Exploration for Beryllium at the Helen Beryl, Elkhorn and Tin Mountain Pegmatites Custer County, South Dakota

GEOLOGICAL SURVEY PROFESSIONAL PAPER 297-C

Prepared on behalf of the United States Atomic Energy Commission

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By MORTIMER H. STAATZ, LINCOLN R. PAGE, JAMES J. NORTON, *and* VERL R. WILMARTH

PEGMATITES AND OTHER PRECAMBRIAN ROCKS IN THE SOUTHERN BLACK HILLS

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By Mortimer H. Staatz, Lincoln R. Page, James J. Norton, and Verl R. Wilmarth

ABSTRACT

The pegmatites of the Black Hills have been one of the largest sources of domestic beryl. This investigation was conducted in order to solve some of the geological and mineralogical problems associated with the increased demands for beryl and with maintaining its production at a higher level than in the past. Three beryl-rich pegmatites were studied—the Helen Beryl, Elkhorn, and Tin Mountain—each of a different type. The Helen Beryl is a lithium-bearing pegmatite in which most of the beryl occurs in small crystals that can be recovered only by milling; the Elkhorn contains no lithium but has beryl in crystals large enough to be recovered by hand-sorting; and the Tin Mountain is a lithium-bearing pegmatite in which part of the beryl occurs in small crystals and part in large crystals. The three pegmatites were explored by 14 diamond-drill holes ranging from 95 to 315 feet in length and totaling 2,432 feet.

The Helen Beryl pegmatite is a large bluntly lenticular body 250 feet long and as much as 140 feet wide. It plunges 60° S., 30° W., and intrudes quartz-mica schist. The great bulk of the pegmatite is relatively fine grained wall zone which is cut in its upper part by numerous fracture fillings. Near the south end of the pegmatite four roughly concentric zones, each with a characteristic texture and mineral assemblage, are enclosed by the wall zone. Inward from the border of the wall zone, they are the first, second, and third intermediate zones, and the core. These inner zones make up only a small fraction of the total pegmatite. In addition, two units of unknown size and shape, which are probably phases of the wall zone, were found in the drill holes. These are a fine-grained granitic pegmatite, and a fine-grained gneissoid pegmatite. The Helen Beryl pegmatite contains deposits of beryl, spodumene, potassium feldspar, mica, and columbite-tantalite. Beryl occurs in all units, but the greater part of it occurs in relatively fine-grained units.

The Elkhorn pegmatite is a long thin tabular body that is 943 feet long and in most places 10 to 35 feet wide. The Elkhorn has an average dip of 58° NW and cuts at a slight angle across interbedded quartz-mica schist, quartz-mica-sillimanite schist, and quartzite. This pegmatite consists of a fine-grained wall zone and a coarse-grained core. Drilling indicates that this pegmatite plunges gently to the west and that the core pinches out a short distance below the surface. The Elkhorn pegmatite contains beryl, feldspar, and mica of potential economic value. Fine-grained beryl occurs in the wall zone and coarse-grained beryl in the core; beryl is most abundant, however, in the outer part of the core, where most of it is in crystals large enough to be readily recovered by hand-sorting.

The Tin Mountain pegmatite is an L-shaped body with one leg 300 feet long and as much as 78 feet wide and the other leg 150 feet long and as much as 55 feet wide. The larger limb plunges 3° S., 85° E. and pinches out within 105 feet of the surface; the smaller limb is highly irregular but plunges steeply in a northerly direction. The pegmatite intrudes amphibolite and quartz-mica schist. The Tin Mountain pegmatite contains six well-developed zones (border and wall zones, first, second, and third intermediate zones, and a core) and a small fracture filling. Beryl, spodumene, amblygonite, pollucite, and feldspar have been produced from the Tin Mountain pegmatite. Beryl is found in all the zones of the pegmatite but is recoverable by hand-sorting only from the inner part of the wall zone, second and third intermediate zones, and core.

The BeO content of beryl varies considerably between different crystals. Fortunately, the BeO content of the beryl varies proportionately with its indices of refraction and it is only necessary to measure either index and convert on a graph to obtain the BeO content of any particular crystal. The measurement of indices of 280 beryl specimens has shown that in each of the three pegmatites the greatest variation is in the wall zone, where the variation is as large as in the whole pegmatite. The average BeO content of the beryl in different zones showed a decrease from the wall zone to the core in the Helen Beryl and Tin Mountain pegmatites, but showed a small increase in the Elkhorn pegmatite.

Grade of BeO in the three pegmatites was determined both from grain measurements and from spectrographic analyses. The calculation of grade by grain measurements involves two steps: (1) calculation of beryl content by measurement of areas of all beryl crystals in an area of a certain size and conversion to weight percent and (2) conversion of beryl content to BeO content by multiplying by the percent BeO in the beryl. As BeO content of beryl shows considerable variation, this figure is an average of the BeO content of a number of beryl crystals in a particular zone.

A comparison of grade determinations showed that where the grain size of the pegmatite is less than about one-quarter of an inch the best results are obtained by spectrographic analyses, where the grain size is from about one-quarter of an inch to about 6 inches, the methods are fairly comparable, and where the grain size is larger, grain measurements give the best result. Spectrographic analyses are generally more advantageous in measuring grade in drilling, as both the core and sludge can be used. Grain measurements are, however, in many places a quick, accurate, and cheap method of obtaining the grade of beryl-bearing pegmatites.

INTRODUCTION

The pegmatites of the Black Hills of South Dakota are one of the largest known sources of beryllium ore in the United States. Many of the thousands of exposed pegmatites contain beryl, but few deposits have an average beryl content of more than 0.5 percent. From 1914 to 1950 about 2,000 tons, or approximately 60 percent of our domestic production of beryl was mined from pegmatites in this area (Matthews, 1943a, p. 794; Matthews, 1943b, p. 819; Matthews, 1945, p. 817; Nighman, 1946, p. 808; Nighman, 1947, p. 814; Matthews, 1948, p. 1267; Gustavson, 1949, p. 1250; Clark, 1950, p. 1311; Clark, 1951, p. 1295; Clark, 1953, p. 1311; and Page and others, 1953, p. 3, 45, and 52). The beryl was recovered largely as a byproduct in the mining of feldspar, mica, or lithium minerals.

The largest and richest known deposits were studied in considerable detail by the U.S. Geological Survey and the U.S. Bureau of Mines during World War II. In the Black Hills the Geological Survey investigated the occurrence and distribution of beryl (Page and others, 1953, p. 44–53) and the Bureau of Mines sampled a large number of properties (Gries, 1949; Tullis, 1952). Between 1945 and 1948, members of the U.S. Geological Survey studied several beryl-bearing pegmatites in greater detail. A report on the geology of the Peerless pegmatite was published by Sheridan, Stephens, Staatz, and Norton (1957).

Although the known beryl deposits of the area include some of the largest and richest beryllium deposits in the United States, they are of small size and value as compared to many metal mines; hence private operators have had little incentive to explore these deposits in advance of mining. By 1948 the rising price of beryl, and work by Lamb (1947), Snedden and Gibbs (1947), and Kennedy and O'Meara (1948) on the recovery of beryl by sink-float and flotation procedures, suggested that within the near future beryl might be recoverable at a profit by milling. This possibility, together with the expanding need for beryl, caused the U.S. Geological Survey to undertake exploration of three pegmatites near Custer on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission. The purpose was to obtain geological and mineralogical data bearing on the mining and metallurgical problems that would arise before domestic production of beryl could be maintained at a higher level.

SELECTION OF DEPOSITS FOR STUDY

The beryl properties explored in this investigation (fig. 71) were selected because their mineralogic composition and structure indicated that large quantities of beryl might be present. In addition, it was hoped that these investigations would disclose (1) if diamond-drilling can be used to determine the grade of beryl-bearing pegmatites, (2) the distribution of beryl in pegmatites, (3) the mineralogical characteristics of beryl and the variation in BeO content of the beryl in the various zones of pegmatites, (4) the reserves of associated industrial minerals, which would help pay the cost of mining beryl, and (5) the mineralogical and structural changes that occur at depth in pegmatites.

The three pegmatites explored during this project—the Helen Beryl, Elkhorn, and Tin Mountain—are among the largest, richest, and best known examples of three common types of beryl-bearing pegmatities. Noteworthy quantities of beryl were exposed at the surface or in mine workings of each property. The dumps of these mines had been sampled for beryl, and the Helen Beryl and Elkhorn pegmatites had also been sampled at the surface (Page and others, 1953, p. 117–118, 129–130; Gries, 1949; and Tullis, 1952, p. 13–17). Because of their differences in size, structure, and mineralogic composition, each of these pegmatites presents a different economic problem. For instance, beryl in pegmatities that are fine grained can be recovered only by milling, and hence grain size is an important factor in the feasibility in mining a fine-grained pegmatite. The three pegmatites chosen are unequal in size: Helen Beryl is by far the largest, containing approximately 70 percent of the calculated total tonnage; the Elkhorn contains 11 percent of this total; and the Tin Mountain pegmatite contains 19 percent. Also beryl from pegmatites that do not contain lithium minerals, like the Elkhorn, is more readily concentrated by flotation than beryl from lithium pegmatites. Beryl enters the lithium-mineral concentrate in flotation procedures that have been attempted (Runke and Riley, 1957, p. 2–3).

The Helen Beryl pegmatite is a distinctly zoned, thickly lenticular body with a relatively small core, three small hood-shaped intermediate zones, and a thick wall zone cut by many fracture-filling and replacement(?) bodies. The beryl in this pegmatite is for the most part in crystals too small to be recovered except by milling. The beryl has a range in composition greater than in most other deposits, and its recovery by milling may present more difficult metallurgical problems than does beryl in the average deposit. The outer units of this pegmatite form one of the largest individual beryl deposits known in the Black Hills, and data obtained by exploration of this deposit provide an estimate of the maximum probable size and expectable grade that might be found in other deposits in this area. Small inner units of this pegmatite contain beryl that is largely recoverable by hand-sorting, but the total quantity of beryl in these units is small. In studying and exploring the Helen Beryl pegmatite, particular emphasis was

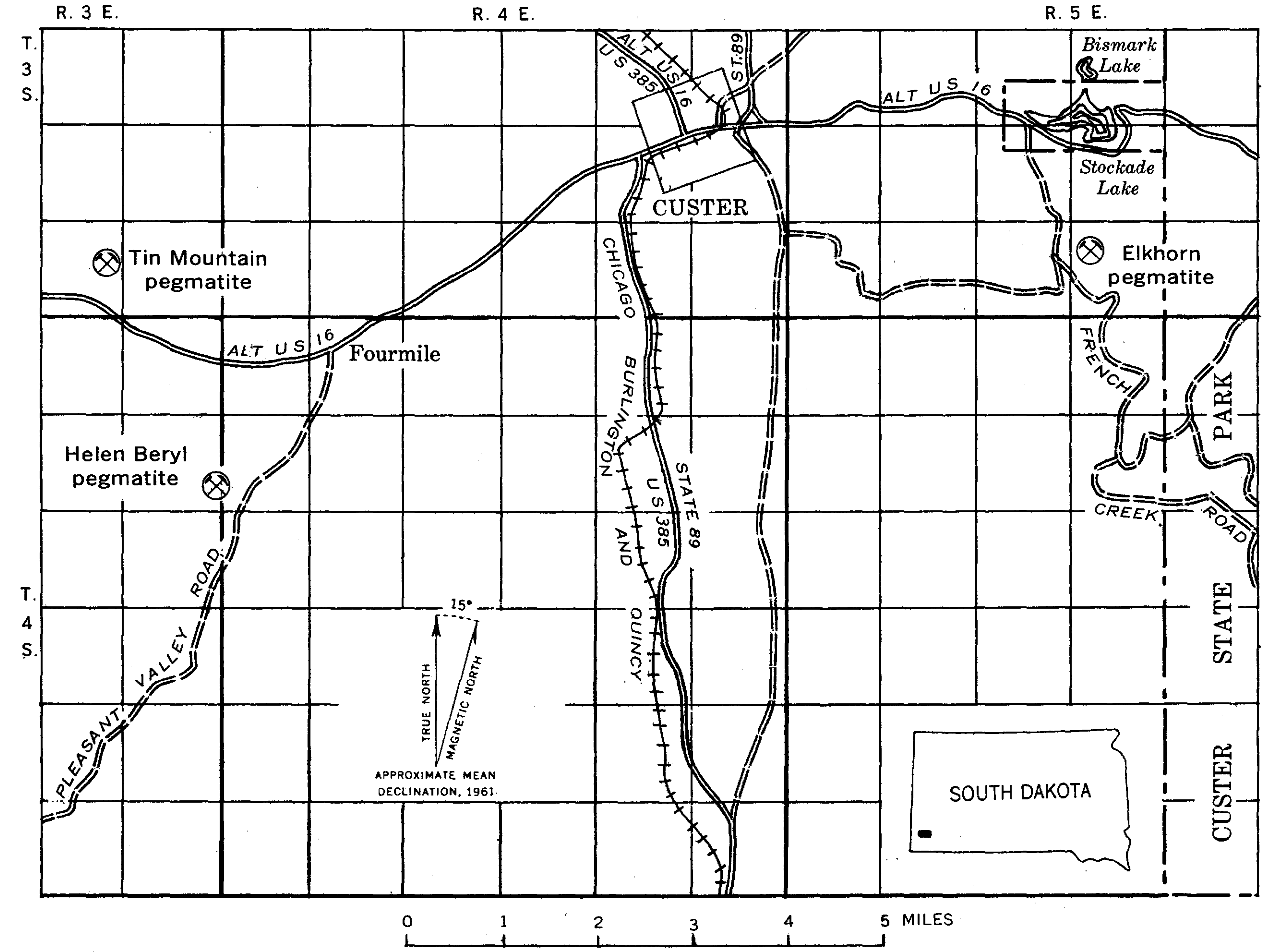

FIGURE 71.—Index map showing location of beryl-bearing pegmatites explored by diamond-drilling, Custer County, S. Dak.

given to determining not only the shape, tonnage, and grade of each type of beryl-bearing unit, but also the variations in composition of beryl within each unit, and the details of mineralogy that might be important in metallurgical research on the recovery of beryl and associated minerals.

The Elkhorn pegmatite is a long, thinly lenticular body composed of a thin wall zone and a thick core. Beryl is concentrated near the outer edge of the core, where the crystals are for the most part large enough to be recovered by hand-sorting. The beryl in the wall zone is fine grained and recoverable only by milling. Exploration of this property was undertaken primarily to outline a deposit from which beryl could be recovered by hand-sorting methods.

The Tin Mountain pegmatite is an irregular body that is L-shaped in plan. It has a thin wall zone, three intermediate zones, and a core. Most of the beryl in the feldspar- and mica-rich wall and first intermediate zones is in small crystals recoverable only by milling. Milling of these units for beryl could be supported in part by the recovery of scrap mica, feldspar, and tin. The large crystals of beryl associated with spodumene and amblygonite in the core and in the second intermediate zone are easily recovered by hand-sorting. The spodumene and amblygonite from these units could be expected to pay the major costs of mining. If the intermediate zones and core were hand sorted for feldspar, spodumene, amblygonite, and beryl, the waste rock could be milled to recover additional spodumene and amblygonite, as well as small quantities of microlite and tantalite-columbite. The emphasis in the study and exploration of this property was on obtaining resource and other data on a beryl deposit in a lithium-bearing pegmatite from which beryl might be recovered both by hand-sorting and milling methods.

FIELD AND LABORATORY WORK

Surface maps of the Helen Beryl, Elkhorn, and Tin Mountain properties were prepared in 1942–43 (Page and others, 1953, p. 199, pls. 16, 19, and 20). The existing map of the Helen Beryl pegmatite, at a scale of 1 inch equals 20 feet, was revised (pl. 3) by L. R.

Page and M. H. Staatz to show the new workings as of September 1947. The main level at the Tin Mountain mine was mapped during the summer of 1947 by R. E. Langen on a scale of 1 inch equals 20 feet. The surface of this property was mapped by Wilmarth and Staatz assisted by W. I. Finch in May 1948 (pl. 17) and the lower level by Page and Wilmarth (pl. 18) after it had been dewatered by Phillip Randall.

Detailed mineralogic studies included (1) measurement of exposed beryl—and in places other minerals—in each pegmatite unit to determine mineral content, (2) study of mineral relations in each unit, and (3) measurement of indices of refraction of beryl and associated plagioclase from various places within each unit. Numerous mineral measurements were made at the Helen Beryl property during 1943 and 1944 by Page, L. C. Pray, and Peter Joralemon (Page and others, 1953, p. 130; Norton and Page, 1956, p. 407). Additional mineral measurements, for the most part in the new workings, were made in the fall of 1947 by Staatz assisted by H. S. Johnson. Mineral measurements made by Norton (Page and others, 1953, p. 118) at the Elkhorn property were supplemented by others made by Staatz. Mineral measurements were made during the summer of 1947 on the main level of the Tin Mountain mine by Langen, and during May 1948 on the lower level by Page and Wilmarth, and on the surface by Staatz, Page, and Finch. Similar mineral measurements were made of beryl in the drill cores from the Helen Beryl and Tin Mountain properties by Staatz and from the Elkhorn property by H. G. Stephens. Staatz, Norton, and R. E. Roadifer compiled the assay data.

The BeO content of each beryl sample was determined by measuring the maximum index of refraction (N_ω) of material from several parts of the crystal and referring to a graph prepared by W. T. Schaller and R. E. Stevens, of the U.S. Geological Survey, on which the index of refraction is plotted against percent BeO (Norton, Griffitts, and Wilmarth, 1958, p. 23). In these studies particular attention was paid to the variation in chemical composition of beryl from place to place within the pegmatite to determine if there is an orderly change from unit to unit. Similar studies were made of the variation in indices of the plagioclase adjacent to beryl crystals to see if a change in alkali content of one mineral accompanied a change in the other mineral. Studies of the index of refraction of one suite of Helen Beryl samples were made by Maurice Deul; others were made by J. W. Adams, Staatz, and Stephens.

Other mineralogic and chemical determinations were made by Miss Jewell Glass and Mr. M. K. Carron, respectively.

Diamond-drilling exploration began in December 1947 and continued through May 1948. It was performed under contract by the E. J. Longyear Co., under the supervision of Staatz. Five holes, which ranged from 140 to 315 feet in length and totaled 1,096.3 feet were drilled on the Helen Beryl property (pls. 13, 14); 6 holes, which ranged from 95 to 249 feet in length and totaled 911 feet were drilled on the Elkhorn property (pls. 15, 16); and 3 holes, which ranged from 110 to 195 feet in length and totaled 425 feet, were drilled on the Tin Mountain property (pls. 17, 18).

Cores were taken from the full length of the holes. Sludge was recovered when the drill was in pegmatite. Both core and sludge samples were analyzed spectrographically for BeO (tables 11, 20, and 27). In addition, assays for Li_2O were made on samples from units containing lithium minerals. Detailed logs of the drill cores from the Helen Beryl and Tin Mountain properties were made by Staatz and of the drill cores from the Elkhorn property by Stephens and Staatz. Wilmarth, Finch, Roadifer, Lawrence Richards, and William Jones collected the core and sludge samples.

ACKNOWLEDGMENTS

Many members of the U.S. Geological Survey had a part in gathering the material that went into this report; where possible, specific credit is given in the text.

It is a pleasure to acknowledge the wholehearted cooperation of the miners in the region, especially Robert McRobbie, operator of the Helen Beryl mine, and Norman Spilde, who assisted by making available mine production records, geologic information, and various items of equipment. Special acknowledgment is due the owners of the properties for permission to undertake the exploration. They include L. H. Jeffries, owner of the Helen Beryl property; C. E. Magnuson and Dewey Tinsley, owners of the Elkhorn property; and the Maywood Chemical Co., owner of the Tin Mountain property.

The E. J. Longyear drill crews, under the supervision of Anders Anderson and Fred Gotblad, did everything possible to facilitate the work.

USES AND PRODUCTION OF BERYLLIUM

Beryllium has a large number of important uses (Clark, 1951, p. 1296–1298; Reno, 1956, p. 99) and would have far wider use if it were more abundant. Beryllium metal is of importance in the field of atomic energy, both as a neutron source with radium or plutonium and as a constituent of certain nuclear reactors in which it is used for its moderating effect on fast neutrons emitted by the fission of U^{235} or plutonium. More recently (Eilertsen, 1959, p. 230), beryllium metal of high purity has been used in inertial-guidance gyroscope and gimbal parts, and experimentally in aircraft and missiles.

In the past 20 years beryllium alloys and compounds also have had increasing use. Beryllium's chief use is in beryllium-copper alloys, which have great strategic significance because of their use in parts that must simultaneously perform a mechanical function and conduct electric current at elevated temperatures. Beryllium-copper alloys are used in many types of instruments. They are important in current-carrying springs and in certain varieties of cams, bearings, gears, electrical contacts, switch parts, electrodes, welding dies, and low-sparking safety tools. Beryllium oxide (beryllia) is highly refractory, has high dielectric strength at both normal and elevated temperatures, and is resistant to thermal shock. Beryllia is important in high-quality porcelains used in aircraft spark plugs and ultra-high-frequency insulators.

The principal commercial beryllium mineral is beryl. Beryl occurs chiefly in granitic pegmatites, and the greater part of all beryl that has been used in industry has come from this source. Beryllium concentrates consist of pieces of beryl that have been hand-sorted from the other pegmatite minerals. These concentrates ordinarily contain from 10 to 13 percent BeO. Most of the beryl recovered in the United States is a byproduct or coproduct of mining for feldspar, mica, or lithium minerals. The beryl content of most pegmatites is too small to warrant continuous mining for beryl alone at 1950 prices. The price of beryl, however, has markedly increased. The average domestic price per unit, consisting of 20 pounds of contained BeO, was $2.19 in 1937, $4.62 in 1941, $17.79 in 1946, $32.10 in 1949, $47.00 in 1953 (Reno, 1956, p. 96), and $46.00 to $48.00 in 1958 (Eilertsen, 1959, p. 231). During this period domestic production increased from 75 tons in 1937 to 751 tons in 1953 (Reno, 1956, p. 96), and then dropped to 463 tons in 1958 (Eilertsen, 1959, p. 230). To encourage the production of beryl the Government started buying domestic beryl for the national stockpile in 1951. Fixed prices were set. When the price of beryl on the world market dropped in 1954 from $47.00 to $38.00, the domestic producers were not affected.

From 1940 through 1958 the United States produced about 6 percent of the world's known production of beryl concentrates. Production in the United States has been reported by Nighman (1946, p. 808) and Clark (1951, p. 1295) from 12 states. The United States is the largest user of beryllium and during the period 1940–58 imported 81,300 short tons, or about 73 percent of all beryl concentrates produced outside the United States (Reno, 1956, p. 96; Eilertsen, 1959, p. 232).

EXPLORATION PROGRAM

Pegmatite studies by the Geological Survey during World War II indicated that the distribution of minerals in pegmatites is closely related to their internal structure and that the mineral content of each unit is reasonably uniform (Page and others, 1953; Cameron and others, 1954; Cameron, Jahns, McNair, and Page, 1949; Jahns, 1946; Pecora and others, 1950; and Norton and Page, 1956). Consequently, if sufficient data on the size and distribution of pegmatite units and their contained minerals were available, the beryl resources of any particular pegmatite could be calculated. After considering various types of physical exploration, it was decided that the cheapest exploration—to give the minimum of data necessary—could be accomplished by means of diamond-drilling.

METHODS AND COSTS

All holes were drilled from the hanging-wall side of the pegmatites at right angles to the strike. The holes were inclined at angles ranging from 31° to 70° in an attempt, wherever possible, to intersect the hanging wall at nearly right angles. The first hole at each pegmatite was located so as to find the exact location and plunge of the keel of the pegmatite. The projection of geologic data from the surface map could then be modified as necessary, and later holes could be located more advantageously than would otherwise be possible.

To obtain the most representative, most economical sample, as much drilling as possible in pegmatite was done with BX bits (1⅝-inch core). All holes were started with NX bits (2⅛-inch core) to allow for reduction in size after casing off caving ground. Seven holes were completed with AX bits (1⅛-inch core); the other seven were finished with BX bits.

