution of pegmatites carrying a given metal or mineral (as lithium or spodumene). One is reminded of the layman visiting the hot springs and geysers of Yellowstone Park. The different colors and types of deposits and other variable manifes-

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L. This is evident from a cursory examination of the paragenetic tables accompanying this report. When these are compared with one another, it is easy to note apparent discrepancies. These tables are the result of preliminary study, and are subject to modification after detailed examination of samples and thin-sections.

tations (size, temperature, etc.) seem to succeed each other in
kaleidoscopic confusion. In short it would hardly seem possible
that all these pegmatite deposits originated from a single magma
reservoir. They probably did, but at a time long after that magma
was first emplaced, when the irregularities in the roof and crys-
tallized portions served effectively to divide it (or at least its
upper portion) into numerous highly irregular "chambers."

Some geologists have assumed that the formation of a pegmatite
was a continuous process, and so conclude that any **separation** of
these minerals into genetic units belonging to various stages is
therefore both arbitrary and artificial. This idea hardly seems
applicable to the pegmatites of the Custer area, since most of them
show a definite sequence of events as is discussed in the next
paragraph. Moreover, it is known that volcanic processes are often
catastrophic; that is, some volcanoes erupt violently at uncertain
intervals, separated by relatively quiescent periods. Like a
geyser, time is needed to build up the forces necessary to overcome
the hydrostatic pressure of the environment. The pinch-and-swell
structure and the blister-like shapes of the pegmatites show that
high pressures prevailed, and these were probably overcome only
momentarily, geologically speaking. At least this picture seems
to fit the original injection stage, though it may well be that in
the later stages, especially the post-hypothermal ones, the pro-
cesses gradually became less-and-less interrupted, and more nearly
continuous. Similarly the products formed during the hypothermal
substages are likely to be found only in a part of the pegmatite,
most often the central or upper portions. Later solutions may tend
more and more to pervade the whole mass, though the results they
effect are generally most notable along the pathways followed by
the hypothermal ones.

In deciphering the order of crystallization in a pegmatite,
the first step is to determine the genetic units or rock types. In
doing this, search the exposed surfaces for the larger units com-
posed of one or more minerals, and determine if possible from
cross-cutting relationships their sequence[1]. Thus in the Old Mike
pegmatite these are thought to be in order: (1) microcline and
quartz, with minor schorl and muscovite; (2) quartz; (3) albite-
quartz-muscovite rock; and (4) cleavelandite-muscovite rock. This
furnishes the broader outlines of the paragenetic sequence, but the
detailed order within any given genetic unit, as well as the dating
of any minerals not part of one of the recognized units, remain to
be worked out. It is thought that unit (3) also includes beryl and

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1. The method used here is well illustrated by Fig. 4 of Rep.
   of Inv. No. 44, 1942, and its explanation on p. 19.

apatite, and unit (4) carries columbite and probably quartz. More-over some of the beryl of unit (3) apparently was dissolved and re-deposited during the unit (4) interval. This accounts for all the primary minerals found (see Table 2) excepting lithiophilite and loellingite, which for reasons discussed later in detail are put between units (2) and (3).

To determine the order of crystallization within any one genetic unit, or indeed in the whole pegmatite if no such units can be recognized, is nearly always very difficult, and therefore is often controversial[1]. If we could be certain of recognizing the pyrogenic stage rock of any one pegmatite, and if we were sure that it formed by the congealing during a single continuous cooling period of the non-fugitive components of an injected magma acting as a closed-system, and also that no reaction-series or replacement was involved, we should normally be able to work out the order of crystallization of the individual component minerals, since euhedral ones would be first, subhedral next, and anhedral last. Within some limits, as is discussed in more detail later[2], such principles have been used for studying the rock of this stage in this report.

However, in attempting to interpret the details of the order of crystallization during any one post-pyrogenic stage, too much significance should probably not be attached to the question of whether a given substance is euhedral, subhedral, or anhedral. It might be more fruitful in deducing this portion of the sequence, to regard a complex pegmatite as a rock some part of which has suffered hydrothermal metamorphism. In this respect it bears a certain resemblance to a contact metamorphic deposit in which replacement has occurred under conditions of high viscosity (of the replaced rock). Becke's concept of the power of crystalliza-tion is then applicable. Thus certain species (as beryl, tourma-line, cleavelandite), tend to form crystals bounded by well-defined faces. Such crystals seem to "shoot through" the others; in short

1. The order of crystallization may be a confused and com-plicated matter, but it is no more so than is the litera-ture on this subject. Unless strong evidence can be ad-duced in favor of each position stated (for a given mineral in the sequence of crystallization), it might be better to omit it, or to group it with minerals of unknown or quite doubtful position, not trying to fix it closer than some-where within the genetic unit to which it belongs.
2. The complexity shown by pyrogenic-stage minerals in pegma-tites is described in more detail under the discussion of the paragenesis in the Custer Mt. Lode.

They have high penetrating power. Others (as spodumene, muscovite) are intermediate as regards this property, while feldspars (except cleavelandite) and quartz have relatively low power to form crystal faces. It is thus possible to arrange crystals in sequence in this respect, giving a morphogenetic series; the terms eumorphogenic, submorphogenic, and amorphogenic may then be used in a sense corresponding to euhedral, subhedral, and anhedral. In general the latter terms have been employed in this report. This question of the power to form crystal faces (morphogenetic power) is discussed in more detail later. It is likely in part a function not only of the mineral species concerned, but also of the temperature and composition of the replacing solutions and of the rock being replaced and of the pressure involved. Thus garnets while generally eumorphogenic are locally amorphogenic. It is also true that later corrosion may destroy crystal faces: this is probably not uncommon in the case of microclines and the poikilitic cleavelandites, and may have occurred in the Custer Mt. lithiophilites. The power to form crystal faces should not be confused with the power of spontaneous crystallization (Tamman) or the forces exerted by the growth of crystals (i.e., the stresses and strains set up by growing crystals). The tendency of cleavable minerals formed by replacement to be elongated in the plane of cleavage is well exemplified in the mica books; the cleavelandites with two cleavages are elongated in the (010) plane, and in particular parallel to the a-axis (which is parallel to both planes of cleavage). Where certain crystals (as the schorls pictured in Figs. 3C and 3D) in pegmatites tend to show a definite orientation, it is clear that the force of crystal growth is vectorial; thus the crystals in this case apparently grew from the walls of the pegmatite in towards its central portion. This matter is discussed further under the description of the Buster Lode. It is not certain that replacement is an important process in this case.

Replacement

It is generally agreed that a common and outstanding type of replacement in granitic pegmatites is that in which albite replaces microcline or microcline perthite. This is shown to a greater or lesser degree in all the mines examined, but particularly striking specimens were found at the High Climb. These were described in an earlier paper (Rep. of Inv. 44, 1942, p. 21), as follows: high up in the north wall 40 or 50 feet from the entrance were found cleavage blocks nearly a foot long broken from large single crystals of microcline perthite. These crystals were cut by vein-like masses of quartz-cleavelandite rock. Along the contact between a vein and the microcline the latter was completely albitized for a thickness of an inch or two.

Figs. 4 and 5 are a matched pair to show photomicrographs of a large thin-section and portions thereof (Fig. 5) and sketches (Fig. 4) of the same to indicate the mineral composition. The thin-section is actually 7 by 9 centimeters (2 3/4 by 3 1/2 inches), about the size of an ordinary lantern slide. Figs. 4A and 5A show a sketch and photomicrograph of the whole thin section; the grid lines are spaced at one-half centimeter intervals. Fig. 5A was taken with the section mounted between a large pair of crossed polaroids. The upper portion of Fig. 5A is largely microcline, with stringers and lenses of perthitic albite; this is interpreted in detail in Fig. 4A. The lower portion of Fig. 5A is mainly albite. The contact between the upper portion (dominantly micro-cline) and the lower portion (chiefly albite) is a very sinuous one, as is brought out in Fig. 4A. Near the contact there are islands of microcline completely surrounded by albite, and vice versa.

The thin-section is parallel the basal pinacoid (001) of the microcline, and the trace of the side pinacoid (010) is approxi-mately that of the horizontal grid lines. The contact with the cleavelandite-quartz vein is essentially along the base of the picture, but none of it appears in the photograph. Both field and laboratory evidence show that this whole mass was once microcline or microcline perthite, and that later soda-bearing solutions advanced through the space where the quartz mass now borders the edge of the microcline at the base of the photograph, Fig. 5 A. These solutions dissolved out the potassium of the microcline ion by ion and simultaneously for each ion of potassium removed left an ion of sodium. Such a process is called replacement. The rock as a whole is never brought into the liquid phase. This is known because of the crystallographic continuity between the albite and microcline; the two are in parallel growth. It is quite likely that the base of Fig. 5A marks the position of the trace of a former (010) crystal face on a large microcline crystal. Such large euhedrons are beautifully exposed in the Ross Lode. The albitization replacement process served to destroy this crystal face and leave a most irregular apparently-corroded surface border-ing the microcline.

The albitization took place starting from the base of Fig. 5A and extending upward. It proceeded along surfaces or incipient fissures whose traces were approximately the direction of the ordinate of the figure (i.e., north-south), producing vein perthite. As these albite laminae were extended they broadened somewhat, and so where closely-enough spaced, they gradually coalesced, resulting in patch perthite. These albite laminae show the typical cross twinning striation of perthitic albite blebs. Where they coalesced (in the lower part of Fig. 5) these striae are offset. This gives the typical chess-board texture to this portion of the albite.

Figs. 4 and 5B-E show details from Figs. 4 and 5A as indicated
Fig. 5B is a photomicrograph from the area of grid coordinates N12.
In it are several tongues of microcline (light colored) extending
down into the dark albite, which in this area did not succeed in
replacing all the microcline. It also shows three poikilitic
cleavelandites discussed under the description of Fig. 5D.

Fig. 5C shows much the same thing from the M20 area, but here
the typical grating structure of the microcline and the chess-board
appearance of the albite are more clearly brought out.

Fig. 5D from the P16 district shows a double pair of V-shaped
cleavelandites in a mass of chess-board albite which carries a few
island remnants of microcline exhibiting the typical grating struc-
ture. The cleavelandite is in poikilitic crystals; that is, they
are irregularly scattered without common orientation through the
albite or microcline. Such cleavelandites are very common in the
feldspar at many of the mines of the area; they are particularly
well shown at the Townsite (Fig. 1, No. 24), the Beecher No. 2
(Fig. 1, No. 16; referred to as the Long View in Rep. of Inv. No.
44), and the Old Mike. These crystals formed earlier than both
perthitic and chess-board albites, and possibly earlier than the
microcline; this matter is further discussed under the paragenesis
of the Custer Mt. Lode (Fig. 12B).

Fig. 5E is from the P13 area; only one tiny fragment of micro-
cline remains here. The main mass is chess-board albite in which
is embedded muscovite, poikilitic cleavelandites, apatite and two
grains of brownish-green material (with index of refraction less
than that of muscovite) that is rather highly altered. The poiki-
litic cleavelandites in most cases seem to be corroded, but those
in the albite are more likely to have a rim of fine muscovite than
those in the microcline. Muscovite in relatively large masses (as
shown in Fig. 5E) is found both in the albite and at the albite-
microcline contact (as at E20 of Fig. 5A). It seems to be post-
albite in the main, and its potash-content may have come from the
microcline replaced by albite.

BUSTER LODE

Location

This mine is 2½ miles south-southwest of Custer; in the SW.
¼, NW. ¼, Sec. 2, T. 4 S., R 4 E. (Fig. 1, No. 8). Take U.S.
Highway 85A 1.1 miles south from where it leaves U.S. 16 at the
west edge of Custer. Here turn off right (southwest) and follow
the road 1.1 miles to the Y, where keep left 0.2 mile to the top
of the hill at the Buster Lode. The mine is located on air photo
BNW 235-107 at 5.6, 2.4. The compass-and-pace traverse shown in
Fig. 6 was located from corners 7, 8, and 9 of H.E.S. 256, plat
of which was examined in the office of the Forest Service in Custer.
This plat was used to locate the position of the west side of Sec.
2, and of the 40-acre square indicated.

History

The lode is operated by the Black Hills Mining Company of
Custer. It was purchased from S.T. Gamber of Custer in May, 1942.
Gamber first opened the pegmatite in 1939. It produced feldspar
with some mica and beryl. It was excavated to a depth of 10 to 12
feet, excluding the shallow trench 15 feet long at the north end;
later the southern portion was deepened to about 20 feet.

The Black Hills Mining Company started operations here in
June, 1942. A 62° incline (Fig. 7A) was sunk 30 feet north of the
south end of the dike and about 20 feet was stoped from approxi-
mately the 65 foot level at this end. At the time of the writer's
visit (early August, 1942) the incline was being deepened; work was
proceeding at 90 feet. A short revisit (September 20, 1942) showed
the incline to be bottomed about 120 feet below the platform (alti-
meter elevation of 5567 feet); drifts had been run from the base
of the incline both ways along the strike about 20 feet. Plans
were to extend these and remove the overlying material by stoping.

Geologic Setting

This mine is in an area of quartz two-mica schist which car-
ries numerous pegmatites, mostly small except where they coalesce.
It is on the west side of a flat-topped rise which slopes very

FIGURE 6

BUSTER LODE

2 1/2 MILES SOUTH SOUTHWEST OF CUSTER S.D.
(COMPASS AND PACE MAP)

N.W.1/4, S.W.1/4, N.W.1/4, SEC.2, T.4S.,R.4E.
10 ACRES

LEGEND

PEGMATITE

SCHIST

PIT

DUMP

INCLINE

BUILDING

CLAIM CORNER

CORNER, HOMESTEAD
ENTRY SURVEY NO. 256

WEST SIDE OF SECTION 2

TO
CUSTER

OLD
DUMP

OLD
MINE

NEW
DUMP

SCHIST
?

?
SCHIST
?

SOUTH DAKOTA
GEOLOGICAL SURVEY

AUGUST 1942

D. JEROME FISHER, GEOLOGIST
ROBERT G. SMALLEY, ASSISTANT

TO
U.S.
85A

TRUE NORTH

MAGNETIC

SCALE

100   0   100   200   300

FEET
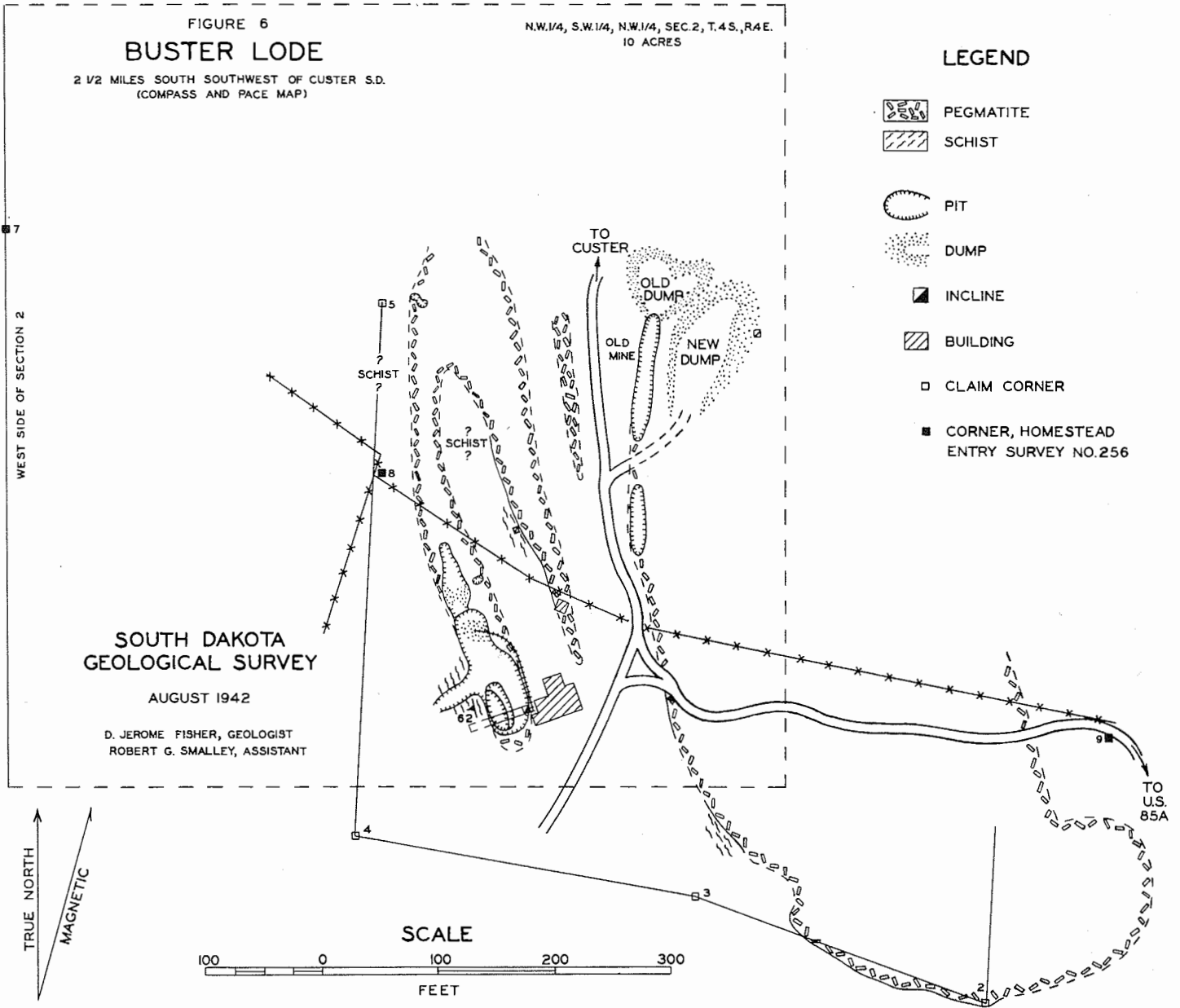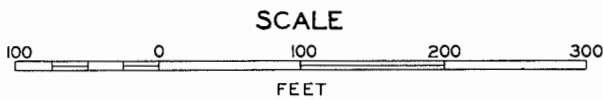
gently to the east, less so to the west; higher land is found to the northwest. Commonly the pegmatites are so thick that there has been little differential erosion in the intervening schist. Thus the pegmatites stand up but slightly, generally only a couple of feet, locally as much as six feet. In general the schist is not exposed except in artificial openings. Some of the pegmatites form dike-shaped bodies that are clearly outlined on the surface. These strike within 15° of N. 10° W. and dip steeply to the west. Few of them can be traced for much over 100 yards, and they are in the main not over 20 feet thick. Others are more irregular and their outlines could be definitely established only by considerable prospecting. The map is more or less generalized to indicate areas dominantly of pegmatite.

The Pegmatite

Two separate pegmatites have been opened on this property as shown by the map, Fig. 6. The first, or "old mine" consists of a vertical trench about 10 feet wide and 110 feet long, and up to 12 or 15 feet deep, partly filled with water in August, 1942. A shallow trench (maximum depth 5 feet) has been opened on the southward extension of this dike, as is indicated on the map; this is little more than a good-size prospecting pit. This old Buster pegmatite is in general a much simpler one than the presently-operated dike, which lies about 100 yards to the southwest. No wall rock is exposed in the old Buster trenches except near the south end of the main one, where quartz-mica schist standing nearly vertical shows as a bulge for a few feet in the east wall.

The present Buster pegmatite is opened for a length of some 170 feet; its south limit is exposed in a drift at about the 55-foot level where the schist curves in sharply along a rather blunt end.[1] Some 25 or 30 feet north of here along the inclined shaft (see Fig. 7A) the pegmatite is some 12 feet thick and dips 62° to the west-southwest; the strike of the pegmatite here is N. 22° W. Both hanging and foot walls of quartz-mica schist are well exposed in this part of the mine. About 35 feet farther northwest there is a west-southwest trench cut through the hanging wall that exposes a weathered quartz two-mica schist with structure parallel the adjacent pegmatite surface. Northwest of here neither hanging nor

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1. This is about as shown at the Crown Mica Mine (No.4 on the index map, Fig. 1), if Fig. 86B on p. 298 of D.B. Sterrett ("Mica Deposits of the United States," U.S. Geo. Sur. Bull. 740, 1923) be considered as a horizontal projection.

foot walls is exposed; this part of the mine was opened by Gamber and in 1942 was being used as a place to dump the muck removed while sinking the incline. As originally developed the muck from this part of the mine was trucked to the "New Dump" (see map, Fig. 6), and also spread over an area to the south of this. The north end of the pegmatite is not exposed.

While on the 50-foot level at the shaft the dike is only 12 feet thick, it is about 30 feet thick at the surface by the shaft. This is because the upper part of the foot wall has a gentler dip than the hanging wall. Below the 50-foot level along the shaft the thickness is as yet unknown, but to a depth of 120 feet it is probably not less than 12 feet. However, immediately north of the shaft the dike is thicker from the 20-to-50 foot levels, since part of the schist foot wall has been broken away here. Many blocks of tourmalinized foot wall are here engulfed in the dike. The probable northward extension of the dike is indicated on the map; it seems to coalesce with a dike to the east as is indicated. However, this area was very hastily traversed, and it would be necessary to sink pits to outline accurately the contacts. Schist is exposed in a small pit 60 feet east of the north end of the Buster mine as is shown on the map. The schist of the hanging wall as exposed in the trench on the west side of this mine shows little metamorphic change. For a foot or so much fine powdery black tourmaline has been developed, but there is no other obvious sign of exomorphic action.

Mineralogy

The north end of the old Buster mine exposes a simple pegmatite consisting mainly of medium gray microcline perthite (spar) in subhedral crystals up to several feet through, with somewhat smaller amounts of light gray massive anhedral quartz in masses locally several feet across filling the spaces between the spar subhedrons. In small part the quartz is graphically intergrown with the perthite. Ten percent or less of the walls exposed here consist of black tourmaline (schorl) and muscovite, with very subsidiary cleavelandite (platy soda spar) and rare anhedral granular medium brown garnets (spessartite) in the perthite. Farther south this trench has a pond in it and so is not readily accessible, since the walls are essentially vertical.