The 14 drill holes ranged in length from 95 to 315 feet, and all of them intersected pegmatite. Most holes were terminated on the far side of the pegmatite after they had passed through 10 to 20 feet of country rock, but where the structure of the pegmatite was uncertain the holes were extended as much as 99 feet beyond the footwall. The total footage drilled on the three properties was 2,432.3 feet. The total cost of drilling, exclusive of geologic services, was $15,309.10. The cost ranged from $7.15 per foot at the Helen Beryl property to $6.20 per foot at the Tin Mountain property and $5.31 per foot at the Elkhorn property; the average was $6.29 per foot. The higher cost of drilling on the

Helen Beryl was caused in large part by broken ground, which required an increased amount of cementing, reaming, and casing. The hardness of pegmatites makes drilling in them more costly than in most rocks.

RESULTS

This project was in large part experimental in nature, and the holes were spaced more closely than would ordinarily be justified by the small size of pegmatite deposits. The results of this exploration show that for mining purposes two or three holes ordinarily would be sufficient to indicate that a property is worth development and would supply adequate data for planning the mining operation.

The diamond-drilling exploration program also furnished a check on structural interpretations of pegmatites. Cross sections showing the expected shape of the pegmatites and of their internal units were prepared before and after each hole was drilled, and they agreed sufficiently well to indicate that the shape of the pegmatite generally can be predicted from surface data. The plunge of concordant pegmatites can be predicted from rolls in the pegmatite contact and from the plunge of minor folds in the adjacent schist. Where the shape of the pegmatite is controlled by fractures in competent rocks, as in the northward-trending limb of the Tin Mountain pegmatite, detailed predictions of the shape and position of the pegmatite are less accurate.

The position of the lower ends of the three pegmatites was not located. Hence, the total tonnage of the pegmatites cannot be accurately determined, and tonnage figures are limited to the parts of the pegmatite where some data on its size are available. Resource figures for the Helen Beryl pegmatite are for all the pegmatite north of the line of the vertical section that contains drill hole 5 (pl. 14); those for the Elkhorn pegmatite are for all the pegmatite east of its westernmost exposure; and those for the Tin Mountain pegmatite are for all the pegmatite south of the line of the vertical section that contains drill hole 3 (pl. 20).

The beryl resources at the Helen Beryl, Elkhorn, and Tin Mountain pegmatites, as of 1948, are estimated to be about 1,024,000 tons of beryl-bearing rock that ranges in grade from 0.0035 to 0.15 percent BeO or 0.03 to 1.2 percent beryl. Of this, about 160,000 tons, estimated to contain 0.066 percent BeO or 0.54 percent beryl, is in intermediate zones and cores of such coarse grain size that probably half of the beryl can be recovered by hand-sorting. The remainder of the beryl-bearing rock contains fine-grained beryl that must be recovered by milling. The beryl has differences in chemical composition that may create milling problems.

In addition, all three pegmatites contain significant quantities of potassium feldspar and scrap mica. The Helen Beryl and Tin Mountain pegmatites also have spodumene and columbite-tantalite; and the Tin Mountain pegmatite contains amblygonite, microlite, and pollucite. Most of the potassium feldspar, spodumeme, and amblygonite in these pegmatites is of a size that can be sorted by hand. The recovery of most of the scrap mica and other minerals that are of small grain size is dependent upon milling. Minerals other than beryl will form a great part of the revenue from these properties, whether the pegmatite minerals are separated by hand-sorting or by milling.

METHODS OF ESTIMATING BERYL CONTENT

In estimating the quantity of beryl or other minerals in a pegmatite three problems must be considered: (1) the content of any mineral is commonly different in each unit of a zoned pegmatite, and consequently the tonnage and grade of each unit must be calculated separately; (2) some pegmatite units have such large grain size that many normal sampling techniques do not give a representative sample; and (3) few analysts produce consistent results in making chemical analyses of low-grade ores of beryllium.

TONNAGE OF BERYL-BEARING UNITS

In determining the tonnage of rock in any pegmatite unit, the surface and underground maps and drill-hole data were used to construct a series of geologic sections (pls. 14, 16, 19, and 20). The area of each of the pegmatite units shown in each vertical section was measured with a planimeter, and the volume of each unit was calculated by averaging the area of the unit in two adjacent sections and multiplying by the distance between sections. Appropriate variations in the method were made where a unit is cut by only one section. Volume was converted to tonnage by dividing the volume by the factor 11.75, the number of cubic feet in a ton, which was obtained by weighing a piece of drill core of known volume.

GRADE

The grade estimates presented in this report are based almost entirely on spectrographic analyses and grain measurements. Chemical analyses have been unsuccessful. (See p. 137.)

The index of refraction of beryl was used to determine the BeO content of the pure mineral. A factor thus obtained was employed to convert the content of BeO in the rock to beryl, or the content of beryl to BeO. (See p. 136.)

SAMPLING

Previously published work concerning these three pegmatites contains grade estimates that are based on chemical and spectrographic analyses of surface samples and on grain measurements of typical exposures (Gries, 1949; Tullis, 1952; Page and others, 1953, p. 117–118, 129–131). During the present study, additional grain measurements were made on surface exposures, and information on grade was extended to the subsurface by determining the BeO and beryl content of drill-core and sludge samples.

Diamond-drill samples had not been used previously to find the grade of beryl pegmatites, and thus it was necessary to determine the conditions under which core drilling yields adequate samples for accurate determination of grade in several kinds of beryl-bearing pegmatite. Where the beryl was relatively fine grained and evenly distributed, there was no reason to doubt that the samples would be representative. It also was clear, however, that the samples would become increasingly less representative as the beryl increased in grain size and became more irregularly distributed. Sludge samples were collected because they more than double the total size of the sample. All core samples of pegmatite were so split as to halve the visible beryl for analysis.

Sludge sampling is desirable not only because the rock is coarse grained, but also because beryl, being brittle and commonly euhedral, has a tendency to break free from the core and enter the sludge. The sludge recovery in the intensely fractured rock encountered in many of the holes was highly variable (table 1); it ranged from 0 to 588 percent of the theoretical value. The losses are caused by sludge going into fractures; the gains are caused by caving of the hole or by washing out sludge that had been lost previously in fractures. As a result the sludge may be a poor sample. Insofar as possible the inaccuracies were reduced by cementing all fractured rock.

TABLE 1.—*Core and sludge recovery at the Helen Beryl, Elkhorn, and Tin Mountain pegmatites*

Property and drill hole	Core recovery (percent) in—			Range of core recovery in pegmatite	Sludge recovery (percent) [1]	
	Country rock (below overburden)	Pegmatite	Entire hole		Average	Range
Helen Beryl pegmatite:						
Hole 1	63	86	78	42–100	38	0–120
2	70	80	72	45–100	55	10–146
3	47	46	46	0–100	189	0–588
4	58	68	63	0–100	80	0–358
5	75	48	65	0–100	95	0–267
1–5	67	65	66	0–100	92	0–588
Elkhorn pegmatite:						
Hole 1	65	82	69	54–98	100	41–276
2	86	83	86	62–100	91	56–159
3	64	82	65	56–68	48	35–60
4	41	75	44	66–90	50	35–62
5	54	68	57	44–98	54	42–64
6	60	19	48	36–94	24	2–80
1–6	59	74	64	36–100	62	2–276
Tin Mountain pegmatite:						
Hole 1	67	87	72	48–96	46	41–58
2	76	75	76	50–92	62	41–78
3	77	47	55	0–100	43	0–134
1–3	73	57	65	0–100	47	0–134
All holes	65	64	65	0–100	76	0–588

[1] Sludge was taken mainly from pegmatite, but in some places a few feet of the wall rock was included.

An overall core recovery of 65 percent and sludge recovery of 76 percent was obtained in the three pegmatites drilled.

SPECTROGRAPHIC ANALYSES

Spectrographic analyses of rock containing small amounts of beryllium have given satisfactory results in the past (Norton and Page, 1956, p. 407). For this reason they were used in analyzing the core and sludge samples. Most of the spectrographic analyses were made under contract by the Saratoga Laboratories of Saratoga Springs, N.Y; a few check analyses were made by the U.S. Geological Survey. The remainder of the analyses were made by the National Spectrographic Laboratories of Cleveland, Ohio.

Beryl is the only beryllium mineral known in the three pegmatites, and it may be assumed that virtually all the beryllium found by analysis is in beryl.

The results of the analyses are recorded in tables 11, 20, and 27. In addition, weighted averages of the core and sludge assays were calculated by using figure 72 to determine the fraction of the hole occupied by the core recovered, and calculating from the following formula:

$$P=P_s\,(1-C)+P_cC,$$

or

$$P=P_s-C\,(P_s-P_c),$$

where

P=average percent BeO
P_s=percent BeO in sludge sample
P_c=percent BeO in core sample
C=fraction of hole occupied by recovered core.

In this method it is assumed that the sludge assay is representative of the space in the hole that was not recovered as core. Methods have been devised for reducing the weight assigned the sludge assay in accordance with the sludge recovery (for example, Moehlman, 1946, p. 11–14), but such precision does not seem justified by the assay data obtained in the present study.

GRAIN MEASUREMENTS

The grain size of most of the pegmatite units is large enough so that the beryl is easily recognizable, and the grade is readily determined by measuring the area of exposed beryl crystals. The ratio of the total area of beryl to the total area of exposure gives percent beryl by volume, and inasmuch as the beryl has nearly the same specific gravity as the rock, it also gives percent beryl by weight.

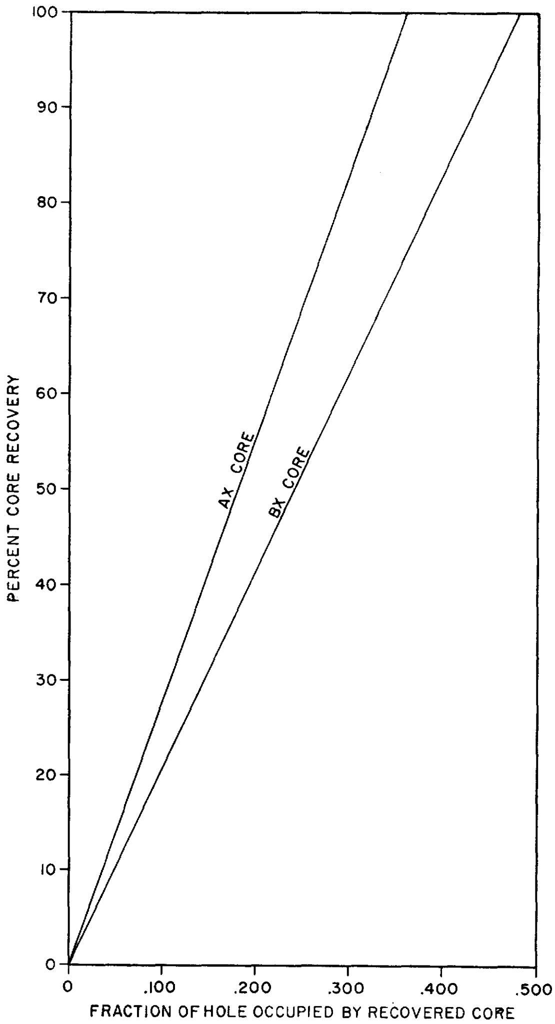

FIGURE 72.—Fraction of hole occupied by recovered core at various percentages of core recovery. Diameter of all AX core assumed to be 1⅛ inches, all AX hole 1⅞ inches, all BX core 1⅝ inches, and all BX hole 2⅜ inches.

Many grain measurements were made of surface exposures at the Helen Beryl, Elkhorn, and Tin Mountain pegmatites. Randomly oriented surfaces were selected for these measurements to eliminate possible bias. Grain measurements were of greatest value in the innermost units of these three pegmatites, where some crystals are more than 1 foot across. Grain measurements of such rock give a speedy, relatively accurate, and cheap method of obtaining the beryl content. Bulk sampling is the only other method that would be suitable.

Grain measurements were also used on drill core to supplement spectrographic analyses. The outlines of all beryl crystals were traced on paper, and the area of each was measured with a planimeter to determine the ratio of exposed beryl to core surface for each unit.

DETERMINATIONS OF INDEX OF REFRACTION

The BeO content of beryl ranges from about 10 to 14 percent. As the BeO content increases, the index of refraction decreases. The correlation between the two is shown in a graph by W. T. Schaller and R. E. Stevens (Norton, Griffitts, and Wilmarth, 1958, p. 23). This graph was used in the present work to obtain a factor to convert the beryl content of the rock (from grain measurements) to BeO content, or to convert BeO content (from analyses) to beryl content.

The maximum index of refraction ($N\omega$) was determined on more than 280 beryl specimens from the three pegmatites studied. A considerable range was found in the index refraction of beryl from different parts of single crystals and of beryl from different units, from different parts of a single unit, and from crystals from the same type of unit in different pegmatites. Many determinations of index of refraction were needed to determine the average BeO content of the beryl in any single unit.

In each pegmatite the range was greatest in the wall zone: in the wall zone of the Helen Beryl pegmatite the range was from 11.1 to 13.1 percent BeO, in the wall zone of the Elkhorn pegmatite the range was from 11.2 to 13.2 percent BeO, and in the wall zone of the Tin Mountain pegmatite it was from 11.6 to 12.9 percent BeO. At the Helen Beryl pegmatite the average index of refraction of the ordinary ray increased from 1.585 (12.5 percent BeO) in the wall zone to 1.590 (11.8 percent BeO) in the core; at the Tin Mountain pegmatite the increase was from 1.586 (12.4 percent BeO) in the wall zone to 1.589 (12.0 percent BeO) in the core. The index decreased in the Elkhorn pegmatite, however, from 1.583 (12.8 percent BeO) in the wall zone to 1.579 (13.1 percent BeO) in the core.

The maximum index of refraction was determined for both the outer and the central parts of 38 zoned beryl crystals from the Helen Beryl pegmatite: 22 specimens showed an increase and 7 a decrease in index of refraction from the center towards the outer edge of crystal. Individual beryl crystals also differ in index of refraction along their length; the end of the crystal nearest the outer border of the pegmatite generally has a lower index than the inner end of the crystal.

The differences in chemical composition indicated by the optical data may be great enough to influence the behavior of the beryl in mineral-dressing processes.

COMPARISON OF METHODS USED IN DETERMINING GRADE

Prior to the exploration of the Helen Beryl, Elkhorn, and Tin Mountain pegmatites, there were various investigations of the problem of determining the grade of beryl-bearing pegmatites (Page and others, 1953, p. 51–52; Tullis, 1952, p. 13–17; Norton and Page, 1956, p. 406–411; Cameron and others, 1954, p. 65, 67, 89, 119, 125, 301, 315, 323, and 324). Diamond-drilling was not used in any of these investigations, and the data obtained were mainly from surface sampling. The results generally indicated, however, that (1) grain measurements are at least as accurate as channel or bulk sampling, provided the beryl crystals exceed half an inch in minimum dimension; and (2) spectrographic analyses to determine the BeO content of pegmatite are more reliable than chemical analyses.

Perhaps the most detailed previous study that bears on grade determination was at the Helen Beryl pegmatite. In 1943 and 1944, the Metals Reserve Co. and the U.S. Bureau of Mines took six samples, weighing 2 to 5 tons, spaced at intervals over the Helen Beryl outcrop (pl. 13). Splits of each sample were sent for analysis to the Mineral Separation Co., American Cyanamid Co., U.S. Bureau of Mines, and U.S. Geological Survey. Four chemical and two spectrographic analyses were made of each sample. The U.S. Geological Survey also made grain measurements of the rock exposed in the sample cuts (Page and others, 1953, p. 130; Norton and Page, 1956, p. 407). The two spectrographic analysts obtained approximately the same results; the average of all the analyses was 0.05 percent BeO. The grain measurements also indicated a grade of 0.05 percent BeO. The average of all determinations by the four chemical analysts was 0.11 percent BeO, but for each sample the highest assay was at least twice as great as the lowest. Only one chemical analyst obtained results comparable to those obtained by the spectrographic analysts.

The Bureau of Mines subsequently took 17 samples, weighing ½ to 12 tons, from the surface; 20 samples, weighing 5 to 18 tons, from a 120-foot sample adit; and 63 air-drill samples (Gries, 1949, p. 7–14). It was found that only 270 pounds of beryl could be picked by hand from 337 tons of rock in the bulk samples, but chemical analyses of the residue after handpicking of beryl, perthite, and scrap mica indicated a grade of 0.14 percent BeO remaining in the surface samples and 0.13 percent BeO in the adit sample. Chemical analyses of the air-drill samples gave an average content of 0.10 percent BeO. In contrast, grain measurements of the surface sample cuts made by the Geological Survey indicated an average BeO content of 0.04 percent. This difference in grade figures is comparable in magnitude to that shown by similar methods on the first group of samples.

The additional grain measurements that have been made on surface exposures and drill core agree reasonably well with spectrographic analyses of core and sludge, except where the rock is fine grained (table 2). As before, these methods give generally lower figures than do chemical analyses.

Grain measurements and spectrographic analyses show that the Helen Beryl pegmatite contains about 0.3 percent beryl, yet a content of about 1.0 percent beryl has been reported on the basis of chemical analyses (Gries, 1949, p. 14). Similarly, the average of the data in table 1 indicates a grade of 0.3 percent beryl in the Elkhorn pegmatite and 0.6 percent beryl in the Tin Mountain pegmatite, yet chemical analyses of minus 2-inch material from the dumps indicate a grade of 0.6 percent beryl (0.07 percent BeO) and 1.8 percent beryl (0.23 percent BeO) in these same pegmatites (Tullis, 1952, p. 15).

The principal reason for these differences is that chemical analyses for beryllium are difficult to make because some of the aluminum tends to precipitate with the beryllium unless done with extreme care. Hence, the grade figure obtained by chemical analysis is generally higher than that obtained on the same sample by either spectrographic analysis or grain measurements.

The greatest discrepancies between grain measurements and spectrographic analyses of drill core in table 2 are in fine-grained rock, especially where the grain size is less than ½ inch. In the Helen Beryl pegmatite the rock having the finest grain size is in the granitic albite-quartz-muscovite and gneissoid albite-biotite-quartz units, where the grain size is $\frac{1}{16}$ to ⅛ inch. The BeO content determined by grain measurements is 0.002 and 0.008 percent, respectively, yet by spectrographic analyses it is 0.022 and 0.030 percent. Similarly, in the Tin Mountain pegmatite, the border zone and the wall zone have 0.003 and 0.006 percent BeO according to grain measurements, but 0.101 and 0.096 percent BeO by spectrographic analyses.

Where the grain size is ½ to 2 inches, and the beryl thus is more easily recognized, the discrepancies are much smaller. Nevertheless, the spectrographic analyses generally show a larger percent BeO than the grain measurements. This may be partly because some beryl grains were not recognized or some of the beryllium is in other minerals. On the other hand, a sampling bias is suggested by the fact that in each of these pegmatites the spectrographic analyses of the wall zone, where most of the drilling was done, indicate more BeO in the sludge than in the core. Thus some of the beryl in these units may break out of the core and go into the sludge. The loss of these crystals would have more effect on the grain measurements than the core assays, because the grain measure-

TABLE 2.—BeO *content of units in the Helen Beryl, Elkhorn, and Tin Mountain drill cores*

[Determined by grain measurements and spectrographic analyses. Core size (inches): AX, 1⅛; BX, 1⅝; NX, 2⅛]

Pegmatite unit	Average grain size of beryl observed on core (sq ft)	Grain measurements: Total area of core measured[1] (sq ft)	Grain measurements: BeO (percent)	Spectrographic analyses: Average BeO in core samples (percent)	Spectrographic analyses: Average BeO in sludge samples (percent)	Spectrographic analyses: Weighted average of BeO in core and sludge samples (percent)	Core: Total footage drilled	Core: Size
HELEN BERYL PEGMATITE								
1. Albite-quartz-muscovite pegmatite (wall zone)	0.00193	61.85	0.030	0.024	0.037	0.034	88.6	BX
							209.1	AX
2. Granitic albite-quartz-muscovite pegmatite (type of unit uncertain)	.00034	10.01	.002	.025	.020	.022	43.4	AX
3. Gneissoid albite-biotite-quartz pegmatite (type uncertain)	.00056	7.57	.008	.018	.032	.030	43.0	AX
4. Perthite-quartz-muscovite-albite pegmatite (fracture filling)	.00180	19.16	.020	.035	.013	.020	41.1	BX
							39.8	AX
5. Quartz-spodumene-perthite-albite pegmatite (core)	.00044	.50	.095	.10	.028	.038	8.1	AX
Entire pegmatite	.00163	99.09	.024	.027	.034	.030	129.7	BX
							343.4	AX
ELKHORN PEGMATITE								
1. Quartz-albite pegmatite (wall zone)	.00022	30.60	.008	.022	.031	.029	82.2	BX
							24.0	AX
2. Perthite-quartz pegmatite (core)	.00009	.38	.009	Trace	.027	.018	1.4	AX
Entire pegmatite	.00021	30.98	.008	.022	.031	.029	82.2	BX
							25.4	AX
TIN MOUNTAIN PEGMATITE								
Muscovite-albite-quartz pegmatite (border zone)	.00008	.72	.003	.096	.105	.101	.1	NX
							1.3	BX
							.8	AX
2. Albite-quartz-muscovite pegmatite (wall zone)	.00031	31.90	.006	.078	.101	.096	3.4	NX
							76.3	BX
							30.4	AX
3. Perthite-quartz-albite pegmatite (first intermediate zone)	------------	2.42	0	.024	.051	.045	8.4	BX
4. Albite-quartz-spodumene pegmatite (third intermediate zone)	.00160	2.89	.007	.031	.021	.023	15.3	BX
5. Quartz-spodumene pegmatite (core)	------------	6.81	0	.003	.015	.012	64.3	BX
Entire pegmatite	.00033	44.74	.005	.047	.062	.060	3.5	NX
							165.6	BX
							31.2	AX

[1] Actual core recovered.

ments apply only to the surface of the core, and the spectrographic analyses are for the entire core. Data for the Helen Beryl pegmatite (table 2), however, indicate that the overall effect of this behavior is small; the grain measurements on all the drill cores give a content of 0.024 percent BeO, core assays 0.029 percent BeO, and sludge assays 0.034 percent BeO.

In rock having a grain size of 2 inches or more, the drill samples have an erratic beryl content. Probably the amount of drilling that would be needed to obtain a fair sample of these units would be more costly than bulk sampling.

It may be concluded that spectrographic analyses of drill samples provide a reasonable estimate of grade in pegmatite having a grain size of less than 2 inches. Grain measurements tend to agree with spectrographic analysis of drill core where the grain size is ½ to 2 inches, but they are inaccurate when applied to finer-grained rock. The beryl content of coarse-grained pegmatite can be determined readily only by spectrographic analyses of bulk samples or grain measurements of large exposures. The great merit of grain measurements is their low cost, but they must be done with care and used with discretion.

HELEN BERYL PEGMATITE

The Helen Beryl pegmatite is on the eastern edge of sec. 12, T. 4 S., R. 3 E., Black Hills principal meridian, Custer County, S. Dak. (fig. 1). It is owned (1950) by L. H. Jeffries of Deadwood, S. Dak., who relocated this claim in 1943 as the Helen Beryl and prospected it at that time for mica and beryl. The property was previously known as the Big Tom and Kem Lode. It was leased to Mr. Robert McRobbie for a short time in 1943 and 1944 and again in March 1946. He operated the property for feldspar, spodumene, and beryl until late in 1949.

The Helen Beryl pegmatite may be reached from Custer, the nearest railroad shipping point, by the following route:

Miles

0.0 Post office, Custer, S. Dak. Go west on U.S. Highway 16.
4.7 Turn south on gravel road.
5.0 Intersection at school house; go straight ahead.
6.5 Turn right through cattle guard in fence.
6.8 Helen Beryl pegmatite.

The Helen Beryl property was mapped and studied by the U.S. Geological Survey in 1942–44 (Page and others, 1953, p. 128–131) and during the same period was sampled by the Bureau of Mines (Gries, 1949). Diamond drilling on this property began late in 1947 and continued into 1948.

MINE WORKINGS

The Helen Beryl pegmatite was originally prospected on the southwest side by a small cut, 33 feet long, 15 feet wide, and 8 feet deep. In 1944 the U.S. Bureau of Mines made 17 sample cuts and a 120-foot adit that went north from the south end of the pegmatite outcrop. Mr. McRobbie, in 1946, opened a pit at the extreme southern end of the pegmatite, where a small perthite-bearing unit was exposed near the portal of the Bureau of Mines adit. In 1948 these workings formed a large pit (pl. 13), the northern half of which was under a roof of pegmatite, the southern half open to the surface. The pit was then 85 feet long, 30 feet wide, and 38 feet deep. The bottom of the pit was reached by a 41° incline from its south end.

PRODUCTION

Feldspar, mica, spodumene, beryl, and tantalite have been produced from the Helen Beryl pegmatite. Mineral production to June 1948 is given in table 3.

TABLE 3.—*Mineral production, 1943 to June 1948, Helen Beryl pegmatite*

Year	Potassium feldspar (tons)	Scrap mica (tons)	Spodumene (tons)	Beryl (tons)	Tantalite ore (tons)
1943–44	150	--------	--------	--------	--------
1946	800	20.0	9.85	--------	--------
1947	1,152.4	[1] 37.3	81.7	15.5	--------
January–June 1948	382.28	--------	[2] 120	[2] 15	[3] 2
Total	2,484.68	57.3	211.55	30.5	2

[1] The scrap mica came from two sources: 8 tons came from books in perthite-quartz-muscovite pegmatite and 29.3 tons came from irregular masses of "bull mica" in quartz-spodumene-perthite-albite and perthite-spodumene-quartz pegnatite.
[2] Stockpiled; tonnage estimated.
[3] Stockpiled: approximately ⅓ tantalite and ⅔ waste rock.

In November 1947 the total rock mined was estimated to be 4,870 tons by measuring the volume of the pit. The rock mined was mostly perthite-spodumene-quartz and quartz-spodumene-perthite-albite pegmatite. Calculated percentages of recovered minerals from the rock mined are perthite, 41.8 percent; spodumene, 1.6 percent; scrap mica, 1.2 percent; and beryl, 0.32 percent. In the months after these calculations were made, a higher proportion of the rock mined was from the quartz-spodumene-perthite-albite core, and there was a consequent increase in the amount of spodumene and tantalite recovered and a decrease in feldspar and scrap mica.

GEOLOGY

METAMORPHIC ROCKS

The Helen Beryl pegmatite is surrounded by quartz-mica schist. Both foliation and bedding have a regional strike of about N. 30° W. and a dip of 50° SW. Isoclinal folds plunge 30° to 50° SSW. In many places within a few feet of the pegmatite a secondary schistosity has been developed that is parallel in detail to the pegmatite contact.

The quartz-mica schist is light to dark gray, fine grained, and thinly laminated. Individual beds are rarely more than 6 inches thick. Quartz is the dominant mineral, and together with feldspar, which cannot be readily distinguished from quartz, it forms 40 to 80 percent of the rock. Muscovite ordinarily forms 10 to 35 percent and biotite 10 to 30 percent of the rock. A few beds are rich in chlorite (as much as 25 percent of the rock), garnet (as much as 15 percent), or sillimanite (as much as 6 percent). The schist also contains lime-silicate lenses consisting of quartz, feldspar, hornblende, epidote, and garnet.

Schist near the pegmatite contact is commonly altered. In places the only effect is the presence of porphyroblasts of muscovite, biotite, and tourmaline. In other places the schist has been altered to a light-gray granulite, as much as 6 feet thick, consisting chiefly of quartz, albite, and mica. The largest grains are rarely more than ⅛ inch across. Ordinarily the rock has no foliation, but in places it has a very weak foliation. Thin pegmatite stringers cutting granulite commonly contain small beryl crystals. Granulite is well exposed near U.S. Bureau of Mines sample cuts 3 and 9, and it was found also in drill holes.

The granulite ranges widely in composition. Quartz comprises 30 to 70 percent, muscovite 5 to 30 percent, and biotite 2 to 15 percent of the rock. Albite locally may be as much as 40 percent of the rock; the minimum index of refraction on cleavage fragments ($N_{\alpha'}$) is 1.529. Tourmaline and apatite are present in minor amounts.

QUARTZ AND QUARTZ-FELDSPAR VEINS

Many quartz and quartz-feldspar veins that range from a fraction of an inch to 4 feet in thickness cut the quartz-mica schist. Most of these veins are parallel to the schistosity; a few are crosscutting and very irregular in size and shape. Glassy intensely fractured quartz forms 80 to 100 percent of the material in these veins, and pink to white oligoclase or albite ($N_{\alpha'}$ 1.529 to 1.541) is the only other common mineral. The most sodic albite is in a vein only a few feet from the pegmatite.

PEGMATITE

The Helen Beryl pegmatite (fig. 13) is a large, bluntly lenticular body 250 feet long and as much as 140 feet wide at the surface. It has been explored by drilling to a maximum depth of 260 feet below the surface (pl. 14). The shape of the present surface exposure probably is virtually the original shape of the top of the pegmatite, except at the south end where perhaps as much as 70 feet of rock has been removed by erosion. The average plunge of the pegmatite, as interpreted from the drilling, is about 60° S. 30° W. Small rolls in the pegmatite contact at the surface plunge in the same direction, but at somewhat more gentle angles.

Though locally the schist adjacent to the pegmatite has an induced foliation parallel to the contact, the pegmatite as a whole is discordant. It strikes north and dips 70° W.; in contrast, the average strike of schistosity is about N. 30° W., and the dip is about 50° SW.

The pegmatite itself is deformed only by strong joints and small faults that strike N. 70° E. and have a dip that is ordinarily between 60° NW. and vertical. No displacement can be recognized along most of these fractures, but some have a horizontal offset of as much as 4 feet.

Six pegmatite units have been mapped on the surface (pls. 13, 14): (1) albite-quartz-muscovite pegmatite (wall zone), (2) perthite-quartz-muscovite-biotite pegmatite (first intermediate zone), (3) perthite-quartz-muscovite pegmatite (second intermediate zone), (4) perthite-spodumene-quartz pegmatite (third intermediate zone), (5) quartz-spodumene-perthite-albite pegmatite (core), and (6) perthite-quartz-albite pegmatite (fracture-filling bodies). Two additional rock types that are probably phases of the wall zone were found during drilling (pl. 14). These consist of fine-grained granitic albite-quartz-muscovite pegmatite and fine-grained gneissoid albite-biotite-quartz pegmatite.

ALBITE-QUARTZ-MUSCOVITE PEGMATITE

[Wall zone]

The outermost unit is the albite-quartz-muscovite wall zone. This unit also includes a small border zone and numerous fracture-filling and replacement(?) bodies that are too small to map separately. The wall zone is the dominant unit of the pegmatite; it makes up at least 70 percent of the entire body.

The average grain size of the wall zone is about ½ inch; individual crystals may be as much as 2 inches in diameter. The border zone is finer grained, and so also are the many irregular albite-rich patches that may be small replacement bodies. Small fracture-filling bodies, mapped with the wall zone, have a grain size ranging from that of the wall zone to medium-grained pegmatite,[1] but a few crystals are as much as 12 inches long.

The average composition of the albite-quartz-muscovite pegmatite was determined by weighting estimates from many surface exposures and drill cores. The unit consists of albite (41 percent), quartz (32 percent), muscovite (16 percent), biotite (5 percent), perthite (4 percent), apatite, (1 percent), tourmaline (1 percent), beryl (0.3 percent), and spodumene (trace). Detailed variations in composition of the wall zone are given in the drill logs and summarized in table 4.

[1] Textural terms used are those suggested by Cameron, Jahns, McNair, and Page (1949, p. 16).

TABLE 4.—*Modes (percent) of the wall zone, Helen Beryl pegmatite*

Location of core sample	Albite	Quartz	Muscovite	Biotite	Perthite	Others
Diamond-drill hole 1:						
81.2–88.8 ft	35	30	16	15	2	Tourmaline, 1 Apatite, <1 Beryl, 0.33
89.4–94.5 ft	45	30	15	5	3	Tourmaline, 1 Apatite, <1 Beryl, 0.016
98.5–100.4 ft	45	34	15	1	3	Tourmaline, Apatite, <1 Beryl, 0.12
102.5–149.4 ft	40	36	15	1	5	Tourmaline, 2 Apatite, <1 Beryl, 0.19
182.5–193.1 ft (includes patches of granitic albite-quartz-muscovite pegmatite)	40	35	15	4	4	Tourmaline, 1 Apatite, <1 Beryl, 0.015
193.4–194.4 ft	40	40	19	----------	----------	Apatite, <1 Tourmaline, <1 Beryl, 0.50
Diamond-drill hole 3:						
55.0–64.3 ft	45	34	15	1	3	Tourmaline, 1 Apatite, <1 Beryl, 0.04
65.2–93.7 ft	35	35	15	----------	13	Apatite, 1 Tourmaline, 1
101.8–117.8 ft	45	34	15	1	3	Tourmaline, 1 Apatite, <1 Beryl, 0.43
120.5–124.3 ft	45	34	15	1	3	Tourmaline, 1 Apatite, <1 Beryl, 0.51

See footnote at end of table.

TABLE 4.—*Modes (percent) of the wall zone, Helen Beryl pegmatite*—Continued

Location of core sample	Albite	Quartz	Muscovite	Biotite	Perthite	Others
Diamond-drill hole 4:						
149.5–233.0 ft	43	37	12	1	5	Tourmaline, 1 Apatite, <1 Beryl, 0.28
253.0–265.0 ft	45	35	15	1	1	Tourmaline, 2 Apatite, 1 Beryl, 0.34
Diamond-drill hole 5:						
207.0–263.0 ft. (No core 195 to 207 ft.)	45	40	12	----------	1	Tourmaline, <1 Apatite, <1 Limonite, <1 Green mica, <1 Beryl, 0.24
298.5–302.0 ft	55	30	13	----------	----------	Apatite, 1 Tourmaline, <1
Weighted average in drill core	42	36	14	1	4	2
Average of surface exposures	40	28	17	9	4	Apatite, <1 Tourmaline, 1 Spodumene, Tr. Beryl, 0.34
Average mineral composition of wall zone (surface and drill holes weighted equally)	41	32	16	5	4	2

[1] Includes sericite.

TABLE 5.—*Indices of refraction of albite and beryl from drill core of the wall zone, Helen Beryl pegmatite*

Location of core sample	Minerals forming more than 5 percent of the rock, in order of abundance	Albite		Beryl	
		Description	$N_{\alpha'}$ [1]	Description	N_{ω} [1]
Drill hole 1:					
81.2–88.8 ft	Albite, quartz, muscovite, biotite	White, irregular stringers in quartz	1.527	White to yellowish, anhedral	1.579
89.4–94.5 ft	do	do	1.528	Yellowish, anhedral	1.586
98.5–100.4 ft	Albite, quartz, muscovite	do	1.529	White, anhedral	1.588
102.5–149.4 ft	Albite, quartz, muscovite, perthite	do	1.529 1.527 1.528	Yellowish, yellowish-green and greenish white, anhedral.	1.581 1.580
182.5–193.1 ft	Albite, quartz, muscovite			White, anhedral	1.580
Range			1.527–1.529		1.579–1.588
Average			1.528		1.582
Drill hole 3:					
55.0–64.3 ft	Albite, quartz, muscovite	White to pinkish, anhedral	1.529 1.527	Yellowish, anhedral	 1.580
65.2–93.7 ft	Albite, quartz, muscovite, perthite	Fine-grained, granular, white to pinkish, anhedral.	1.528		
101.8–117.8 ft	Albite, quartz, muscovite	Pale green to white, anhedral	 1.528 1.527 1.527 1.530 1.529 1.528	Pale green to white, anhedral	1.582 1.585 1.583 1.582 1.588 1.582 1.581
120.5–124.3 ft	do	White, anhedral	1.530	Pale green, anhedral	1.584
Range			1.527–1.530		1.580–1.588
Average			1.528		1.583
Drill hole 4:					
149.5–233.0 ft	Albite, quartz, muscovite, perthite	White, pinkish, anhedral to euhedral.	1.529 1.531 1.527 1.529 1.529 1.527	Yellowish-white to light-green, very irregular, anhedral.	1.591 1.579 1.581 1.590 1.583 1.585 1.583
253.0–265.0 ft	Albite, quartz, muscovite	White, anhedral	1.528 1.529	Yellowish-white to yellowish-brown, anhedral.	1.592 1.595
Range			1.527–1.531		1.579–1.595
Average			1.529		1.587
Drill hole 5:					
207.0–263.0 ft	Albite, quartz, muscovite	White to pinkish, anhedral	1.528 1.528 1.528 1.529 1.528	White to light green, anhedral	1.592 1.591 1.581 1.586 1.592
298.5–302.0 ft	do	White to pinkish, in part platy	1.527		
Range			1.527–1.529		1.581–1.592
Average			1.528		1.588
Total range			1.527–1.531		1.579–1.595
Overall average			1.528		1.584

[1] Where two or more figures are given they are in the order of increasing depth in the drill hole.

Albite occurs as white-to-pink equant grains in most of the wall zone; it is equant to platy and anhedral to euhedral in the small replacement(?) units, and it occurs as stringers and equant grains in the small fracture-filling units. The minimum index of refraction on cleavage fragments (N_{α}') in drill cores ranges from 1.527 to 1.531; the average is 1.528 (table 5). For surface samples, N_{β} was determined by Maurice Deul (table 6); the range is from 1.532 to 1.536, and the average is 1.534.

Vugs in some of the replacement(?) bodies are lined with euhedral colorless to white platy crystals of albite (N_{α}' 1.527); the groundmass is composed of fine- to sugary-grained white and pink to red albite.

TABLE 6.—*Indices of refraction of albite and beryl from the surface exposure of the Helen Beryl pegmatite*

[Determinations by Maurice Deul, except as otherwise indicated]

ALBITE-QUARTZ-MUSCOVITE PEGMATITE

[Wall zone]

Specimen	Albite N_β	Albite $N_{\alpha'}$	N_ω of beryl [1]	Specimen	Albite N_β	Albite $N_{\alpha'}$	N_ω of beryl [1]
MHS 38-47	1.536			MHS 120-47	1.533		1.582→1.585
21-47	1.536			127-47			1.583→1.586
32-47	1.535						1.590←1.592
51-47	1.535			LRP 63c-46			[2] 1.583
82-47	1.535			63d-46			[2] 1.583
20-47	1.534			MHS 118-47	1.535		1.583-1.588
55-47	1.534			28-47	1.536		1.584
59-47	1.534			47-47	1.532		1.584-1.586
61-47	1.534			68-47			1.584-1.586
64-47	1.534			92-47	1.536		1.584-1.586
65-47	1.534			54-47	1.535		1.584-1.589
74-47	1.534			77-47	1.535		1.585
87-47	1.534			88-47	1.535		1.585
117-47	1.534			48-47	1.533		1.585
119-47	1.534			116-47	1.533		1.585→1.586
35-47	1.533			69-47	1.535		1.585←1.593
44-47	1.533			30-47	1.532		1.587
73-47	1.532			72-47	1.535		1.587-1.590
121-47	1.533		1.580-1.591	76-47	1.532		1.588
129-47			1.581	52-47			1.588-1.590
63-47			1.581→1.587	36-47	1.534		1.589-1.592
49-47	1.533		1.582-1.592	29-47	1.535		1.590
24-47	1.535		1.582-1.583	45-47	1.535		1.590-1.592
46-47	1.534		1.582→1.588				

PERTHITE-QUARTZ-ALBITE PEGMATITE

[Fracture-filling units]

Outer part

Specimen	Albite N_β	Albite $N_{\alpha'}$	N_ω of beryl [1]	Specimen	Albite N_β	Albite $N_{\alpha'}$	N_ω of beryl [1]
MHS 19-47	1.534		1.579→1.584	MHS 18-47	1.535		1.585
31-47	1.533		1.582	41-47	1.535		1.584→1.591
50-47	1.536		1.583→1.585	15-47	1.533		1.585-1.588
62-47	1.535		1.583→1.585	17-47	1.535		1.585→1.591
86-47			1.584-1.586				

Inner part

Specimen	Albite N_β	Albite $N_{\alpha'}$	N_ω of beryl [1]	Specimen	Albite N_β	Albite $N_{\alpha'}$	N_ω of beryl [1]
MHS 53-47			1.579-1.581	MHS 40-47			1.587-1.591
84-47	1.533		1.581→1.583	33-47			1.587←1.592
81-47			1.581→1.584	78-47			1.587→1.595
16-47			1.582→1.589	79-47			1.589-1.592
34-47			1.583→1.586	42-47			1.589←1.594
			1.590←1.592	23-47			1.590→1.592
85-47			1.584→1.588	37-47			1.590←1.593
39-47			1.585-1.591	71-47			1.591
27-47			1.587	58-47	1.533		1.591-1.595
60-47			1.587				

PERTHITE-QUARTZ-MUSCOVITE PEGMATITE

[Second intermediate zone]

Specimen	Albite N_β	Albite $N_{\alpha'}$	N_ω of beryl [1]	Specimen	Albite N_β	Albite $N_{\alpha'}$	N_ω of beryl [1]
MHS 135-47			1.585	MHS 133-47			1.591
134-47			1.589←1.591	132-47	1.534		1.592

PERTHITE-SPODUMENE-QUARTZ PEGMATITE

[Third intermediate zone]

Specimen	Albite N_β	Albite $N_{\alpha'}$	N_ω of beryl [1]	Specimen	Albite N_β	Albite $N_{\alpha'}$	N_ω of beryl [1]
LRP 63e-46			[2] 1.589	LRP 63a-46			[2] 1.594

QUARTZ-SPODUMENE-PERTHITE-ALBITE PEGMATITE

[Core]

Specimen	Albite N_β	Albite $N_{\alpha'}$	N_ω of beryl [1]	Specimen	Albite N_β	Albite $N_{\alpha'}$	N_ω of beryl [1]
MHS 140-47		[3] 1.528	[2] 1.588	MHS 139-47	1.535		1.589-1.590
141-47		[3] 1.529	[2] 1.588	114-47			[2] 1.590-1.594
143-47			[2] 1.588	142-47			[2] 1.590-1.595

[1] Arrows point away from determinations of the inner parts of crystals and toward determinations of the outer parts.
[2] Determinations by J. W. Adams.
[3] Determinations by M. H. Staatz.

Quartz occurs as irregular white to gray grains with a average diameter of ½ inch. The proportion of quartz varies from place to place in the zone; the range in drill core is from 28 to 44 percent, but the surface exposures may contain somewhat less quartz.

Muscovite is uniformly disseminated throughout the wall zone in flakes as much as 1½ inches long. It is locally abundant in the border zones.

Biotite is in the form of thin lathlike blades that transect the boundaries of other minerals and also the boundaries of the various units included in the wall zone. It is most abundant in and near the replacement(?) and fracture-filling units. Some biotite can be found in nearly all parts of the wall zone, but it is scarce in the border zone.

Black tourmaline and green apatite are disseminated throughout the border and wall zones, but they are most abundant in or near the replacement(?) bodies.

Beryl is present throughout the wall zone as euhedral to anhedral and skeletal crystals as much as 2 inches in diameter and 6 inches long. Beryl is most abundant in the border zone and the outer part of the wall zone. Skeletal crystals are also most abundant in these places. The *c*-axis of most crystals is approximately normal to the schist contact. Beryl associated with replacement(?) bodies is, for the most part, in irregular grains, but euhedral crystals have also been found. The The irregular grains commonly have a characteristic yellow-green to yellow-brown color. The euhedral crystals are deep yellow green.

The index of refraction of the ordinary ray ranges from 1.579 (13.1 percent BeO) to 1.595 (11.1 percent BeO). The average from drill core and surface samples (tables 5 and 6) is 1.585 (12.6 percent BeO). Crystals having an index greater than 1.590 are commonly near replacement or fracture-filling units. Table 6 shows that the cores of beryl crystals ordinarily have a lower index than the outer parts.

At places greenish sericite and traces of spodumene occur in irregular patches. Probably the sericite has replaced spodumene.

GRANITIC ALBITE-QUARTZ-MUSCOVITE PEGMATITE

Granitic albite-quartz-muscovite pegmatite of unknown origin and structure was intersected in drill holes 1 and 5 (pl. 14). This unit may be a phase of the wall zone, perhaps similar to the smaller very fine grained replacement(?) bodies. The rock has an even granular texture and a grain size of $\frac{1}{16}$ to ⅛ inch. It grades into typical coarser grained albite-quartz-muscovite pegmatite of the wall zone.

The granitic unit consists of albite (39 percent), quartz (31 percent), muscovite (19 percent), biotite (6 percent), perthite (1 percent), and tourmaline, beryl, and apatite (table 7). In places biotite is more abundant than muscovite. The minimum index of refraction of typical albite in cleavage fragments is 1.530, but in some albite it is as low as 1.527. Beryl was rarely seen, though analyses indicate an average content of 0.022 percent BeO. N_ω of four specimens ranges from 1.582 to 1.594.

TABLE 7.—*Modes of granitic albite-quartz-muscovite pegmatite*

Location of sample (distance in feet)	Length of sample (feet)	Mode (percent)					
		Albite	Quartz	Muscovite	Biotite	Perthite	Tourmaline, beryl, and apatite
Hole 1:							
149.4–163.4	14	35	30	25	4		6
163.4–172.7	9.3	34	34	20	6	2	4
172.9–175.7 and 177.7–182.5	7.6	40	30	8	15	2	5
Hole 5:							
286.0–298.5	12.5	45	32	18	3		2
Weighted average or total	43.4	39	31	19	6	1	4

GNEISSOID ALBITE-BIOTITE-QUARTZ PEGMATITE

Another variety of rock that may be a phase of the wall zone, though its structure is not well known, is gneissoid albite-biotite-quartz pegmatite. It was intersected on the east side of the pegmatite by drill holes 4 and 5. The unit is about 20 feet thick. Its average grain size is ⅙ inch; biotite blades ⅛ to 1 inch long give the gneissoid structure to the rock.

In hole 4 the minerals are albite (40 percent), biotite (33 percent), quartz (20 percent), muscovite (5 percent), apatite (1 percent), and tourmaline (1 percent), and in hole 5 they are albite (41 percent), biotite (30 percent), quartz (25 percent), muscovite (4 percent), tourmaline (<1 percent), apatite (<1 percent), and beryl (0.06 percent). The albite is in distinct white platy euhedral crystals having $N_{\alpha'}$ of 1.528 to 1.530. Eight small yellowish-white to pale-green anhedral beryl crystals were recovered between 282 and 285 feet in drill hole 5. These were the only beryl grains observed, but analyses indicate an average BeO content of 0.030 percent.

PERTHITE-QUARTZ-ALBITE PEGMATITE

[Fracture-filling units in wall zone]

The wall zone is cut by one large and numerous small tabular and branching fracture-filling bodies consisting of perthite-quartz-albite pegmatite. Probably at least 10 percent of the pegmatite outside of the first intermediate zone belongs to these fracture-filling units. Lithologically the fracture fillings are very similar to the first intermediate zone, and some of them are probably offshoots from this zone. The fracture-filling bodies extend in places to the outer contact of the wall zone and turn parallel to it, thus forming a unit that simulates a discontinuous wall zone.

Several of the fracture-filling units have a poorly developed zoning parallel to their walls. The outer parts of the fracture fillings are similar to the albite-quartz-muscovite wall zone of the pegmatite but commonly are coarser grained; contacts with the surrounding rock are gradational. The central part of fracture fillings is ordinarily rich in perthite and quartz. Variations in composition are shown in table 8 by 24 modes of drill core; 9 are entire fracture-fillings and the rest are of parts of zoned fracture fillings. The following mineral assemblages after Cameron, Jahns, McNair, and Page (1949, p. 59–70) are represented in the 24 modes.

Mineral assemblage	*Number of modes*
1. Plagioclase, quartz, and muscovite	9
2. Plagioclase, quartz	3
3. Quartz, perthite, plagioclase, with or without muscovite, and with or without biotite	6
4. Perthite, quartz	4
5. Perthite, quartz, plagioclase, amblygonite, and spodumene	1(?)
11. Quartz	1

The outer parts of fracture fillings commonly belong to assemblages 1 and 2, and the inner parts are mostly assemblages 3 and 4.