The small opening farther south on this same dike exposes increasing quantities of a cleavelandite-quartz rock and at its south end this is associated with important amounts of muscovite

7B. View easterly along the trench at the Earl Lode
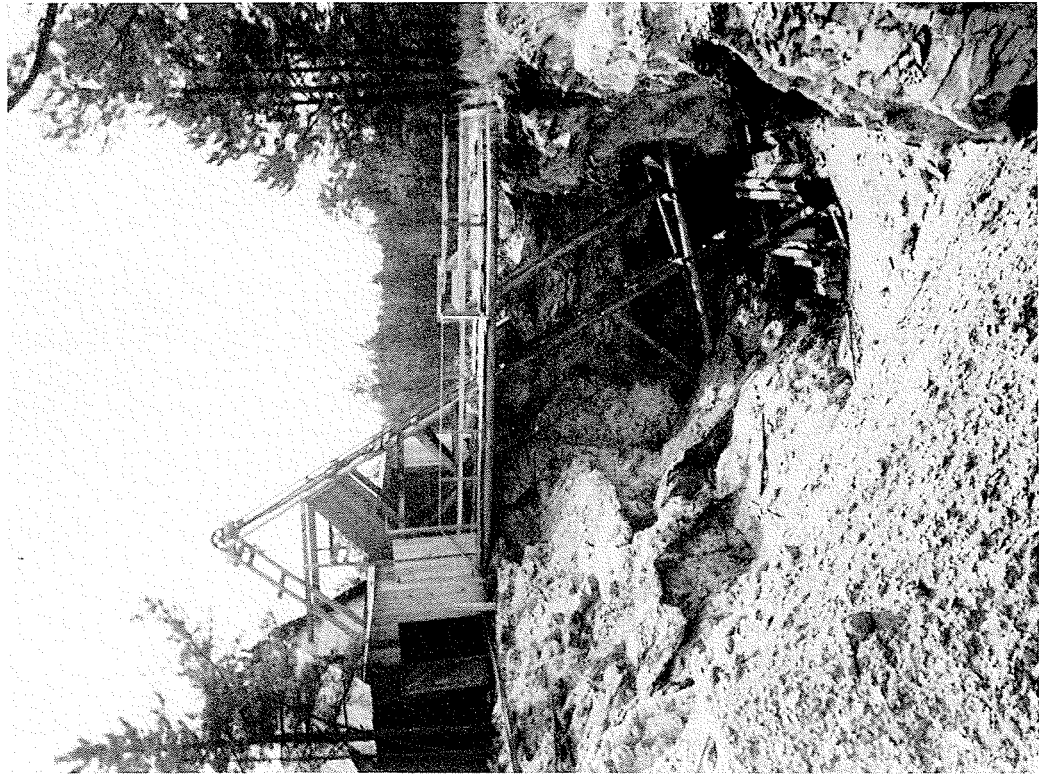
7A. Looking south along the pit towards the incline at the Buster Lode

and dark-brown spessartite crystals up to 2 inches across which
show well-developed icositetrahedron (trapezohedron) forms (211),
rarely modified by small dodecahedral faces. This part of the
pegmatite is quite similar to the rock in the central portion of
the presently-operated Buster dike, except it carries more spar.

The main Buster pegmatite produces muscovite with subsidiary
beryl at the present time. The pegmatite consists of four main
rock types described below in order of formation. (1) Microcline
perthite, with which is presumably associated quartz, coarse schorl,
muscovite, and minor anhedral garnet. (2) Moderately coarse cleave-
landite-quartz rock carrying minor (and mostly small) muscovite as
well as euhedral garnet, columbite, beryl, and apatite. (3) Very
coarse muscovite-cleavelandite rock, with most of the beryl, much
quartz, and minor euhedral garnet and tourmaline. (4) Moderately
coarse muscovite-cleavelandite rock, with minor quartz and nearly-
associated anhedral garnets.

The feldspar exposed in the dike is dominantly white soda-
spar, chiefly of the cleavelandite variety. Isolated chunks of
light gray microcline perthite, mostly apparently solution remnants
of large single crystals in the main, are well exposed in the
central part of the pit. See Fig. 8, which shows the appearance
of a portion of the dike near the west wall immediately north of
the trench. These may be up to 3 or 4 feet long and 12 to 18
inches across. They are surrounded and penetrated by moderately
coarse cleavelandite-quartz rock ($\frac{1}{2}$ to 1 inch crystals in the
main) which contains subsidiary muscovite (mostly about $\frac{1}{4}$-inch
plates) and smaller amounts of euhedral dark brown garnets (spes-
sartite of index of refraction 1.80 and specific gravity 4.02)
and pale green beryl, the latter generally showing the hexagonal
prism and not uncommonly the basal pinacoid. Also associated with
this cleavelandite rock have been found a few small striated tabu-
lar crystals of dark brown to black mangan-columbite (specific
gravity of 5.55) without end terminations, but with minop prism
faces as well as the front (large) and side (small) pinacoids.
The streak is brownish gray-black with hardness slightly under 6,
and the soda bead shows a pronounced test for manganese. Tiny
grains of green apatite are also locally present.

This cleavelandite-quartz rock consists of about equal por-
tions of these two minerals, though perhaps the quartz is slightly
more abundant. In places it consists mostly of quartz outlined by
thin shells of cleavelandite; this gives the appearance of an
augen ("eye-shaped" masses of quartz) structure, or of a cataclas-
tic structure healed by cleavelandite. Elsewhere the cleavelandite
is dominant and the quartz appears more like isolated remnants. In

places cleavelandite laths shoot out into the quartz. As a whole, in spite of this local variation the rock is a very distinct petrographic unit, and is of a type commonly present in Custer pegmatites carrying an important amount of cleavelandite. It will be referred to as "augen rock."[1]

Pale rose and light gray quartz, both banded and massive, are found plentifully on the dump, and large chunks may be seen in the upper part of the mine near its ends. Most of the quartz seen in place is that with the cleavelandite described above, which is nearly colorless, and a similar quartz between the muscovite-cleavelandite rosettes or masses described below.

A couple of small nodules of amblygonite are reported to have been found recently deep in the mine, but these were not seen by the writer. No lepidolite or spodumene has been discovered.

Most of the better pieces of muscovite occur in books up to two feet across which are associated with rather coarse cleavelandite. These appear to be portions of partial globular masses in which the muscovite fans out from a center (wedge structure) to be succeeded by cleavelandite as an outer aureole (see Fig. 10A). The muscovite is mostly pale amber as seen in trimmed sheets, but both lighter and darker shades are present. Beryl is common, especially at the contact between these two. These crudely-globular masses may be separated from adjacent similar ones by quartz. This type of occurrence is discussed in more detail in the next section.

Occasionally sheets of mica are found which are partly muscovite and partly biotite in parallel orientation, separated by sharp straight contacts. Such mica is more common at the Lincoln Lode (Fig. 1, No. 9). The wedge mica has its fan-shaped books separated by irregular platy masses of quartz and cleavelandite. It is very common to find irregular sheets of quartz of an inch or more in area and 1/32 of an inch or less in thickness between the mica cleavages; feldspar is rare or absent in such sheets. These sheets show delicate tracings resembling frost on a window pane except instead of skeleton crystals the quartz is made up of euhedral crystals highly flattened parallel the _c_-axis (which lies in the plane of the sheet) and bounded by prism and rhombohedron faces. These are often surrounded by a rim of very fine-grained

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1. A good picture of such augen rock appears as Fig. 7 of F.L. Hess, "Natural History of Pegmatites," _Eng. Min. Jour. Press_, _120_, 1925, 293.

material, possibly chalcedony. The flattened faces of the quartz show triangular-shaped growth marks.

Dark-colored tourmalines, highly flattened parallel the c-axis, which is aligned with the mica cleavage, are not very common. Unlike the quartz sheets described above, which are between mica plates, these tourmalines lie in shallow polyhedral cavities within the mica. More common are highly flattened rich-brown garnet (spessartite) icositetrahedrons up to $\frac{1}{4}$ an inch across. Like the tourmalines these lie in polyhedron-bounded cavities in the mica. Some of these garnets have a center of mica (oriented parallel the main mica plate) and in fact consist of a flattened annulus of garnet bounded by plane surfaces, both inside and outside, set at the icositetrahedron angles.

The beryls of this mine, most of which seem to be in this coarse muscovite-cleavelandite association, range in size up to prisms at least 5 inches through. Most of them are distinctly euhedral, cutting across whatever is in their way, including the muscovite. Many of them are relatively pure, but from the small stock pile (3 bushels) a dozen crystals were picked which show cores of extraneous material, similar to, but less pronounced, than those of the Tip Top Lode (Fig. 1, No. 10. See Rep. of Inv. 44, 1942,15). The core materials observed included quartz, cleavelandite, and muscovite. Two samples contained subhedral garnets; in one these were in the core; in the other they were more definitely euhedral and distributed through the beryl as if the latter could not assimilate them (assuming the garnets formed prior to the beryl, though it is possible the garnets replaced the beryl or that the two crystallized more or less simultaneously).

Another rock type occurring in this mine consists of irregular masses or nests ("pockets") of cleavelandite-muscovite in about equal proportions with minor quartz. This rock is in crystals $\frac{1}{4}$ to $\frac{1}{2}$ an inch through in the main. These nests appear on the face as irregular masses several feet long and a foot or two across, and locally from them branch vein-like extensions an inch or two wide and two feet or more long. These "bull-heads" are valuable sources of scrap mica. They are homogeneous units that cut across the cleavelandite-quartz rock in crudely vein-like fashion with a fairly sharp but highly irregular contact. Along this contact but outside the cleavelandite-muscovite there tends to be a concentration of anhedral granular rich-brown garnets (spessartite) in masses up to an inch or two through.

27

Paragenesis

It is believed that the two dikes described above for the Buster property together represent both of the first two stages (pyrogenic and hypothermal) described for the pegmatites of the Custer area. There is no indication of a slight hydrothermal stage.

The north end of the old Buster trench apparently contained a "simple" pegmatite that corresponds to little more than the pyrogenic stage. This stage is here represented by subhedral microcline microperthite (in small part graphic) in a matrix of anhedral quartz. Apparently the microcline and the quartz crystallized practically simultaneously, but where the two came in contact the feldspar showed its greater morphogenetic power by tending to develop its faces rather than vice versa, or else the feldspar crystallized a little before the quartz; the writer tends toward the former explanation. The muscovite is relatively minor here; as is always true in these pegmatites, it tends to grow in planes parallel the cleavage, thus yielding small books which cut across the feldspar and quartz. This may mean the mica formed somewhat earlier, or that (as the writer believes) the mica has the greater crystallizing power and where during growth it met these other two minerals it tended to grow at their expense, the directions of dominant growth lying in the plane of the mica cleavage. Such a statement seems to explain satisfactorily the relations of these minerals as here observed, though some writers have made up a more complex story.

The question of the tourmaline is perhaps slightly more complex, though here too it fits into this type of picture. Crystals of schorl (black tourmaline) occur in striated prismatic forms up to 2 or more feet long and 3 inches across. They cut through any of the other three minerals encountered. More of them are normal to the walls than are parallel thereto, but the orientation is reasonably haphazard. In all probability there was less schorl in the central part of the dike than is now exposed in the walls. That those schorls formed in part early is clearly indicated by the fact that they are concentrated along the dike walls, presumably the first portion of the pegmatite to solidify. Moreover some of the schorls are fractured normal to the c-axis and these fractures, up to $\frac{1}{2}$ an inch wide, are healed by quartz and perthite continuous with the same minerals outside the schorl. Some prism faces inside the tourmaline are coated with muscovite flakes which would indicate that the mica formed parallel growths on schorl surfaces later buried under more schorl; in short these two minerals are in part contemporaneous. It would be unlikely that the tourmalines would form a boxwork along the dike wells projecting into the still

Figure 8. Corroded perthites in augen rock (quartz-albite-muscovite) at the Buster Lode; photograph with interpretative diagram

LEGEND

MUSCOVITE

GARNETS

AUGEN ROCK

QUARTZ

PERTHITE

ALBITE-QUARTZ VEINS
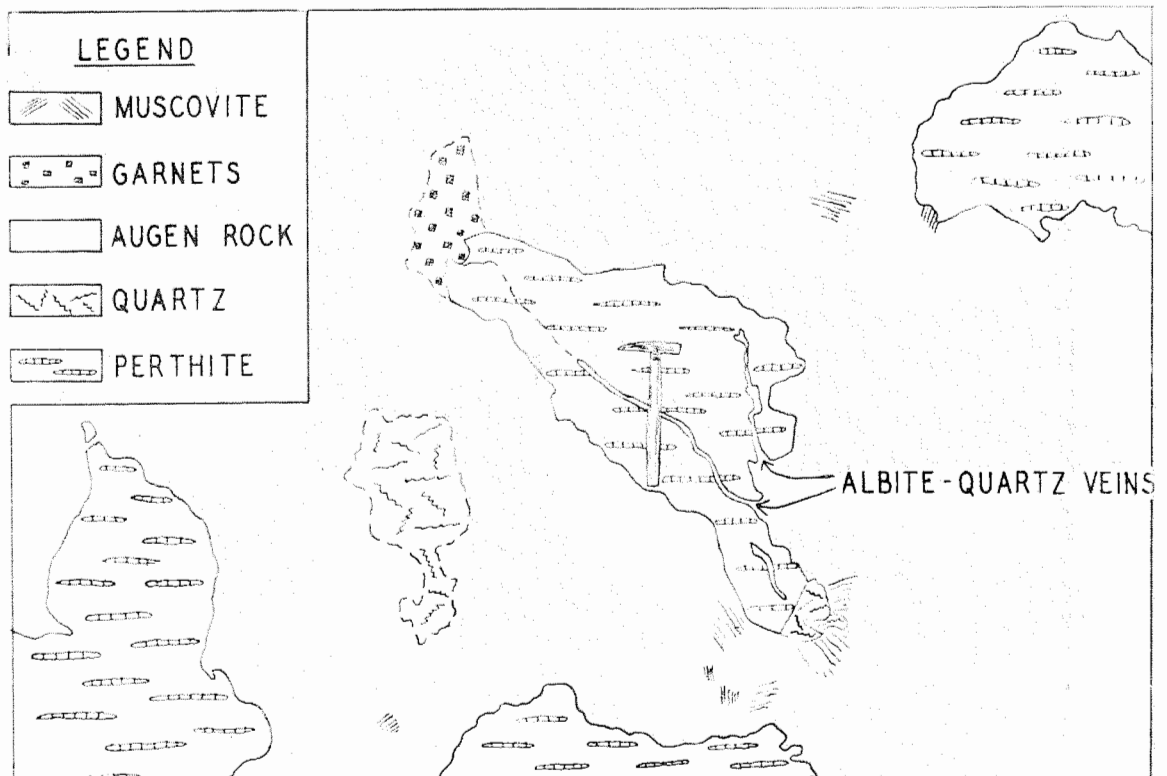
liquid pegmatite, except in a limited fashion. It would seem more probable that the feldspar, quartz, and mica were crystallizing at the same time within this frame-work. If a tourmaline crystal growing in the direction of its c-axis met one of these minerals in the process of growth it either engulfed and partially replaced the latter, or else pushed it to one side. Tourmalines carrying blebs of anhedral quartz either show engulfment at this stage, or partial replacement later, probably the former. There is much evidence that quartz did not replace tourmaline as the former is always anhedral, the latter euhedral.

The conclusion long established is thus reached--that in a simple pegmatite in which only the pyrogenic stage is found, the crystallization is simultaneous in a geologic sense. Some schorls were complete before all quartz and feldspar had formed; others continued to grow after some quartz had formed. Likely the time over which tourmaline formed was relatively great. The textural relations observed do not really serve to explain order of crystallization as much as they do a morphogenetic power; that is, a power to develop crystal faces. In the case cited this is in the order tourmaline, muscovite, microcline, quartz.

We now come to the case of the presently-worked Buster dike. We find here a rock, apparently first to form, which represents the pyrogenic stage, the same four minerals as just described being present, and the same principles of crystallization holding for this stage. But in this case this type of rock makes up a small fraction of the total dike, perhaps only 15 to 20 percent. Moreover in general this rock is not clear cut, but in isolated and more or less engulfed masses that make it appear as if the original rock had suffered great changes. The evidence points to the fact that in this dike there were successively developed largely by alteration (addition and subtraction) and replacement from this original rock through the action of new solutions at least three new rock types, one after another, all of which are classed as high-temperature hydrothermal. This hypothermal stage may be divided into three substages, each corresponding to a rock type developed in a definite order as shown by the structural relations observed in the field.

Fig. 8 shows a photograph (including an interpretative sketch) made in the main Buster pegmatite looking west at the hanging wall just north of the trench cut into the west side of the mine (see map, Fig. 6). Here a mass of microcline perthite, likely part of a single crystal, now some $2\frac{1}{2}$ feet long is practically surrounded by the cleavelandite quartz rock. A similar condition may be observed at many places in this portion of the mine. On the right side the

cleavelandite-quartz rock distinctly embays into the perthite, and just below here a long replacement vein of this rock an inch or so wide projects into the perthite for nearly two feet. Clearly the cleavelandite-quartz is later than the perthite, and the solutions which deposited the former corroded the latter. At the lower right corner of the large perthite is some quartz with muscovite books an inch or two across; the perthite is subhedral against the quartz; these three minerals likely represent the pyrogenic deposit. In the neighborhood are black schorls much like those described above which probably also belong to this stage. The upper right portion of the large perthite contains some graphic quartz. Near the upper left corner of the perthite, but in the cleavelandite-quartz rock, are a number of euhedral garnets. This is the association in this mine where the garnets are found in greatest abundance.

Fig. 10A is a sketch made in this mine in the roof exposed 10 feet from the south end of the pegmatite at the 40-foot level. It looks as if there had been nests or crudely globular-shaped masses of cleavelandite in crystals several inches in length. Near one edge of these, muscovite started to grow into the mass in radiating fashion yielding large wedges of mica books. These jut out into and cut across the cleavelandite crystals in irregular fashion with serrate ends, and the mica plates may be separated by sheets of feldspar or quartz. The chief occurrence of beryl in this mine is in this association, and the beryl is typically euhedral against both the muscovite and cleavelandite. Such masses may abut against other similar masses or be separated from them by quartz in a roughly arcuate pattern as shown in the sketch. In detail tiny cleavelandite plates may be seen projecting out into the quartz a short distance. It is also to be noted that all the albite in this coarse mica rock is not of the cleavelandite variety, and some of it shows up to 13 percent of the lime component.

Such rock yields essentially all the commercial muscovite now exposed in this mine (except for the source of scrap mica described in the next paragraph). It is the major rock-type in the south part of the mine, but is absent or unimportant in that portion of the north part now exposed. Where it comes in contact with the cleavelandite-quartz rock it embays into the latter in such fashion as to clearly indicate it to be the later of the two.

Finally the nests of cleavelandite-muscovite in crystals $\frac{1}{2}$ inch or less in size are very distinctive, though they constitute but a tiny portion of the whole pegmatite. They were observed only in the south central part of the mine, and are distributed in highly irregular fashion at any depth. This "bull-head" rock is a

distinctive petrographic unit easily told from the other rock types
and is saved as a source of scrap mica. It is clearly later than
the quartz-cleavelandite rock as shown by the field relations de-
scribed above. At one place it seemed to cut across the coarse
muscovite rock, and so it is here assumed to be later; but the
writer observed no situation that was sufficiently clear to estab-
lish this sequence unequivocally.

EARL LODE

Introduction

The Earl Mine is four miles east-southeast of Custer (Fig. 1, No. 13). It is near the northeast corner of the NW. $\frac{1}{4}$, MW. $\frac{1}{4}$, NE. $\frac{1}{4}$, Sec. 33, T 3 S., R 5 E. Take U.S. 16 east from Custer (3.1 miles from where it leaves U.S. 85A) to the French Creek Road. Here turn south for 1.1 miles to where the road first comes alongside of French Creek. From this point a side road leads west up the small valley (between the two ridges running east from Mt. Erin) to the mine, a distance of about a half-mile. The mine is at an elevation of about 5350 feet, some 300 feet vertically above the road. It was visited by the writer August 7, 1942. It appears on air photo BNW 147-205 at 2.8, 3.8.

The mine was staked in June, 1937, by L. ("Bud") Landis of Custer. It was leased as a feldspar mine first to Ray Gould, then to Lee Burrows, and finally to Maynard & Walters. A trench 10 to 15 feet wide was cut in from near the west end of the dike and continued some 150 feet easterly with a face as much as 30 feet high along the far end of the footwall. (See Fig. 7B.) The mine was later idle, but recently Landis has cut a trench in from the northwest corner at a level about 8 feet below the first cut. Muscovite has been obtained mainly by drifting along the hanging (north) wall. There are five sacks of beryl in the stock pile.

The Pegmatite

The dike lies high up in the wall on the south side of a small valley, about 100 feet below the top of the quartzite ridge to the south. The valley wall slopes about 25° to the north. The dike is a bit over 200 feet long, has a maximum average thickness of about 25 feet, and appears to be quite regular in shape as far as revealed by present operations, though of course some pinch and swell structure is present in the walls. It strikes N. 75-80° E. and dips 60° to the north in general in conformity with the enclosing rocks which are impure quartz sandstone or graywacke. The hanging wall is well exposed in the trench cut by Landis. The rock contains 10 to 20 percent mica and is quite friable, except for a hard zone at best a few inches thick along the contact. The footwall on the south is exposed at only one or two small places in the mine, and is very similar to the hanging wall although it is more coherent, since it has not been so subjected to weathering.

Mineralogy

The whole central part of all but the east end of the dike has been removed by the earlier trenching. Since this did not expose the walls, and was primarily to recover potash spar, it is reasonable to assume that the present walls of the trench which show soda spar quite dominant over potash spar hardly represent the composition of the dike as a whole.

The rock types present include: (1) the standard simple pegmatite unit, dominantly of gray microcline perthite and quartz, with subsidiary muscovite and schorl; (2) cleavelandite-quartz rock of the crude augen type showing variations from largely quartz to largely cleavelandite; in close association and probably to be classified with this unit are relatively large amounts of ordinary gray albite which is distinctly less fresh than the perthite; there is so little of the coarse globular type of cleavelandite that it also may be taken as a minor variant of this rock; and (3) minor deposits closely associated with the cleavelandite-quartz rock of probable meso-or epithermal origin.

The central portion of the quarry may have contained considerable amounts of the perthite-quartz rock relatively free from the other types, but so far as seen at the time of the writer's visit, masses of perthite up to 6 feet long and 2 feet through, apparently largely portions of single crystals, some in close association with masses of quartz up to half this size, were in all cases surrounded by albite-bearing material. The trench walls at first glance gave the aspect of a relatively fine-grained pegmatite consisting of cleavelandite-quartz with considerable portions of less fresh albite containing isolated remnants of the relatively fresh perthite and massive quartz, the latter two composing probably less than one quarter of the whole.

In short, in this dike the albitizing process has been very pervasive, and were one to see this type of pegmatite alone, or for the first time, it is doubtful that good evidence would be adduced for the sequence considered to have occurred. Some of the perthite contains graphic quartz, and some of the cleavelandite-quartz penetrating the massive perthites as vein-like deposits contain so little cleavelandite as to resemble certain ribbon-spar types of graphic granite.

Black tourmaline is quite conspicuous in the exposed rock. Some of this high up along the foot wall in the east part of the trench is remarkable in that it consists of partial negative crys-

tals. These are shells of schorl up to half an inch thick which are parts of prismatic crystals up to 3 inches through, with crystal faces on both the inside and outside; they are filled with polycrystalline muscovite in 1/16-inch crystals.

Practically all the commercial muscovite is now recovered from near the hanging wall in the west portion. Since the associated rock is highly albitized it is impossible to tell what proportion of muscovite formed here as part of the original pegmatite and what came later in time association with the albitization, However, the fact that all the important muscovite-producing dikes contain considerable albite and those lacking albite in significant amounts are not important muscovite producers is good evidence in this regard.

Garnets are not common. One $\frac{1}{4}$-inch red-brown grain surrounded by a $\frac{1}{4}$-inch aureole of muscovite was found within the perthite.

A considerable fraction of the massive quartz shows a dim banding. This quartz as a whole appears very pale gray; no rose color was observed. The bands consist of indistinctly-bounded whitish or milky layers about 1/16-inch thick spaced $\frac{1}{2}$ to 1 inch apart which are probably caused by sheets of microscopic inclusions (some appear to be liquid in part, since they carry bubbles) running through colorless glassy quartz. These layers can often be traced for a foot or two, indicating that such quartz is composed of large single crystals. While in many places the banding is approximately vertical, it seems probable that it is parallel the prism or rhombohedron faces of the quartz. The perthite is locally subhedral against this massive quartz.