The fracture fillings as a group consist of medium to very coarse grained perthite-quartz-albite pegmatite. The fracture-filling body that covers a large part of the geologic map (pl. 13) is lean in albite and rich in perthite but otherwise has the same composition as the subsurface fracture fillings.

The grain size ranges from fine to very coarse. The average is about 12 inches in the inner part of the largest body; crystals more than 4 feet long are rare. In bodies 0.5 to 3 feet thick the average grain size is about 2 inches thinner bodies have an average grain size of about 1 inch.

At the center of the large fracture-filling body exposed at the surface (pl. 13), perthite occurs as large pink blocky subhedral to euhedral crystals in greasy-white quartz. Pale greenish-white beryl crystals and masses as much as 18 inches across occur in the quartz. These minerals decrease in grain size toward the outer edges of the body. Mica, tourmaline, and beryl crystals are most abundant in the outer parts of the fracture fillings, where they are rarely more than 6 inches long. They are commonly oriented at right angles to the wall of the fracture-filling unit. The muscovite is characteristically in wedge-shaped and "tied" books; the small proportion of sheet mica contains abundant, unidentified black and red mineral inclusions.

TABLE 8.—*Modes of fracture-filling units, Helen Beryl pegmatite*

Location of core sample in—		Mode (percent)				
Drill hole (distance in feet)	Fracture-filling	Perthite	Quartz	Albite	Muscovite	Others
Drill hole 1:						
72–73.1	Wall zone	--------	50	36	13	Apatite, 1
73.1–77	Core	69	20	1	10	Apatite, <1 Tourmaline, trace
77.0–81.2	Wall zone	8	54	30	5	Tourmaline, 2 Biotite, <1
88.8–89.4	Entire body	38	30	10	20	Tourmaline, trace Biotite, 2
94.5–98.5	do	5	49	40	5	Tourmaline, <1 Apatite, <1
100.4–102.5	do	5	16	60	15	Tourmaline, 2 Apatite, 1 Beryl, 0.66
172.7–172.9	do	96	2	--------	2	
175.7–177.7	do	63	30	2	2	Tourmaline, 1 Beryl, 1.99 Apatite, trace Biotite, trace
Drill hole 2:						
102.4–103.2	Border zone	--------	55	33	10	Apatite, 1 Tourmaline, <1
103.2–104.6	Outer part of wall zone	10	25	55	8	Apatite, 1 Tourmaline, 1
104.6–107.3	Inner part of wall zone	3	44	30	20	Tourmaline, 2 Apatite, <1 Beryl, 0.02 Biotite, trace
107.3–110.4	Core	3	94	2	1	
110.4–114.4	Wall zone	10	20	60	8	Apatite, 1 Tourmaline, 1 Beryl, 0.017
114.4–114.5	Border zone	--------	50	20	30	
116.0–116.3	Wall zone	--------	35	50	13	Apatite, 1 Biotite, <1 Tourmaline, <1
116.3–132.6	Core	50	25	20	5	Tourmaline, <1 Biotite, <1 Apatite, <1
132.6–133.1	Wall zone	5	20	50	25	Tourmaline, <1
Drill hole 3:						
37.2–55.0	Entire body	70	20	5	3	Biotite, <1 Tourmaline, <1 Apatite, <1 Beryl, 0.12
64.3–65.2	do	15	23	50	4	Green mica, 6 Tantalite-columbite, 1 Apatite, <1 Spodumene, trace
117.8–120.5	do	5	45	15	35	Tourmaline, <1
124.3–128.5	do	15	7	67	10	Apatite, <1 Tourmaline, trace
Drill hole 4:						
141.5–147.7	Wall zone and core	35	20	25	15	Tourmaline, 4 Biotite, <1 Beryl, 0.83 Apatite, trace
147.7–149.5	Wall zone	--------	25	66	8	Tourmaline, 1 Apatite, <1 Beryl, trace
Weighted average in drill core	--------	36	30	25	7	All, 2
Average composition of several surface exposures of the larger fracture-filling bodies.	--------	52	32	7	7	Biotite, 1 Tourmaline, <1 Apatite, <1. Beryl, 0.52 Lithiophilite-triphylite, trace
Average of drill core and surface exposures.	--------	44	31	16	7	All, 2

The maximum index of beryl ranges from 1.579 (13.1 percent BeO) to 1.595 (11.1 percent BeO); the average is 1.585 (12.6 percent BeO). (See tables 6 and 9.) Beryl from the outer parts of the fracture fillings has a slightly lower index than that from inner parts; in individual crystals the index tends to increase from the center outwards.

Most of the albite has a mottled pinkish color. It commonly forms and cuts or embays both perthite and quartz. The minimum index of albite cleavage fragments ranges from 1.527 to 1.531 and averages 1.528.

Fine-grained albite is the main constituent of small bodies that may have formed by replacement of the wall zone. These contain vugs lined with clear colorless albite.

PERTHITE-QUARTZ-MUSCOVITE-BIOTITE PEGMATITE

[First intermediate zone]

The inner edge of the wall zone forms a sharp contact with perthite-quartz-muscovite-biotite pegmatite of the first intermediate zone. This unit is a hood-shaped body, with a maximum thickness of 9 feet (pl. 14), that caps the upper part of the second intermediate zone.

Lithologically this zone is in many respects similar to fracture-filling units in the wall zone, and the two

Table 9.—*Indices of refraction of albite and beryl in drill core from fracture-filling units, Helen Beryl pegmatite*

Location of sample (distance in feet)	Minerals forming more than 5 percent of the rock, in order of abundance	Location in fracture-filling	$N_{\alpha'}$ of albite	N_ω of beryl
Drill hole 1:				
72–73.1	Quartz, albite, muscovite	Wall zone	1.528	
77.0–81.2	Quartz, albite, perthite, muscovite	do	1.527	
88.8–89.4	Perthite, quartz, muscovite, albite	Entire body	1.529	
94.5–98.5	Quartz, albite, muscovite, perthite	do	1.527	
100.4–102.5	Albite, quartz, muscovite, perthite	do	1.529	1.585
			1.528	1.583
175.7–177.7	Perthite, quartz	do	1.528	1.590
Drill hole 2:				
102.4–103.2	Quartz, albite, muscovite	Border zone	1.531	
103.2–104.6	Albite, quartz, perthite, muscovite	Outer part of wall zone	1.527	
104.6–107.3	Quartz, albite, muscovite	Inner part of wall zone	1.530	1.595
			1.529	1.587
107.3–110.4	Quartz	Core	1.529	
110.4–114.4	Albite, quartz, perthite, muscovite	Wall zone	1.527	1.586
114.4–114.5	Quartz, muscovite, albite	Border zone	1.528	
116.0–116.3	Albite, quartz, muscovite	Wall zone	1.529	
116.3–132.6	Perthite, quartz, albite, muscovite	Core	1.527	
132.6–133.1	Albite, muscovite, quartz, perthite	Wall zone	1.528	
Drill hole 3:				
37.2–55.0	Perthite, quartz, albite	Entire body	1.529	1.581
64.3–65.2	Albite, quartz, perthite, mica	do	1.527	
117.8–120.5	Quartz, muscovite, albite, perthite	do	1.528	
124.3–128.5	Albite, perthite, muscovite, quartz	do	1.528	
Drill hole 4:				
141.5–147.7	Perthite, albite, quartz, muscovite	Wall zone and core	1.529	
			1.527	1.580
Range			1.527–1.531	1.580–1.595
Average			1.528	1.585

may be connected. It is also similar to the second intermediate zone but differs in its higher biotite content. It consists of perthite (52 percent), quartz (22 percent), muscovite (10 percent), biotite (10 percent), albite (5 percent), tourmaline (<1 percent), apatite (<1 percent), and beryl (0.45 percent).

The most distinctive characteristic of this unit is the presence of thin blades of biotite, as much as 5 feet long and 4 inches wide, extending inward from the wall zone. The biotite blades intersect each other, as well as all the other minerals, cutting the rocks into prisms about 2 inches wide. Next to biotite, the largest crystals in this zone are of perthite, which if the splitting by biotite is disregarded, may be as much as a foot or more across. The perthite crystals are set in a finer grained matrix of quartz, muscovite, and accessory minerals. Tourmaline and muscovite are commonly intergrown with the biotite. Most of the muscovite that is not intergrown with the biotite is oriented at right angles to the zone contact, and is subgraphically intergrown with minerals of the matrix. Beryl is most common in albite-rich parts of the zone.

PERTHITE-QUARTZ-MUSCOVITE PEGMATITE

[Second intermediate zone]

The second intermediate zone is coarse-grained perthite-quartz-muscovite pegmatite. It is hood-shaped, has a maximum thickness of 11 feet (pl. 14), and wraps around the top of the third intermediate zone. The outer boundary is gradational with the biotite-rich first intermediate zone; the inner boundary grades into perthite-spodumene-quartz pegmatite.

This zone was estimated to contain perthite (59 percent), quartz (26 percent), muscovite (10 percent), albite (5 percent), tourmaline (<1 percent), biotite (<1 percent), apatite (<1 percent), spodumene (<1 percent), and beryl (0.03 percent).

Perthite is in pink euhedral crystals several feet long separated by a finer matrix of other minerals, most of which are less than 2 inches across. The beryl crystals in this matrix are white and as much as an inch long. The average value of N_ω for the beryl is about 1.590 (table 6) indicating a content of 11.9 percent BeO.

PERTHITE-SPODUMENE-QUARTZ PEGMATITE

[Third intermediate zone]

Very coarse grained perthite-spodumene-quartz pegmatite as much as 16 feet thick forms the hood-shaped third intermediate zone. This zone grades outward into perthite-quartz-muscovite pegmatite and inward into the quartz-spodumene-perthite-albite pegmatite of the core. In places it extends to a greater depth than the outer intermediate zones, and comes directly in contact with the wall zone.

This zone was estimated to contain perthite (65 percent), spodumene (20 percent), quartz (10 percent), muscovite (3 percent), albite (2 percent), lithiophilite-triphylite (<1 percent), and beryl (<1 percent).

The spodumene crystals form a network in which the interstices are occupied mostly by pink blocky crystals of perthite as much as 10 feet long. The spodumene is gray, white, green, or yellow. Crystals are as much as 1.5 feet in diameter and 10 feet long. Some that are normal to the zone contact are terminated at their inward ends by pyramid faces. At the top of the zone several spodumene pseudomorphs were noted that consist of dense compact greenish-yellow aggregate of sericite. At greater depths the spodumene is either fresh or partly altered along cleavage planes and fractures to an aggregate consisting largely of clay and micaceous minerals. Many crystals in or near intensely fractured zones of the pegmatite are completely altered to clay.

The proportion of quartz, lithiophilite-triphylite, and beryl increases toward the core. Beryl (N_ω 1.589–1.594) is most commonly associated with lithiophilite-triphylite and its alteration products. Muscovite also is most abundant as irregular masses associated with lithiophilite-triphylite, but it is sparsely scattered throughout the zone in flakes and books as much as 2 inches across. White to pink albite is most common in narrow bands separating crystals of spodumene and quartz.

QUARTZ-SPODUMENE-PERTHITE-ALBITE PEGMATITE

[Core]

The core of the Helen Beryl pegmatite is very coarse grained quartz-spodumene-perthite-albite pegmatite. It is as much as 30 feet thick, about 70 feet long, and extends an estimated 70 feet downplunge.

The core contains quartz (51 percent), spodumene (18 percent), perthite (11 percent), albite (10 percent), muscovite (8 percent), beryl (1.1 percent), lithiophilite-triphylite and its alteration products (0.8 percent), tantalite-columbite (0.1 percent), and cassiterite (trace). The outer few inches to a foot of the core consists chiefly of albite; it is finer grained than the adjacent pegmatite. Most of the spodumene in this albite-rich part of the core is in crystals less than a foot long, the muscovite is in flakes as much as 0.5 inch in diameter, the albite is in equant to platy grains as much as 0.5 inch long, and the tantalite-columbite is in crystals or aggregates as much as 4 inches in size. Farther inward tantalite-columbite is absent, and the size of the spodumene crystals increases to as much as 8 feet long and 1 foot in diameter. Some large spodumene crystals extend across the boundary between the third intermediate zone and the core.

Muscovite occurs mostly in clots of interlocking muscovite and albite grains ranging from 0.5 inch to as much as 3 feet in diameter. These muscovite-albite aggregates are commonly associated with round masses and crystals of lithiophilite-triphylite and its alteration products as much as 3 feet in maximum dimension. Secondary phosphates, such as purpurite and childrenite, form concentric layers around fresh lithiophilite-triphylite. Cassiterite is very rare—only two small grains were identified.

Beryl is most abundant in the outer part of the core, where it occurs in green and white anhedral masses interstitial to spodumene crystals. In 6 samples from the opencut, N_ω ranges from 1.588 to 1.595 (table 6), and in three samples from the drill core it ranges from 1.591 to 1.592. Albite associated with beryl both on the surface exposures and in drill core has N'_α of 1.528 to 1.529, showing that the change in the alkali content is much greater in the beryl than in the adjacent albite.

DIAMOND-DRILLING

The Helen Beryl pegmatite was explored at depth by 5 diamond-drill holes having a total length of 1,096.3 feet. As plate 14 shows, the holes were spaced at approximately equal intervals and were drilled at inclinations such that they would intersect the pegmatite at high angles. Logs of these holes are presented in table 10.

TABLE 10.—*Logs of diamond-drill holes, Helen Beryl pegmatite*

[Logged by M. H. Staatz. Modes of the pegmatitic units not given here are given in tables 4, 7, and 8 and on page 143; indices of refraction of albite and beryl in wall zone and fracture filling are given in tables 5 and 9]

Hole 1

[pl. 14]

Location: 65 ft W. of U.S. Bureau of Mines sample cut 2 (pl. 13)
Altitude of collar: 5333.8 ft.
Inclination: Minus 50°
Bearing: East
Total length: 216 ft.

Interval (feet)	*Description*
0–32	Overburden. No core.
32–72	Quartz-mica schist with thin beds of quartz-biotite-garnet schist. Minor minerals are chlorite, tourmaline, and garnet. Tourmaline occurs as widely disseminated microscopic black euhedral grains. Garnet and chlorite are most abundant in the lower part of the drill core. Schistosity is 69° to 79° to the drill core above 51 ft. The bedding is 77° to the drill core at 51.5 ft. and 70° at 52.6 ft. The bedding and schistosity are parallel and flatten to 51° to the drill core at 71.8 ft. Sparse lime-silicate rock occurs in layers as much as 3 in. thick. Irregular quartz veins with pinkish-white plagioclase (N'_α of 1.534 to 1.541) are between 52.7 and 58.3 ft and 69.6 and 70.9 ft. Adjacent schist is rich in mica and chlorite.
72–193. 1	Pegmatite. The pegmatite contact at 72 ft forms an angle of 50° with the drill core.
72–73. 1	Quartz-albite-muscovite pegmatite.[1] Wall zone of fracture-filling. Mixed with thin stringers of partly altered schist. Near the schist stringers the pegmatite (border zone of fracture-filling) contains more quartz, muscovite, and apatite than elsewhere, and has a grain size of about 1/16 in. Elsewhere albite is more abundant and may occur with quartz in grains as much as half an inch in diameter.

[1] In the logs the names of varieties of pegmatite show the dominant minerals in their order of abundance in the part of the core that is being described. The names are not necessarily the same as the names of units in the geologic sections, where the names are based on average composition throughout the pegmatite.

TABLE 10.—*Logs of diamond-drill holes, Helen Beryl pegmatite*—Continued

Hole 1—Continued

Interval (feet)	*Description*
73.1–77.0	Perthite-quartz-muscovite pegmatite. Core of fracture-filling. Blocky pink perthite crystals, as much as 4 in. in length, contain 1-in. inclusions of clear quartz, in places having graphic texture. Most of the muscovite flakes are ½ to ¾ in. across, irregular in form, and fill cracks in quartz or perthite. One book, 0.6 in. in diameter and 1.5 in. thick, at 75.5 ft. contains medium to heavy air-stained and red-stained sheet mica. Albite is in streaks and patches in quartz and perthite. Minor apatite occurs as irregularly scattered small blue-green grains about 1/32 in. in diameter.
77.0–81.2	Quartz-albite-perthite-muscovite pegmatite. Wall zone of fracture-filling. Average grain size is 1.5 in. White to pinkish albite is in streaks in clear quartz. A muscovite book, 1 in. thick, containing sheet mica was cut between 79 and 81.2 ft. Perthite is in 3.5-in. pink blocky crystals. One ¾-in. and many ⅛-in. grains of black tourmaline occur in the albite. Narrow crosscutting blades of biotite are 1 to 1.5 in. long.
81.2–88.8	Albite-quartz-muscovite-biotite pegmatite. Wall zone. The average grain size is ¾ in. White albite is in irregular stringers in quartz. Small irregular books of muscovite are as much as ¾ in. long. Thin blades of biotite from ¼ to 2 in. long cut quartz, albite, and muscovite. Small blue-green apatite and black tourmaline grains are associated with the biotite. Tourmaline is disseminated in other minerals. Four white to yellowish-white anhedral crystals of beryl (total exposed surface is 0.0094 sq ft) occur at 83.3, 83.5, and 84.6 ft.
88.8–89.4	Perthite-quartz-muscovite-albite pegmatite (fracture-filling). The perthite is in a pink crystal about 2 in. long; the muscovite is in irregular books as much as 1.5 in. across; the albite is in ½- to ¾-in., lathlike crystals; accessory biotite is in thin crosscutting blades, ½ in. long.
89.4–94.5	Albite-quartz-muscovite-biotite pegmatite. Wall zone. Similar to the rock between 81.2 and 88.8 ft. Three small yellowish anhedral crystals of beryl occur at 90 ft, and two at 92.1 ft; total surface exposure is 0.0004 sq ft.
94.5–98.5	Quartz-albite-muscovite-perthite pegmatite. Fracture-filling. Albite embays perthite.
98.5–100.4	Albite-quartz-muscovite pegmatite. Wall zone. Similar to rock between 89.4 and 94.5 ft, except that it has only about one-fifth as much biotite and considerably more beryl. The average grain size is ¾ in. One white anhedral beryl crystal at 100.3 ft has a surface area of 0.0008 sq ft.
100.4–102.5	Albite-quartz-muscovite-perthite pegmatite. Fracture-filling. Average grain size is about 1 in. Abundant streaks of pink albite occur in 3- to 4-in. perthite crystals. Most of the muscovite is in irregular books, ¼ to ¾ in. long. One book at least ¾ in. thick and 1¼ in. in diameter was cut at 102.0 ft. The mica is heavily air stained, is a little red stained, has minor reeving, and shows dark-red ruby to a lighter ruby color zoning. Three yellowish-white to white anhedral beryl crystals (total area is 0.0036 sq ft) occur at 101.2 ft.
102.5–149.4	Albite-quartz-muscovite pegmatite. Wall zone. Similar to rock between 98.5 and 100.4 ft, but the rock contains more perthite. Most of the muscovite is in small chunky irregular ½-in. books; some is in knifelike blades that cut albite, quartz, and the muscovite books. Thin knifelike blades of biotite, 1 in. long, are most abundent between 146 and 148.5 ft. Tourmaline is common between 141.5 and 144.5 ft. Eight yellowish, yellowish-green, and greenish-white, anhedral beryl crystals were observed; one at 110.6 ft, one at 113.0 ft, three at 119.2, two at 125.2 ft and one at 144.2 ft. Total surface exposed is 0.0220 sq ft.
149.4–163.4	Granitic albite-quartz-muscovite-tourmaline pegmatite. Even-textured granitic rock with average grain size of ⅛ in. An irregular 1- to 3-in. stringer of coarser material (average grain size ½ in.) is at 159.4 ft. Tourmaline is 10 percent of the rock between 158.3 and 161.6 ft. Accessory biotite occurs as ⅛-in. books and in a few thin blades as much as ¾ in. long in the lower part of the interval. Less than 1 percent of apatite is in clear green rounded grains about 1/32 in. in size. N'_α of the yellowish-white albite is 1.530 at 150.5 ft and 159.6 ft.
163.4–172.7	Granitic quartz-albite-muscovite-biotite pegmatite with irregualr patches (25 percent) of coarser-grained quartz-albite-muscovite pegmatite. The grain size is about ⅛ in. N'_α of albite is 1.530 at 164 and 167.7 ft (fine-grained variety) and 1.529 at 171.1 ft (coarse-grained variety). Beryl is in two brown glassy anhedral crystals at 170.3 ft (N_ω 1.582), one round glassy crysral at 171.4 ft (N_ω 1.582), and one white euhedral crystal at the contact of perthite pegmatite at 172.7 ft (N_ω 1.587). Exposed area of beryl is 0.0016 sq ft.
172.7–172.9	Perthite pegmatite. Fracture-filling. Massive pink perthite crystal with 2 percent of quartz and muscovite.
172.9–175.7	Granitic albite-quartz-biotite-muscovite pegmatite. Average grain size is ⅛ in. A 1-in. band of coarser grained material occurs at 174.4 ft. The lower contact is irregular, but approximately 90° to the drill core.
175.7–177.7	Perthite-quartz pegmatite. Fracture-filling. Blocky pink perthite crystals are as much as 8 in. long and include lathlike albite grains. Small amounts of biotite are intergrown with accessory muscovite. One large greenish euhedral crystal of beryl at 175.7 ft has a total exposed area of 0.0105 sq ft.

TABLE 10.—*Logs of diamond-drill holes, Helen Beryl pegmatite*—Continued

Hole 1—Continued

Interval (feet)	*Description*
177.7–182.5	Granitic albite-quartz-biotite-muscovite pegmatite. Similar to that between 172.9 and 175.7 ft. The lower contact is irregular and is about 45° to the drill core.
182.5–193.1	Albite-quartz-muscovite pegmatite. Wall zone. Patches of granitic albite-quartz-muscovite pegmatite constitute 35 percent of the core between 182.5 and 184.3 ft, and they appear again as scattered patches between 186.3 and 188.0 ft. Otherwise the pegmatite has an average grain size of ¾ in. Blades of accessory biotite are as much as 6 inches long. One white anhedral crystal of beryl has a surface exposure of 0.0005 sq ft.
193.1–193.4	Albite-quartz-muscovite-biotite granulite. Contains albite (38 percent), quartz (30 percent), muscovite (18 percent), biotite (12 percent), apatite (1 percent), and tourmaline (1 percent). Muscovite is near the contacts, and biotite in the center of this unit. Albite has N'_α of 1.529. The contacts are irregular and in places gradational. The rock is fine grained (about 1/16 in.), light gray, and contains mica-rich bands that are 45° to the drill core at 193.3 feet. The contacts have an angle of 80° to the core.
193.4–194.4	Albite-quartz-muscovite pegmatite. Wall zone. Contains one white anhedral beryl crystal with a surface exposure of 0.0015 sq ft.
194.4–195.4	Albite-quartz-muscovite granulite. Similar to that between 193.1 and 193.4 ft except that it contains less biotite and more tourmaline. Layers are at 60° to the drill core.
195.4–216.0	Mica-quartz schist. Muscovite predominates in the upper part and biotite in the lower part of this interval. The schistosity and bedding are at 71° to the drill core at 196.5 and 204 ft. The schist-granulite contact is 75° to the drill core.
End of hole.	

Hole 2

[pl. 14]

Location: 73 ft W. of the back of U.S. Bureau of Mines sample cut 3 (pl. 13).
Altitude of collar: 5340.8 ft.
Inclination: Minus 36°.
Bearing: East.
Total length: 146.3 ft.

Interval (feet)	*Description*
0–15.8	Overburden. No core.
15.8–19	Mica-quartz schist. Low core recovery. At 16 ft the schistosity cuts the drill core at an angle of 88°
19–23	Quartz vein. Contains biotite (3 percent) and albite (3 percent). One large patch of biotite books, ⅛ in. across, is at 21.5 ft; albite and a few flakes of biotite occur as streaks in quartz. At 22.5 ft white to pink anhedral crystals of albite have $N_{\alpha'}$ of 1.531.
23–27	Quartz-mica-sillimanite schist. Sillimanite is in white to pinkish aggregates, 1/16 to ⅛ in. long, parallel to schistosity, in a finer grained matrix of quartz, muscovite, and biotite. The schistosity is at 89° to the drill core at 26.7 ft.
27–102.4	Quartz-mica schist. Mostly uniform in composition and texture. From 95.5 to 98.5 ft the muscovite is in heterogeneously arranged porphyroblasts about ⅛ in. long. Bedding is 70° to the drill core at 35.5 ft, and 82° at 60.2 ft; bedding and schistosity are 52° at 84 ft and 25° at 91.1 ft. Many quartz veins, as much as 6 in. thick, occur throughout the drill core. Most of the veins less than ⅛ in. thick contain only quartz. The thicker ones contain white to pink oligoclase, biotite, and green apatite. The largest of these, at 88.7 to 90 ft, contains about 1 percent oligoclase ($N_{\alpha'}$ 1.526). Oligoclase in a vein at 101 ft has $N_{\alpha'}$ of 1.533.
102.4–114.5	Pegmatite. The contact at 102.4 ft is about 15° to the core, but it is extremely irregular and has many apophyses extending into the schist. The lower contact is 60° to the core.
102.4–103.2	Quartz-albite-muscovite pegmatite. Border zone of fracture-filling. The true thickness of this unit is about 0.2 ft. Average grain size is ⅛ in. White to pink albite is interstitial to clear quartz; muscovite is in irregular books as much as ¼ in. across; and minor apatite, near the schist contact, is in green 1/16-in. round grains. A few inclusions of schist are dominantly biotite.
103.2–104.6	Albite-quartz-perthite-muscovite pegmatite. Outer part of wall zone of fracture-filling. Average grain size ½ in. White to pink albite at 104.4 ft is in ¼- to ½-in. grains. Albite in mottled-pink red-stained grains containing 1/16-in. vugs cuts perthite crystals. Muscovite occurs in irregular ¼-in. to 1-in books.
104.6–107.3	Quartz-albite-muscovite pegmatite. Inner part of wall zone of fracture-filling. Average grain size 1 in. Clear anhedral quartz and white to pinkish albite grains range from ⅛ in. to 1½ in. in length. Part of the albite occurs as streaks in quartz, but about one-third of it is mottled pink, contains small vugs, and cuts accessory perthite. Perthite occurs as irregular pink crystals. Muscovite is in extremely irregular books, ⅛ to 1½ in. across. It is light rum in color, shows moderate air-staining, and has a little red stain. Minor tourmaline forms black anhedral to subhedral crystals. Four small yellowish anhedral crystals of beryl have a total surface exposure of 0.00073 sq ft.
107.3–110.4	Quartz pegmatite. Core of fracture-filling. A single piece of pink perthite is found, which is about an inch square. Accessory albite at 107.6 ft is in white to slightly pinkish veinlets in quartz. Muscovite occurs in ⅛-in. flakes on a fracture in quartz.

TABLE 10.—*Logs of diamond-drill holes, Helen Beryl pegmatite*—Continued

Hole 2—Continued

Interval (feet)	*Description*
110. 4–114. 4	Albite-quartz-perthite-muscovite pegmatite. Wall zone of fracture-filling. Same as 103.2 to 104.6 ft, except for about 5 percent more albite, less quartz, and 0.017 percent beryl.
114. 4–114. 5	Quartz-muscovite-albite pegmatite. Border zone of fracture-filling. Similar to the rock at 102.4 to 103.2 ft, except that there is 30 percent muscovite and less albite and quartz.
114. 5–116. 0	Quartz-mica schist. A gray compact fine-grained rock containing a few coarser-grained (⅛-in) beds. Muscovite is more abundant than biotite near the pegmatite, but scattered porphyroblasts of muscovite occur throughout the interval. At 114.9 ft the schistosity is 74° to the drill core; both upper and lower contacts are parallel to the schistosity.
116. 0–133.1	Pegmatite. The upper contact is 83° to the drill core; the lower contact was not recovered.
116. 0–116. 3	Albite-quartz-muscovite pegmatite. Wall zone of fracture-filling. Average grain size ⅛ in. Part of this unit consists of irregular patches of sugary-textured rock; other parts have interlocking grains ¼ in. in size. Albite is in white anhedral crystals; quartz is in clear anhedral crystals; muscovite is in small ragged books; minute amounts of apatite occur in scattered green anhedral crystals, ranging from 1/32 to 1/16 in. in size; tourmaline is in small black specks; and biotite occurs adjacent to the upper contact. The lower contact is gradational.
116. 3–132. 6	Perthite-quartz-albite-muscovite pegmatite (core of fracture-filling). Pink perthite is in crystals 1 to 4 in. long; in part it is graphically intergrown with clear quartz in lenticular, anhedral crystals, about an inch long. Perthite crystals are in a finer (¾ in.) matrix of quartz, muscovite, and albite. White to pinkish albite is common along the quartz-perthite contacts and in many places embays the perthite. Part of the albite is mottled and contains small (1/16 in.) vugs. Muscovite, tourmaline, and apatite are rare. White and, in a few places, pinkish albite is interstitial to the quartz and muscovite. Black tourmaline is in 1/16 to ⅛ in. subhedral to euhedral crystals; apatite is in 1/16 to ⅛ in. anhedral crystals; small amounts of biotite are commonly intergrown with muscovite.
132. 6–133. 1	Albite-muscovite-quartz-perthite pegmatite. Wall zone of fracture-filling. Albite and muscovite increase in abundance, and quartz and perthite decrease near the lower contact. Many fractures.
133.1–146.3	Quartz-mica-chlorite schist. Fine grained. Layered. A well-defined schistosity, parallel to the bedding, is 41° to the drill core at 133.1 ft, 48° at 136.7 ft, 64° at 138.8 ft, and 58° at 143 ft. A 3-in. bed of quartz-chlorite schist is at 136.3 ft. The chlorite is in small lenticular blebs about 1/16 in. long in fine granular quartz. Hematite staining is common along edges of the chlorite.
End of hole.	

Hole 3

[pl. 14]

Location: 107 ft S. 41° E. of hole 1.
Altitude of collar: 5320.9 ft.
Inclination: Minus 37°

Bearing: East.
Total length: 140 ft.

Interval (feet)	*Description*
0–29.3	Overburden. No core.
29.3–30.5	Quartz-vein.
30.5–37.2	Quartz-mica schist with interbedded quartz-biotite-garnet schist. Fine grained. Biotite is in irregular lenticular masses as much as ¼ in. in length; the garnet is in round red porphyroblasts about ⅛ in. in diameter. The bedding is 59° and the schistosity 79° to the drill core.
37.2–128.5	Pegmatite. No contacts recovered.
37. 2–55. 0	Perthite-quartz-albite pegmatite. Fracture-filling. Pink blocky perthite is in crystals as much as 3 in. in diameter. Clear anhedral quartz in crystals as much as ½ in. across forms inclusions in the perthite or is associated with albite and accessory muscovite in the matrix. Most of the pinkish albite is in thin white stringers in quartz or perthite, or along contacts between the two minerals. Muscovite is in ¼- to ½-in. books associated with quartz and in thin blades, intergrown with small amounts of biotite and tourmaline, that cross perthite, quartz, and albite. Small blue-green grains of apatite are near biotite and muscovite. One crystal of yellowish green anhedral beryl at 51.9 ft had an exposed area of 0.0019 sq ft.
55. 0–64. 3	Albite-quartz-muscovite pegmatite. Wall zone. Same as rock at 98.5 to 100.4 ft in hole 1, except that it contains 0.04 percent beryl. White to pinkish anhedral albite is the most abundant mineral. One yellowish anhedral crystal of beryl at 61.9 ft has an exposed area of 0.0012 sq ft.

TABLE 10.—*Logs of diamond-drill holes, Helen Beryl pegmatite*—Continued

Hole 3—Continued

Interval (feet)	*Description*
64. 3–65. 2	Albite-quartz-perthite pegmatite. Fracture-filling. Albite occurs as streaks in perthite, as white to pinkish mottled plates with pseudomorphic perthitic structure, and as a fine-grained aggregate with green mica. Pink perthite, in 2-in. crystals, is embayed by platy albite. Accessory fine-grained (1/16-in.) light green mica with N_β of 1.586 and $2V$ of 35° to 40° occurs with albite at either end of this interval. Irregular books of accessory muscovite, 1/4 to 3/4 in. in size, are associated with quartz. About 1 percent of columbite-tantalite in dark-brown anhedral to euhedral grains are as much as 1/4 in. across.
65. 2–93. 7	Albite-quartz-muscovite-perthite pegmatite. Wall zone. Average grain size is about 1/2 in., but there are several small patches of finer granular quartz and albite in small replacement (?) units. Most of the albite is in white to pinkish anhedral crystals associated with clear anhedral quartz and irregular 1/4- to 3/4-in. books of muscovite. Pink perthite crystals as much as 1 1/2 in. long are associated with clear quartz; smaller crystals occur with albite, quartz, and muscovite. Minor tourmaline is found as fine (1/36- to 1/8- in.) black grains scattered throughout the rock. In the upper part of this interval some of the tourmaline crystals have a linear arrangement in thin blades of muscovite. Minor apatite is in rounded blue-green grains 1/16 in. in diameter. The rock is highly fractured; no drill core was recovered between 73.8 and 78.8; 6 percent was recovered between 83.8 and 88.8; and 5 percent between 88.8 and 93.7 ft.
93. 7–101. 8	Quartz-albite-muscovite pegmatite. Core. No drill core was recovered between 93.7 and 99 feet. Drill core recovered contained quartz (77 percent), albite (15 percent), muscovite (7 percent), beryl (0.97 percent), tourmaline ($<$1 percent), and apatite ($<$1 percent). The average grain size for all minerals except quartz is about 3/4 in.; quartz is as much as 3 in. Platy albite (N'_α 1.528 to 1.529) ranges in color from clear transparent crystals through white, yellowish white, and pink; a few crystals show all variations. It is most abundant in the upper part of this interval. Muscovite is in irregular books, 1/2 in. in size, in the quartz. Apatite in rounded green grains (about 1/8 in. across) is sparse throughout the rock. Tourmaline forms small black crystals 1/16 in. long. Nine white to pale-green anhedral crystals of beryl have a total exposed area of 0.0040 sq ft. N_ω of beryl at 101.3 ft is 1.592, at 101.4 ft it is 1.591, and at 101.5 ft it is 1.592.
101. 8–117. 8	Albite-quartz-muscovite pegmatite. Wall zone. Similar to rock between 55.0 and 64.3 ft except that it has 0.45 percent beryl. Contains 15 pale-green to white anhedral crystals of beryl having a total exposed area of 0.02007 sq ft.
117. 8–120. 5	Quartz-muscovite-albite pegmatite. Fracture filling. Low core recovery. Quartz grains, as much as 1.5 in. long, are glassy and opaque. One 2.5-in. thick book of muscovite yielded sheet mica at least 1 1/8 in. long; it is moderately air-stained and has mineral stain; other muscovite is in smaller books. White to pink albite and one crystal of pink perthite occur with the quartz and muscovite.
120. 5–124. 3	Albite-quartz-muscovite pegmatite. Wall zone. Similar to rock between 55.0 and 64.3 ft, but contains 0.51 percent beryl. One crystal of perthite associated with a beryl crystal at 122.1 ft. The beryl is pale green and anhedral; the area of exposure is 0.00576 sq ft.
124. 3–128. 5	Albite-perthite-muscovite pegmatite. Fracture filling. Average grain size is 1 inch. Mottled white to pink platy albite has abundant bright red stains on fractures; in the lower part of this interval it contains vugs, as much as 1/4 in. across, that are commonly lined with clear albite crystals. Part of the albite forms plates in perthite and pseudomorphically preserves the perthitic structure; part is in wormlike veinlets. Pink perthite is in crystals as much as 4 in. long. Light-brown muscovite is in 1/4 to 1 in. irregular books. The muscovite has a medium to heavy air-stain, and a little red stain.
128. 5–136. 2	Quartz-mica schist. Contains quartz (55 percent), biotite (27 percent), muscovite (15 percent), and chlorite (3 percent). Fine grained, light gray. Porphyroblasts of muscovite, about 1/8 in. in diameter, are common from 128.5 to 130 ft. The schistosity is 56° to the drill core at 129.2 ft. and 82° at 135.4 ft. Contains small quartz veins, both parallel and discordant to the schistosity. Some of the quartz contains white plagioclase streaks.
136. 2–138	Quartz-albite vein. Contains 7 percent of albite and 2 percent of biotite. Quartz is clear and glassy with many small fractures. The albite (N'_α 1.529 at 137 ft) is in irregular white patches or streaks in the quartz. The upper contact is 30° to the drill core, but is irregular.
138–140 End of hole.	Mica-quartz schist. Schistosity is 75° to the core.

TABLE 10.—*Logs of diamond-drill holes, Helen Beryl pegmatite*—Continued

Hole 4

[pl. 14]

Location: 98 ft W. of hole 3 (pl. 13).
Altitude of collar: 5340.9 ft.
Inclination: Minus 60°.

Bearing: East.
Total length: 279 ft.

Interval (feet)	*Description*
0–22. 5	Overburden. No core.
22. 5–135. 4	Quartz-mica schist interbedded with quartz-biotite-garnet schist and lime silicate rock. Thin-bedded fine-grained quartz-mica schist comprises about 98 percent of this interval. Pink porphyroblasts of garnet, as much as 1/16 in. in diameter, are sparsely distributed in some beds. Sillimanite (about 5 percent) occurs only between 64.5 and 67.0 ft, where it is in white lenticular blebs as much as 1/8 in. in length. The angle between schistosity and bedding is rarely more than a few degrees. The angle to the core is 36° above 38 ft and mostly 50° to 60° from 42 to 135 ft. Hornblende, garnet, and biotite in the lime-silicate rock are as much as 1/8 in. across. Widely distributed quartz-feldspar and quartz veins contain 85 to 100 percent clear quartz, and the remainder is mostly white to pink oligoclase (N_{α}' 1.532 to 1.538) as streaks in the quartz. Biotite and chlorite are in and adjacent to the veins. The largest veins are at 38.7 to 40.2, 114.8 to 117.5, and 118.0 to 118.6 ft. Some veins are conformable and some wholly or in part discordant. Between 64.7 and 68.2 ft the rock has several small shears with slickensides and as much as 1/16 in. of gouge. Attitudes of shears are:

Depth (feet)	*Angle with core*	*Angle with schistosity*
64.7	54°	71°
64.8	66°	43°
68.0	41°	55°
68.2	30°	10°

135. 4–141. 5 Quartz-muscovite granulite (95 percent, or more) and 1 in. stringers of pegmatite. The granulite contains quartz (66 percent), muscovite (25 percent), albite (5 percent), biotite (3 percent), tourmaline (1 percent), and apatite (<1 percent). Uniform sugary texture; the grain size averages about 1/32 in. The dominant minerals are white quartz and light-green muscovite; in places, biotite, albite, or tourmaline are abundant. White euhedral crystals of albite, as much as 1/8 in. in length, are common. At 140.5 ft N_{α}' of albite is 1.529. In some places the rock has a weak schistosity at 63° to the drill core. Pegmatite stringers have average grain sizes of 1/8 to 3/4 in. Their mineralogic composition is:

Mode
[In percent]

Depth (feet)	Quartz	Albite	Perthite	Muscovite	Apatite	Tourmaline	Beryl	$N\alpha'$ of albite
136.4	35	1	35	20	2		7	
137.0	13	4	65	18				1.527
138.0	35	5	40	20	<1	<1		
141.0	15	25	50	10	<1	<1		1.527

Beryl at 136.4 ft is light greenish yellow and euhedral; it covers 0.0020 sq ft; N_{ω} is 1.592.

141. 5–265. 0 Pegmatite. Contacts not recovered.

141. 5–149. 5 Albite-perthite-quartz-muscovite pegmatite. Fracture-filling. Average grain size 1 in. Pink blocky crystals of perthite are as much as 1.5 in. long. In some places lath-shaped pinkish albite crystals are included in the perthite, and in other places the albite is in small stringers that cut perthite. White to mottled-pink albite is most common in the extreme upper and lower parts of the interval. It shows relict perthitic structure. Quartz is in clear anhedral crystals about 1 in. in size. Most of the muscovite is in irregular books 1/8 to 1½ in. across; one book is at least 2 in. thick. The muscovite is moderately air-stained and has red stain. Black euhedral crystals of accessory tourmaline, about ½ in. long, are most abundant near the middle of this unit. A little biotite, commonly interlayered with muscovite, is found in crosscutting, knifelike blades as much as 2 in. long. The exposed area of eight light-greenish clear anhedral to subhedral crystals of beryl ranges from 0.00019 to 0.00554 sq ft; the total is 0.01391 sq ft.

149. 5–233. 0 Albite-quartz-muscovite pegmatite. Wall zone. Average grain size is ½ to ¾ in. Between 230 and 233 ft the grain size diminishes and in patches the rock has a sugary texture. Albite occurs as white and occasionally as pinkish, anhedral to euhedral crystals. It veins the quartz in many places. Most of the euhedral crystals of albite have good albite twinning and are from ½ to ¾ in. long. Quartz is in clear anhedral crystals, and muscovite is in very irregular books, from 1/8 to 1 in. in length. Large pink crystals of accessory perthite, 1 to 6 in. long are found chiefly between 160 and 180 ft; they have small inclusions of muscovite, quartz, and albite. Minor tourmaline is in black anhedral to subhedral grains ranging from 1/32 to ½ in. in size. Some of the crystals are alined along blades of accessory biotite; some occur along planes where there is no

TABLE 10.—*Logs of diamond-drill holes, Helen Beryl pegmatite*—Continued

Hole 4—Continued

Interval (feet)		*Description*
141.5–265.0	149.5–233.0	biotite, and some are scattered at random. Minor apatite occurs as small (1/32- to 1/8-in.) round blue-green grains with N_ω and N_ϵ between 1.635 and 1.64, or as larger (1/8- to 1/2-in.) irregular light-green grains with N_ω and N_ϵ between 1.625 and 1.63. Biotite is in thin knifelike blades, from 1/2 to 2 in. long, commonly associated with tourmaline and apatite. The blades cut albite, quartz, and muscovite. Fifteen yellowish-white to light-green extremely irregular, anhedral crystals of beryl occupied an area of 0.05555 sq ft of core. Individual crystals of beryl ranged from 0.00010 to 0.01663 sq ft. There is only one beryl grain, exposed area of 0.00010 sq ft, between 184 and 233 ft.
	233.0–253.0	Gneissoid albite-biotite-quartz pegmatite. Average grain size is 1/16 in. The biotite is in thin knifelike sheaves from 1/8 to 1 in. in length. These are subparallel, and form a gneissoid structure that cuts the drill core at an angle of 55° at 234 ft, 67° at 238 ft, 58° at 239.2 ft, 34° at 242 ft, 70° at 246.3 ft, and 65° at 251.5 ft. Albite is in white euhedral crystals ranging from 1/32 to 1/8 in across. N_α' is 1.530 at 234.5 ft and 1.528 at 249.5 ft. Clear anhedral crystals of quartz are interstitial to the albite. Accessory muscovite is in small scattered books ranging from 1/64 to 1/16 in. across. Round blue-green grains of apatite, and black subhedral to euhedral grains of tourmaline are 1/64 in. in size. No beryl observed, possibly because the rock is too fine-grained to recognize it.
	253.0–265.0	Albite-quartz-muscovite pegmatite. Wall zone. Similar to the rock between 149.5 and 233.0 ft. Seventeen crystals of beryl observed, occurring in yellowish-white to yellowish-brown anhedral grains. The rock has a granular appearance and in part contains brown iron oxide. The beryl crystals range in exposed area from 0.00002 to 0.00163 sq ft; the total area is 0.00673 sq ft.
265.0–279.0		Quartz-mica schist with interbedded quartz-chlorite-garnet schist. Quartz-mica schist makes up 92 percent of this interval. Some parts of the drill core are mica-rich; others are quartz-rich. Muscovite is more common in the upper part of the interval, biotite in the lower. Porphyroblasts of muscovite, 1/16 to 1/8 in. across, are common for 0.5 ft below the pegmatite contact, and also on the sides of quartz-feldspar veins. Bedding and schistosity are inclined 45° to the drill core at 265.4 ft, 61° at 268 ft, 55° at 273 ft, and 59° at 278 ft. Quartz-chlorite-garnet schist at 275.2 to 275.5 ft contains about 5 percent of biotite. Quartz forms a fine granular groundmass with grains less than 1/64 in., and chlorite occurs in lenticular porphyroblasts as much as 1/8 in. long. Garnet is in rounded pink porphyroblasts 3/16 in. across. A quartz-feldspar vein between 270.6 and 271.2 ft contains quartz (84 percent), albite (15 percent), pale-green mica (1 percent), and tourmaline (trace). Upper contact is at 30° to the drill core, and the lower contact is at 40°. Quartz is clear and cut by many fractures, some of which are coated with iron stain. Albite is white; some of it has an irregular contact with the quartz, and some of it is in rectangular euhedral crystals. At 270.7 ft the albite has N_α' of 1.529. Very fine grained light-green mica is associated with albite.
End of hole.		

Hole 5

[pl. 14]

Location: 92.5 feet, S. 22° E. from hole 4 (pl. 13)
Altitude of collar: 5341.4 ft
Inclination: Minus 70°.

Bearing: East.
Total length: 315 feet

Interval (feet)		*Description*
0–14.4		Overburden. No core.
14.4–195.0		Gray quartz-mica schist forms 95 percent of the interval. Remainder is garnet-rich schist, lime silicate rock, and quartz veins. Sillimanite is in white lenticular blebs as much as 1/16 in long, erratically distributed between 151.5 and 174 ft. Schist is isoclinally folded. Bedding and schistosity are approximately parallel, and are at angles of 30° to 50° to the core. Quartz and quartz-feldspar veins are mostly conformable or partly conformable to the schistosity; some are crosscutting and extremely irregular. The thickest veins are at depths of 32.9 to 34, 82.6 to 84.5, 146.1 to 147, and 185.8 to 187.8 ft. Most of the veins are entirely quartz; others contain as much as 20 percent white to pink oligoclase (N_α' 1.538 to 1.548), though ordinarily the oligoclase content is 1 to 5 percent. Porphyroblasts of biotite, and in places chlorite and garnet, are abundant adjacent to the quartz veins. Stringers of biotite and chlorite are in some veins, especially crosscutting veins. A fault with 1/4 in. of light-gray gouge at 23.8 ft is at 45° to the drill core in the opposite direction to the schistosity. Several fractures cemented by 1/4 to 1/2 in. of hard dark-blue gouge, between 153.5 and 154.5 ft, are at 10° to the schistosity and at about 45° to the core, both in the same direction.
195.0–302.0		Pegmatite. Contacts not recovered.
	195.0–207.0	No core recovered. Probably wall zone.
	207.0–263.0	Albite-quartz-muscovite pegmatite. Wall zone. Average grain size is 1/2 in.; the last few inches, however, have a sugary texture. White to pinkish anhedral albite, with a few vugs, and clear anhedral quartz are dominant minerals. The contacts between these minerals are irregular. Most of the muscovite is in chunky irregular books, 1/8 to 3/4 in.