The quartz-cleavelandite rock seems to consist of massive quartz which has been replaced to a greater or less degree by cleavelandite. It appears typically as consisting of masses of light gray quartz about $\frac{1}{2}$ or 1 inch across, outlined by veins of nearly white cleavelandite about 1/16 of an inch thick. It is as if masses of quartz had been fractured (possibly in connection with the inversion of high to low quartz) and albite had been deposited in the fractures. In many cases the albite veinlets are curved, and yet they may be of constant thickness for $\frac{1}{4}$ inch or so. In other cases they are straight and consist of single cleavelandite plates. In many cases they vary in width. The quartz fragments thus show outlines on a plane surface both convex and concave outward. Some fragments are embayed by cleavelandite plates shooting straight in from a vein, others by irregularly curving branch veins. The contacts are always sharp, and appear to be either the euhedral surfaces of cleavelandite or the curved surfaces of quartz fractures

filled by cleavelandite which in part also replaces the quartz. Some places were noted where the banding in the quartz fragments extended in a single direction through many fragments for a foot or so. This would indicate that these fragments were once part of a single quartz mass, possibly part of a single crystal. One sample was found in which small schorls outlined the quartz pieces in lieu of cleavelandite. This would indicate tourmalinization extended into the stage of albitization.

From the type of rock described above it is possible to find all gradations to rocks containing much less quartz and much more cleavelandite. This takes place by gradually increasing size of the feldspar plates, and in places masses of cleavelandite an inch or two across are encountered. At only one place (near the center of the mine on the hanging wall side) was cleavelandite in very coarse crystals (about 2 inches long) and radiating partly-globular masses found, and here there was no conspicuous coarse muscovite association.

In this mine all the soda spar is not cleavelandite; much of it is ordinary albite. This is intimately associated with the quartz-cleavelandite rock, tends to show a faintly greenish tinge, and in considerable part is much less fresh than the perthite; it is locally somewhat limonite-stained. Some masses of such albite are the size of a cube of 6-inch edge. It is also characterized by a (110) cleavage about as good as the (001) and much better than the poor (010). Since all gradations from typical curved platy cleavelandite to thicker less-curved platy cleavelandite to this massive albite were observed, these two forms of albite may be genetically associated, though likely the cleavelandite is younger. The coarser cleavelandite seems to be in the central portion of the dike, the massive albite more along the walls. Apparently the massive albite did not form by alteration of the perthite, since perfectly fresh samples of perthite near the foot wall were seen embayed into by the massive albite. However, the fact that the large perthites were probably corroded and certainly embayed by the albitizing solutions indicates that they may have been a source of potash needed for the formation of the muscovite so intimately associated with the albite.

Other minerals of the quartz-cleavelandite association are relatively minor; muscovite, beryl, and schorl are the more abundant, and of course muscovite is the most important. The opening at the lower level, being pushed east in 1942 along the hanging wall, showed nice muscovite in fair amounts. However, the big muscovite books and wedges such as seen in the coarse cleavelandite-

albite association in the Buster Lode have not been exposed.[1] Also much less schorl is present. Locally the footwall is considerably indurated for a thickness of a few inches at the contact. This is due to the development of new minerals including garnet (medium to dark brown and rose red) grains forming masses up to an inch long, tiny euhedral schorls, rare green small euhedral apatites, along with cleavelandite and muscovite in crystals $\frac{1}{2}$ inch or less in length.

The beryl of this mine is all in or near the quartz-cleavelandite rock, and is likely genetically associated. Five sacks were in the stock pile and it is easily found in the mine. Fairly good prismatic crystals up to 2 or 3 inches through were observed. No beryl with clean cut cores of other minerals was seen. A plate of columbite from this association, said to have come from the dump of this mine, was shown to the writer; also a half-nodule of montebrasite[2] (3 inches across) with a $\frac{1}{4}$-inch rim of albite, the two in irregular jagged but sharp contact. Apatite (omega = 1.634, epsilon = 1.632, and so fluorapatite) in bluish gray subhedrons containing tiny needles of tourmaline (?) giving it a fine-striated appearance was found in a number of places; locally rich green portions are present. Landis showed the writer a sample of cassiterite an inch long from this association; it carried fine flakes of muscovite. It gave an excellent tin reaction using the zinc test.

At the west end of the mine a crudely spherical mass of lithiophilite 6 inches across more or less altered to manganese heterosite (purpurite) was observed. It carried and stained muscovite, quartz, and possibly feldspar and included small specks of a black submetallic mineral. At the east end of the mine a 2-inch diameter mass consisted of crudely spherical shells of loellingite with much limonite and a core largely of stained quartz. This massive loellingite is quite like that at the Hugo Mine near Keystone and very different from the euhedral crystals of the High Climb Mine described in Rept. of Inv. No. 44, 1942. Except for these minerals, the paragenesis is not appreciably different from that of the Buster Lode, insofar as the same mineral suites are represented.

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1. Two weeks after visiting the mine, Landis showed the writer a remarkably flat V-shaped book of beautiful muscovite over an inch thick with quite smooth crystal faces along the two sides of the V which were at least a foot in length.
2. This is hydroxyl-rich and fluorin-poor amblygonite with alpha 1.610, beta 1.619, gamma 1.630.

CUSTER MOUNTAIN LODE

Introduction

The Custer Mountain Lode (Fig. 1, No. 12) is $1\frac{1}{2}$ miles east-
southeast of Custer in the SW. $\frac{1}{4}$, SE. $\frac{1}{4}$, Sec. 30, T. 3 S., R. 5 E.
Go south on the Old Pringle Road (8th Street, Custer) from U.S. 16
a distance of 1.7 miles, where turn left (east) along the road lead-
ing to lower French Creek for 0.5 mile, then again left (north)
along the lane 0.5 mile to the mine; this appears on air photo BNW
176-22 at 8.3, 3.1.

This claim was bought from E.E. Howard (now of Hot Springs)
by B.M. Dilley of Custer in 1935. Up to that time only an insigni-
ficant amount of work had been done. In the main the mine as ob -
served in August, 1942, was developed by Dilley during 1938, as
described by Guiteras.[1] It is reported to have produced over 3000
tons of feldspar, 75 tons of spodumene, 10-12 tons of beryl, and
perhaps 15 tons of mica. The pegmatite was originally opened near
the center of the present main hole (Fig. 9), which is now about
130 feet long sloping from the surface at the south end down to the
north end, where there is a face some 35 feet high. See Fig. 11A.
Most of the spodumene and mica came from the north half of this
pit. Immediately to the southeast of this main pit, just northwest
of the present power house, there is a prospect trench about 60 feet
long and some 6 feet deep at the southeast end, sloping up to the
ground surface to the northwest. Apparently little of the largely
albitized material removed from this trench was sold. Some 150 feet
to the southwest of the main pit there is a small pit about 35 by 20
feet with exposed walls about 6 feet high. This pit contains a pond
said to be about 6 feet deep. From this small pit Dilley reports
that much clean feldspar was produced. This pit is also stated to
have supplied several tons of amblygonite, but this was not recog-
nized by the miners who sold it as feldspar. Beryl came from both
pits. Some prospecting has been carried out on the east edge of the
dike about 100 feet south of the small pit, but the rock here con-
tains a good deal of fine-grained heterogeneous pegmatitic material,
including schorl in quite deleterious amounts.

This property was sold by Dilley to G.W. Beach on August 6,
1941. Beach has built the present power house and crushing and
sieving plant for recovering mica, and states that he removed about
a carload of mica, mainly scrap, from the main pit. In August,

1. U.S. Bureau of Mines *Inform. Circ. 7112*, 1940, 59.

FIGURE 9

CUSTER MOUNTAIN LODE

1 1/2 MILES EAST SOUTHEAST OF CUSTER, S.D.
(COMPASS AND PACE MAP)

N.W. 1/4, S.W. 1/4, S.E. 1/4, SEC. 30, T. 3 S., R. 5 E. (10 ACRES)

LEGEND

PEGMATITE AND GRANITE

MICA SCHIST WITH QUARTZ LENSES

SILLIMANITE-ANDALUSITE SCHIST

X5382 ALTIMETER ELEVATION

□ S.W. CORNER SKOOKUM CLAIM

■ CORNER HOMESTEAD ENTRY SURVEY NO. 178

DUMP

PIT

POND

SWALE

FLOAT QUARTZITE

MAIN PIT

X5437

POWER HOUSE

CRUSHER HOUSE

BARBED WIRE FENCE

POND PIT

12

2

M.S. 590

+5346

(NOT SURVEYED)

HEIDEPRIEM CREEK

5382

TO CUSTER

TRUE NORTH

MAGNETIC

10

SOUTH DAKOTA GEOLOGICAL SURVEY

AUGUST 1942

D. JEROME FISHER, GEOLOGIST
ROBERT G. SMALLEY, ASSISTANT

SCALE

100   0   100   200

FEET
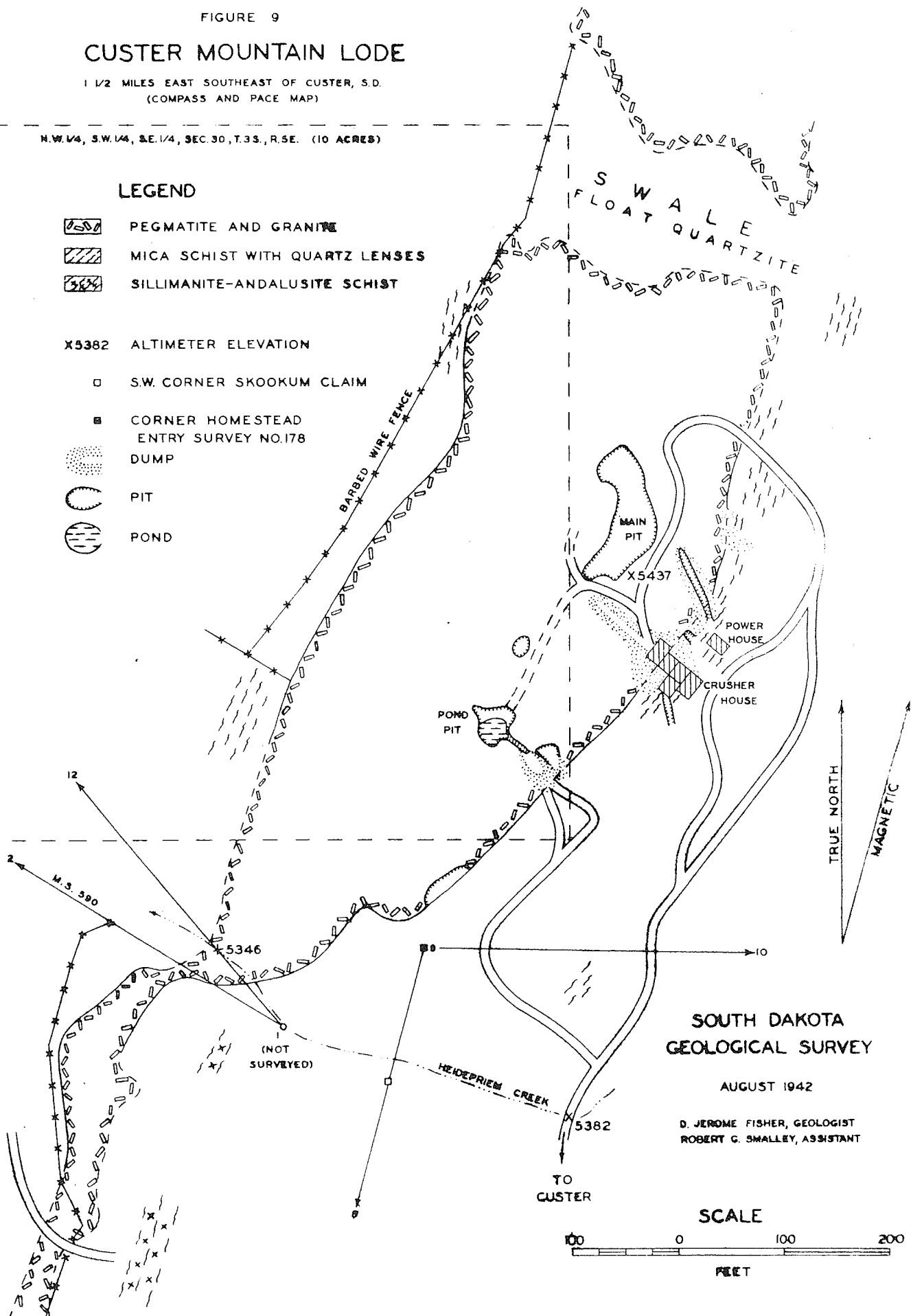
1942, the machinery was being changed to some extent, but mining operations were nearly at a standstill, though Beach and one helper were obtaining a little feldspar from a point about midway between the two pits, and also from a place at the east edge of the dike some 30 feet east of the small pit. It was stated that mica operations in the main pit were to be resumed after the arrival of certain equipment expected shortly.

The Pegmatite

The dike lies well down on the west flank of Custer Mountain, where it forms a ridge striking about N. 20° E. on the north side of Heidepriem Gulch, above which it rises a total of 55 feet as measured along the road. Heidepriem Gulch drains westerly to Pearl (Sidney) Creek, a south tributary of French Creek. The narrowed southern extension of the westerly portion of the dike actually crosses Heidepriem Creek, in which it causes a falls 15 feet high, and continues on south-southwest nearly to the quarter corner on the south side of Section 30. The north end of the dike as mapped on Fig. 9 is a grassy saddle slightly over 50 feet across which lacks outcrops but contains float quartzite, possibly in part washed down from the east. Beyond the swale the dike widens out and continues to Calamity Peak (two miles to the northeast) and beyond, according to the map of U.S. Geological Survey Folio 219, which shows it all as part of the Harney Peak granite.

The dike stands nearly vertical, perhaps dipping very steeply (about 85°) to the west-northwest. It is about 275 feet wide at the north and about 175 feet in the south-central part of the map, Fig. 9, some 750 feet south of the swale at the north end. Farther to the south-southwest across Heidepriem Creek it is much thinnner, perhaps about 20 feet or less, as is shown on the mpa. It is intruded into quartz-two mica schist which locally is highly tourmalinized at the contact. This schist contains lenticular masses of quartz of greatly varying size and quantity. A short distance (about 40 yards) to the east it carries andalusite and sillimanite spread through a zone extending at least 75 yards across the schistosity. These minerals were also seen in the schist just east of the dike on the south side of Heidepriem Creek. Graphitized schists are exposed within a half-mile of the main mine, both to the southeast and the southwest. So far as exposures indicated, the dike is conformable to the structure of the enclosing schists. The schists a short distance (about 50 yards) to the northwest of the dike contain two thin pegmatites (one 1-2 feet, the other 4-5 feet thick) striking N. 15° E. Their northern portions dip about 85° W., their southern ones 85° E. The larger one has been quite thoroughly prospected. It consists of a light gray perthite-quartz

dike, with schorls up to 3 inches through concentrated near the walls and standing crudely normal to them. Some samples of these resembled orthite (allanite), but the tests were negative for this uncommon epidote. The central portion has been extensively albitized and contains large muscovite books, some in association with quartz masses. Unusual is the abundance of medium light brown subhedral garnets in masses up to an inch or more across; these were not observed in the Custer Mountain Lode.

The ridge extending northwest from the main mine for about one-half a mile to Pearl (Sidney) Creek is covered with float quartzite to the northwest of the small pegmatites just described. As shown by outcrops on the south flank of this ridge, these strike N. 10° W. and dip 85° to the west. On the north flank the strike is the same, but the west dip is less steep. This is a notable variation in strike from that of the schists near the Custer Mountain Lode.

It has already been mentioned that this pegmatite is considered to be a part of the Harney Peak granite massif. Of course it must be remembered that this is not an ordinary text book type of granite[1] that is taken to consist of the relatively simple product caused by the regular, even consolidation of a fairly simple magma. Rather it is this sort of thing which in its upward border phases contains numerous inclusions of more or less altered roof rock, and which in this portion has been repeatedly injected by pegmatites rising from the deeper parts of the magma reservoir. It is to be noted that similar commercially-important pegmatitic deposits are likely to be found in other places mapped as Harney Peak granite; these will probably be found mainly near its border, however.

The material mapped as pegmatite on Fig. 9 is thus somewhat more heterogeneous than is possibly true of the average pegmatite, in that it involves some more strictly granitic material. However, this has been so saturated with pegmatitic juices that the two could not well be differentiated on a map of such small scale as here presented. Moreover the mass has been opened at relatively few places, and ordinary natural exposures are not sufficient for this purpose. On the whole pegmatitic material is exceedingly abundant, though some of the border rocks of the main pit are nothing but coarse-grained granite.

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1. J.J. Runner, "Structure and Origin of Black Hills pre-Cambrian Granite Domes", Jour. of Geology, 51 (7) 1943, 431-57.

Practically all the detailed work done on this pegmatite was carried out in the Main Pit and the Pond Pit, together with the dumps accumulated from these. These pits lie in from the east wall a matter of 75 to 90 feet, though they are distinctly east of the central part of the pegmatite as mapped on Fig. 9. This condition must be kept in mind in connection with the following discussion.

The Pond Pit

Study of the exposures in the walls of this pit and of the specimens collected from its dump indicate the following sequence. First as always in this area there was formed a so-called simple pegmatite composed dominantly of light gray microcline (which is now perthitic and in important part graphic) along with quartz. Subsidiary black tourmaline and muscovite were likely deposited during this stage, but were not important so far from the wall rocks. This was followed by the intrusion of an aplite-like rock which, because of its content of tiny acicular schorls in a crudely banded pattern, at first glance seems to consist of xenoliths of schist. This was succeeded by the development of albite-quartz-muscovite rock which in part cuts through and alters the previous types. Loellingite was deposited in a late hydrothermal stage in quantities larger than seen at any other mine of the Custer area. In part this has been oxidized and hydrated yielding the light blue powder of symplesite ($Fe_3As_2 O_8 .8H_2O$) which lines an occasional cavity, and the rusty stain of limonite.

The microcline perthite consists mainly of more or less corroded crystals up to 2 feet long, but it is locally subhedral along quartz contacts. It shows a very interrupted cleavage and breaks into blocks rather than slabs. Much of it exposed in the entrance trench is graphic with the quartz appearing in parallel bands on the fracture surface giving the effect known as corduroy or ribbon spar. The blocky character of the perthitic microcline is apparently due largely to the presence of numerous poikilitic cleavelandites. The grating structure of the microcline stands out even without an analyzer, because of tiny inclusions along the contacts between the twinned individuals. In part this structure is so coarse that it can be seen readily with an ordinary hand lens.

The aplite-like rock may be regarded as a coarse soda aplite consisting of albite, quartz, and tourmaline, with minor muscovite, and a few tiny apatites. It appears to have been injected after the perthites had formed but possibly before they had been cemented by quartz, since in places (south side of pit) the soda-aplite

meets a subhedral perthite along a fairly straight contact as shown in Fig. 10D. Under the microscope it is seen that this contact is not smooth; the albites project into the perthite, and isolated masses of the perthite in crystallographic continuity with the main perthite crystal are surrounded by albites. The light bands in the soda-aplite are about one-half inch wide and are due to a relative scarcity of the unoriented schorl needles. These bands tend to meet the perthite crystal surface tangentially, and where not too close to the crystal are curved slightly in arcuate fashion. Apparently the soda-aplite succeeded the perthite since the former contains corroded fragments of the latter. This soda-aplite somewhat resembles the granulite (page 61) at the Old Mike Lode. They are both fine-grained rocks of about the same mineral composition carrying schorl needles as an abundant accessory. However, the soda-aplite is composed of crystals averaging 5 times as coarse as those of the granulite. The albites of the granulite show rather uniform and fairly regular twinning. Those of the soda-aplite are complexly intergrown with one another, giving a picture-puzzle or "landscape-marble" texture with concomitant interruption of the twinning lamellae. Moreover some of these albites seem to have grown by stages or waves, as shown by the peculiar offsets of the twinning lamellae along curved lines; some of the twinning lamellae are curved, too.

The albitizing solutions played a dominant role in this pit, since nearly half the walls are covered with albite-quartz-muscovite rock, which consists largely of albite and so is definitely not of the "augen" type. Very few of the mica books are as much as 1 inch across. There is some cleavelandite; however, much of the albite is not in the platy form, but is instead massive pale grayish material split up badly by prismatic plus pinacoidal cleavages. Associated with this rock are pale greenish euhedral beryls and dark green euhedral elbaites[1] with a dark blue rim. The latter may belong near the end of this paragenesis as is discussed later, but the former probably antedate the albite, although some of the beryls are entirely within this mineral. These beryls are relatively clean and do not carry a partially-digested core of other minerals.

Amblygonite was mined from this pit, but none of it was seen in place. Several samples were collected from the dump. Some of these were cut by or included fragments of quartz and crystals of muscovite and are thus thought to antedate the albite-quartz-muscovite rock. In the Main Pit the amblygonite is definitely post-lithiophilite, and in the absence of evidence to the contrary may

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1. The alkali (lithium) tourmaline, here called elbaite, embraces shades varying from deep green (emeralite) to deep blue (indigolite) at the Custer Mt. Lode.

be so dated here. A little spodumene was reported from this pit,
but none was seen. Apparently it occurs from here all the way to
the main mine.

More or less rust-stained masses of silvery loellingite are
found without difficulty on the dump of this mine. They are more
common in the albite rock in which they may occur in crude vein-
like form or as apparently corroded (but unaltered) tabular crystals
extending across small elongate cavities (roughly normal an albite-
perthite contact) as a series of parallel plates almost like shelves
in a pantry. They often show the "gothic-window" type of habit so
typical of marcasite. These may be coated with an olive green
somewhat botryoidal substance.

Main Pit

The south end of this pit shows microcline perthite as in the
Pond Pit together with very large masses of quartz, both rather
notably limonite-stained. There is also some albitization, but
this seems to increase to the north. Beryls, apatites, and loel-
lingite (the last cut by pyrite) were also noted in this part of
the mine. Columbite in important amounts was reported from the
center and north end of the pit. The north central part well below
the surface carries the striated, blade-shaped molds where spodu-
menes cut through the earlier minerals, especially quartz, at all
angles. Fig. 11B is a photograph of one of these, showing the way
the quartz is radially cracked out from the spod, indicating later
release of pressures that were developed during the growth of the
spod logs. These were found here up to 30 inches wide, a foot thick,
and at least several feet in length. The mine has partly been
filled with rubble to serve as a roadway, and so no very long crys-
tals are fully exposed.

Extending northeast from the "hook" on the west side of the
mine, about 35 feet south of the north end, is a rough contact
between spod-rich rock to the southeast and spod-poor rock composed
largely of albite-muscovite-quartz with minor gray-blue apatites
and deep green tourmalines.

In this mine the lithiophilite is more abundant than anywhere
seen in the Custer area. What is more important, much of it is
perfectly fresh. No pieces were found that did not have an altered
periphery, however. The typical occurrence is as beautifully-cleav-
able masses of smoothly-irregular nodular form up to 18 inches
across. One such large mass seen at the foot of the east wall 35

feet from the north end of the main pit appeared as in Fig. 10B. It was nearly surrounded by massive quartz; that above the nodule contained much cleavelandite, as is indicated. A small section of the lower right portion of the lithiophilite was cut off by the end of a large spodumene crystal. Radial cracks extended upward through the quartz from the end of the spodumene. Apparently this mass of lithiophilite constituted a single crystal as shown by the cleavage. It might once have had crystal faces, but if so these had been completely corroded.

One specimen with lithiophilite euhedrons was found on the dump. This was badly altered but contained a core of fresh material. The crystals were much like those seen at the Tip Top. These grew in quartz and are cut by a muscovite vein.

The alteration around the borders of the lithiophilite[1], Li $(Mn", Fe") PO_4$, first results in the oxidation of the iron yielding the rich brown sicklerite[2], $(Li, Mn", Fe"') PO_4$, that exists in cleavage continuity with the lithiophilite. Further oxidation (this time of the manganese), along with hydration and loss of lithium, leads to a black opaque material[3] (mineral name not identified); manganese heterosite (purpurite), $(Mn"', Fe"') PO_4$, may be formed as an intermediary, though this is not common in this mine. Continued alteration possibly removes the phosphorus, leaving a residue of manganese and iron hydroxides, though this has not been established.

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1. Analysis of this Custer Mt. lithiophilite by Prof. Ernest Griswold of the University of South Dakota shows 8.95 + .01 percent iron and 25.17+ .05 percent manganese; this corresponds to 26.0 molecular percent of triphylite $(LiFePO_4)$.
2. In some cases between fresh lithiophilite and sicklerite there occurs a greenish mineral that may be a manganese dufrenite.
3. P. Quensel stated that such material at Varutrask (12 miles southeast of Boliden, Sweden) had 31.2% P_2O_5, 23.2% Fe_2O_3, 29.1% Mn_2O_3, and 14.1% H_2O. See Geol. For. (Stockholm), Forh. Vol. 59, 1937, 77-96. The formulae given above for sicklerite and heterosite are taken from B. Mason (Ibid., 63, 1941, 117-75). The minerals listed above, as well as the sequence of alteration given, was determined independently by the writer before he ever heard of the outstanding series of papers on the Varutrask pegmatite published by Professor Quensel and his collaborators.

Besides this sort of alteration of the periphery, the nodules often show cracks parallel a cleavage stained with a greenish film; both yellow and white powders were also seen. Along some of these cracks there has been more extensive change; sicklerite or its alteration products may appear as lilypad-shaped discs. Fringing these (but never overlapping them) occasional surfaces are coated with beautiful colorless drusy triclinic crystals of a new mineral ("Mineral A"), possibly a hydrous phosphate of Mn. "Mineral A" is a triclinic phosphate of lithium with iron and manganese, and is to be described under the name "Bastinite." It has H. 4, F. 1, and n-values of 1.649, 1.655, and 1.658 with (-) 2V of 73°. It is readily soluble in dilute mineral acids. It is probably not supergene (as is shown in Table 1, page 54) but more likely belongs in Stage V following sicklerite. In fact, its lithium may have been derived from the breaking down of the sicklerite. Another fine-grained crystalline material associated with Mineral A is as yet unidentified. A few samples of lithiophilite carried narrow veinlets containing a film of a blue mineral doubtfully identified as lazulite. Locally, coatings of a deep green color (a Mn dufrenite?) were seen in limited areas.

With one exception all samples of cassiterite found in the mine were in the lithiophilite; this piece of cassiterite was in quartz. Cassiterite was not by any means found in every lithiophilite nodule broken, but if it was present, 20 or 30 small cassiterite crystals were likely to be found. The largest mass seen was not over an inch across. The crystals were generally rather poorly formed euhedrons bounded by the normo-dipyramid (101). Curved faces were common. A few samples were found in which the cassiterite (sometimes associated with quartz) seemed to make tiny veinlets through the lithiophilite for a short distance. The cassiterite is entirely fresh, but occasional pieces are fractured and have these tiny gashes filled with a greenish yellow mineral; some crystals show coatings of the sulphur-yellow powder so common in the lithiophilite. The associated quartz may be coated with a bright green mineral, possibly a chlorite close to daphnite.

The lithiophilite rarely contains small medium-brown resinous masses of a fusible (F.=4) isotropic mineral of hardness 4 and very high refringence (well above 1.84) which answers most of the simpler tests for ampangabeite, a rare columbite carrying uranium and titanium. It is probably not this mineral, but pending further work may be designated "Mineral B." This occurs in irregular granular masses with the cassiterite, or as tiny veinlets in the lithiophilite.

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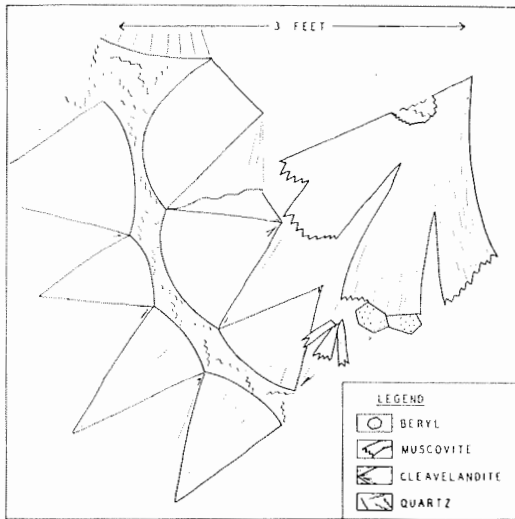
10A. Very coarse cleave-
landite-muscovite rock
with quartz and beryl,
Buster Lode
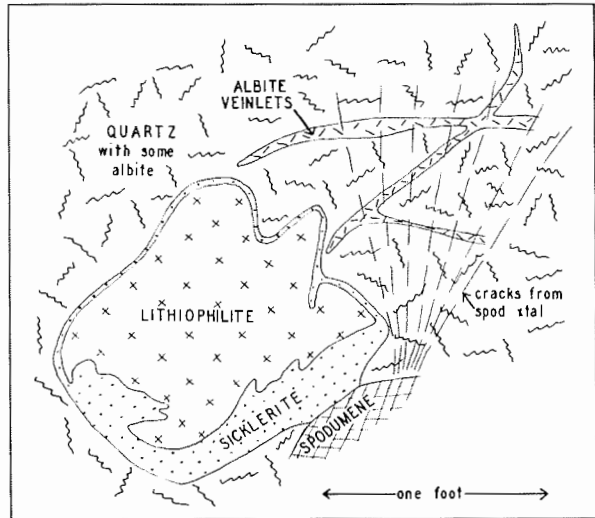
10B. Mass of lithiophilite
in quartz and associated
minerals at the Custer Mt. Lode
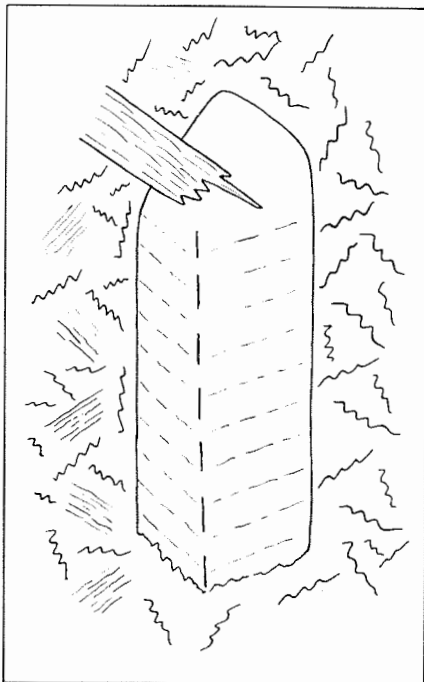
10C. Spodumene crystal
over a foot long cut
half in two by a mus-
covite book at the
Custer Mt. Lode; ma-
trix quartz, with
muscovite on the left

10D. Peculiar straight contact
between aplite and perthite;
Pond Pit, Custer Mt. Lode

Veins of the replacement type consisting of loellingite, mus-covite (often stained dark-brown to black), and cleavelandite (stained greenish) were found cutting the lithiophilite.

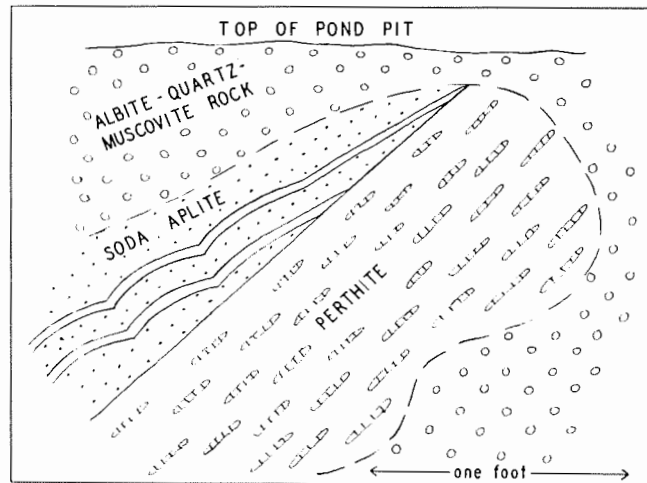Most of the beryl in this mine is grayish white or nearly so; however, some of it is pale greenish and pale yellow or golden. The former is very difficult to tell from certain types of quartz, feldspar, or amblygonite, unless the crystal form can be made out, and some of it is in such large masses (several inches to a foot through) and so broken up that it appears massive. All the green-ish beryl seen was in the typical hexagonal crystals; these were associated with quartz or in the albite-quartz rock; some samples were found entirely in albite. The yellow beryl observed might rate as a very low grade golden beryl and was entirely massive, somewhat sugary. An anhedron about 8 inches across was seen just north of the middle of the mine about 6 feet above the base of the east wall, entirely surrounded by quartz, which a short distance away carried a book of ruled muscovite 5 inches across.

The albite-muscovite-quartz rock making up the lower portion of the northwest part of the pit is a well-defined petrolgic unit; it carries apatite and tourmaline as accessories. In some places muscovite is very dominant, and locally are found "bull head" masses or nests a few feet across of nearly pure muscovite books in crystals about a half-inch wide. Rather similar occur-rences were seen at the Buster and Ross Lodes. (Fig. 17A) Coarse muscovite consisting of books up to 3 inches (rarely 4 or 5 inches) across is also locally developed. In other places albite or cleave-landite is in excess. The cleavelandite variety is most conspicu-ous as aureoles to the spods or in the rock rich in muscovite. Most of the rest of the soda-spar is not of the cleavelandite variety, but the two types locally appear to grade into one another. The apatites are dark greenish gray subhedrons up to 2 inches across which weather light blue; small green ones were also seen. The tourmalines are mainly elbaites of the deep green-nearly black-variety, often flattened parallel the cleavage when cutting through mica books.

The lower part of the pit near the north end carried lepido-lite with spodumene, cleavelandite, etc. This rock was not exposed in place, but many blocks of it may be seen in the rubble of the mine and on the dumps. The blocks are mostly bounded by crude striated planar surfaces from which spodumene crystals have been knocked away. Many of these obviously had a fringe of cleavelandites

up to an inch long growing out from them roughly normal to their surface. Fig. 12A is a photomicrograph of the contact between such a spodumene euhedron (upper half) and the bordering cleavelandites. The plates of the latter are roughly normal to the crystal face of the spodumene; the trace of this is approximately horizontal and parallel the cleavage cracks. At the magnification shown it is clear that the cleavelandites have partly replaced the spodumene, though on observing hand specimens with the naked eye the contact is seen to be approximately that of the spodumene crystal face. Fig. 12A also shows a single crystal of muscovite (lower middle part of the left edge, and to the left and below the center) on either side of the lower left cleavelandite mass; in general muscovite is found in only very minor amounts here, and is much less important than might be concluded from the photograph. However, there is commonly a selvage of very fine grained muscovite bordering the cleavelandites, as may be seen in Fig. 12A.

Such a cleavelandite aureole may be seen beautifully on many (but by no means all) of the spods at the Beecher No. 1 and Etta mines too. This fringe obviously grew out from the surface of the spod, since it is inconceivable that an aureole of this nature was already waiting for a spod to form on its inside. There is also additional evidence given later to show that the spods preceded the cleavelandite. The lepidolite post-dates the other two; both it and muscovite replace spod. A little amblygonite was found in one of these samples, but no clue appeared as to whether it antedated the spods; it is veined by quartz, muscovite, and lepidolite.

Two columbite samples were collected from the dumps, others were donated by Dilley and by Beach, and small ones were seen in place in the mine. They all showed subhedral to poor euhedral platy black shiny striated crystals, some cutting through cleavelandite as well as quartz, others cut by cleavelandite and also quartz. Columbite-cleavelandite are thus regarded as being essentially contemporaneous in this mine, though it is thought that much of the albite antedated the columbite.

Paragenesis

Table 1 gives an approximate picture of the sequence of mineralization as worked out for this mine. It is subject to considerable qualification, as is presented in the following paragraphs, where reasons for the order shown are stated. In this table the minerals are grouped in part according to associations, and the

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11B. Mold of spodumene crystal in quartz (base of left wall in shadow, Fig. 11A) Note cracks radiating outward and upward from top part of crystal cavity.

11A. Looking north down the slope towards the back of the Main Pit, Custer Mt. Lode

lines which follow the mineral names represent the relative times
and sequences of crystallization. The observed field and labora-
tory evidence was insufficient for adducing an air-tight sequence
in the cases of all minerals; thus the table also serves the pur-
pose of a target for riddling based on further field or laboratory
studies.

The basic or primary pegmatite represented by Stage I (pyro-
genic) is locally shown in the two pits, but in general it is
always true that the muscovite and schorl are better represented
along the walls. However, in the Pond Pit good examples of schorls
cutting microcline perthite were collected. The best evidence that
microcline and quartz are the chief products of Stage I is that the
microclines are never subhedral against any mineral except Stage I
quartz, and when in contact with other minerals, as is especially
common with those of the Stage III sequence, it is clear that the
perthites represent remnants with partially corroded edges; more-
over, they carry indentations and veins of the replacement type
filled with some of these minerals. It will be noted that the
minerals of Stage I constitute a petrologic type. All other miner-
als are considered to represent replacements of those of Stage I
or later stages with the exception of some of those of Stages V
and VI which formed along cracks or as a lining of cavities.

Actually Stage I is not a simple one consisting of four simple
minerals, as is implied in the preceding paragraph. Thus Fig. 12B
is a photomicrograph of microcline (reticulate or grating structure)
which carries a poikilitic cleavelandite showing polysynthetic
twinning (long crystal extending from the center to the middle of
the right edge). Both these minerals are cut by perthitic albite
(light gray, nearly white) with only a hint of the albite twinning
showing, though this is very clear under the microscope. Since
these poikilitic cleavelandites are commonly seen in hand specimens
of perthite distributed through the microcline in vein-like fashion,
they would appear to represent replacement veins and be later than
the microcline. But they are generally anhedral[1], and have what
appear to be corroded edges (compare Fig. 4B, D). For this reason,
and because they are not uncommonly bent, Andersen[2] thinks they

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1. Andersen (see p. 173 of reference below) and Adamson (see
   p. 30 of reference below) note that some of them are euhe-
   dral. Compare the subhedral cleavelandite (in quartz) in
   the lower left central part of Fig. 14B; also see Fig. 12F.
2. Olaf Andersen, "The Genesis of Some Types of Feldspar from
   Granite Pegmatites." Norsk geologisk tidsskrift, 10, 1928,
   153, 173.

Figure 12: Photomicrographs from Custer
Mt. Lode thin sections.   Magnification
about 10X.

A. Spodumene (upper half) with cleave-
landites (lower right and lower left) and
muscovite (lower left center and middle of
left edge).

B. Microcline (cross-line twinning) with
poikilitic cleavelandite crystal (center
to middle of right edge), both cut by per-
thitic albite (nearly white) of the vein
and patch types.

C. Cleavelandite (lower half) replacing
spodumene. Fringes of tiny muscovites bor-
der the cleavelandites. The dark cleave-
landite at the lower left is part of a
strongly curved crystal.

D. Lepidolite (lower half) extending into
and replacing cleavelandite. Crystals of
the latter in the upper right are separated
from each other by fringes of tiny musco-
vites.

E. Spodumene (upper right), cleavelandite
(upper part, to left of spodumene), and
lepidolite. Note small mass of spodumene
(in lower right center) surrounded by lepi-
dolite; all spodumene is part of a single
crystal.

F. Quartz (upper right), cleavelandites
(right center and along top), and part of
a single crystal of green tourmaline (re-
mainder, except for black area in lower
right, beyond edge of specimen).
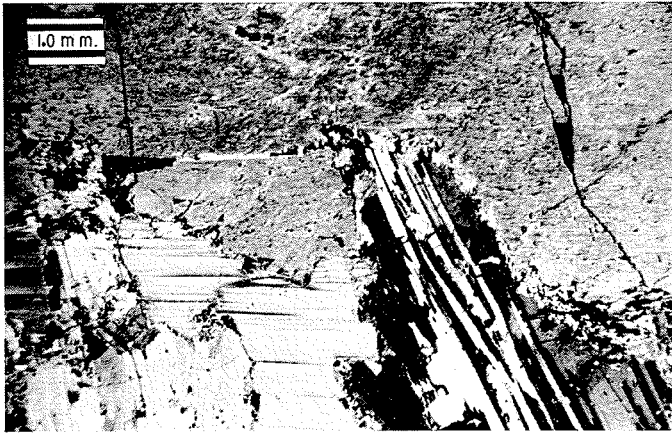
FIGURE 12

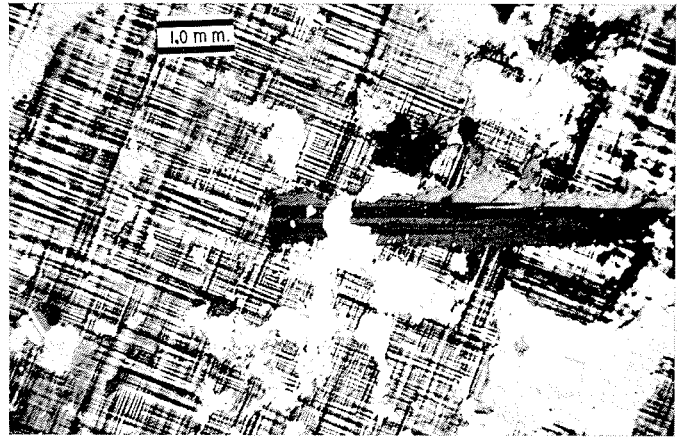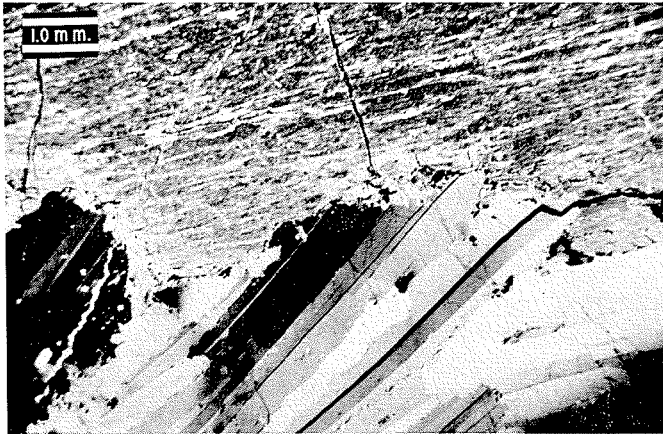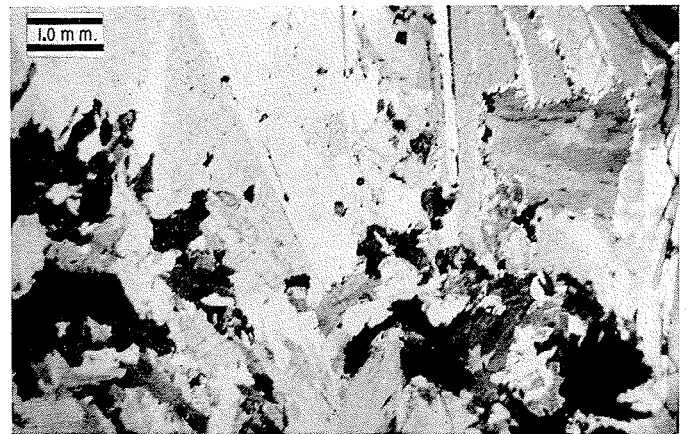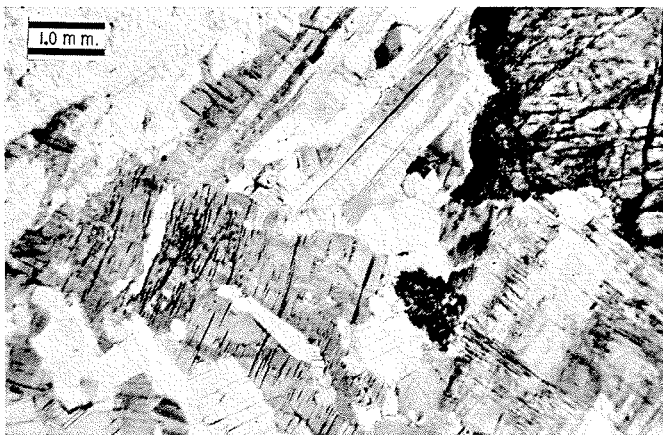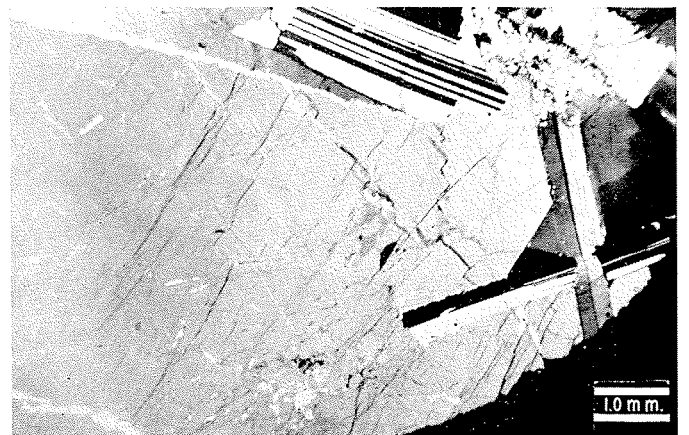formed before the microcline had completely crystallized, and were crowded into vein-like masses between growing microcline crystals[1]. Their unoriented character is also difficult to explain on the replacement theory. Adamson[2] considers that there are two ages of such crystals; the older ones (which carry 10 percent of the lime feldspar component) formed before the microcline and occur isolated in it; the younger ones (essentially pure albite) formed after the perthitic albite of the vein type, since they replace it, and are found either as isolated crystals or in fissure veins. Still later are formed the replacement veins of cleavelandite with other minerals (compare Fig. 14B). The explanation of Fig. 5 indicates that continued perthitization of the microcline producing chess-board albite may occur in connection with these. In any case it is clear from Fig. 12B that the perthitic albite is not (solely) due to unmixing[3], but at least in part is of replacement origin[4].

The five (or six including probable quartz) minerals of Stage II (early hypothermal) in general do not occur in a single association, and so do not represent a petrologic type; thus their relative orders of crystallization are known only in part. However, it is fairly certain that spodumene was later than lithiophilite, since a spod crystal was observed to slice through the edge of a lithiophilite nodule, as has already been described (Fig. 10B).

Lithiophilite and its several associated alteration products, together with cassiterite and Mineral B, constitute a petrologic unit that occurs as more or less isolated nodular masses (euhedrons quite rare) apparently sporadically distributed through the lode, as has been described earlier. Not only is the lithiophilite cut

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1. If this theory is correct, some of them must also have been engulfed in vein-like masses between two prongs growing out from a single microcline crystal. This concept is not highly improbable, as can be seen by comparison with some impure beryl crystals having a core of foreign material.
2. O.J. Adamson, "Minerals of the Varutrask Pegmatite, XXXI, The Feldspar Group," Geol. For. (Stockholm), Forh. Vol. 64. 1942, 30-33.
3. Compare Rept. of Invest. No. 44, 1942, 12.
4. F.L. Hess, "Natural History of Pegmatites," Eng. Min. Jour. Press, 120, 1925, 289-98. On p. 293 (col. 2, and Fig. 3) tiny poikilitic cleavelandites in the microcline of the Ingersoll Mine (at Keystone, S. D.) are said to have formed by replacement.

by spodumene, but also by replacement veins of the cleavelandite and muscovite of Stage IV. On the other hand most of its occurrences are in the quartz (presumably of Stage I); none of it was noted in the perthite[1]. It is thus assumed to be later than these minerals and so considered to be the first mineral of Stage II. The writer is at a loss to explain its nodular shape, though it may be noted that in general amblygonite also tends to take this form. While both minerals are occasionally found as euhedrons or subhedrons, they normally appear to be substances of relatively low morphogenetic power (meaning power to develop crystal faces).