TABLE 10.—*Logs of diamond-drill holes, Helen Beryl pegmatite*—Continued

Hole 5—Continued

Interval (feet)		*Description*
195. 0–302. 0	207. 0–263. 0	long. It also occurs as thin knifelike blades as much as 2 in. long, commonly associated with abundant tourmaline and apatite. Small amounts of tourmaline are in black anhedral to subhedral grains 1/64 to 1/4 in. in diameter. Small amounts of apatite occur dominantly in rounded blue-green grains 1/32 to 1/8 in. long; it also occurs as irregular light-green grains 1/16 to 1/4 in. long. A few pink crystals of perthite as much as 1.5 in. long are commonly veined by albite. The upper part of the interval contains light-green mica in books as much as 1/16 in. across. The exposed area of 10 white to light-green anhedral crystals of beryl ranges from 0.00052 to 0.00740 sq ft; the total area is 0.02446 sq ft.
	263. 0–286. 0	Gneissoid albite-biotite-quartz pegmatite. Average grain size is 1/16 in. Numerous thin knifelike blades of biotite, 1/8 to 2 in. long, have a general orientation that is 30° to the drill core at 266 ft, 45° at 270 ft, 18° at 274.5 ft, 62° at 275.8 ft, 35° at 278 and 279.1 ft, 25° at 281 ft, and 68° at 284 and 285.5 ft. White rectangular crystals of albite are as much as 1/4 in. in size. The exposed area of eight small yellowish-white to pale-green anhedral crystals of beryl between 282 and 285 ft, ranges from 0.00009 to 0.00201 sq ft. One crystal at 282.2 ft has an N_ω of 1.583, and another at 284.2 ft has an N_ω of 1.582. The upper contact of this rock was not recovered in the core, and the lower contact is gradational.
	286. 0–298. 5	Granitic albite-quartz-muscovite pegmatite. The average grain size of this uniformly textured rock is 1/16 in. White anhedral crystals of albite at 296.0 ft have $N_{\alpha'}$ of 1.527. The quartz is in clear anhedral crystals, and the muscovite is in irregular books, 1/64 to 1/16 in. across. Minor biotite is in thin knifelike blades that are most abundant adjacent to the gneissoid albite-biotite-quartz pegmatite. Small amounts of apatite are scattered throughout this unit in roundish blue-green anhedral crystals less than 1/32 in. across. Minor tourmaline is for the most part in anhedral black crystals less than 1/64 in., although a few are as much as 1/16 in. One yellowish white crystal of beryl, 0.0001 sq ft in exposed area, was observed; N_ω is 1.594.
	298. 5–302. 0	Albite-quartz-muscovite pegmatite. Wall zone. Only 3 in. of broken drill core recovered. Average grain size is 1/2 to 3/4 in. The albite is in white to pink, in part platy crystals. Quartz is in clear anhedral crystals 1/4 in. across, and muscovite is in irregular books 1/2 in. across. Several roundish blue-green anhedral crystals of apatite as much as 1/8 in. in length and a few black grains of tourmaline less than 1/64 in. across were observed.
302. 0–315.0		Mica-quartz schist. Sillimanite (3 percent) is in porphyroblastic, ellipsoidal grains, 1/16 to 1/8 in. in diameter, between 311.0 and 314.0 ft. Bedding and schistosity are parallel and are at 35° to the core at 303 and 305.2 ft, 44° at 310.5 ft, 50° at 313.3 ft, and 42° at 314.2 ft.
End of hole.		

Hole 1 was drilled beneath the thickest part of the pegmatite on the surface. As plate 14 shows, it indicated the approximate rate of thinning of the pegmatite in depth, and the plunge of the keel could thus be predicted. It also showed that the inner zones do not extend to the depth of the drill hole, that they also plunge to the south, and that in consequence they form only a small part of the pegmatite.

Hole 2 (pl. 14) was planned to locate the keel of the pegmatite, and it apparently passed only a few feet above it. Hole 3 (pl. 14) was successfully aimed at the lower part of the spodumene-bearing inner units, and hole 4 (pl. 14) was drilled beneath it in the same section to explore the wall zone and the contained fracture-filling units. Holes 1 to 4 indicate that the pegmatite plunges to the south beneath the surface as a very large body. Hole 5 (pl. 14) was drilled 65 feet beyond the southernmost outcrop, and downplunge from the known position of the central zones on the surface. This hole indicated that the central zones probably have lensed out, but that the pegmatite is still very large. Though doubtless the pegmatite continues much farther downplunge, the likelihood that such deeply buried parts of the body would soon be of economic interest was so remote that drilling was discontinued.

Cores and sludges from pegmatite, granulite, and a quartz vein, and in most drill holes from country rock immediately adjacent to the pegmatite, were analyzed quantitatively by spectrograph for BeO. The results of these individual analyses for each hole are given in table 11. These tables also summarize the BeO content, beryl content—assuming all the BeO to be in beryl—and amount of beryl visible on the drill core for each rock type.

TABLE 11.—BeO *and beryl content, diamond-drill holes 1–5, Helen Beryl pegmatite, Custer County, S. Dak.*

Rock unit	Depth (feet)	Average BeO and beryl content of rock units							Drilling data from—						Weighted-average percent BeO
		Percent BeO—			Percent beryl—				Core samples			Sludge samples			
		From core	From sludge	From average of assays	From core	From sludge	From average of assays	Observed on core	No.	Length (feet)	Percent BeO	No.	Length (feet)	Percent BeO	
Diamond-drill hole 1 [See rock-unit numbers pl. 14]															
1. Mica schist	68.0– 69.6	0.000	0.000	0.000	0.000	0.000	0.000	0	C 1	1.6	0.000	S 1	4.8	0.0035	0.000
2. Quartz vein	69.6– 70.9	.007	.004	.007	.056	.032	.056	0	C 2	1.3	.0066				.007
3. Mica schist	70.9– 72.0	.007	.004	.007	.056	.032	.056	0	C 3	1.1	.0066				.007
4. Wall zone of fracture filling (albite-quartz-muscovite pegmatite)	72.0– 73.1	.067	.007	.067	.67	.056	.67	0	C 4	.8	.075				.075
									C 5	.3	.045	S 2	1.0	.18	.030
5. Core of fracture filling (perthite-quartz-albite pegmatite)	73.1– 77.0	.037	.017	.027	.30	.14	.22	0	C 6	.7	.0071				.013
									C 7	2.5	.055	S 3	5.0	.017	.035
									C 8	.7	.0034				.012
6. Wall zone of fracture filling (quartz-albite pegmatite)	77.0– 81.2	.002	.033	.024	.016	.26	.19	0	C 9	1.8	.000				.011
									C 10	2.4	.0034	S 4	5.0	.045	.033
7. Wall zone, (albite-quartz-muscovite-biotite pegmatite)	81.2– 88.8	.045	.023	.028	.36	.18	.22	.33	C 11	2.6	.13				.064
									C 12	5.0	.0010	S 5	5.0	.011	.006
8. Fracture filling (perthite-quartz-muscovite-albite pegmatite)	88.8– 89.4	.004	.009	.007	.032	.072	.056	0	C 13	.6	.0041	S 6	2.0	.0088	.007
9. Wall zone (albite-quartz-muscovite pegmatite)	89.4– 94.5	.002	.004	.003	.016	.032	.024	.02	C 14	1.4	.000				.007
									C 15	.3	.000	----------	----------	----------	.000
									C 16	2.2	.0084	S 7	2.2	.0029	.003
									C 17	1.2	.000	----------	----------	----------	.000
10. Fracture filling (perthite-quartz-albite pegmatite)	94.5– 98.5	0	----------	0	0	----------	0	0	C 18	3.8	.000	----------	----------	----------	.000
									C 19	.2	.000	----------	----------	----------	.000
11. Wall zone (albite-quartz-muscovite pegmatite)	98.5–100.4	.003	----------	.003	.024	----------	.024	.12	C 20	1.3	.0026	----------	----------	----------	.002
									C 21	.6	.0034	----------	----------	----------	.003
12. Fracture filling (perthite-quartz-albite-muscovite pegmatite)	100.4–102.5	.026	----------	.026	.21	----------	.21	.66	C 22	1.8	.030	----------	----------	----------	.030
									C 23	.3	.0042	----------	----------	----------	.004
13. Wall zone (albite-quartz-muscovite pegmatite)	102.5–149.4	.035	.023	.026	.28	.18	.21	.19	C 24	2.0	.0022	----------	----------	----------	.002
									C 25	5.5	.000	S 8	5.5	.0024	.002
									C 26	5.0	.059	S 9	5.0	.090	.080
									C 27	2.8	.000	S 10	2.8	.0037	.003
									C 28	5.0	.25	S 11	5.0	.056	.103
									C 29	4.6	.0037	----------	----------	----------	.004
									C 30	5.0	.0016	----------	----------	----------	.002
									C 31	4.2	.0029	----------	----------	----------	.003

									C 32	5.0	.000	S 12	5.0	.0092	.003
									C 33	5.0	.0067	S 13	5.0	.044	.031
									C 34	2.8	.000	S 14	5.0	.019	.012
14. Granitic unit (albite-quartz-muscovite pegmatite)	0149.4–172.7	0.035	0.017	0.022	0.27	0.13	0.17	0.03	C 35	2.2	.014				.017
									C 36	5.0	.12	S 15	5.0	.029	.058
									C 37	5.0	.0030	S 16	5.0	.0034	.003
									C 38	1.8	.0037	---	---	---	.004
									C 39	1.0	.0022	---	---	---	.002
									C 40	.2	.0037	---	---	---	.004
									C 41	4.1	.0052	---	---	---	.005
									C 42	4.0	.034	---	---	---	.034
15. Fracture filling (perthite pegmatite)	172.7–172.9	.000	---	.000	.000	---	.000	0	C 43	.2	.000	---	---	---	.000
16. Granitic unit (alibite-quartz-muscovite pegmatite)	172.9–175.7	.004	.026	.015	.033	.21	.12	0	C 44	.8	.0041	---	---	---	.004
									C 45	2.0	.0039	S 17	2.8	.026	.019
17. Fracture filling (perthite-quartz pegmatite)	175.7–177.7	.602	.026	.219	4.84	.21	1.76	1.99	C 46	.8	1.5				.520
									C 47	1.2	.0037	S 18	5.0	.026	.019
18. Granitic unit (albite-quartz-muscovite pegmatite)	177.7–182.5	.006	.023	.017	.048	.018	.14	0	C 48	3.8	.0043				.019
									C 49	1.0	.011	S 19	4.7	.011	.011
19. Wall zone (albite-quartz-muscovite pegmatite)	182.5–193.1	.009	.010	.009	.072	.080	.072	.02	C 50	1.8	.0033				.008
									C 51	1.9	.018				.013
									C 52	1.7	.014	S 20	5.0	.011	.012
									C 53	3.3	.0034				.008
									C 54	1.9	.0099	S 21	2.2	.0060	.007
20. Albite-quartz-muscovite granulite	193.1–193.4	.003	.006	.005	.024	.048	.040	0	C 55	.3	.0034				.005
21. Wall zone (albite-quartz-muscovite pegmatite)	193.4–194.4	.15	---	.15	1.11	---	1.11	0	C 56	1.0	.15	---	---	---	.15
22. Albite-muscovite-quartz granulite	194.4–195.4	.003	---	.003	.023	---	.023	0	C 57	1.0	.0030	---	---	---	.003
23. Mica-quartz schist	195.4–196.2	.000	---	.000	.000	---	.000	0	C 58	.8	.000	---	---	---	.000

Diamond-drill hole 2

[See rock-unit numbers, pl. 14]

1. Quartz-mica schist	99.7–102.4	0.006	---	0.006	0.048	---	0.048	0	C 91	2.7	0.0060	---	---	---	0.006
2. Border zone of fracture filling (quartz-albite-muscovite pegmatite)	102.4–103.2	.006	---	.006	.048	---	.048	0	C 92	.8	.0061	---	---	---	.006
3. Wall zone of fracture filling (albite-quartz-muscovite pegmatite)	103.2–107.3	.007	---	.007	.056	---	.056	.040	C 93	1.4	.012	---	---	---	.012
									C 94	2.7	.0048	---	---	---	.005
4. Core of fracture filling (quartz pegmatite)	107.3–110.4	.000	.003	.002	.000	0.024	.016	0	C 95	3.1	.000	S 22	3.7	0.0026	.002
5. Wall zone of fracture filling (albite-quartz-perthite pegmatite)	110.4–114.4	.006	.005	.005	.048	.040	.040	.016	C 96	.6	.000				.002
									C 97	1.0	.0081	S 23	1.0	.0026	.005
									C 98	2.4	.0060				.006
6. Border zone of fracture filling (quartz-muscovite-albite pegmatite)	114.4–114.5	.003	.005	.004	.024	.040	.032	0	C 99	.1	.0031				.004
7. Quartz-mica schist	114.5–116.0	.004	---	.004	.032	---	.032	0	C 100	1.5	.0041	S 24	4.5	.0053	.004

TABLE 11.—BeO *and beryl content, diamond-drill holes 1–5, Helen Beryl pegmatite, Custer County, S. Dak.*—Continued

Rock unit	Depth (feet)	Average BeO and beryl content of rock units							Drilling data from—						Weighted-average percent BeO
		Percent BeO—			Percent beryl—				Core samples			Sludge samples			
		From core	From sludge	From average of assays	From core	From sludge	From average of assays	Observed on core	No.	Length (feet)	Percent BeO	No.	Length (feet)	Percent BeO	
Diamond-drill hole 2—Continued															
8. Wall zone of fracture filling (albite-quartz-muscovite pegmatite)	116.0–116.3	0.005	0.005	0.005	0.040	0.040	0.040	0	C 101	0.3	0.0047				0.005
									C 102	.2	.0052				.005
									C 103	5.0	.0027	S 25	5.0	.0035	.003
9. Core of fracture filling (perthite-quartz-albite pegmatite)	116.3–132.6	.001	.001	.001	.008	.008	.008	0	C 104	5.0	.000	S 26	5.0	.000	.000
									C 105	4.8	.000	S 27	4.8	.000	.000
									C 106	1.3	.000				.002
10. Wall zone of fracture filling (albite-quartz-muscovite pegmatite)	132.6–133.1	.000	.004	.002	.000	.032	.016	0	C 106	.5	.000	S 28	5.0	.0035	.002
11. Mica-quartz schist	133.1–136.3	.000	---------	.000	.000	---------	.000	0	C 107	3.2	.000				.002
Diamond-drill hole 3 [See rock-unit numbers, pl. 14]															
									C 60	1.3	0.000	S 29	1.3	0.0042	0.003
									C 61	5.0	.0026	S 30	5.0	.0012	.001
									C 62	2.0	.000	S 31	2.0	.0074	.007
1. Fracture filling (perthite-quartz pegmatite)	37.2– 55.0	0.015	0.006	0.007	0.12	0.048	0.056	0.11	C 63	1.5	.000	S 32	1.5	.0040	.004
									C 64	4.5	.000	S 33	4.5	.0040	.004
									C 65	3.0	.085	S 34	3.0	.019	.028
									C 66	.5	.000	--------	--------	--------	.000
									C 67	1.5	.000	--------	--------	--------	.000
2. Wall zone (albite-quartz-muscovite pegmatite)	55.0– 64.3	.005	.006	.006	.040	.048	.048	.04	C 68	3.7	.000	S 35	3.7	.0095	.007
									C 69	4.1	.014	S 36	5.0	.0060	.009
3. Fracture filling (albite-quartz-perthite pegmatite)	64.3– 65.2	.008	.006	.007	.064	.048	.056	0	C 70	.9	.0076				.007
									C 71	3.6	.000	S 37	3.6	.047	.040
									C 72	5.0	.000	S 38	5.0	.0057	.006
4. Wall zone (albite-quartz-muscovite-perthite pegmatite)	65.2– 93.7	.002	.016	.015	.016	.13	.12	0	--------	--------	--------	S 39	5.0	.0040	.004
									C 73	5.0	.0032	S 40	5.0	.0078	.007
									C 74	5.0	.0051	S 41	5.0	.022	.022
									C 75	4.9	.000	S 42	4.9	.016	.016
									--------	--------	--------	S 43	5.3	.029	.029
									C 76	1.5	.000	S 44	2.0	.023	.020
5. Core (quartz-albite pegmatite)	93.7–101.8	.10	.028	.038	.87	.24	.33	.81	C 77	.5	.000				.020
									C 78	.8	.35	S 45	4.5	.032	.146

6. Wall zone (albite-quartz-muscovite pegmatite)	101.8–117.8	.046	.036	.041	.36	.28	.32	.45	C 79	3.7	.040				.035
									C 80	5.0	.085	S 46	5.0	.026	.047
									C 81	5.0	.032	S 47	5.0	.048	.042
									C 82	2.3	.0034	S 48	5.0	.039	.032
7. Fracture filling (quartz-muscovite-albite pegmatite)	117.8–120.5	.002	.039	.031	.016	.31	.25	.0	C 83	2.7	.0024				.031
8. Wall zone (albite-quartz-muscovite pegmatite)	120.5–124.3	.036	.12	.090	.24	.96	.70	.51	C 84	3.8	.036	S 49	4.5	.12	.090
9. Fracture filling (albite-perthite-muscovite pegmatite)	124.3–128.5	.029	.055	.049	.23	.44	.39	0	C 85	.7	.000				.077
									C 86	3.5	.032	S 50	4.0	.055	.050
10. Quartz-mica schist	128.5–136.2	.000	----------	.000	.000	----------	.000	0	C 87	.5	.0063				.044
									C 88	7.2	.000	----------	----------	----------	.000
11. Quartz-albite vein	136.2–138.0	.000	----------	.000	.000	----------	.000	0	C 89	.1	.000	----------	----------	----------	.000
									C 90	1.7	.000	----------	----------	----------	.000

Diamond-drill hole 4

[See rock-unit numbers, pl. 14]

1. Quartz-mica schist	134.5–135.4	0.002	----------	0.002	0.016	----------	0.016	0	C 108	0.9	0.002	----------	----------	----------	0.002
2. Quartz-muscovite granulite	135.4–141.5	.013	----------	.013	.11	----------	.11	.07	C 109	6.1	.013	----------	----------	----------	.013
3. Wall zone and core of fracture filling (perthite-albite-quartz-muscovite pegmatite)	141.5–147.7	.13	0.015	.064	1.00	0.12	.49	.83	C 110	1.2	.12	----------	----------	----------	.12
									C 111	5.0	.13	S 51	5.0	.015	.050
4. Wall zone of fracture filling (albite-quartz pegmatite)	147.7–149.5	.007	.023	.017	.054	.18	.13	.087	C 112	1.8	.0071	S 52	2.8	.023	.017
									C 113	1.0	.036				.028
5. Wall zone (albite-quartz-muscovite pegmatite)	149.5–233.0	.032	.036	.035	.25	.29	.28	.28	C 114	5.2	.0088	S 53	5.2	.058	.034
									C 115	5.0	.055	S 54	5.0	.022	.038
									C 116	5.0	.074	S 55	5.0	.065	.069
									C 117	5.0	.040	S 56	5.0	.068	.055
									C 118	5.0	.0017	S 57	5.0	.020	.011
									C 119	2.5	.17	S 58	2.5	.041	.103
									C 120	5.0	.034	S 59	5.0	.012	.009
									C 121	4.8	.22	S 60	4.8	.092	.128
									----------	2.0	----------	----------	----------	----------	----------
									C 122	5.0	.0014	S 61	5.0	.015	.013
									C 123	5.7	.0015	----------	----------	----------	.0015
									C 124	3.8	.0016	S 62	3.8	.031	.030
									C 125	5.0	.0012	S 63	5.0	.013	.012
									C 126	5.0	.0022	S 64	5.0	.017	.015
									C 127	5.0	.0011	S 65	5.0	.017	.017
									C 128	4.5	.0022	----------	----------	----------	.002
									C 129	6.0	.0012	----------	----------	----------	.0012
									C 130	3.0	.028	S 66	5.0	.033	.032

654869—62——3

TABLE 11.—BeO *and beryl content, diamond-drill holes 1–5, Helen Beryl pegmatite, Custer County, S. Dak.*—Continued

Rock unit	Depth (feet)	Average BeO and beryl content of rock units							Drilling data from—						Weighted-average percent BeO
		Percent BeO—			Percent beryl—				Core samples			Sludge samples			
		From core	From sludge	From average of assays	From core	From sludge	From average of assays	Observed on core	No.	Length (feet)	Percent BeO	No.	Length (feet)	Percent BeO	
Diamond-drill hole 4—Continued															
									C 131	2.0	.017				.030
									C 132	5.0	.029	S 67	5.0	.032	.031
6. Gneissoid unit (albite-biotite-quartz pegmatite)	233.0–253.0	0.020	0.027	0.027	0.16	0.21	0.21	0	C 133	5.0	.0064	S 68	5.0	.023	.022
									C 134	5.0	.035	S 69	5.0	.026	.031
									C 135	3.0	.0034	S 70	5.0	.027	.022
									C 136	2.0	.011				.024
7. Wall zone (albite-quartz-muscovite pegmatite)	253.0–265.0	.018	.127	.106	.14	1.01	.84	1.34	C 137	5.0	.0075	S 71	5.0	.031	.026
									C 138	5.0	.031	S 72	5.0	.27	.220
8. Quartz-mica schist	265.0–279.0	.021	.087	.077	.17	.69	.61	0	C 139	5.0	.021	S 73	5.0	.17	.143
									--------	--------	--------	S 74	9.0	.041	.041
Diamond-drill hole 5 [See rock-unit numbers, pl. 14]															
									--------	--------	--------	S 75	5.0	0.0056	0.006
									--------	--------	--------	S 76	5.0	.030	.030
									C 140	5.0	0.0013	S 77	5.0	.016	.014
									C 141	3.0	.011	S 78	3.0	.058	.038
									C 142	5.0	.0031	S 79	5.0	.016	.013
									C 143	5.2	.036	S 80	5.2	.073	.060
1. Wall zone (albite-quartz-muscovite pegmatite)	195.0–263.0	0.017	0.054	0.039	0.14	0.44	0.32	0.24	C 144	5.0	.0012	S 81	5.0	.18	.139
									C 145	5.0	.0014	S 82	5.0	.013	.009
									C 146	5.0	.12	S 83	5.0	.29	.238
									C 147	5.0	.0016	S 84	5.0	.018	.013
									C 148	5.0	.0013	S 85	5.0	.0049	.004
									C 149	5.0	.0012	S 86	5.0	.0053	.005
									C 150	5.0	.00099	S 87	5.0	.0085	.008
									--------	--------	--------	S 88	2.0	.027	.027
									--------	--------	--------	--------	3.0	--------	--------

									C 151	4.0	.0022	S 89	4.0	.048	.044
									C 152	5.0	.032	S 90	5.0	.046	.044
2. Gneissoid unit (albite-biotite-quartz pegmatite)	263.0–286.0	.016	.036	.032	.13	.28	.25	.11	C 153	5.0	.021	S 91	5.0	.020	.020
									C 154	5.0	.0073	S 92	5.0	.030	.022
									C 155	2.5	.013	S 93	5.0	.040	.033
									C 156	2.5	.045				.041
3. Granitic unit (albite-quartz-muscovite pegmatite)	286.0–298.5	.018	.025	.025	.14	.20	.20	.008	C 157	5.0	.020	S 94	5.0	.025	.024
									C 158	5.0	.0021	S 95	5.0	.018	.017
4. Wall zone (albite-quartz-muscovite pegmatite)	298.5–302.0	.013	.051	.050	.10	.41	.40	0	C 159	3.0	.013	S 96	3.0	.057	.056
									--------	--------	--------	S 97	3.3	.045	.045
5. Mica-quartz schist	302.0–309.8	--------	.013	.013	--------	.10	.10	0	--------	--------	--------	S 98	5.0	.013	.013

MINERAL DEPOSITS

The Helen Beryl pegmatite contains valuable amounts of beryl, spodumene, perthite, mica, and columbite-tantalite. The beryl and mica occur in all the pegmatite units, but their proportion varies from one unit to another. Spodumene is abundant only in the third intermediate zone and in the core. Perthite is most abundant in the intermediate zones and fracture-filling units and is an accessory mineral in other units. Tantalite-columbite has been found only in the outer part of the core.

BERYL

Beryl has been found throughout the pegmatite, and it forms approximately 0.3 percent of the entire pegmatite. The beryl content ranges from a low of 0.03 percent in the perthite-quartz-muscovite pegmatite of the second intermediate zone to 1.1 percent in the core.

Extensive data on grade have been obtained by grain measurements of both drill core and surface exposures and by spectrographic analyses of core and sludge samples (tables 11, 12, and 13). The figures indicate that the beryl-bearing units can for practical purposes be divided into two categories: (1) the large outer units—chiefly the wall zone and the fracture-filling units—in which the beryl is too fine grained and the grade is too low for recovery by hand-sorting, and (2) the small inner units—chiefly the outer part of the core—where the beryl is sufficiently coarse grained and the grade high enough so that beryl can be obtained by hand-sorting.

Determinations of the beryl content of the wall zone by the various methods used are fairly consistent. A figure of 0.24 percent beryl was determined by mineral measurements of the drill core, a figure of 0.27 percent by calculation from spectrographic analyses of the drill core, and a figure of 0.34 percent by measuring surface exposures, indicating that the wall zone has an average content that is very close to 0.3 percent beryl.

The beryl content of the fracture-filling units has a somewhat greater range. A figure of 0.16 percent beryl was determined both by mineral measurements of the drill core and calculation from spectrographic analyses of the drill core, and a figure of 0.52 percent by measuring surface exposures. The average grade probably is slightly higher than 0.3 percent beryl but almost certainly not above 0.4 percent. On the other hand, the beryl content of the granitic and gneissoid units is somewhat less than 0.3 percent (table 13).

On the basis of these figures, the overall grade of the wall zone and the associated fracture-filling granitic and gneissic units is 0.3 percent beryl. Although some

TABLE 12.—*Summary of mineral measurements on surface exposures, Helen Beryl pegmatite*

[ND, not determined]

Zone	Mineral	Number of separate areas measured	Total area measured (sq ft)	Number of crystals	Size range (sq ft)	Area of mineral (sq ft)	Percent mineral	Cobbable crystals [1]		
								Number	Area (sq ft)	Percent of rock
Wall zone	Beryl	39	787	828	[2] 0.00005–0.066	2.67	0.34	[2] 61	[2] 1.07	[2] 0.15
Fracture-fillings	Beryl	34	621	202	.0001– .550	3.23	.52	63	2.80	.45
First intermediate zone	Beryl	4	91	53	.0001– .026	.41	.45	9	.21	.23
	Beryl	---	100	23	.0001– .006	.03	.03	0	0	0
Second intermediate zone	Matrix [3]	---	100	ND	ND	40.8	40.8	---	---	---
	Perthite [4]	1	100	ND	ND	59.2	59.2	ND	ND	ND
	Beryl	5	1,004	69	.0025–2.35	11.16	1.11	59	11.11	1.11
	Phosphates	5	1,004	80	.0052– .64	8.0	.8	---	---	---
Core	Perthite	2	534	17	.08–42.0	57.1	10.7	17	57.1	10.7
	Spodumene	1	149	129	.002– .4	27.5	18.5	112	27.4	18.4
	Tantalite columbite	1	180	31	.0001– .0065	.025	.01	0	0	0

[1] Crystals that have an exposed area of 0.01 sq. ft. or larger.
[2] Data from U.S. Bureau of Mines cut #12. This cut contained 0.22 percent beryl in 93 sq. ft.
[3] Made up chiefly of a relatively fine grained mixture of quartz, muscovite, and plagioclase.
[4] Perthite obtained by subtraction.

TABLE 13.—*Beryl content of drill samples from the Helen Beryl pegmatite*

Pegmatite unit	Number of holes, cutting unit	Total lengths of units (feet)	Area of core surface (sq ft)	Number of crystals	Size range (sq ft)	Area of beryl noted on cores (sq ft)	Percent beryl on core surface	Cobbable crystals [1]			Spectrographic analyses	
								Number	Area (sq ft)	Percent	Percent BeO	Percent beryl (calculated)
Wall zone	34	297.7	61.85	77	0.00002–0.01663	0.14837	0.24	3	0.0418	0.068	0.034	0.27
Granitic unit	2	43.4	10.01	5	.00017– .0008	.0017	.017	0	0	0	.022	.17
Gneissoid unit	2	43.0	7.57	8	.00009– .00201	.00445	.059	0	0	0	.030	.23
Fracture-fillings	4	80.9	19.16	17	.00016– .01050	.03064	.16	1	.0105	.055	.020	.16
Core	1	8.1	.50	9	.00006– .0016	.0040	.80	0	0	0	.038	.33
All units	5	473.1	99.09	116	.00002– .01663	.18916	.19	4	.0523	.053	.030	.24

[1] Crystals that have an area of 0.01 sq. ft. or more.

of this can be recovered by hand-sorting, no significant production will be accomplished without milling.

The intermediate zones and core, however, do contain coarse-grained beryl that is obtained as a coproduct with other minerals. Measured crystals (table 12) have an exposed area of as much as 2.35 square feet, and larger crystals have been mined. The richest zone is the core, which contains 1.1 percent beryl. Parts of the outer part of the core are very rich: one measured area of 180 square feet contained 4.4 percent beryl, virtually all of which was in crystals large enough to be recovered by hand-sorting.

The beryl has a great range in physical and mineralogic properties. Most of it is yellowish green, grading to yellow or green; some is brown, white, colorless, or smoky. Shades of yellow are most common in the outer units, and white or green in the inner zones.

The crystal form ranges from anhedral to euhedral. Subhedral crystals are common in the inner zones, and to a lesser degree in the fracture-filling units. Much of the beryl in the wall zone is anhedral, but skeletal euhedral crystals are also common. The skeletal crystals consist of shells of beryl bounded on the outside by sharply defined crystal faces but having irregular boundaries on the inside with included aggregates of albite, quartz, muscovite, perthite, and tourmaline.

Indices of refraction indicate a rather large range in chemical composition (table 14), and also suggest differences in the properties that affect susceptibility to flotation reagents. N_ω of beryl in the wall zone, the fracture-fillings, and the pegmatite as a whole, ranges from 1.579 (13.1 percent BeO) to 1.595 (11.1 percent BeO). Beryl of inner zones has a smaller range in index and the average index is generally higher than that of the outer zones. The average N_ω in 101 specimens from the wall zone, the fracture-fillings, and the granitic and gneissic units is 1.585, indicating a content of 12.6 percent BeO. In contrast, 15 specimens from the intermediate zones and core have an average N_ω of 1.590 and a BeO content of 11.9 percent.

FELDSPAR

Perthite (potassium feldspar) is in sufficiently large crystals to be hand-cobbed in the intermediate zones, core, and some fracture-filling units, but only the two inner intermediate zones contain feldspar that can be mined profitably alone. Some feldspar, however, can be derived as a byproduct of spodumene, when mining the core. The two inner intermediate zones contain about 60 percent perthite, of which more than half is cobbable.

The outer units contain perthite, especially in the fracture-fillings, and abundant albite. Possibly these can be recovered by milling. Handsorting of 337 tons of rock from the wall zone and fracture filling by the U.S. Bureau of Mines yielded only 12 tons of perthite (Gries, 1949, tables 2 and 3).

SPODUMENE

Spodumene is obtained from the third intermediate zone and the core. The spodumene content ranges from about 4 to 30 percent; the average is about 20 percent. The greater part of the spodumene is in large crystals, some as much as 1.5 feet in diameter and 10 feet long. Commonly, however, crystals are less than 1 foot long, especially in the albite-rich outer part of the core.

Most of the spodumene is firm relatively unaltered material that is gray, white, green, or yellow.

As table 15 shows, however, some of it is pseudomorphically altered to sericitic muscovite, albite, possibly eucryptite, and an unidentified claylike material. Two specimens—one fresh (MHS–1–48) and one highly altered (MHS–2–48)—were analyzed by M. K. Carron, and found to contain 6.90 and 0.08 percent Li_2O, respectively. J. M. Axelrod found by X-ray that the low-lithia material is intermediate between kaolinite and halloysite.

TABLE 14.—*Summary of indices of refraction of albite and beryl, Helen Beryl pegmatite*

Pegmatite unit	N'_α of albite			N_ω of beryl		
	Number of determinations	Range	Average	Number of determinations	Range	Average
Wall zone	68	1. 526–1. 531	1. 528	58	1. 579–1. 595	1. 585
Granitic unit	5	1. 527–1. 530	1. 529	4	1. 582–1. 594	1. 586
Gneissoid unit	2	1. 528–1. 530	1. 529	2	1. 582–1. 583	1. 582
Fracture-fillings	33	1. 527–1. 531	1. 528	37	1. 579–1. 595	1. 585
Second intermediate zone	1	------------	1. 528	4	1. 585–1. 592	1. 589
Third intermediate zone	------------	------------	------------	2	1. 589–1. 594	1. 592
Core	4	1. 528–1. 529	1. 528	9	1. 588–1. 595	1. 590

TABLE 15.—*Optical properties of spodumene and its alteration products, Helen Beryl pegmatite*

[Optical data by Jewell J. Glass, U.S. Geological Survey]

Sample	Description	Mineral	Optic sign	2V	N_α	N_β	N_γ	Remarks
MHS-100-47	Fresh spodumene from quartz-spodumene-perthite-albite pegmatite (core). Associated with altered spodumene, albite, muscovite, and black oxide (MnO_2?).	Spodumene	Positive	70°	1.660	1.667	1.677	
MHS-111-47	Spodumene from quartz-spodumene-perthite-albite pegmatite (core). Close to outer contact. Pale greenish spodumene with a fibrous alteration product resembling eucryptite ($LiAlSiO_4$) and a small amount of albite and black oxide (MnO_2?).	Spodumene (traces of alteration).	Positive	Large, near 70°.	1.659	1.665	1.675	Dispersion, $r < v$.
MHS-103-47	Fresh spodumene from perthite-spodumene-quartz pegmatite (third intermediate zone). Associated with hydrous fibrous spodumene, muscovite in cleavage cracks, black oxide (MnO_2?), and undetermined fine-grained pinkish-lavender scaly material.	Spodumene	Positive	70°	1.657–1.659	1.664–1.666	1.674–1.676	Indices of refraction are variable because of incipient alteration.
MHS-112-47	Spodumene crystal that has been entirely altered pseudomorphically to muscovite (sericite), albite, and a fibrous unknown. From perthite-spodumene-quartz pegmatite (third intermediate zone).	Muscovite	Negative	25–30°	1.554		1.598	Pale maize yellow. No lithium by flame test.
		Albite	Positive	Large	1.529		1.539	Colorless.
		Fiberous unknown (may be eucryptite altering to muscovite).	Negative	Large		Variable, about 1.555.		
MHS-104-47	Compact claylike material pseudomorphous after spodumene. From perthite-spodumene-quartz pegmatite (third intermediate zone). Fine grained. Pale greenish gray. Soft. Low birefringence. Qualitative tests show no Li_2O, almost no K_2O, high Al_2O_3, and high H_2O.	Pale-tan waxy fibrous material that appears to be the latest stage of alteration of spodumene.	Negative	70° ± 3°	1.520	1.540	1.550	
MHS-125-47	Cymatolite pseudomorph after spodumene from outside edge of perthite-spodumene-quartz pegmatite (third intermediate zone). Made up of sericitic muscovite (75 percent), albite (23 percent), and quartz (2 percent).	Muscovite	Negative	Variable, near 30°		1.596–1.598	1.596–1.598	Pale greenish yellow. Fine-grained. Scaly.
		Albite	Positive	Variable, large.	1.529		1.539	Colorless.

Mr. McRobbie reported that 9.85 tons of spodumene sold in 1946 contained 6.0 percent Li_2O and that 43.7 tons sold in 1947 contained 5.55 percent Li_2O. The variation in percent Li_2O in these shipments reflects a variation in the proportion of alteration products adhering to the spodumene.

MICA

The scrap mica recovered from the Helen Beryl pegmatite to date has been derived from the perthite-quartz-muscovite pegmatite of the second intermediate zone and from "bull mica" aggregates scattered through the spodumene-rich zones. Books of muscovite sufficiently large to yield sheet mica occur locally within 1 to 2 ft of the contact of the pegmatite and also in the outer parts of some fracture-filling bodies, but even in these places they are rare. A total of 100 pounds, mostly heavily stained, was recovered in 1943 (Page and others, 1953, p. 129). About 8 pounds from the hanging-wall side of the pegmatite was sold as No. 2 inferior quality.

Muscovite forms an estimated 16 percent of the wall zone, 19 percent of the granitic unit, and 3 to 10 percent of the other units. Thus scrap mica and even sheet mica have possible value if the pegamtite is mined for other minerals.

TANTALITE-COLUMBITE

Most of the tantalite-columbite in the Helen Beryl pegmatite is in a band as much as a foot thick at the outside edge of the core. At the top of the core a few grains ⅛ inch thick and 1 inch long were found. Ten feet lower tantalite-columbite was more abundant, and grains were as much as 4 inches long. Many of the grains are euhedral; others are blocky and irregular.

The specific gravity of five specimens, as determined by Theodore Botinelly of the U.S. Geological Survey, ranged from 6.81 to 7.10; the average was 6.83. These specific gravities indicate a range in composition of from 66 percent Ta_2O_5, 19 percent Nb_2O_5 to 73 percent Ta_2O_5, 12 percent Nb_2O_5; the average is 70.5 percent Ta_2O_5, 14 percent Nb_2O_5.

In April 1948, Mr. McRobbie took a 101.8-pound sample of hand-cobbed tantalum ore to the Bureau of Mines laboratory in Rapid City, S. Dak., where it was crushed and jigged to obtain a 38-pound concentrate having a specific gravity of 6.13. A specimen free of all waste rock had a specific gravity of 6.99.

ELKHORN PEGMATITE

The Elkhorn (Tinsley) beryl property is on the northern limb of an irregular U-shaped pegmatite that consists of two parallel, zoned segments, approximately 480 feet apart, that are connected by a crosscutting unzoned segment. The northern limb is referred to as the Elkhorn pegmatite and the southern limb, which we did not explore, as the Hot Shot pegmatite. The unzoned segment trends northwestward and connects the east ends of the Hot Shot and Elkhorn pegmatites and extends northwestward beyond the Elkhorn pegmatite as a body 270 feet long. Exploration for beryl was limited to the Elkhorn pegmatite and northwestward-trending part of the unzoned segment.

The Elkhorn pegmatite (fig. 71) is 4 miles east-southeast of Custer, in the NW¼ sec. 34, T. 3 S., R. 5 E., Black Hills principal meridian. It may be reached from Custer, the nearest railroad shipping point, by the following route:

Miles
0.0 Post office, Custer, S. Dak. Go east on U.S. Highway 16.
3.7 Junction, turn south on gravel road (French Creek road).
5.5 Fork in road, turn left.
5.8 Turn left off French Creek road over cattle guard.
6.1 Elkhorn pegmatite on left.

The Elkhorn pegmatite is owned by Dewey Tinsley of Guernsey, Wyo., and C. E. Magnuson of Chelan, Wash., who mined feldspar from this pegmatite from two opencuts (pl. 15) during 1938, 1939, and 1940. A total of 3,330 tons of potassium feldspar and 2,820 pounds of beryl was produced from the two opencuts. The amount of material on the dumps at the two pits was calculated to be 7,700 tons. From the tonnage of the dumps and the quantity of material sold, the recovered feldspar made up 30 percent and the recovered beryl 0.013 percent of the rock mined.

The Elkhorn pegmatite was mapped and studied by the U.S. Geological Survey in August and September 1943 (Page and others, 1953, p. 114–118). At that time the geologic map (pl. 15) used in this report was made by J. J. Norton, L. C. Pray, and D. M. Kinney. The U.S. Bureau of Mines sampled the dumps in June and July 1943 (Tullis, 1952, p. 15, fig. 6), and in November 1943 sampled the beryl-bearing exposures in the two large opencuts by means of 10 small cuts (pl. 15). The material from these cuts was hand-sorted and the residues were chemically analyzed for BeO.

MINE WORKINGS

The Elkhorn pegmatite was mined from two opencuts: the East pit, near the east end of the pegmatite, is 120 feet long, 48 feet wide, and 29 feet deep; and the West pit, near the center of the pegmatite, is 110 feet long, 24 feet wide, and 25 feet deep (pl. 15). A small prospect cut, 26 feet long and 12 feet wide, was made near the west end of the pegmatite.

GEOLOGY

METAMORPHIC ROCKS

The metamorphic rocks consist of interbedded quartz-mica-schist, quartz-mica-sillimanite schist, and quartzite, which in the vicinity of the Elkhorn pegmatite are probably in isoclinal overturned folds with eastward-trending axes. The schistosity of the metamorphic rocks strikes from N. 50° W. to S. 70° W. and dips 35°–85° N.; bedding has a general westward strike and a nearly vertical dip. A few quartz veins, in general parallel to the schistosity, cut the metamorphic rocks; the largest one, found in drill hole 6, is 8.0 feet thick.

The metamorphic rocks except for the quartzite are poorly exposed; the rocks cut in the drill holes consist of 42 percent quartz-mica schist, 36 percent quartz-mica-sillimanite schist, and 22 percent quartzite. The average grain size of most of these rocks is one thirty-second of an inch.

Quartz-mica schist occurs in beds 0.2 to 38 feet thick, and is made up of quartz (50 to 80 percent), muscovite (5 to 40 percent), biotite (trace to 15 percent), tourmaline (trace to 3 percent), sillimanite (0 to 3 percent), garnet (0 to 2 percent), and apatite (1 percent).

Quartz-mica-sillimanite schist occurs in layers ranging from 0.6 to 77 feet thick and is most abundant near the east end of the Elkhorn pegmatite. This rock is similar to the quartz mica schist, and differs in having white elliptical to spindle-shaped blebs of quartz and fibrous sillimanite. The blebs are 1/16 to ⅛ inch across by ⅛ to ¼ inch long. The overall composition of this rock is estimated to be quartz (40 to 60 percent), muscovite (20 to 40 percent), biotite (4 to 15 percent), sillimanite (8 to 15 percent), tourmaline (0 to 3 percent), garnet (0 to 2 percent), and andalusite (trace).

The quartzite, a light-gray to tannish-gray dense rock, is best exposed along the ridge north of the Elkhorn pegmatite, where it occurs in layers 0.2 to 23 feet thick. The quartzite consists of quartz (80 to 93 percent), biotite (trace to 8 percent), muscovite (trace to 10 percent), tourmaline (trace to 2 percent), apatite (0 to 3 percent), and garnet (0 to 1 percent). Hornblende, limonite, and sillimanite occur in a few beds. This rock grades into quartz-mica schist with the decrease of quartz and increase of muscovite.

The metamorphic rocks commonly are altered adjacent to the pegmatite, especially along the footwall side; porphyroblasts of muscovite, biotite, tourmaline, and apatite are developed, and albite is altered to clay minerals. Tourmaline commonly forms thin bands immediately adjacent to the pegmatite. The drill core contains gray granulite in several places between stringers of pegmatite on the footwall side of the pegmatite. The granulite consists chiefly of quartz, muscovite, and tourmaline, but in a few places biotite and albite also are common.

PEGMATITE

The Elkhorn pegmatite is a thin dike at a small angle to the foliation although at any particular point it may appear parallel to it. This dike trends N. 80° E. (pl. 15), has an average dip of 58° NW. (pl. 16), is 943 feet long, and for the most part is between 10 and 35 feet thick. Near its eastern end, however, it swells to 80 feet thick where it joins the northwestward-trending unzoned segment of this complex pegmatite. This unzoned segment strikes about N. 30° W. and dips steeply southwest. The plunge of the main Elkhorn dike varies from 0° to 15°, N. 35° W. to S. 75° W. At the surface the intersection of the main Elkhorn dike with the northwestward-trending segment plunges 60° west; at depth, however, it flattens.

The main part of the pegmatite is composed of a quartz-albite pegmatite wall zone and a perthite-quartz pegmatite core. The contacts of the zones are gradational. The unzoned northwestward-trending branch of the pegmatite consists of quartz-albite-perthite pegmatite. This unit grades laterally into both quartz-albite and perthite-quartz pegmatite.

QUARTZ-ALBITE PEGMATITE

[Wall zone]

The quartz-albite pegmatite makes up the outer portion of the Elkhorn pegmatite, and is composed chiefly of anhedral quartz and albite ½ to 1½ inches in grain size. The average composition is quartz (46 percent), albite (42 percent), perthite (6 percent), muscovite (4 percent), tourmaline (1 to 2 percent), biotite (<1 percent), beryl (<1 percent), apatite (<1 percent), garnet (<1 percent), other phosphates (trace), and loellingite (trace). In some places albite may exceed quartz in amount. In other places there is muscovite-rich, perthite-rich, or tourmaline-rich rock. The perthite-rich rock is adjacent to the core; the tourmaline-rich rock commonly is adjacent to the outer contact of the pegmatite. Some of the variations in composition are shown in the modes of the wall zone from the drill core (table 16). On cleavage fragments as determined on 29 specimens albite has a minimum index of refraction ($N_{\alpha'}$) of from 1.528 to 1.534; the average is 1.530 (table 17). Most of the muscovite in this zone is a reeved irregularly laminated white mica. No sheet mica was observed. Biotite occurs as blades as much as three feet long which are intergrown with muscovite in some places. Beryl is scattered irregularly through the wall zone, although in general it is most common near the pegmatite core.

TABLE 16.—*Modes, in percent, of the wall zone from the diamond-drill core, Elkhorn pegmatite*

Location in core (feet)	Albite	Quartz	Muscovite	Tourmaline	Apatite	Beryl	Others
Diamond-drill hole 1							
60.1-65.0	56	40	1	2	<1	--------	
66.9-67.3	5	35	40	20	--------	--------	
70.9-79.7	50	30	8	10	1	0.018	Garnet, 1.
80.0-83.6	50	30	8	10	1	--------	Garnet, 1.
84.5-87.9	90	7	--------	2	1	--------	
Diamond-drill hole 2							
118.7-129.3	47	40	8	2	1	0.015	Lithiophilite-triphylite, 1. Perthite, 1.
129.3-130.4	30	25	4	41	--------	--------	Garnet, <1.
132.3-133.5	25	14	15	25	1	--------	Garnet, 20.
133.5-134.3	57	20	20	3	--------	--------	
134.5-134.6	57	20	20	3	--------	--------	
149.0-150.4	8	25	40	20	5	--------	Garnet, 2.
Diamond-drill hole 3							
69.3-69.6	10	85	--------	--------	--------	--------	Biotite, 5.
72.0-72.4	20	40	--------	40	--------	--------	
72.4-73.8	28	65	3	3	--------	--------	Garnet, <1.
73.8-75.4	30	15	27	28	--------	--------	
Diamond-drill hole 4							
118.7-130.0	54	20	5	<1	<1	0.051	Perthite, 20.
130.0-135.5	25	9	51	10	1	--------	Biotite, 3. Garnet, 1.
Diamond-drill hole 5							
72.8-83.1	64	8	3	25	--------	--------	
83.1-93.8	62	30	5	1	<1	0.066	Garnet, 1.
93.8-95.5	30	10	49	7	1	--------	Garnet, 3.
Diamond-drill hole 6							
88.0-90.5	2	74	20	2	2	--------	Cassiterite, <1.
90.6-91.1	10	67	15	4	1	--------	Garnet, 3.
91.1-91.6	------	25	50	25	--------	--------	
91.6-95.0	15	60	25	--------	--------	--------	
95.0-95.6	15	83	2	--------	--------	--------	
97.0-115.5	64	30	4	<1	<1	0.061	Perthite, 2.

PERTHITE-QUARTZ PEGMATITE

[Core]

The perthite-quartz pegmatite forms the central portion of the Elkhorn pegmatite and has a gradational contact with the quartz-albite wall zone. The core, which is lenticular in plan and section, is 926 feet long and as much as 47 feet thick. The core consists of perthite (58 percent), quartz (30 percent), albite (9 percent), muscovite (2 percent), tourmaline (<1 percent), biotite (<1 percent), garnet (<1 percent), beryl (<1 percent), phosphates (<1 percent), and loellingite (trace). The accessory minerals decrease in abundance toward the center of the unit; the central part is almost entirely anhedral to subhedral perthite and quartz in crystals 3 to 5 feet long. Commonly perthite and quartz are graphically intergrown. Fine-grained quartz and albite are commonly interstitial to the large crystals of perthite and quartz in the outer part of the core.

The albite has a minimum index of refraction on a cleavage fragment ($N_{\alpha'}$) ranging from 1.527 to 1.533, and the average of 16 determinations is 1.529 (table 18). The muscovite is white, is irregularly laminated, and has "A-structure." Beryl occurs along the outside of this zone in scattered clusters of crystals.