Cassiterite occurs in the lithiophilite as euhedrons and also more rarely as vein-like masses. Since it is found in fresh material, and since the lithiophilite alters very readily, it seems certain that the two are in part contemporaneous but in part the cassiterite is slightly later. It could not have been enough later that the character of the solutions had changed much, else it would be found only in altered lithiophilite. Mineral B occurs in small granular masses and also in veinlets in the fresh lithiophilite. In some cases it seems to sort of encrust a part of a cassiterite crystal; it is thus taken to be contemporaneous with the later cassiterite. The age relation of these two minerals with respect to the spodumene or other minerals is unknowm.

The spodumene is later than the lithiophilite and has replaced quartz in most cases; only one sample was observed to cut perthite. It is also found in the rock of Stage III, but may then be cut by veins of muscovite or cleavelandite. Fig. 10C shows a spod crystal 5 inches wide and over a foot long (with quartz on the right and coarse muscovite-quartz on the left) cut half in two by a book of muscovite; note how the mica plates had proceeded different distances into the spod. Some spod crystals in this environment carried numerous rhombic-outlined euhedrons of muscovite up to $\frac{1}{4}$-inch across, developed by replacement. Similar examples of spods cut by cleavelandite were also collected. Fig. 12C is a photo - micrograph of such a case. One spodumene often cuts off another generally smaller crystal of the same substance.

It is thus assumed that where spodumene is found in the rock of Stage III it represents a remnant from an earlier deposit, generally in quartz. The spodumene was quite resistant to corrosion

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1. At the Tip Top Lode (altered) lithiophilite occurs in quartz veins clearly cutting the perthite; thus there is here no question that it is not one of the minerals of Stage I.

by the liquid of Stage III; only well along in Stage IV when lepidolite was forming did the spodumene become slightly less stable, since while lepidolite often forms an aureole for spodumene, it also replaces it as shown by many excellent samples. Thus in Fig. 12E a single crystal of spodumene has been partially replaced by lepidolite, thus isolating a small mass of the former. The spodumene and cleavelandites are surrounded by narrow fringes of tiny sericite (muscovite) flakes. Three small masses of lepidolite appear in the upper left, between the cleavelandites.

Many of the spodumenes show aureoles of cleavelandites. These are thought to have formed during Stage IV by growing out from the spod surface nearly normal to it, replacing the surrounding rock (generally quartz). These were seen at the Beecher, Etta, and Hugo (Fisher, 1942, p. 31) mines. The presence of similar cleavelandite aureoles around amblygonites at the High Climb (Fisher, 1942, pp. 22, 24) are the main reason for putting the amblygonites of the Custer Mountain Lode as belonging to Stage II. Some of the amblygonite samples collected at this lode are subhedral. They are difinitely later than the lithiophilite, since thin sections of the latter carry veinlets of amblygonite and quartz.

The minerals of Stage III (middle Hypothermal), the quartz-albite-muscovite rock with apatite, beryl, and elbaite, constitute a well-defined petrologic unit. The apatites show crystal faces only against quartz or perthite, and are cut by veins of muscovite and more rarely cleavelandite. Their size varies greatly, and in general is in keeping with the texture of their host rock. Where this rock has invaded the perthite the latter may contain nice euhedrons of apatite formed by replacement; one rather large single mass of apatite is thus euhedral in perthite and anhedral in the quartz-muscovite parent rock. The very definite association of the apatite with the quartz-albite-muscovite rock indicates that it belongs to this stage; of course in part it is conceivably an earlier deposit in quartz now largely replaced by albite-muscovite.

The beryl of the Custer Mountain Lode is in general relatively pure, lacking undigested fragments as seen at the Tip Top and Crown Mica (Fisher, 1942, p. 15). It is in part euhedral, in part massive. It may be that two generations are represented. It cannot be dated definitely. Some of the massive material may be contemporaneous with quartz of the first stage, or in view of the high crystallizing (morphogenetic) power of beryl, it may represent even earlier material partially replaced by quartz I. On the other hand some of the euhedral beryls cut through quartz and perthite in such fashion as to indicate replacement of these. The beryl is

Table 1: Paragenesis at the Custer Mt. Lode

Stage / Mineral	Pyrogenic I	Hypothermal Early II	Hypothermal Middle III	Hypothermal Late IV	Meso-Epithermal V	Supergene VI
Schorl	— – –					
Muscovite	— – –		—	—		
Microcline#	——		—			
Quartz	——	—?—	——	—?——	—?—	
Lithiophilite		——				
Cassiterite		——				
Mineral B		——				
Spodumene		——?				
Amblygonite		——				
Beryl	?		—?—			
Apatite			——			
Albite	– –?–		——	—?—		
Elbaite				——		
Cleavelandite	—?					
Columbite				——		
Lepidolite				——		
Loellingite				——		
Mn dufrenite				—→		
Sicklerite					——	
Pyrite					——	
Daphnite					—?	
Lazulite					—?	
Mineral A						——
Symplesite						——
Mn hydroxide*						——
Limonite						——

\# Commonly perthitized
* Some of this black manganian coating still carries phosphate as well as ferric iron

thought to antedate the muscovite-cleavelandite, since locally the cleavelandite seems to be slightly replacing a bit of the outside of a beryl crystal, and also the striations seen on beryl where some muscovite plates meet a crystal of this substance are very similar to those seen on quartz where the mica plates are growing against the quartz.

The elbaites found at the Custer Mt. Lode vary from deep green (emeralite) to deep blue (indigolite), though the thin transparent tabular crystals growing in muscovite may be a light olive green. They occur in cavities in the muscovite books; they also cut the books and impress tourmaline striations on the edges of the mica (indicating that the tourmaline is the actively growing agent and not the reverse). Both elbaite and muscovite impress similar striations on the earlier quartz; the mica makes sharp angular-walled grooves and the tourmaline, fine grooves with slightly rounded sides. Some of these tourmalines carry unabsorbed masses of quartz completely surrounded by the former. Since tourmalines have great crystallizing (morphogenetic) power, they are ordinarily euhedral, nearly always at least subhedral. They occur growing through mica books in all sizes from tiniest flat plates up to large crystals. This is a common association in many parts of the world. Fig. 12F is a photomicrograph made from a quartz-albite-muscovite vein carrying green tourmaline. It is interesting because the cleavelandites appear euhedral against the tourmaline. Elbaites were not observed in association with the lepidolite. The former are often fractured (commonly roughly parallel the basal pinacoid) and healed along these cracks by gash veins of quartz. Much more rarely muscovite or/and cleavelandite may be associated with such quartz. This indicates that at least some of the tourmaline is definitely earlier than Stage IV, as is shown in Table 1. However, it also seems certain that in part these elbaites are contemporaneous with or even slightly later than Stage IV muscovite.

The writer could make no choice as regards sequence of cleavelandite and muscovite (Stage IV, late hypothermal). Each, at places, gives evidence of having replaced the other; the two are thus regarded as contemporaneous. Columbite occurs in the association of Stage IV, though apatites were not noted; spodumene is present in some cases. Samples collected showed columbite plates cutting through cleavelandite and vice versa; the two are thus considered to be contemporaneous, though the columbite occurs in relatively very limited amounts.

As has already been described, lepidolite was not seen in place, since it comes from a deeper section of the mine now buried by rubble. It is closely associated with the cleavelandites found

fringing the spodumenes; the former mineral definitely postdates the spod, which also shows beautiful replacement by lepidolite, the violet flakes of which cut it quite irregularly. In similar fashion, but less commonly, lepidolite replaces the cleavelandite; see Fig. 12D. Some lepidolite is so pale colored that it becomes difficult to distinguish from muscovite, and in general the two may be in small part contemporaneous. They were distinguished by the low fusibility of lepidolite, and spectroscopic tests for lithium.

The sequence of minerals in Stage V (mesothermal and epithermal) is doubtful. These minerals occur in two associations, loellingite-pyrite and lithiophilite. Loellingite is quite abundant at the Pond Pit, where it occurs typically veining the albite; samples similarly cutting muscovite and lithiophilite were noted, however. Much or all of the loellingite may date from late in Stage IV. One loellingite sample from the Main Pit showed a central vein of pyrite. The lithiophilite association of alteration products has already been described.

Stage VI minerals are regarded as supergene and due mainly to the action of oxidizing ground waters. The loellingite first goes to symplesite, the light blue hydrous arsenate, and then (like pyrite) to limonite. The products of the alteration of lithiophilite have already been discussed; it is conceivable that the final residue is an impure iron-bearing manganese hydroxide, possibly still carrying some phosphorus.

OLD MIKE MINE

Introduction

The Old Mike Lode (Fig. 1, No. 3) is 3 miles north-northwest
of Custer just southeast of the center of the west side of Sec. 2,
T. 3 S., R 4 E. Take the Tenderfoot Gulch (Oreville) road (Fifth
Street, Custer) northwest and north from Custer 3.9 miles, where
turn off to the right (northeast, 0.6 miles beyond the railroad
crossing, shortly before reaching Berne siding), and follow the
lane across Laughing Water Creek and up to the mine, 1.5 miles from
the main highway. It lies high up(about 6000 feet altitude) on
the south side of a col separating tributaries of Laughing Water
and Willow Creeks, at 6.0, 6.1 on air photo BNW 235-111.

This mine has been operated since July 16, 1941, by Mineral
Mills, Inc., as a mica and beryl producer. It is leased from the
Maywood (N.J.) Chemical Works who purchased it in March, 1929.
Maywood also leased it to other operators during portions of the
1930 decade, at which time feldspar was obtained from the face of
the cliff above the old mica workings, according to Guiteras[1].
It produced[2] some mica in 1935. The mine was visited in 1908 by
D.B. Sterrett[3], who described an adit 120 feet long, from the end
of which a drift was run along the strike of the dike; there was
also an 80-foot shaft a short distance southwest of the end of the
adit. It was reported that the mine was operated during World
War I as a mica property, at which time the "dead-end" tunnel
(Inset I) was cut.

Much mica was obtained by stoping upwards to the northeast
from the main drift, following the pegmatite footwall. Operations
by the present lessees continued this process, breaking out to the
surface at the base of the cliff along 5 or 6 openings; thus a
large portion of the base of the main mass of the pegmatite has
been shot away. A view looking west down one of these openings is
shown in Fig. 13A.

Operations in August, 1942, were limited to the continuation
of the robbing of some of the pillars in the stoped-out area de-
scribed in the last paragraph, and the driving of a new drift

1. U.S.Bur. of Mines Infor. Circ. 7112, 1940, 66.
2. Lincoln et al., S. Dak. Sch. of Mines Bull. 17, 1937, 72.
3. U.S. Geol. Surv. Bull. 740, 1923, 299-300.

Figure 13: Views at the Old Mike Lode.

A. Looking west down an opening made by
stoping from the northwest drift along the
granulite-pegmatite contact to the base of
the cliff.

B. View southeast along the cliff face.

C. View southeast along the top of the
cliff at the northwest end of the pegma-
tite. Granite occurs above the white line,
pegmatite below.

D. Looking about west, giving a half-pro-
file view of the cliff face. Granite is on
the left of and above the white line, peg-
matite lies to the right.
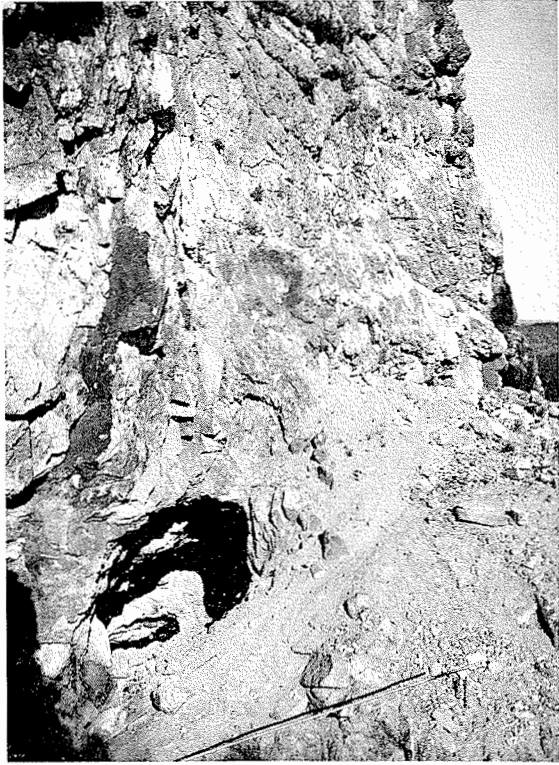
A

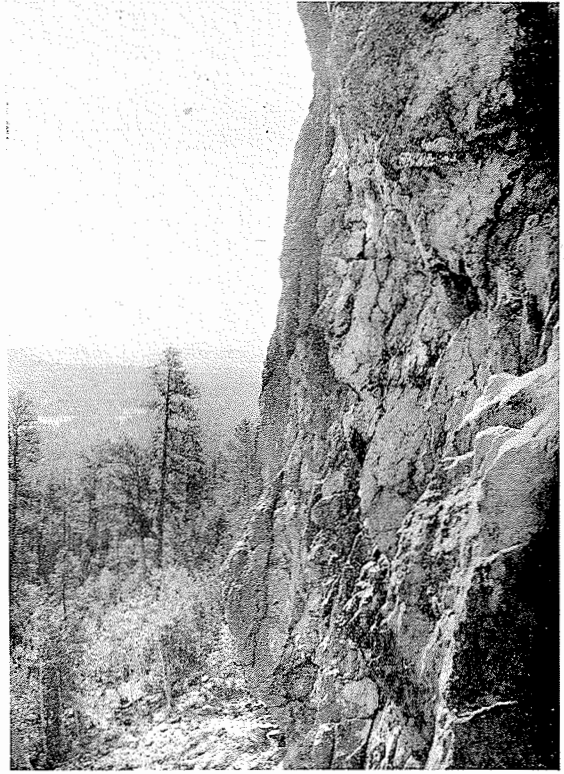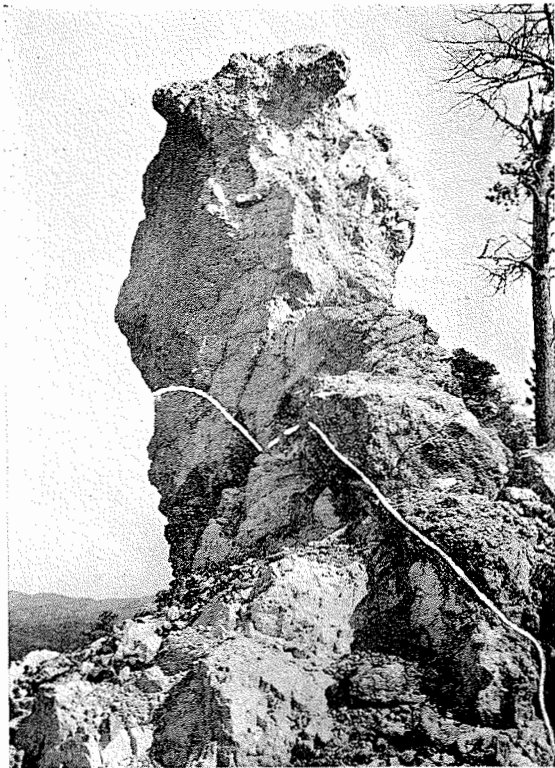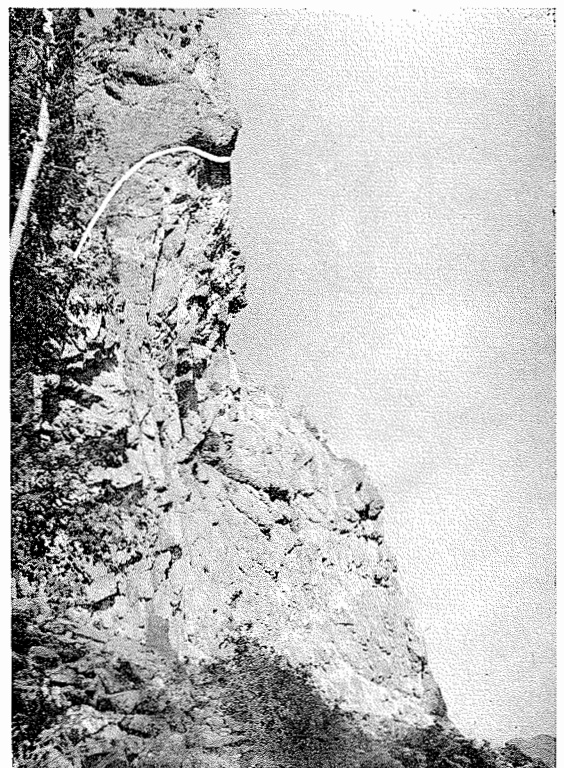

B

C

D

FIGURE 13

(15 feet below the old one) which was being run from the extreme southern tip of the mine working (see map, Inset IA).

During July and August of 1942 two carloads of mica were shipped, and a stock pile of some 60 to 70 cubic feet of beryl was accumulated, along with a pailful of cleavelandite specimens carrying minor amounts of tantalite. Most of the mica shipped was scrap, but there were 500 pounds of small sheet mica and about seven tons of punch. From February to September, 1942, a carload (about 45 tons) of mica was shipped approximately every 35 days on an average. This ran about 1% sheet, 16% punch, and 83% scrap by weight, according to J.W. Sharp, who also stated that some 300 pounds of tantalite (roughly 75% tantalum molecule) has also been sold.

The Pegmatite

The dike stands nearly vertical (with numerous irregularities) and is exposed for a northwest-southeast length of almost 400 feet, with a maximum thickness of about 35 feet, although its end and lower portions are much thinner; see the map, Inset IA. It comprises the northeast end or wall of the northward extension of Buckhorn Mountain, and holds up this end of the mountain in striking fashion. Viewed looking up and across the valley of Willow Creek from the Sylvan Lake road (U.S. 85A) some 3 to 4 miles north of Custer, the dike seems to make a turret-like end to the Buckhorn ridge. The upper 100 feet of its northeast face is bare rock (Fig. 13B), but below this point the pegmatite cuts back (southwest) and down into a steep slope of pine-covered quartz-two mica schist dipping generally nearly 30° to the S. 35° W., but as described below there are local pronounced changes in the attitude of this schist. Inset IC shows a sort of a composite vertical northeast-southwest section through the thicker part of the dike. This brings out well its massive character, especially in its upper portion. While it is quite discordant as regards dip, it strikes in about the same direction as the enclosing schists.

The Old Mike dike is composite; for convenience the two portions will be spoken of as granite and pegmatite. The granite is of giant size, but is not pegmatite, at least it would not normally be so regarded in an area of granite of the Harney Peak type. The average size crystals in the granite are 1-to-2-inch; few non-accessory components are larger or smaller except for an occasional small nest of typically pegmatitic material and except for some of the biotites locally present. For instance these last are beautifully exposed in the highest portion of the dike where in part they

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form thin plates up to 3 feet long and a half foot wide. Some of these large biotites have a partial rim of muscovite, all one single crystal orientation. Similar biotites are present at the Green, Tip Top, and Lincoln Lodes. This granite is rich in muscovite and (locally) biotite of normal size; it carries perthite and quartz, and has been extensively albitized. Euhedral beryls are also present in very subordinate quantity. Small euhedral schorls and grainlets of green apatite also occur.

The granite portion of the dike makes up the highest part of it, as well as the two ends or wings (Inset IA), and is found all along the hanging wall (southwest) side of its upper section, though its presence was not recognized in the mine workings. The contact between the granite and pegmatite is well exposed on the top of the hill near the northwest end of the pegmatite. It is here remarkably sharp, as shown in Fig. 13C (looking southeast at the highest portion of the dike), where it consists of a half-foot thick zone striking with the dike and dipping about 65° to the southwest. This zone is somewhat sheeted and there probably has been some slipping along it, but there is no evidence that it marks a fault. It is in most places rather badly stained, apparently largely with the alteration products of lithiophilite. Near the base of Fig. 13C there is a nearly horizontal vein-like mass of quartz about 6 inches thick which seems to extend from the pegmatite into the granite for a distance of about 2 feet. This indicates that the pegmatite is younger than the original granite, and also that faulting has not been important at the contact. This exposure, however, was hardly satisfactory to establish this point beyond question, and it is surprising that so far as observed the contact between the two rock types is so sharp, smooth, and regular. It is unfortunate that this contact is nowhere else exposed in position accessible for detailed study. The contact zone is rather highly albitized, and while albite-quartz veins cut through the large perthites (Fig. 14B) immediately below the contact, they cannot be traced across it into the granite. Assuming these were later than the granite, which seems certain from the albitized nature of the granite as well as on the basis of the evidence given above, the solutions which deposited them seem to have been diverted along the sheeted zone, and from this pervaded the granite in diffusive fashion rather than along any specific channel-ways.

The pegmatite occurs only in the central (lengthwise) third of the dike, extending for about 150 feet along the foot-wall (northeast) side of the granite. Granite "wings" project to the southeast about 90 feet beyond the pegmatite, and about 150 feet beyond to the northwest[1], as shown on the map, Inset IA. The appearance

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1. According to A.I. Johnson (pers. com. Sept. 18, 1942) the granite extends some 750 feet farther northwest than is indicated on Inset I.

of the pegmatite here however is somewhat misleading, since its southerly portion is largely covered by the granite. In similar fashion the schist hanging wall hides a considerable part of the southerly section of the granite. The manner in which the granite covers a part of the pegmatite is well brought out in Fig. 13D, which is a half-profile view of the cliff face, looking about west; granite is on the left of the white line, pegmatite to the right. The central part of the pegmatite contains a large lens of massive quartz; the shape and extent of this are indicated in Inset IB and C. The quartz mass does not extend as low as is shown in the cross-section in the plane of the adit, but reaches this level about 50 feet to the northwest. Fig. 14A shows the general appearance of the cliff face, looking southwest (compare Inset IB). The granite appears outside the white line above and to the left (southeast) as the darker shade; the quartz mass is roughly outlined by the black line, and the approximate position of the base of the cliff is indicated.

In shape the pegmatite is about like a section of a washer, with a lower "feeder" that is quite thin, but shows pronounced pinch-and-swell structure. It is essentially squeezed out where the adit first hit it, with the result that the dead-end tunnel, cut many years ago, was extended over 20 feet beyond the locale of the pegmatite into the barren schist. The footwall of the pegmatite dips very steeply to the southwest in the northwestern portion of the works, somewhat less so in the southeastern part. The top of the granite part of the dike contains numerous altered schist inclusions, indicating it never extended much higher into the once-overlying schist. Its ridge-like apex slopes down from the central part along the strike either way at a relatively steep angle (26° to 28°). This, together with the remarkable manner in which the pegmatite thins below where the hill-slope meets the cliff that is the northeast face of the dike, is what makes the writer liken it to a section of a giant washer. This thinning is accomplished by the foot (northeast) wall of the dike cutting sharply back (southwest) across nearly vertical beds of schist which have here been metamorphosed into a granulite. This is a tough, compact, light-colored, fine-grained, quartz-rich rock that locally contains many fine schorls and green apatites as well as crystals of albite and quartz up to a half inch across. It appears to the unaided eye to be in considerable part essentially mica-free. It is as if the pegmatite had sucked the abundant mica from the schists of this zone into itself where it had recrystallized as coarse muscovite. It is near this granulite that nearly all the best mica was obtained. All stages between mica schist and granulite contact rock were observed, but the actual granulite-pegmatite contact is quite sharp.

Besides the irregularities already mentioned, there was formerly a sleeve-like branch extending off from the lower part of the pegmatite at the southeast end of the present workings (see map, Inset IA) in a northeasterly and then a northwesterly direction which came out in the large pit above the present adit; the northwest portion of this sleeve was shaped like an inverted metal gutter and sloped up fairly steeply to the northwest. This shoot has now been completely mined out; it is shown in Inset IC by dashed lines, projected on to the plane of the cross-section.

The regional dip of the schist appears to be some 27° to the S. 35° W. as measured on the hill back (southwest) of the top of the dike, though vertically below here in the dead-end tunnel extending on from the adit the dip is gentler, about 20° in a direction S. 45° W. Across the valley to the north, a dike-like extension of the main Harney Peak granite crops out, like a great wall running down the side of the valley. In the adit near the entrance the dip is 30° to the southwest, but this shortly gives way to a syncline plunging 15° to the southeast (the trough of this appears horizontal in the vertical cross-section of Inset IC). This disturbance may be related to the shoot from the pegmatitee described in the last paragraph, but this shoot does not come up the axis of the syncline; rather it is about 35 feet to the southwest where the beds are dipping very steeply (up to 80°) in a northeasterly direction.

In 1942 the writer stated (p. 5) that the typical pegmatites of the Custer District "seem to be more or less isolated masses suspended at bulges in the schist." In short it was not to be expected that they would extend down to the original parent granite mass; their materials had come up along probably narrow channels or passageways. These may have been pinched off, leaving only isolated blobs to mark the course of ascent. The Old Mike pegmatite is mearly an ideal illustration of this principle, as here the dike-like feeder passage shows pronounced pinch-and-swell structure; at the level of the present adit the main dike varies from 0 to 10-12 or even 15 feet in width; much of it is only 6-8 feet wide, or even less. Of course it does not follow from this that the dike entirely pinches out a short distance below the level of the present workings. It may do this; on the other hand it may expand out into an increased thickness. Either case is a reasonable possibility in a locale of such pronounced pinch-and-swell structure.

Looking at the vertical section of Inset IC, and assuming that the normal regional dip is about 30° to the southwest, one can easily imagine that the plunging asymmetrical syncline shown in the schist here had its southwest limb caused by the intrusion of an igneous mass from the southeast slpping up to the northwest; if

this is true, such a mass may now be found below the workings of the
[illegible] mine. On the other hand such a mass may once have been
intruded at this level, but having succeeded in breaking (faulting)
the schist roughly along the plane of the present dike and having
thrown the rocks on the northeast side of the fault up, as is
indicated by the dip of the beds, the pressure may have been so
relieved that the mass (assuming it to have been still fluid)
broke through to a higher level and thus became emplaced at the
locale of the present dike as shown in Inset IC. In this case, the
dike might essentially pinch out a short distance below the level
of the present workings.

Mineralogy

In a crude way the pegmatite may be said to have a central
mass of dominantly light gray quartz (silexite), well exposed in
the lower part of the cliff face (outlined by the black line in
Fig. 14A) about due northeast of all but the extreme northwest
portion of the main northwest drift shown on the map, Inset IA.
This quartz is shaped like the lower half of a steeply-inclined
biconvex lens having a very irregular surface. Its lower portion
is well exposed in the stoped-out opening at the base of the peg-
matite about 50 to 75 feet northwest of the adit; this is indicated
on Inset IC, projected on to the plane of the cross-section. The
outlines of the quartz shown in Inset IB are highly approximate,
since the cliff-face is not fresh enough in all places to be cer-
tain of its mineral composition.

Above this mass, pale pink microcline perthite is a dominant
mineral; it occurs in large anhedrons up to several feet across in
a quartz groundmass. The perthites are cut by albite-quartz-
muscovite veins (carrying minor green apatite grainlets) to a
variable extent; locally the latter rock is very prominent, and
only corrosion remnants of the perthite remain embedded in it.
This sort of rock is well exposed in the lower left portion of
Fig. 13C. Here some of the perthites contain remarkably fine
veinlets that appear to be of the replacement type composed of tiny
albite plates. Fig. 14B is a photomicrograph showing part of a
single crystal of microcline, characterized by the grating struc-
ture, along the upper and lower edges, with a central vein. The
left half of the latter is chiefly of quartz (white), all with
practically the same orientation, though it is thought to be poly-
crystalline. The black areas in the upper left and along the mid-
dle of the right side mark the absence of mineral matter. There is
a "balled-up" mass of tiny cleavelandites (coarser at the peri-
phery) in the right center, and this is surrounded by muscovites.
The microcline contains perthitic-albite of the vein and patch

(lower left corner) types. There are also oriented remnants of
perthitic albite completely surrounded by muscovite. Poikilitic
cleavelandites occur in both the perthite and the quartz; these are
mainly anhedral, but part of the faces are euhedral against the
quartz.

The quartz albite rock varies all the way from nearly pure
quartz with thin white albites outlining augen-shaped apparently-
brecciated quartz masses of irregular lenticular form up to an
inch or so across, to rock consisting largely of rather platy
white albite (semi-cleavelandite). Much of this albite formed
by replacement of the quartz, as is shown by the fact that this
feldspar is not confined to fracture fillings, but platy crystals
extend out into the quartz. On the other hand, a good deal of
quartz was deposited along with the albite, at least in the re-
placement veins cutting through the perthites. While some of this
quartz may have come from solution of quartz already present when
the albite was introduced into the augen-type rock, there is so
much more of it than was likely present in the original perthite-
quartz pegmatite rock that it seems necessary to postulate a later
addition of this mineral. There is no question of deposition of
quartz at this stage, since it (along with contained albite) veins
and corrodes the perthite. Muscovite is relatively unimportant
in this rock in this area.

Below this dominantly-quartz mass (and to a much smaller extent
on its sides and even somewhat above it), the dike is chiefly a
remarkable cleavelandite-muscovite-quartz rock. This statement
refers to the exploited portion of the dike as indicated on the
map, Inset IA. The pale buff cleavelandite is in radiating masses
of plumose crystals up to 8 inches long. These radiating masses
may be crudely spherical or entirely pipe-like. One of the latter
type is shown in the center of Fig. 15A; here there is a cylindrical
mass of cleavelandite which is two feet long and six inches in
diameter. At first glance this resembles a jelly-roll; however,
on closer examination it is seen that the cross-section is not
spiral, but more like a letter C, so that the whole mass is similar
to a section sawed off a log of wood from one side of which one
stick has been chopped away. There is a limb of massive, greasy,
light-gray quartz about four inches in diameter making up the core
of the cylinder. The outer portion of this (where it is against
the cleavelandite) is shot through with thin hexagonal books of
muscovite $\frac{1}{2}$ to 3/4 inches across arranged crudely radially. This
core is succeeded quite sharply by about 3/4 of a cylindrical shell
composed of radially-arranged plumose cleavelandites up to 3/4 of
an inch long (the thickness of this part-shell). The contact is
clear-cut, but is gradational over a short distance, say 1/8 inch.
Outside of this occurs the same sequence in reverse (as though
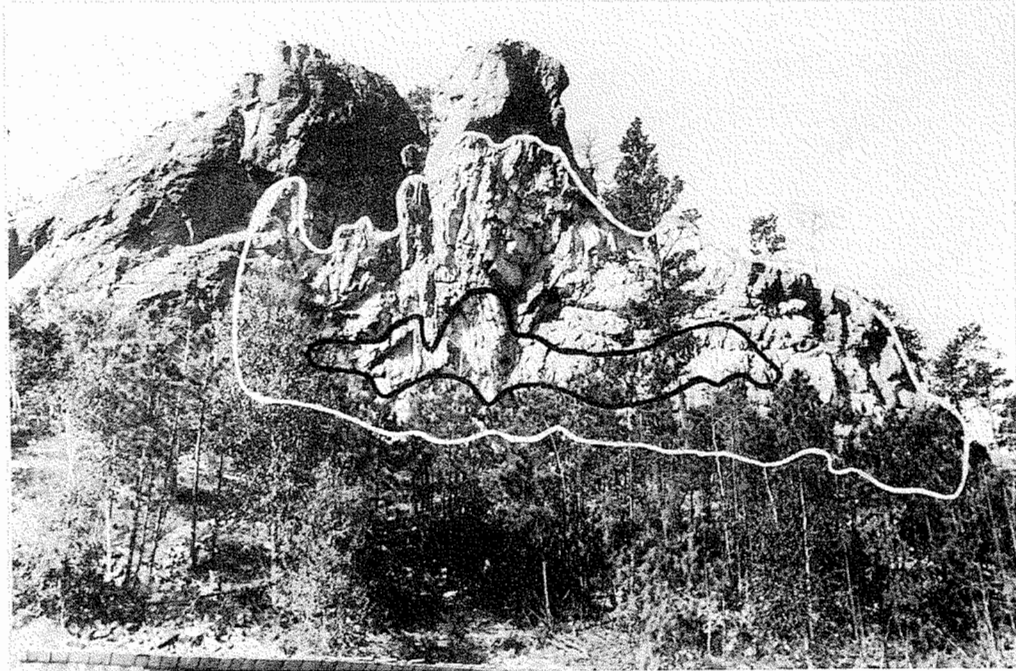
14A. Looking southwest at the cliff face of the Old Mike.
Granite lies above and to the left of the white line. The
pegmatite is within the white line, the lower part of which
marks the base of the cliff. The black line denotes the
mass composed mainly of quartz.
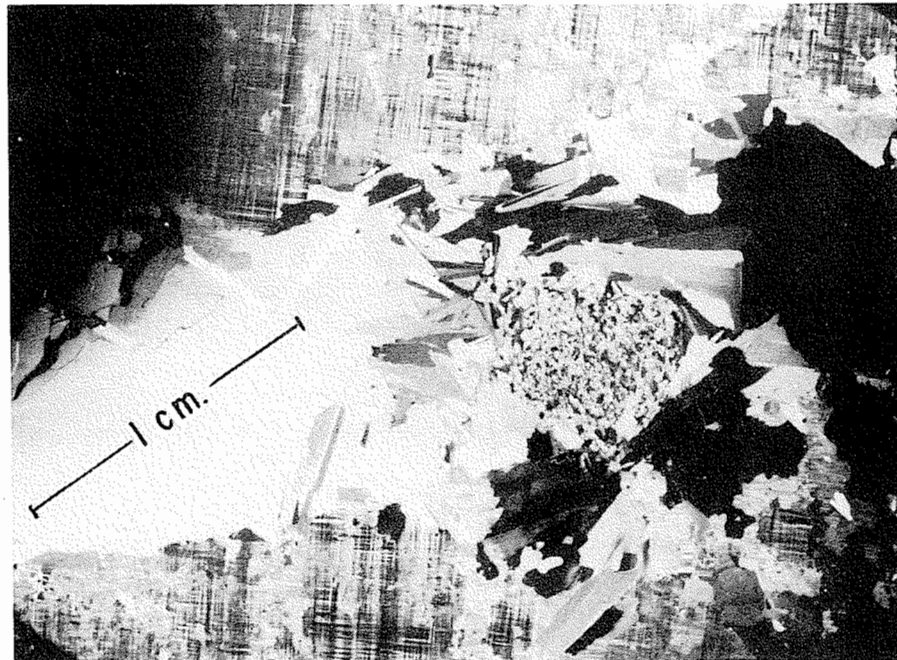
14B. Photomicrograph (X 5, crossed polaroids) showing a
single crystal of microcline (reticulate structure
along top and bottom) cut by a quartz (white) vein
carrying cleavelandite ("balled-up" mass at right cen-
ter, and elsewhere as poikilitic crystals showing
polysynthetic twinning) and muscovite

the outer surface of the cleavelandite shell were a mirror); to wit, a part-shell of cleavelandites about 3/4 inches thick, succeeded quite sharply by quartz, with thin muscovite books cutting the quartz near the cleavelandite contact. The only difference is that this outer quartz locally carries beryls cut by the thin muscovite books, just like those shown in Fig. 16A, B. The two part-shells of cleavelandite meet along quite a smooth surface which is well exhibited in Fig. 15A, which shows mainly the inner shell of cleavelandite, though a part of the outer shell may be seen clearly all along the right side. The material outside of this pipe is chiefly quartz (see Fig. 15B), though along the upper part of the pipe this carries much muscovite in books averaging $\frac{1}{4}$ inch across. Euhedral beryls are common here, too, as is described ahead. In fact, the samples shown in Fig. 16A, B came from this immediate neighborhood.

Such cleavelandite pipes stand at all angles. The one in the center of Fig. 15A is double, with cleavelandites back-to-back. Other pipes are single, and then the cleavelandite may be succeeded on the outside by a layer of muscovite. Fig. 15A was taken looking nearly vertically upwards at a gently dipping section of the roof of the stope. On the right appears the outline of the left side of a nearly vertical pipe approximately 6 feet in diameter. All that can be seen are the cleavelandites (about 8 inches long) in radiating plumose crystals; two other masses of cleavelandite are also present, as is indicated in Fig. 15B.

The radiating nature of the globular or cylindrical masses of cleavelandite is astounding; some of them are 6 or 8 feet through. These may have a central zone of cleavelandite-muscovite ($\frac{1}{4}$ inch crystals) rock, or they may have a core composed of some books of coarse (one foot) muscovite. Rarely they are cut by vein-like masses of muscovite. These cleavelandites have a surface which is pronouncedly mammilliary, as is shown in Fig. 15C, a view of a near-vertical face. These masses cut each other in complicated fashion, but the host rock in which they formed seems to have been quartz. No perthite was observed in this area. If colloform-type structures on a grand scale are evidence of colloidal origin, it is likely that such processes have been important here; Merritt[1] has advocated colloidal growth to explain the tremendous sizes of some of the crystals of pegmatites. However, to the writer a more logical explanation is somewhat as follows. Advancing solutions carrying solutes to form cleavelandite and muscovite (probably in part by interaction with pegmatite materials already present) reached a locale where these minerals started to crystallize at a number of centers. If these centers were spherical, as a marble or

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1. Trans. Royal Soc. of Canada, Sec. IV, 1923, 61-68.

grapefruit, the resulting masses could also become roughly spherical, and the lengths of the individual cleavelandite crystals were determined by how long a given advancing wave of solution lasted. If a later wave advanced from the same central position, a shell of radiating cleavelandites was added to the mass already formed. In some cases successive waves of solution built out crudely-concentric masses several feet in diameter. This accounts for both the radiating nature of the masses, as well as the concentric shells with mammillary surfaces. Uspensky[1] has postulated analogous advancing waves of metasomatic solutions to explain both radiating and concentric structures of the quartz in graphic granite of pegmatites of eastern Siberia. Where the centers from which solutions advanced were not spherical, but rod-like, the result would be pipes. All sorts of intermediate irregular shapes may have been due to inhomogeneities of the wall rock, or variations in the directions of travel of the replacing solutions effected by any other causes. It is the lower portion of this cleavelandite-muscovite rock in which the rich muscovite deposits of the Old Mike stopes were found, overlying the nearly mica-free granulite of the footwall here.

Where this cleavelandite-muscovite rock meets the massive quartz there is an abundance of beryls. These are locally very thick in euhedrons up to a foot long and 6 inches through. Fig. 16A shows a mass from this contact zone in its natural attitude (the ruler is one foot long). The lower two-thirds of this specimen is plumose cleavelandite, the plates standing roughly vertical. Thin muscovite books appear in the upper left center, at the top of the cleavelandite. The upper third of the mass consists of beryls, euhedral except at their lower contacts where they are partially replaced. The material at the center of the top is quartz in the foreground, beryl at the rear; no other quartz shows in the photograph, though quartz capped the whole specimen (surrounding the euhedral portions of the beryls) as it occurred in the mine. These beryls are on the whole small and relatively pure, and many of them do not show partial replacement by the cleavelandite-muscovite rock, but the writer collected a few specimens through which the rim of a cleavelandite-muscovite mass continues uninterruptedly, as if no beryl had been in the way. Fig. 16B is a photograph of one such beryl euhedron (4 inches across the basal pinacoid which appears at the top) in which this phenomenon is very pronounced; it seems obvious here that the once-complete beryl euhedron has had its lower end corroded off by the replacing cleavelandite-muscovite-bearing solutions.

These beryls seem to have formed by replacing the quartz. When the rock is broken down in mining the beryls come out as relatively

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1. Amer. Mineral. 28, 1942, 444.

perfect euhedrons. This portion of the pegmatite around the base and the lower part of the outer (northeast) side of the quartz mass (see Fig. 14A and Inset IB, C) seems to have formed by advancing waves of the muscovite-cleavelandite generating solutions attacking the lower portion of the quartz mass which had already suffered partial replacement by beryl. Each advance of the cleavelandite-muscovite is lead by muscovite. Any beryls in the way tend to be dissolved, though they are far more resistant than the quartz. It seems likely that the dissolved beryls were simply carried on a short distance and then replaced the quartz again. The whole thing may be analagous to, but the reverse of, the development of the secondary enrichment zone at the water table by descending solutions. Only in this way could the writer develop a theory to explain the concentration of beryls in the quartz just ahead of or beyond the cleavelandite-muscovite zone in which they are obviously relatively unstable. Fig. 15D shows an approximately vertical face near the base of the cliff almost directly below the right edge of the highest part of the cross-section, Inset IB. It is only a few feet northwest of the area of Fig. 15C. In fact these two photographs were taken on the two sides of the third entry (counting from the northwest) at the base of the cliff. This Fig. 15D shows a near-vertical beryl 14 inches long just to the right of the hammer handle. The country rock is cleavelandite with minor quartz and muscovite below the hammer head, and quartz grading into augen rock above it and on the right (cleavelandite and muscovite at lower right). This beryl, which is only one of several such crystals at this point, seems to have been badly corroded, especially in its lower part.

The pegmatite in the lower portion of the dike as exposed in the underground workings in the extreme south part is dominantly of albite, quartz, and muscovite. Locally there is much small beryl, but it is a common saying around the mine that where the beryls are thick the muscovite is poor. This albite-rich pegmatite constitutes a very hard, tough rock, since the albite is polycrystalline and cleavages extend for only short distances. This is fair evidence that it is of replacement origin. No cleavelandite or perthite was observed, though cleavelandite pipes were seen on the walls of the drift 15 to 20 feet higher up. This rock, on the whole, seems much like that present near the granulite as is described in the next paragraph.

There is an interesting occurrence of beryl in the pegmatite adjacent to the granulite just above and a short distance northwest of the vertical stope that cuts the main adit about 90 feet in from the entrance (see map, Inset IA). The beryls are in general euhedrons and mostly not over an inch in diameter and 3 inches long. In spots they are thick, cutting each other. They are in a matrix of light gray albite, locally slightly limonite-stained, carrying small grains of green apatite. The rock contains books of muscovite from

Figure 15: Detailed views at the Old Mike Lode.

A. Pipe-like mass of cleavelandite two feet long in quartz (with muscovite above). Part of a six-foot diameter pipe appears along the right side.

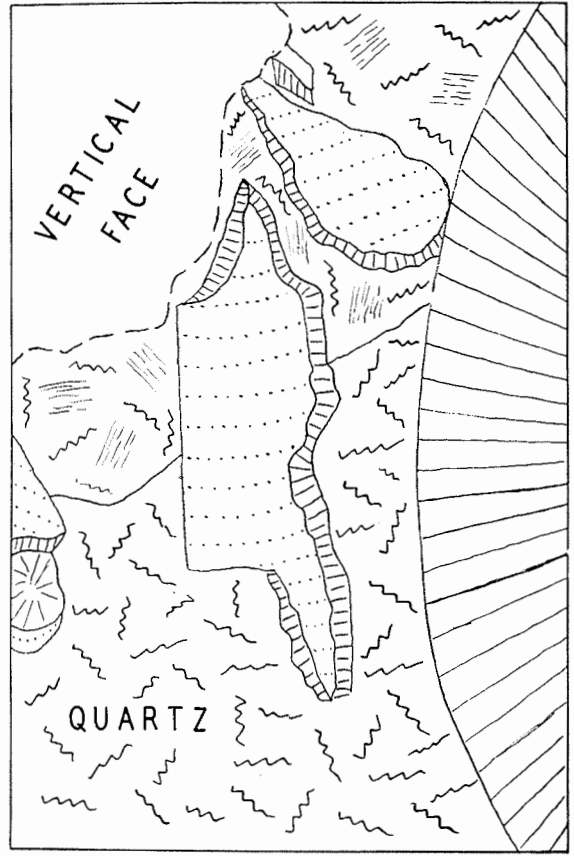B. Explanatory sketch for Figure 15A.

C. Large mammillary surface of cleavelandite. Note hammer along (above) its upper right surface. It is surrounded by quartz except for the mass of cleavelandite in the upper right corner.

D. Barrel-shaped beryl crystal 14 inches long in a matrix of quartz (above) and cleavelandite with minor muscovite.

A

VERTICAL FACE

QUARTZ

B

C

D

FIGURE 15

tiny things to plates 5 inches across. Quartz and greenish scaly muscovite (the latter often coating the beryls) are minor constituents. There is no cleavelandite or perthite. The rock is very tough. Both beryl and quartz cut the albite, but in places the albite seems to cross through the edge of a beryl.

In the stock pile containing some 75 cubic feet of small pale to very pale green beryls, mostly not over 2 inches across, but rarely up to 6 inches, only a few impure specimens were found. Some of these carried cores of other minerals, including quartz, muscovite, and albite, the last the most abundant. Small schorls and apatites are rare, but present in some cores. No perthite was observed, though several tests were made on suspected fragments.

No tantalite was found in place. Sterrett (op. cit., p. 300) says that masses and crystals weighing several pounds were obtained alongside of and in a streak of quartz in the pegmatite cliff. The samples seen by the writer consisted of a pail-full of pieces of cleavelandite carrying small poor subhedrons and groups of tantalite. A little muscovite and quartz were associated. Sterrett also reports the occurrence of cassiterite in the finer-grained parts of the pegmatite. This was not seen by the present writer.

Fresh lithiophilite was found on the dump both at the foot of the cliff and where waste from the present northwest part of the mine is now accumulating; it also occurs along the hanging wall from 60 to 80 feet northwest of the adit and 20 to 30 feet above the floor of the northwest drift. This lithiophilite consists of pale gray masses which carry tiny greenish fibers (index of refraction of 1.75) that give the whole a grayish olive green appearance. It is surrounded by albite and cleavelandite stained blue by vivianite. The presumption is that there were nodular-shaped masses of lithiophilite formed in the second stage similar to those in the Custer Mountain Lode, but carrying about 13 percent of the triphylite molecule, as well as the greenish included microlites. These nodules were penetrated and largely replaced by albite, and later by the cleavelandite-muscovite-quartz rock, leaving corrosion fragments of the lithiophilite. While a little iron was available to form vivianite in the lithiophilite, it is possible that the green microlites were the major source of this metal. Some of these nodules also have the same brownish (sicklerite?) and dirty yellow-greenish stains that are commonly present near lithiophilite. These lithiophilite masses carry schorls that are easily recognized when in the muscovite as a rule; but they occur in granular form also, and then much resemble the cassiterite of the Custer Mountain Lode. The writer tested a number of such pieces which he felt sure were cassiterite, but in all cases they proved to be schorls. A few

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silvery rhombic cross-section "prismatic" loellingites up to 3/4 inch long were seen in this association. They resembled closely those found at the High Climb Lode (Fisher, 1942, p. 23).

The mineralogy of the coarse granite part of the dike (as opposed to the pegmatite) has previously been described briefly. This carries rather abundant muscovite, mostly in the form of small books generally under a couple of inches across. The rather numerous inclusions of more or less metamorphosed schist found along the top of the dike have already been noted; the enclosing schist is also especially prominent along both wings, high up on the hanging wall (southwest) side, lower down to the northeast. It is possible that this granite mass is shaped something like an inverted U, since its central portion does not appear in the present mine workings. It should be noted that little development and no underground work have been done in the wing areas.

Paragenesis

This lode is of considerable interest as here it first became firmly established in the writer's mind that there are two stages of soda-spar, with ordinary albite preceding the beryl, and cleavelandite succeeding it. The evidence backing up this concept has already been presented. Both these forms of soda-spar are stained blue by vivianite where associated with the masses carrying lithiophilite. However, it is significant that loellingite was found only in close association with the lithiophilite, whereas at the Custer Mountain Lode the loellingite occurred veining the albite (p. 56), and cassiterite occurred in the lithiophilite. In short if it be assumed that the lithiophilite antedates the albite, and it seems to occur in part as corroded remnants in the albite as already outlined, then it may be that the loellingite was here an early mineral, as otherwise it would be difficult to explain the apparently close association of the two. Perfectly fresh loellingite is found in vivianite-stained soda-spar, which on this theory would be regarded as unreplaced remnants of the original lithiophilite rock. Unlikely as this theory may seem, there are only two alternatives; (1) the loellingite formed later by replacement, but only in close association with the lithiophilite; (2) the loellingite (which is rare) is not really limited to the lithiophilite association, but was only observed here. The tourmalines found with the lithiophilites probably came in during the later stages of the cleavelandite-muscovite rock, since they occur as euhedrons cutting across and so apparently replacing the muscovite.

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Stage / Mineral	Pyro-genic I	Early II	Middle III	Late IV	Meso-Epi-thermal V	Super-gene VI
Schorl	— -			—		
Muscovite $	— - -		— —	—— —		
Microcline #	———					
Quartz	— ——	—?—	— —	———		
Lithiophilite		— ——				
Loellingite		— — —				
Apatite			——	— —		
Albite	—?—		——			
Beryl				—— — —		
Cleavelandite	—			——		
Tantalite				— — —		
Sicklerite(?)etc.					———	
Vivianite						——
Mn hydroxides*						——
Limonite						——

$ Some hypothermal biotite is present in the granite
# Commonly perthitized
* Some of this black manganian coating still carries phosphate as
 well as ferric iron

From the foregoing evidence it is thus concluded that an extremely coarse granite mass was first intruded; this had essentially the typical pegmatite primary composition, consisting of microcline and quartz with some biotite and muscovite and a little schorl. Biotite is the only unusual component, and much of it, probably all of it in large crystals, came later. This was succeeded by a typical early type pegmatite in which large microclines carrying poikilitic cleavelandites (Fig. 14B) developed in a quartz matrix, with muscovite and schorl very subsidiary; Stage I, pyrogenic. There was also a large central boss or lens of quartz. The microclines are perthitized. It is not certain that some of the vein perthite did not form as a result of unmixing which possibly began to occur while the temperature was dropping during the later part of this stage. The patch perthite, especially that showing chess-board texture, is considered to have formed by replacement, as did some or all of the vein perthite. This process may have begun late in Stage I, but it continued on (possibly intermittantly) into Stage IV.

This pegmatite may have extended considerably farther up dip than it does now. This is indicated by Inset IC from which it is clear that any erosion on the cliff face would mean stripping off the pegmatite rather than the granite in the main. This pegmatite is thought to have been injected along side of the granite without effecting any important change in the latter, the two not differing greatly in composition. The shape of the pegmatite rather favors the idea that it was intruded diagonally up from the southeast at a steep angle; the associated sleeve is also in harmony with this idea, though this shoot or pipe may have been solely a product of later action.

The above sequence and that which followed are indicated in the accompanying Table 2, in which minerals are grouped by associations, and the lines which follow the mineral names represent the relative times and sequences of crystallization. This presents in graphical form the assembled data regarding this subject. There is no certainty as to when the lithiophilite arrived. It is definitely earlier than the muscovite-cleavelandite, since these minerals penetrate the remains of the lithiophilite nodules in vein-like fashion. One sample containing beryl showed the latter as euhedral and apparently cutting through the lithiophilite mass; from this piece alone it is not certain the beryl replaces the lithiophilite; it would be conceivable that the beryl was a residual mass not easily replaced by lithiophilite. However, if the lithiophilite precedes the albite, which it is thought to do on the basis of evidence already presented, then it is the first recognized mineral product to follow the Stage I sequence. The relation of loellingite to lithiophilite has already been presented. These are grouped in Stage II, early hypothermal.

16A. Plumose cleavelandite (below) partly replacing beryl euhedrons (above) from the Old Mike. Muscovite plates appear at the contact in the upper left center. There is a mass of quartz in the upper center (front) partially surrounded by three beryl euhedrons. Natural position as found in mine. One foot scale.
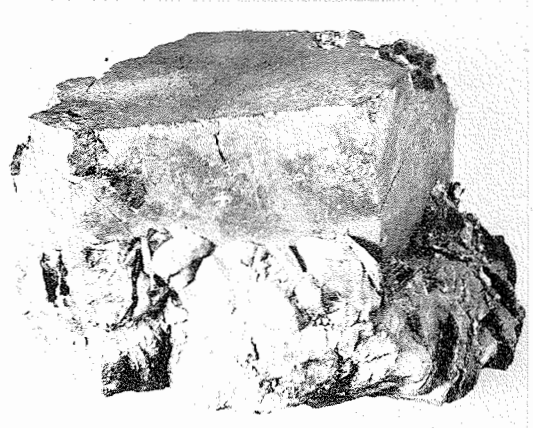
16B. Beryl euhedron (4 inches across basal pinacoid at top) with its lower portion replaced by plumose cleavelandite carrying some muscovite. Plate of muscovite replacing beryl at upper right corner. Old Mike.

16C. Looking northeast at the top of the Ross pegmatite. The schorl-rich zone is at the highest point, just below the main cloud.

The next genetic suite (Stage III, middle hypothermal) is marked by extensive albitization. This was very effective in the lower reaches of the mine; in the upper part of the pegmatite this took the form of semi-cleavelandite cutting the quartz and perthites. Minor muscovite was introduced at this time. The associated granite was also extensively albitized as already sketched. Apparently these solutions were much less effective as attacking agents on the quartz boss than were the later ones from which cleavelandite-muscovite were deposited.

The beryls are thought to have formed originally in the latter part of Stage III by replacement in albite and quartz. None was seen in perthite, and it would appear that the solutions which deposited the beryls were not effective in attacking this feldspar. As in the case of albitization, the formation of beryl was effected in both the pegmatite and the granite, though it is most abundant in the albite-rich portions of the pegmatite and in the edge of the quartz boss.

The succeeding cleavelandite-muscovite solutions (Stage IV, late hypothermal) carried minor amounts of tantalite and possibly apatite. They had little or no affect on the already albitized portion of the pegmatite, but replaced great portions of the quartz boss, so that now the latter is presumably much smaller than it was when the pegmatite was young. They replaced and possibly "drove on" the beryl as already outlined. This was the major stage of mica formation in all probability. Most of the muscovite that occurs closely associated with the cleavelandite clearly formed essentially contemporaneously with it. Masses of it project up from the cleavelandite-muscovite rock penetrating the quartz farther than did the cleavelandite; it thus seems to have constituted sort of an advance infantry ahead of the cleavelandite field-artillery. On the other hand, locally it clearly veins the cleavelandite, and so is in part somewhat later. As already sketched, in part some of the muscovite materials may have been derived from the mica schist wall rock during its alteration to the granulite.

It is impossible to say how much of the mica of the dike away from this cleavelandite association was introduced at this time, but the evidence favoring the concept that a large part of the mica formed by replacement is strong indication to the writer that much of it was likely introduced in Stage IV (see Table 2). Thus the mica of the coarse granite at the top of the dike cuts through other minerals in remarkable fashion; it slices through feldspar (perthite or albite) and quartz masses as if they had been metals cut by an oxyacetylene torch. Similarly in the albite-muscovite-beryl rock (p. 67) the mica penetrates the albites in striking manner. Micas, however, in this rock are not able to cut the beryls, and yet that

they are later is indicated by the fact that they leave a striated
(parallel the mica laminae) surface where they meet the beryls, and
in general the latter show signs of an attack which they had diffi-
culty in repelling. Thin-sections show tiny muscovites replacing
the albite. As already sketched it seems the cleavelandite-musco-
vite solutions more effectively attacked the beryl in a quartz
environment than they could when it was in the albite matrix.

Meso- and epithermal processes (Stage V) are represented only
by alteration products of lithiophilite, and in part it is likely
that these were formed by post-early hypothermal solutions, since
thin-sections show the lithiophilite to be altered most noticeably
near its contacts with the replacing albite. As at the Custer Mt.
Lode, the first alteration is to brown sicklerite, which then is
changed to a black opaque material. Both of these alteration pro-
ducts show up well in thin-section, but are very rarely seen in
hand specimens (sicklerite is common in hand specimens from the
Custer Mt. Lode); the Old Mike hand specimens, however, are commonly
blue from the stain of vivianite, absent or very rare at the Custer
Mt. Lode. Further study is necessary before it can be determined
whether this vivianite is hydrothermal or supergene. In fact, as
already stated it seems unlikely that the vivianite was derived from
the lithiophilite (which according to optical properties has a
lower iron content than that at the Custer Mt. Lode), although it
is obviously closely associated with it in hand specimens. Super-
gene minerals (Stage VI) are represented by stainings of limonite
and also possibly some manganian hydroxide, though the existence
of the latter is not definitely established.

ROSS LODE

Introduction

The John Ross Lode (Fig. 1, No. 5) is 4 miles west of Custer, near the northeast corner of Sec. 30, T. 3 S., R. 4 E. Go 1.7 miles west of Custer on U.S. 16, where turn northwest and follow the Upper French Creek road 2.8 miles. Here just before reaching the mine keep to the left leaving French Creek and going up Crow Creek. It appears on air photo BNW 109-54 at 1.6, 6.1.

The mine was staked by J.L. McKenna as the Highland Lode and sold by him to Westinghouse late in 1906. The latter company worked it during 1907[1]. James McKenna who served as foreman reported that very little mica was obtained from the 85 foot adit along the narrow dike on the southeast side of the lode (see Inset IIA), but that about 50 tons, mostly scrap, were taken from the "cap" of the Ross Hill and from the "prospect pit" just to the southeast; this scrap was sold to the Standard Oil Company for axle grease.

When Westinghouse ceased operations in the Black Hills in 1911, their seven odd mines were let go; these were obtained about ten years ago by the New York Holding Company (consisting of five Custer residents) on a tax-delinquency sale. Ross has leased the mine from this group since February, 1938, in which time he has produced about 9000 tons of feldspar which was sold to Consolidated at Keystone (now trucked to the Custer Mill which Consolidated acquired from Schundler in 1942), about 400 tons of muscovite, all scrap except for 140 pounds of punch and 8 pounds of sheet, and some 60 tons of beryl, which ran about 13 percent BeO. There is also a small yield of columbite (roughly 17 to 20 percent of the tantalum molecule with specific gravity reported as 5.75).

Ross first opened the mine by cutting a trench-like opening at the west end, heading east (see cross-section B-B' on the map, Inset II); this was below the present loading chute and floored at an elevation of about 5575 feet. It has since been largely filled with dump. Next the north trench was cut, with a floor level of about

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1. According to James McKenna (son of J.L. McKenna), but D.B. Sterrett (U.S. Geol. Sur. Bull. 380, 391) states that this mine (presumable Westinghouse No. 3) had not been actively developed prior to August, 1908.

5610 feet. Then the northwest (present main) cut was made, with a floor at about 5605 feet. This was followed by the connecting auxiliary south trench, now used for everything but spar. In the summer of 1941 a 45° inclined shaft was sunk heading N. 55° E. starting at 5570 feet and reaching the 5538 foot level. The floor of this was then extended some 30 feet and a stope run from here some 40 feet up the dip of the dike and above the roof of a mass of quartz. The underground workings shown on the cross-section AA' of Inset II are taken with slight modification from a map prepared by W.C. Stoll and J.B. Hanley of the U.S. Geological Survey in July, 1942. Grateful acknowledgement is made for the loan of this map.

The Pegmatite

This shoot crops out for a width of 150 feet and a length of 400 feet on the upper part of a small sharp subconical hill (Fig. 16C) encircled on three sides by French and Crow Creeks. The circular hill has a radius of about 400 feet, and rises 175 feet above French Creek to the east (Inset IIA). The country rock is quartz-two mica schist which has a north-northwest strike and a southwesterly dip of about 45°. It contains lenses and masses of bull quartz which probably antedate the pegmatite. It is best exposed on either side of the main portion of the dike, but outcrops are also seen to the northwest and southeast. Wherever observed the contact between pegmatite and schist is essentially parallel the schistosity; in short the pegmatite "blister" has bowed out the schist, which now wraps around it.

In plan the pegmatite is shaped something like a cross-section of a plano-convex lens. That is, the lower wall of the shoot is roughly a slightly warped plane surface, striking N. 40° W. with a mean dip of about 40° to the southwest, but the dip is somewhat steeper on the southeast, gentler on the northwest. Because of the relatively flat dip, and the fact that the pegmatite crops out at so much lower a level to the northwest than it does to the southeast, the longitudinal section (Inset IIB) trends N. 73° W., to the west of the actual strike direction. The upper wall of the pegmatite is pronouncedly convex, with a considerable bulge out to the southwest.

To picture the shape of the dike in three dimensions, consider a metal rain trough like that used along the edge of a roof. Regard this as a solid, and it is shaped like a hemicylinder. This is the form of the Ross dike in its upper portion. The axis of this hemicylinder is thought to plunge in about the direction S. 45° W. This deduction is founded on two reasons: (1) at the base of the Ross
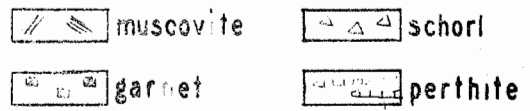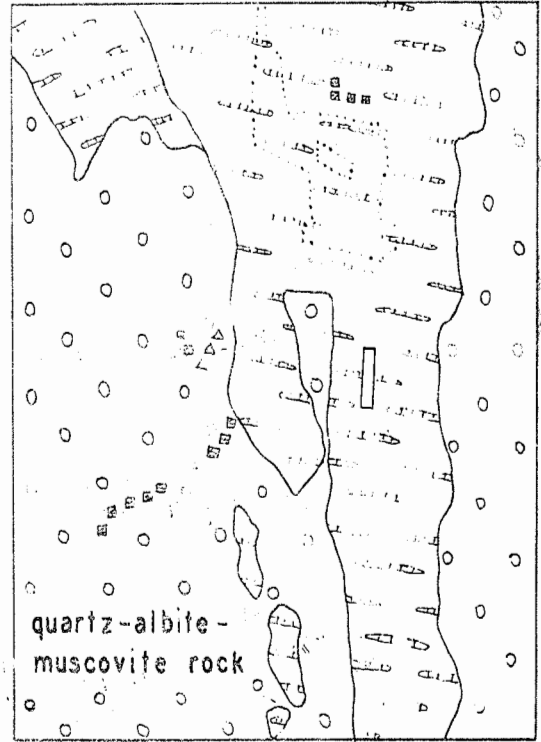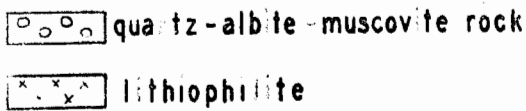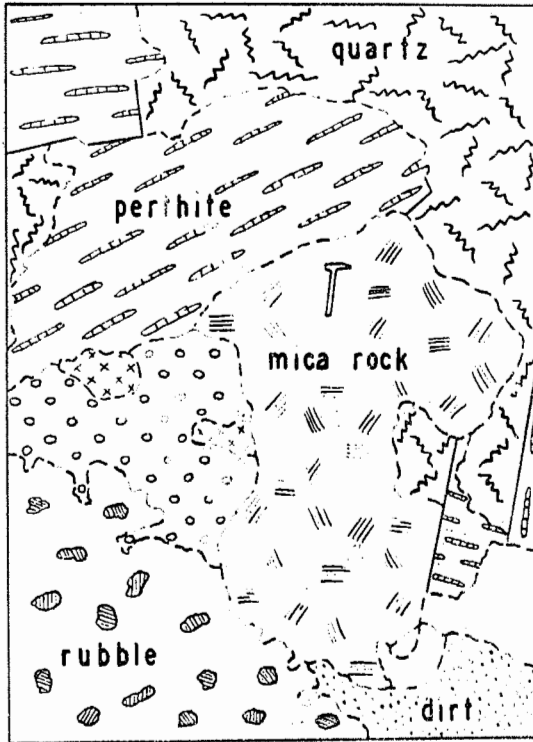
76

A

B

C

D

FIGURE 17

A. This fits Fig. 17A. The continuous lines represent the traces of perthite crystal faces.

quartz-albite-muscovite rock

lithiophilite

B. Sketch interpreting Fig 17B

muscovite   schorl

garnet   perthite
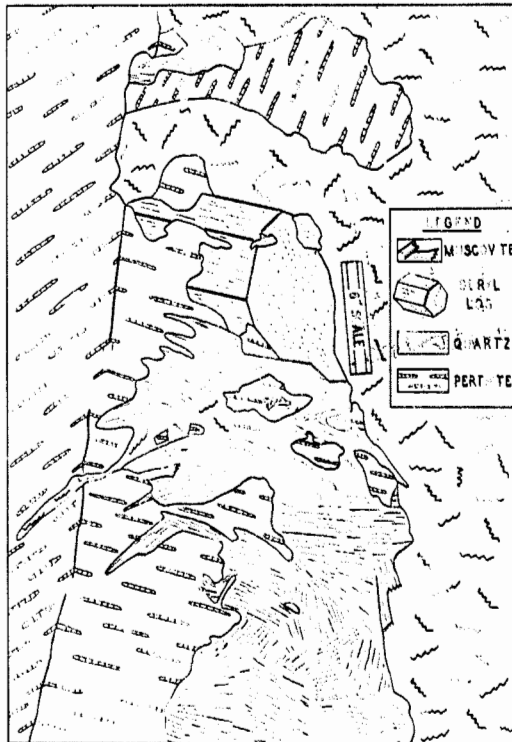
C. Drawing to interpret Fig. 17C

LEGEND
MUSCOVITE
SCROLL LOG
QUARTZ
PERTHITE
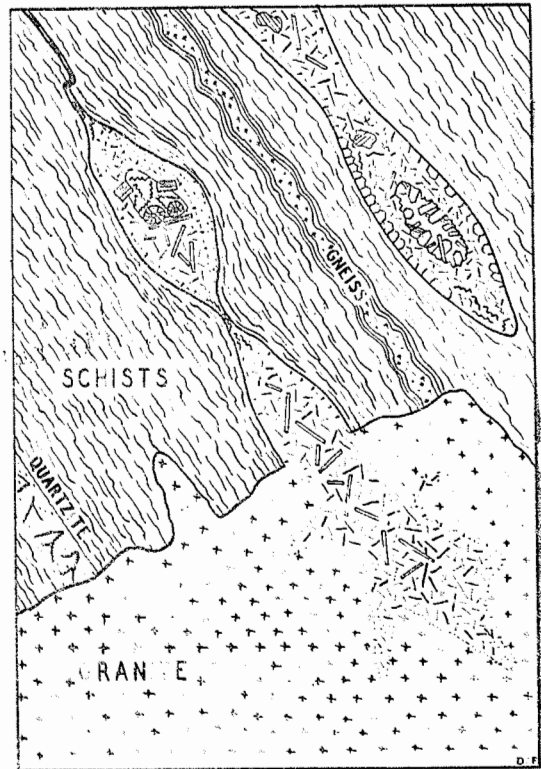
D. Diagrammatic cross-section or plan to bring out the characteristics and peculiarities of pegmatite deposits.

Figure 18. Diagrams to explain Fig. 17

Figure 17: Detailed views in the pit of the Ross Lode.

A. Mass of mica rock, carrying some feldspar and quartz. See interpretative sketch (Fig. 18A) on the opposite page.

B. Corroded remnant of a large pink perthite crystal in quartz-albite-muscovite rock. The scale is six inches long. Compare Fig. 18B.

C. Beryl log, immediately left of the six-inch scale. The beryl lies approximately at the quartz-perthite contact; but it seems to be mainly in the quartz. See Fig. 18C.

D. Schorl-rich zone at the top of the pit (compare Fig. 16C). The black tourmaline is mainly in quartz, but an elongated mass of slightly albitized pink microcline occurs along the right side of the hammer handle in such a manner that it and the handle roughly form an inverted V. The right side of this photograph should be held horizontally (and below) to fit natural conditions.

incline where the pegmatite is first reached it is clear from the strike of its upper surface that the maximum "bulge" on the upper wall of the dike is some distance to the southeast; (2) taking the southeast tip of the pegmatite as composed of two planes (lower wall dipping 60° to S. 50° W. and upper wall dipping 50° to S. 5°E.) their line of intersection plunges approximately 30° to the S. 45° W. (as worked out graphically on the stereographic projection).

Of course this dike must not be thought of as shaped like a hemi-cylinder for any great depth. It possibly expands somewhat for a short distance down, but presumably at no great depth it pinches out, or at least gets much less bulging; it is thought to be more or less blister-like in a transverse vertical cross-section along the direction of dip (compare Inset IIC). From pockets of schist in the roof of the pegmatite just southeast of its highest point, and also at the top of the southeast wall of the present pit, it seems clear that the shoot never extended much above its present level. Erosion has removed most of the overlying schist, but little of the pegmatite itself (Fig. 16C). It ended as quite a blunt affair, something like the south end of the Buster Dike (p. 23) in plan. This is indicated by the steep dips in the schist (75° to the southwest) which may be seen just on the northeast edge of the center of the footwall of the shoot. In short the schist was badly deformed here by the relatively blunt end of the dike (see upper portion of inset IIC).

This shoot has other peculiarities of shape rather difficult to describe, but made fairly clear from the left portion of cross-section B-B' of Inset II. This shows how instead of a smoothly-curving upper surface in this cross-section, it rises by a series of bulges. This is very evident from a study of the shape of the curving upper wall of the pegmatite near the south end of the main dump, and also of the block-like mass of original pegmatite exposed along the west side of this dump just northwest of the lower end of the loading chute. The map, Inset IIA, shows by dashed lines with ditto-like cross-marks the positions of such breaks of slope between successive bulges. There is a series of disjoined pegmatites to the northwest of the reservoir (see the map) which may represent a thinned continuation of the Ross dike, possibly offset to the northeast by three vertical cross faults striking about northeast, the least important and southeasternmost of which may run along Crow Creek. These dikes extend beyond the Highland Lode on to the Dottie Lode; they were not investigated in this study.

Blocks of pegmatite litter the ground to the east of the entrance to the incline. These cannot be traced beyond the small southerly dump (Inset IIA), but they may mark the continuation of a

flying-buttress like dike which branches off from the southeast end of the Ross shoot. This is indicated hypothetically on the map, though it is merely a guess based on the assumption that this dike dips about 40° to the southwest and that it connects up with the dike which may be observed branching off from the southeast end of the main shoot; of course, if the two are connected, it is a subsurface phenomenon.

Approximately parallel to the lower (nearly plane) wall of the Ross shoot, and about 60 feet below it (normal to the plane of schistosity) is a dike which may be traced from the main dump some 150 feet in a southeasterly direction, where it pinches out in the schist. This is essentially in the same stratigraphic position as the dike 150 feet and more southeast of the Ross shoot in which Westinghouse ran an adit 86 feet long (Inset IIA) heading northwest from Mayflower Gulch, and on the upper end of which they cut a prospect pit 14 feet deep. It is possible that these two dikes are connected underground or once were connected above the present surface, as is indicated on the map. This dike thickens and thins, and contains remarkable schist inclusions. In the prospect pit it is 8 feet thick high up near the southeast end, but only 2½ feet thick at the lowest point near the northwest end.

Mineralogy

The first impression one gets from seeing the Ross Mine is that in the main it consists of a mass of large euhedrons or subhedrons of beautiful pink perthitic microcline in a groundmass dominantly quartz. These large feldspars are up to 10 feet long (parallel the a-axis) and 2 by 2 feet in cross-section; graphic quartz was not observed.

Such lithology is well shown along the southwest wall of the pit, particularly near its northwest end, and also in the lower part of the south wall of the pit. Much of the rock removed from the pit is thought to have been of this character, the "perthite zone" of Inset IIC. From observations in the stope and pit, it seems as if this rock forms a sort of heavy layer, quite irregular, averaging perhaps 20 feet in thickness, which lies in the stratigraphic upper half of the dike throughout its "bulged portion." This rock-type may be somewhat thicker in the higher part of the dike than is shown on the cross-section of Inset IIC, but observations in the northwest (main) trench indicate not. This rock type is further discussed

"Stratigraphically" above and below this perthite-quartz rock ("perthite zone") the amount and size of the perthites decrease, gradually in most places, quite suddenly at a few spots. However, in nearly all surface exposures perthite is an important constituent of the dike, providing one does not limit his observations to a relatively small area. In general as perthite becomes less important, albite appears in increasing amount. But only locally is albite the dominant feldspar; it probably does not constitute 15 percent of the whole dike as seen in surface exposure, whereas some portions (especially much of that now mined out) are over 50 percent perthite. With the exceptions and wide variations noted below, that portion of the main part of the dike mapped simply as "pegmatite" (InsetII) is composed of this second rock-type, which consists of more or less corroded perthites in a matrix of quartz-albite-muscovite with subsidiary beryl, garnet, schorl, columbite-tantalite, and phosphate minerals. This rock apparently formed by the partial replacement of quartz by albite, etc.; there was a noticeably less tendency for these minerals to replace the perthite. Some of the albite might be classed as semi-cleavelandite, but no typical cleavelandite was observed in the Ross Lode. Muscovite generally is a relatively minor constituent of this rock type, except locally where it is the dominant mineral (see the sixth rock type).

Along the front (northeast) side of the floor at the base of the incline, there is exposed a steep face of quartz about six feet high. The stope is bottomed approximately on this material, which may be regarded as a third rock type. Its upper portion along the northeast side of the floor carries three excellent euhedrons of perthite from $\frac{1}{2}$ to 1 foot across. Ross said that at one place he broke through this mass of quartz into albitized rock. The quartz rock (silexite) may thus be about as shown on Inset IIC, though little is known of its true shape. Some of the (stratigraphically) higher rock around the south end of the north trench is rich in quartz, and may be regarded as intermediate between this rock type and the first (perthite-quartz) type.

A fourth rock-type present is the tourmaline-rich zone at the top of the dike (Inset II and Fig. 16C). The tourmaline in this rock is all of the black variety known as schorl; no other kinds of tourmaline were observed in this dike. Fig. 17D shows a detailed view of this zone, and Fig. 19A is a photograph of a large crystal with hexagonal prism and basal hemipinacoid. Other crystals were terminated by the trigonal pyramid. This schorl rock is shaped like a biconvex lens, or possibly like a plano-convex one, with the plane side down. This lower contact is very indefinite, grading down into the regular pegmatite with less and less schorl. The schorls are very thick for a distance of about 10 feet from the top of the pit. as is well shown on the face of the pit (Fig. 17D). This schorl

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zone apparently forms a flattish cap at the highest part of the dike, and Inset IIC should probably be slightly modified to better bring this out.

In the main the schorls are in a matrix of quartz carrying a fair number of perthites. Unlike most crystals, schorls grow through these, though not so readily as they do through the quartz; thus the larger schorls tend to be in a quartz matrix. The schorls formed as crudely radiating spindles growing out in all directions from a central spot, which spot is generally composed of albite-muscovite; elsewhere albite is not a common constituent of this rock. The schorls are slightly club-shaped, with the larger ends away from these central spots. These schorls apparently represent the same thing as is shown in the Smith Mine (see Fig. 3A), but tourmalinization at the Ross Lode was carried out much more extensively. Somewhat similar development[1] appears in the S.P. Mine 1½ miles southeast of Nuevo, Riverside County, California. Only in the Ross Lode, however, do the schorls seem to be concentrated at the highest spot. Muscovite is commonly associated with these schorls; it may occur as plates, parallel tourmaline prism faces, and even be included in the schorls giving results resembling a jelly roll; or it may occur as plates clearly cutting into and apparently replacing the schorl.

Near the southeast edge of the tourmaline-rich zone (Inset IIA), brown garnets are found associated. These occur as 2-inch icositetrahedra (211), and also as anhedrons, especially the latter when against or within the schorl. One such euhedron was pierced by a prismatic acicular mass, half schorl and half musocvite, the whole resembling a cupid's arrow through a heart.

A fifth rock type may be designated the phosphatic, because of the presence of lithio hilite and other phosphates. These occur as nodules or irregular masses which rarely show crude vein-like shapes. This rock type is distributed in units too small and too scattered to indicate on a map made on as small a scale as is Inset II. They are most abundant in the west and south walls of the main pit near the south trench. The phosphate minerals are found in close association with the albitized rock. However, it is thought probable that the major phosphate deposition preceded that of the albite suite, and formed by partly replacing the quartz between the perthites. Later albitizing solutions followed much the same pathways and so resulted in albite forming near the phosphates, and in fact partly replacing them.

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1. See L.H. Dykes in Bull. Geol. Soc. Amer. 44 (1)1933, 161.

Lithiophilite seems to be the most abundant of the phosphates; other similar associated phosphates not yet positively identified include the isomorphous triphylite, as well as triplite or childrenite. Lithiophilite alteration products sicklerite, Mn heterosite (purpurite), and vivianite are also present. Montebrasite (fluorine poor-hydroxyl rich amblygonite, as shown by the relatively high indices of refraction) occurs in nodules up to a foot across, much like the lithiophilite, but it is not a common mineral. These white nodules are often limonite-stained; one of them in the quartz-albite-muscovite rock seemed to definitely embay into a large perthite and it in turn was cut by albite. Some of the white montebrasite nodules were surrounded by quartz carrying small euhedrons of a pale greenish-yellow montebrasite; montebrasite of this latter color was also found by Ross in the Prospect Pit (Inset IIA). At only one place were montebrasite and altered lithiophilite seen in contact; here the former was poorly subhedral, and so was possibly slightly later than the lithiophilite. Nodules of the latter mineral slightly embaying the perthites were observed.

Greenish blue apatites are found as small euhedrons in the quartz-albite rock, and as slightly larger irregular masses, in part subhedral, in association with the montebrasite of the Prospect Pit. The apatite is regarded as a late mineral of the phosphate sequence extending over into the earlier part of the albite suite; it is quite uncommon. The indices of refraction fit fluorine apatite.

A few masses of a dark green to greenish-black fibrous pleochroic substance found associated with phosphate minerals appear very similar to dufrenite; the indices are a bit low, and so tentatively the substance is classed as a manganese dufrenite. Further work on this mineral, which was also observed at the Green Mine (No. 21 of Fig. 1), is required. It is probably not the same mineral as the Mn dufrenite (?) of the Custer Mt. Lode(p. 44).

Locally there are irregular "bull-head" masses of rather fine muscovite (crystals 1 inch across or less) that may be regarded as a sixth rock type. Only a few of these were seen, and this rock type is quantitatively the least important. One such mass shown in Fig. 17A is near the base of the south wall just east of the south trench. This mica rock carries some feldspar and quartz, but rather less of these than is seen in similar rock in the Buster Lode (see page 23), or in the Custer Mt. Lode (page 47). Those perthite boundaries denoted in Fig. 18A by continuous lines represent the traces of crystal faces. The large perthite is corroded by the quartz-albite-muscovite rock in the left center, and by the muscovite rock just above the center. It is likely that this mica rock is formed by partial replacement by muscovite of the quartz-albite-muscovite rock, and so this rocktype can be regarded as a special

phase of the second rock type (perthite-quartz-albite-muscovite rock). Besides this muscovite that is thought to have formed rather late in the albite stage, most of which is in plates not over one inch across, there is similar muscovite along the wall rock that is believed to have formed early, and also somewhat later and much coarser muscovite (often associated with the beryl logs which are described in the following paragraphs).

Beryl occurs in three manners in the Ross Lode: (1) as large green beryl logs up to at least 5 feet long and $1\frac{1}{2}$ feet through in the perthite-quartz rock; these are deeply grooved and subhedral; (2) as small green beryls, generally subhedral, in the quartz-albite-muscovite rock; rarely this beryl is in 1/8-inch diameter columns forming radiating masses; (3) as massive golden beryl (indices of refraction 1.575-1.581), mostly badly flawed, but in part of gem quality, in the quartz-albite-muscovite rock.

Fig. 17C shows a typical beryl log high up in the Ross Mine near the east end of the south face. It lies in quartz at its contact with perthite, along which contact just below the log there has been much replacement by large sheets of muscovite up to 8 inches across. Some of these muscovites have also replaced the beryl. Essentially all of the perthite appearing in Fig. 17C belongs to two crystals; the one above the beryl log is much the smaller, and it exhibits several crystal faces. That side of the other one farthest from the observer nearly coincides with the rock surface over the right-hand three-quarters of the picture; this accounts for the apparently irregular contact between it and the beryl log as shown in Fig. 18C; the perthite here constitutes but a thin layer which has not yet been stripped from much of the side of the beryl log. A much larger beryl log showing identical phenomena (except that part of the associated quartz is rose quartz) is found in the same wall 20 feet farther west. A dozen logs averaging nearly 6 inches through were seen in this mine. One such crystal 5 inches across exposed underground on the northwest wall 20 feet from the base of the incline showed a near-perfect hexagonal outline, except that one side and its two angles (edges) had been eaten away by albite rock.

Fig. 19B is a photomicrograph of a thin section of the albite-quartz-muscovite rock showing a central beryl crystal surrounded by quartz and albite. Two prong-like masses of albite extend toward the lower right corner running through quartz (black). There is also another beryl crystal (black) just above the middle of the right side, causing the rectangular notch here in the albite. An enlarged view of the central beryl (gray) appears as Fig. 19C. This beryl is euhedral against the quartz on the left, anhedral towards that on the right. The lower albite mass has apparently corroded

19A. Large schorl crystal show-
ing hexagonal prism and basal
hemipinacoid. The scale is one
foot in length. Ross Lode.
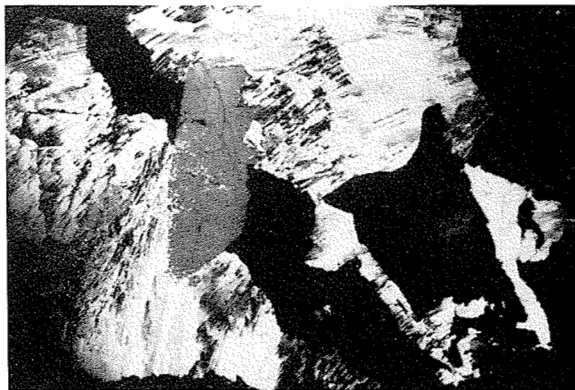
19B. Photomicrograph showing
vein-like mass of quartz
(black, upper left to lower
right) interrupted by beryl
(gray, left center) in al-
bite (crossed polaroids,
        2 1/2 X)
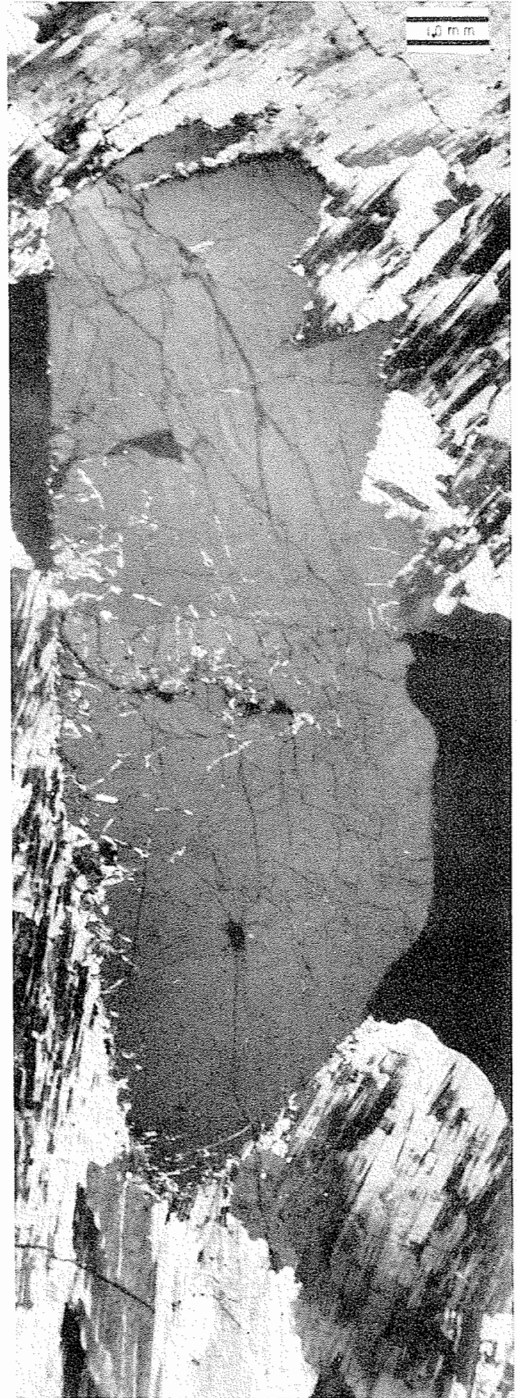
19C. Enlargement (to 12 X)
of beryl from Fig. 19B

the edge of the beryl crystal only slightly, but the upper one pene-
trates it in irregular jagged fashion strongly suggestive of replace-
ment. All this albite shows a pronounced wavy structure, as if the
albitizing solutions advanced by successive stages. The twinning
lamellae are bent, possibly due to stress at the time of crystalli-
zation. Tiny unoriented muscovite flakes are found in the albite
along its contact with the beryl; in general these are not present
along the albite-quartz or the beryl-quartz contacts. These flakes
are especially prominent along the beryl contact with the lower
albite crystal; here they even extend some distance into the beryl
along cracks in this mineral. The albite is cloudy (no analyzer);
this is due to many tiny needle-like inclusions visible at 450
diameters; these are mostly oriented parallel the twinning lamellae.
Since the quartz is all approximately of the same orientation, it
probably formed first; then it may have been partly replaced by
beryl; last to form would thus be albite, with minor amounts of
muscovite.

        Garnets are quite common in the Ross Lode. Some are chocolate
brown (211) icositetrahedra modified by small dodecahedra, and others
are translucent light-reddish-brown, granular anhedra. They occur
mainly in the quartz-albite-muscovite rock, but are also present
near this in the perthites. The latter have dark-colored reaction
rims and just outside of these there are generally a few grains of
quartz. Some euhedral perthites (in quartz) are surrounded by a
corona of albite which carries numerous garnets along the practical-
ly uncorroded perthite boundary. All these garnets are isotropic
spessartites with index of refraction about 1.803 and specific
gravity of 4.2. The interiors of the dark garnets contain irregu-
lar masses of the light-colored ones.

        Schorls are present not only in the "schorl rock" previously
described, but are also common in the quartz-albite-muscovite rock.
They are generally euhedral, but often carry or engulf muscovite,
though some schorls are clearly partially replaced by muscovite.
Schorls occur in this rock in the west wall of the south trench, at
the contact with the overlying schist. Euhedrons here normal to the
hanging wall as in Fig. 3C are up to 7 inches long and 1 inch across.
Similar schorls normal to the footwall are present in the basal part
of the pegmatite at the extreme southeast end of the dike. They are
also well shown in the small dike (some 60 feet stratigraphically
below the main Ross pegmatite) at the Prospect Pit, and at the mouth
of the Old Adit (see Inset IIA). A few schorls were observed out-
side of the "schorl rock" which cut into a perthite crystal, but
this is not a common relation.

        Some of the quartz of the Ross Lode shows a pale rose color,
though most of it varies from clear and limpid to grayish-white,

today. Banding due to milky layers is not common. A little smoky quartz was observed, as were one or two vugs carrying euhedral rock crystals. The rose quartz occur in the central portions of quartz masses, well away from the perthites; its color is apparently destroyed by any later albitization, since it is found only in the relatively pure quartz masses. No amethystine quartz was seen in any of the Black Hills pegmatites; this is in line with the fact that pegmatitic amethyst is found only as a vug mineral[1], and vugs are rare in the Black Hills pegmatites. In the Ross Lode there are all gradations between masses of nearly pure quartz, through quartz with here and there a little albite or/and muscovite, to typical quartz-albite-muscovite rock showing a poor augen-structure and carrying corroded remnants of perthites, to the muscovite rock itself, carrying only minor amounts of quartz and albite.

Fig. 17B shows the macropinacoidal cleavage face of a pink perthite crystal, with the basal cleavage cracks and the a-axis nearly vertical. See Fig. 18B for an explanatory diagram. The crystal is about six feet long (parallel the a-axis) and some two feet across at the top. It lies on the west side of the north trench of the Ross Lode. Just to the left of the 6-inch scale there is a vein-like mass of albite-rock projecting up into the crystal. Two isolated fragments of the same perthite crystal (as shown by cleavage orientation) appear near the middle of the lower part of the photograph. A second smaller perthite crystal is present in the shadow of the upper left corner. It is thought that this large perthite formed as a euhedron in quartz, and that later albitizing solutions dissolved away part of the quartz and perthite, replacing them with albite, garnet, schorl and muscovite. The garnets in the upper part of the large perthite have reaction rims, as has already been described. The perthite also shows replacement-type veinlets consisting of small platy albites, as is so common in the Custer area (see the discussion of the paragenesis of the Stage I minerals of the Custer Mt. Lode).

John Ross had a few small splinters of white spodumene that he collected from the mine. These samples did not carry associated minerals, so no conclusions regarding occurrence can be drawn, since the writer did not find this mineral in place.

The metallic or submetallic-lustered minerals present in the Ross Lode include columbite, cassiterite, arsenopyrite, and pyrite. The columbite is found in typical striated black platy masses cut-

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1.   E.J. Holden, "The Cause of Color in Smoky Quartz and Amethyst," Amer. Mineral. 10 (9) 1925, 210 (203-52).

ting through the albite as a rule, though the mass of lithiophilite near the center of Fig. 17A also carried it. Since albite was also found cutting this lithiophilite mass, this one association of columbite and lithiophilite is regarded as fortuitous. The columbite clearly cuts the albite. This relationship could be interpreted as (1) earlier crystallization of the columbite (in quartz, later replaced by albite), (2) simultaneous crystallization of the two, the columbite having the greater morphogenetic power, or (3) replacement of albite by columbite. The last seems the simplest and most logical concept. Where a plate of columbite meets a muscovite cleavage, the former ends, and is not found beyond the muscovite even though the latter is quite thin. It thus seems that the muscovite preceded the columbite.

Small euhedrons of cassiterite up to $\frac{1}{4}$ inch across were found associated with an irregular vein of pink albite cutting through a sample of lithiophilite collected by John Ross. Minor muscovite, garnet, and quartz are also present, and the lithiophilite shows alteration to purpurite and vivianite.

Pyrite with minor arsenopyrite were found in two samples of phosphatic nodules; these carried altered lithiophilite, montebrasite, and a greenish black manganese-rich dufrenite (?) which were cut by vein-like masses of pyrite.

Paragenesis

Table 3 is an attempt to show the relative times of formation of the minerals of the Ross Lode by means of horizontal lines following their names. The minerals are grouped into four main associations, outside of which is pyrite and certain iron and manganese alteration products. Enough evidence was not observed to be certain of all the data indicated in this table; certain qualifications have already been presented and others appear below.

The original or pyrogenic Stage I in the Ross Lode is thought to have yielded a pegmatite consisting of microcline euhedrons in a groundmass of quartz; near the walls schorls and muscovites also formed. An important period of time was involved in this stage, not only because the large size of the microclines would require this, but also since there are certain minor complications of detail (poikilitic albites, perthitization of microcline) which have been discussed under the paragenesis of Stage I minerals of the Custer Mt. Lode.

Stage ⟍ Mineral	Pyro-genic I	Hypothermal			Meso-Epi-thermal V	Super-gene VI
		Early II	Middle III	Late IV		
Schorl	— - - -			——		
Muscovite	— - - -	——		——		
Microcline#	——					
Quartz	——			— ? —	— ? —	
Beryl		——	?			
Lithiophilite		? ———	——			
Montebrasite			——			
Mn dufrenite(?)			?			
Apatite			———			
Cassiterite			——			
Albite	— —?	—?—	—?—	——		
Garnet				——		
Columbite				——		
Arsenopyrite				—?—		
Sicklerite				——		
Pyrite				———		
Mn heterosite					——	
Vivianite					——	
Mn hydroxides*						——
Limonite						——

\# Commonly perthitized
* Some of this black manganian coating still carries phosphate as well
as ferric iron

The large beryl logs that are such a striking feature of the Ross Lode probably do not belong to the pyrogenic stage, since they are closely associated with coarse muscovite that in fact partially replaces them, as well as the perthite and quartz. It is not known whether these minerals formed before or after the phosphate stage, but they show no close relationship to albitization, and so presumably antedate it. They are here grouped in Stage II (early hypothermal) of Table 3. In this table the phosphate suite is considered to have succeeded the beryl-muscovite stage, and so is taken to be middle hypothermal, Stage III. The main phosphate minerals (except the apatite) definitely antedate the albite stage, as is shown by evidence given earlier.

This was followed by an albitization Stage IV that may be regarded as late hypothermal. This stage includes albite, garnet, schorl, muscovite, and columbite, in this order. Evidence substantiating this sequence has already been presented. Other minerals in this suite include minor apatite and cassiterite (both thought to be early) and important amounts of beryl, both massive golden and ordinary greenish varieties. At least the latter apparently antedates the albite (Fig. 19B,C). Rare arsenopyrite veinlets and euhedrons probably belong late in this stage, but the euhedrons may be earlier. It is thought probable that lithiophilites reached by these solutions may have been partially altered to sicklerite, though later mesothermal or epithermal solutions (Stage V) may also have effected this, as well as have caused sicklerite to partially change to manganese heterosite (purpurite); some vivianite may have developed late in Stage V. Veinlets of pyrite mainly seen cutting dufrenite (?) masses may also have formed about this time.

Meteoric waters formed the supergene deposits (Stage VI) which are thought to include some Mn heterosite (purpurite) and vivianite. They also caused the manganese phosphate minerals to yield films and irregular masses of hydrated black unanalyzed material, possibly close to manganese hydroxide, and similar solutions caused iron minerals to alter to limonite, the brown hydroxide.