TABLE 17.—*Indices of refraction of albite and beryl in the wall zone, Elkhorn pegmatite*

[Average indices for all samples:
$N\alpha'$ of albite, 1.530; $N\omega$ of beryl, 1.584.
Measurements made by H. G. Stephens and M. H. Staatz]

Location of sample (feet)	Essential minerals (in order of abundance)	$N\alpha'$ of albite	$N\omega$ of beryl
Drill-hole samples [Depth given in feet]			
Hole 1:			
60.1–65.0	Albite, quartz	[1] 1.530 1.529	
70.9–79.7	Albite, quartz, tourmaline, muscovite.	---------- 1.531 1.529 1.529	[1] 1.585 1.585 1.584 1.587 1.584 1.583 1.581 1.580 1.580 1.581 1.591
80.0–83.6	Albite, quartz, tourmaline, muscovite.	1.532 1.530	
84.5–87.9	Albite, quartz	1.531 1.532 1.532	
Hole 2:			
118.7–129.3	Albite, quartz, muscovite	----------	1.592 1.592 1.592 1.592 1.594 1.594 1.592 1.578 1.583 1.581 1.583 1.581 1.581 1.581 1.580 1.580 1.590 1.590 1.581 1.578 1.581 1.580 1.588 1.586 1.586 1.580 1.580
Hole 3:			
72.4–73.8	Quartz, albite	1.530	
73.8–75.4	Albite, tourmaline muscovite, quartz.	1.529	
Hole 4:			
118.7–130.0	Albite, quartz	1.529 1.530 1.530	1.579 1.578 1.578 1.578 1.580 1.579 1.579 1.579 1.578 1.578 1.580 1.578 1.579 1.578 1.581 1.580
130.0–135.5	Muscovite, albite, tourmaline, quartz.	1.531	
Drill-hole samples—Continued			
Hole 5:			
72.8–83.1	Albite, tourmaline, quartz	1.531	
83.1–93.8	Albite, quartz	----------	1.579 1.582 1.580 1.590 1.582 1.580 1.580 1.584 1.583 1.584 1.583 1.584 1.584 1.582 1.587 1.582 1.584 1.579 1.589 1.584 1.578 1.578 1.578 1.580 1.592 1.578
Hole 6:			
88.0–90.5	Quartz, muscovite	1.531	
91.6–95.0	Quartz, muscovite, albite	1.531	
97.0–115.5	Albite, quartz	1.529 1.529 1.531	1.579 1.581 1.580 1.581 1.583 1.582
Surface samples			
Center of east pit:			
Near hanging-wall contact	Quartz, albite	1.529	
Middle of wall zone on hanging-wall side of the pegmatite.	do	1.529	
East end of west pit:			
Near hanging-wall contact	do	1.534	
Middle of wall zone on hanging-wall side of the pegmatite.	do	1.530	
Near inner edge of the wall zone on the hanging-wall side of the pegmatite.	do	1.529	1.580
West end of west pit:			
Near hanging-wall contact	do	1.531	
Middle of wall zone on foot-wall side of the pegmatite.	do	1.529 1.528	1.579 1.580

[1] Where two or more figures are given, they are in the order of increasing depth of drill hole.

QUARTZ-ALBITE-PERTHITE PEGMATITE

The quartz-albite-perthite pegmatite makes up the unzoned northwestward-trending segment that joins the zoned part of the Elkhorn pegmatite at its east end (pl. 15). This unit consists of a granular mixture of quartz and albite with large scattered crystals of perthite. Muscovite and tourmaline are the only accessory minerals. The minimum indices of albite measured on cleavage flakes range from 1.529 to 1.531. Quartz and albite rarely occur in crystals more than half an inch across, but perthite crystals are as much as 1 foot across. Beryl was not noted in this unit.

TABLE 18.—*Indices of refraction of albite and beryl in the core, Elkhorn pegmatite*

Location of sample	$N_{\alpha'}$ of albite	N_{ω} of beryl
Center of east pit:		
At hanging-wall edge	1.530	----------
Central part	----------	1.578
Do	1.527	1.578
Do	1.530	----------
Do	1.529	1.579
Do	1.527	1.579
Footwall side	1.528	1.580
At footwall contact	1.530	----------
East side of west pit:		
Hanging-wall side	1.529	1.579
Do	1.528	1.581
Central part	1.529	----------
Footwall side	1.530	----------
Do	1.529	1.579
Do	1.530	----------
West side of west pit:		
At hanging-wall contact	1.529	1.580
Near hanging-wall side	1.529	1.579
Central part	----------	1.579
Footwall side	1.533	----------
Average	1.529	1.579

DIAMOND-DRILLING

The Elkhorn pegmatite was explored at depth by 6 diamond-drill holes having a total length of 911 feet. The lines of drilling were spaced from 80 to 191.5 feet apart (pl. 15) and were drilled so as to strike the pegmatite at a high angle (pl. 16). Logs of these holes are presented in table 19.

Geologic studies by Norton in 1943 (Page and others, 1953, p. 114–118) indicated that the Elkhorn pegmatite had appreciable quantities of rock containing about 0.6 percent beryl, from which a large proportion of beryl could be recovered by hand-cobbing.

Drill hole 1 (pl. 16) was designed to intersect the pegmatite near the keel so as to determine its position and plunge. The hole passed through stringers of schist and quartzite intercalated with pegmatite (pl. 16) between 60.1 feet and 87.9 feet (table 19) and indicated its approximate position.

TABLE 19.—*Logs of diamond-drill holes, Elkhorn pegmatite*

[Logged by H. G. Stephens and M. H. Staatz. Modes of the pegmatite wall zone are given in table 16; indices of refraction of albite and beryl in the wall zone are given in table 17]

Hole 1

[pl. 16]

Location: 68 ft north of East pit.
Altitude of collar: 5187.2 ft.
Inclination: Minus 50°.

Bearings: S. 4° E.
Total length: 95 ft.

Interval (feet)	*Description*
0–10.8	Overburden. No core.
10.8–13.0	Rock. No core.
13.0–60.1	Quartz-mica-sillimanite schist with thin interbeds of quartzite. Well foliated, slightly friable. Average grain size about 1/32 in. Muscovite, in clear silvery flakes as much as 1/8 in. in diameter, generally predominates over biotite. Sillimanite is in white spindle-shaped fibrous blebs. Small amounts of tourmaline are found in scattered subhedral black grains. Rare pale-red garnet in anhedral grains. At 53 ft pink andalusite is intimately intergrown with sillimanite. A bluish-gray fine-grained quartzite containing biotite (5 percent), tourmaline (2 percent), and garnet (trace) is at 38.5 to 39.0, 39.5 to 39.8, 50.0 to 52.0, and 58.0 to 60.1 ft. Foliation is at an angle of nearly 90° with the drill core between 15 and 40 ft, approximately 60° between 40 and 50 ft, and 67° at 60 ft.
60.1–65.0	Albite-quartz-pegmatite (wall zone). No contacts. Albite is in yellowish-white bladed crystals as much as 1½ in. long; the average is ¾ in. Albite is irregularly intergrown with translucent gray quartz. Quartz is ½–1 in. in size except between 60.6–61.1 ft, where the drill core is chiefly quartz. Accessory tourmaline is in black subhedral to anhedral grains, as much as ⅜ in. long. Accessory muscovite is generally in disseminated, fine-grained greenish-white flakes ⅛ in. or less in size. Minute amounts of blocky bluish-green anhedral apatite crystals average 1/16 in. in diameter.
65.0–66.9	Quartzite, with accessory muscovite, biotite, albite, tourmaline, and garnet. Foliation is 82° to core at 65.0 feet.
66.9–67.3	Muscovite-quartz-tourmaline pegmatite. Wall zone. Average grain size is ¾ in. Upper contact is gradational; lower contact is sharp and at an angle of 76° to core.
67.3–70.9	Quartz-mica schist, interbedded with quartzite. Average grain size is less than 1/32 in. Muscovite, however, occurs in porphyroblasts as large as 1/16 in. Quartzite beds occur in the intervals 68.0–69.8 ft and 70.3–70.9 ft; these beds are similar to the quartzite described above except that at 70.8 ft there is a concentration of tourmaline. Bedding is 85° to core at 68.0 ft, and 50° at 70.2 ft.
70.9–79.7	Albite-quartz-tourmaline-muscovite pegmatite. Wall zone. Upper contact 68° to drill core. Bladed anhedral grains of yellowish-white to greenish-white albite as much as 3 in. long; aggregates are as much as 1 ft across. Irregular grains of quartz are as much as 4 in. long; the average is 2 in. Blocky tourmaline crystals as much as 2 in. in diameter—the average is ½ in.—are scattered throughout the pegmatite but are especially abundant between 74.2 and 75.2 ft. Fourteen colorless to yellowish-white beryl crystals occur between 72.8 and 78.5 ft. Many are intensely kaolinized. The smallest crystal measured was 0.00005 sq ft in exposed area, and the largest was to 0.00116 sq ft; the total is 0.00386 sq ft.
79.7–80.0	Quartz-muscovite-tourmaline granulite. Fine-grained. Contains quartz (71 percent), muscovite (15 percent), tourmaline (10 percent), garnet (2 percent), and biotite (2 percent). Muscovite very abundant in lower part.

TABLE 19.—*Logs of diamond-drill holes, Elkhorn pegmatite*—Continued

Hole 1—Continued

Interval (feet)	*Description*
80.0–83.6	Albite-quartz-tourmaline-muscovite pegmatite. Wall zone. Same as at 70.9 to 79.7 ft, except no beryl was observed. $N_{\alpha'}$ of plagioclase was 1.532 (oligoclase) at 80.6 ft and 1.530 (albite) at 82.4 ft.
83.6–84.5	Quartz-muscovite granulite. Contains quartz (77 percent) muscovite (20 percent), tourmaline (3 percent), and garnet (4 percent).
84.5–87.9	Albite-quartz pegmatite. Wall zone. The plagioclase crystals are about 1 in. long and are either albite or oligoclase.
87.9–93.0	Quartz-mica schist. Contains quartz (85 percent), muscovite and biotite (12 percent), and tourmaline (3 percent). Muscovite is very abundant (60 percent) from 90.3 to 90.7 ft. Foliation is 55° to 65° to the drill core.
93.0–95.0	Quartz-mica-sillimanite schist. Contains about 10 percent sillimanite in irregular white fibrous patches 1/16 to 1/8 in. in diameter. Poor foliation is at 55° to the drill core at 93.5 ft.
End of hole.	

Hole 2

[pl. 16

Location: 108 ft N. 70° W. of drill hole 1
Altitude of collar: 5,190.9 ft
Inclination: Minus 35°

Bearing: S. 4° E.
Total length: 249 ft

Interval (feet)	*Description*
0–17.0	Overburden. No core.
17.0–29.8	Quartz-mica-sillimanite schist. Contains quartz (40 percent), muscovite (30 percent), biotite (15 percent), sillimanite (10 percent), tourmaline (3 percent), and limonite (2 percent). Fine grained, moderately well foliated; grain size is 1/64 to 1/8 in. with muscovite forming the largest crystals. Grades downward into quartz-mica schist.
29.8–71.3	Quartz-mica schist, interbedded with thin units of muscovite-quartz schist, and quartz-mica-sillimanite schist, and quartzite. In the lower part of this unit yellow-brown limonite coats mineral grains and fracture planes. Muscovite-quartz schist containing about 65 percent of muscovite is found between 31.6 and 35.0 ft and between 46.3 and 48.5 ft. White sillimanite blebs (5 to 10 percent) occur from 51.6 to 54.0 ft. Fine-grained quartzite layers occur from 56.7 to 58.0 ft, from 58.4 to 59.0 ft, from 60.4 to 62.0 ft, from 65.7 to 66.3 ft, and from 68.7 to 71.3 ft. Average composition of this rock is quartz (85 percent), muscovite (8 percent), biotite (4 percent), sillimanite (2 percent), and tourmaline (1 percent). Foliation is at an angle to the drill core as follows:

Angle		*Depth (feet)*	*Angle*		*Depth (feet)*
65°	at	29.9	35°	at	36.3
36°	at	31.8	45°	at	37.8
38°	at	33.3	55°	at	40.6
40°	at	34.0	46°	at	46.0

71.3–80.5	Thinly interbedded quartz-mica schist, quartz-mica-sillimanite schist, and quartzite. Divided as follows:
71.3–71.9	Quartz-muscovite-sillimanite schist.
71.9–72.6	Quartzite.
72.6–74.5	Quartz-mica-sillimanite schist.
74.5–76.5	Quartzite; micaceous and sillimanite-bearing in center.
76.5–77.1	Quartz-mica-sillimanite schist; quartz-rich.
77.1–79.0	Quartzite; fine-grained, micaceous, not foliated.
79.0–80.5	Quartz-mica schist; minor sillimanite and andalusite (1 percent or less).
80.5–95.0	Quartz-mica-sillimanite schist with interbeds of quartzite. Contains quartz (46 percent), muscovite (45 percent), sillimanite (8 percent), biotite (1 percent), and andalusite ($<$1 percent). Pink andalusite is within the blebs of sillimanite and constitutes 2 to 3 percent of the rock between 80.5 and 83.7 ft. A few thin bands of coarse-grained muscovite are present. Quartzite occurs in layers between 90 and 90.5 ft and between 91 and 92 ft. Foliation is 63° to drill core at 81.7 ft and 75° at 83.0 ft.
95.0–109.8	Quartz-mica schist. Fine grained; contains quartz (89 percent), biotite (6 percent), muscovite (4 percent), and sillimanite (1 percent). Foliation poor to absent. Sillimanite occurs as scattered blebs from 97.3 to 109.8 ft. These layers are interbedded with coarsely crystalline mica-bearing fine-grained quartz-rich schists. At 106.0 to 107.0 ft is a hard gray quartzite.
109.8–111.9	Quartz-mica-sillimanite schist. Sillimanite constitutes 10 to 15 percent of this interval.
111.9–118.5	Quartzite. Hard gray coarsely crystalline quartz-mica schist from 116.7 to 117.2 ft. Foliation is 35° to drill core at 117.0 ft.
118.5–118.7	Mica-quartz schist.

TABLE 19.—*Logs of diamond-drill holes, Elkhorn pegmatite*—Continued

Hole 2—Continued

Interval (feet)		*Description*
118.7–130.4		Pegmatite. Upper contact not recovered. The lower contact is 43° to the core.
	118.7–129.3	Albite-quartz-muscovite pegmatite. Wall zone. Average grain size is 3/4 in. Yellowish-white bladed anhedral albite crystals range up to 3 in. in length. Translucent gray anhedral quartz grains have average maximum diameter of 3/4 in. Most common below 124 ft. Silvery white flat muscovite books are as much as 2 in. long and 1/2 in. thick. They are irregular in shape and are intergrown with albite and quartz. Fine-grained yellowish-green muscovite is interstitial and fills small fractures. Scattered black subhedral accessory tourmaline crystals are as much as 1 in. long; the average is commonly 1/2 in. They are rare above 124 ft. A few irregular patches of a dark-brown altered phosphate mineral of the lithiophilite-triphylite group occur at 123.8 ft. They are 1/2 to 3/4 in. in diameter. This mineral also occurs as thin veins between mineral grains and small fractures. Scattered bluish-green to grass-green anhedral apatite crystals are as much as 1/2 in. in diameter; the average is less than 1/4 in. Beryl occurs as small yellowish-white anhedral crystals embedded in albite, quartz, and muscovite. The 27 crystals identified range in exposed area from 0.000025 to 0.001 sq ft; the total area is 0.00575 sq ft. Most of the beryl was highly altered to kaolin. The maximum index of refraction ($N\omega$) of beryl ranges from 1.578 to 1.594; the most highly altered crystals have the highest index.
	129.3–130.4	Tourmaline-albite-quartz pegmatite. Wall zone. The tourmaline is in aggregates of grains less than 1/32 in. in size and in a few subhedral crystals as much as 3/4 in. long, intimately mixed with quartz and albite. Albite averages 1/2 in. in size and is more abundant above 129.8 ft. Quartz is more abundant and finer grained in the lower part of the core interval. Scattered books and flakes of accessory muscovite, 1/4 in. in maximum diameter, are most common in the upper part of the drill core. One euhedral garnet crystal was observed embedded in tourmaline-rich rock.
130.4–132.3		Muscovite-quartz schist. Well foliated; contains muscovite (65 percent), quartz (32 percent), and tourmaline (3 percent). Muscovite is in books 1/4 to 1/8 in. in diameter, and quartz is in anhedral grains, less than 1/32 in. in diameter. Foliation is 42° to the drill core at 131.5 ft.
132.3–134.3		Pegmatite. Upper and lower contacts 65° to drill core.
	132.3–133.5	Albite-tourmaline-garnet-muscovite-quartz pegmatite. Wall zone. Contains albite (25 percent), tourmaline (25 percent), garnet (20 percent), muscovite (15 percent), quartz (14 percent), and apatite (1 percent). The average grain size is between 1/4–1/2 in. Blocky subhedral black tourmaline crystals and dark reddish-brown garnet are as much as 1 in. long. Muscovite occurs in flat silvery-white books as much as 2 in. in diameter and 1 in. thick.
	133.5–134.3	Albite-quartz-muscovite pegmatite. Wall zone.
134.3–134.5		Muscovite-quartz schist. Contains muscovite (58 percent), quartz (40 percent), and biotite (2 percent). Foliation makes an angle of 65° with the drill core.
134.5–134.6		Albite-quartz-muscovite pegmatite. Wall zone. Similar to rock at 133.5 to 134.3 ft.
134.6–149.0		Mica-quartz schist. Coarsely crystalline; contains muscovite (53 percent), quartz (30 percent), biotite (15 percent), and tourmaline (2 percent). Mica flakes average 1/16 to 1/8 in. in size and most are well oriented parallel to plane of schistosity. Between 142 and 146 ft fine-grained very thinly laminated schist alternates with more coarsely crystalline schist.
149.0–150.4		Muscovite-quartz-tourmaline pegmatite. Wall zone. Muscovite is in books as much as 2 1/2 in. long and 1 in. wide.
150.4–151.3		Mica-quartz schist. Coarsely crystalline; a well-foliated rock containing muscovite (50 percent), biotite (30 percent), and quartz (20 percent). Muscovite flakes exceed 1/8 in. in diameter; flakes of biotite average 1/16 in. Foliation is 52° to the drill core at 151.0 ft.
151.3–154.0		Micaceous quartzite. Hard gray compact unfoliated rock. Contains quartz (73 percent), biotite (15 percent), muscovite (10 percent), and tourmaline (2 percent).
154.0–162.9		Quartz-mica schist. Average composition is quartz (50 percent), muscovite (32 percent), biotite (10 percent), sillimanite (3 percent), garnet (3 percent), and tourmaline (2 percent). Contains alternating layers of coarsely crystalline and finely crystalline mica. Irregular quartz veins occur between 151.0 to 151.3 ft and between 158.7 and 159.5 ft.
162.9–249.0		Quartz-mica-sillimanite schist. Light brown to dark gray poorly foliated rock. Contains quartz (46 percent), muscovite (30 percent), biotite (12 percent), sillimanite (10 percent), tourmaline, kaolin and other accessory minerals (2 percent). Fine-grained quartzose intervals interbedded with the more micaceous intervals occur between 233 and 249.0 ft. Foliation is 44° to drill core at 165.0 ft, 37° at 166.5 ft, and 40° at 171.2 ft.

End of hole.

TABLE 19.—*Logs of diamond-drill holes, Elkhorn pegmatite*—Continued

Hole 3

[pl. 16]

Location: 176.5 ft. S. 38.5° W. from hole 2
Altitude of collar: 5,179.6 ft.
Inclination: Minus 50°
Bearing: S. 4° E.
Total length: 137 ft.

Interval (feet)	*Description*
0–10.7	Overburden. No core.
10.7–12.5	Quartz-mica schist. Dark-greenish-gray, slightly foliated; contains quartz (80 percent), biotite (10 percent), muscovite (5 percent), tourmaline (3 percent), sillimanite (2 percent), and apatite (trace). Average grain size is 1/64 to 1/32 in.
12.5–19.9	Quartz-mica-sillimanite schist. Well foliated; contains quartz (43 percent), muscovite (25 percent), biotite (15 percent), sillimanite (15 percent), and tourmaline (2 percent). Small biotite flakes are conspicuous in the upper 1.0 ft and the lower 1.5 ft. Average grain size of quartz and mica is less than 1/16 in. Sillimanite is most abundant from 18.5 to 19.9 ft. The foliation is 70° to the drill core at 15.2 ft; 64° at 18.5 ft, and 52° at 19.4 ft.
19.9–35.5	Quartz-mica schist. Fine grained; contains quartz (59 percent), muscovite (20 percent), biotite (15 percent), tourmaline (3 percent), and sillimanite (3 percent). Foliation is 55° to the drill core at 20.0 ft, 58° at 23.1 ft, 50° at 24.2 ft, 55° at 25.3 ft, 58° at 28.0 ft, 65° at 34.3 ft.
35.5–64.0	Quartz-mica-sillimanite schist. Contains quartz (43 percent), muscovite (30 percent), biotite (15 percent), and sillimanite (12 percent). Rock characterized by coarse muscovite and conspicuous blebs of fibrous sillimanite. Coarse- and fine-grained bands of quartz-mica schist alternate between 46.4 to 64 ft. The coarse-grained bands contain abundant coarse muscovite flakes. A quartz vein occurs between 52.3 and 52.6 ft.
64.0–69.3	Quartzite. Consists of quartz (79 percent), muscovite (10 percent), biotite (8 percent), and sillimanite (3 percent). Between 69.1 and 69.3 ft the quartzite is interbedded with 1/8- to 1/4-in. layers of altered quartz-mica schist containing sillimanite. A white quartz vein was cored between 69.0 and 69.1 ft.
69.3–69.6	Quartz-albite pegmatite. Wall zone. Quartz is in irregular anhedral crystals averaging 3/4 in. in size intergrown in 1/2-in. crystals of albite. Accessory biotite occurs in aggregates along fractures roughly parallel to the upper and lower contacts.
69.6–72.0	Quartzite. Contains quartz (80 percent), biotite (15 percent), muscovite (5 percent)), tourmaline (<1 percent), and apatite (trace). Grain size 1/64 to 1/32 in. Lower 3 in. is more micaceous. Foliation is 65° to the drill core.
72.0–75.4	Pegmatite. Sharp upper contact is 65° to drill core.
	72.0–72.4 Tourmaline-quartz-albite pegmatite. Wall zone. Tourmaline is in aggregates of subhedral to anhedral black grains as much as 1/8 in. in diameter; average is less than 1/16 in.; embedded in quartz and albite. Quartz occurs as rounded to irregularly shaped grains as much as 3/4 in. diameter. Albite is in large anhedral light-tan crystals 1/8 to 1/4 in. long.
	72.4–73.8 Quartz, albite pegmatite. Wall zone. Average grain size 3/4 in. Quartz occurs as rounded to irregular anhedral crystals; partly rimmed by 1/32-in. layers of fine-grained tourmaline. Albite is interstitial to quartz grains, and increases in abundance downward. Muscovite occurs as silvery-white to greenish-yellow flakes, as much as 1/4 in. in size, and as small grains along fractures and quartz-albite boundaries.
	73.8–75.4 Albite-tourmaline-muscovite-quartz pegmatite. Wall zone. Light-tan anhedral albite crystals average 1/2 to 3/4 in. in length. Most of the tourmaline is in aggregates, and the upper 0.2 ft consists of at least 60 percent of fine-grained tourmaline. Felted aggregates of muscovite constitute 90 percent of the drill core from 74.7 to 75.0 ft. Quartz is most common near base of interval. The lower contact grades into quartzite.
75.4–76.6	Quartzite. Hard compact rock with average grain size of 1/32 in. Contains quartz (81 percent), muscovite (10 percent), biotite (5 percent), tourmaline (3 percent), apatite (1 percent), and albite (<1 percent).
76.6–81.4	Quartz-mica-sillimanite schist. Light-tan to light-gray; contains quartz (59 percent) muscovite (20 percent), sillimanite (15 percent), biotite (4 percent), and tourmaline (2 percent). Between 75.9 and 76.6 ft the rock has little mica and is relatively quartzitic. Foliation is approximately 90° to the drill core.
81.4–87.2	Quartzite. Similar to quartzite between 75.4 and 76.6 ft.
87.2–93.7	Quartz-mica schist. Contains quartz (60 percent), muscovite (25 percent), biotite (10 percent), tourmaline (3 percent), sillimanite (1 percent), apatite (1 percent), and kaolin (trace). Schist has an average grain size of 1/32 in. Lower 2 ft is poorly foliated and contains quartzite beds as much as 3/4 in. thick. Foliation is 80° to drill core at 91.0 ft, 71° at 92.6 ft and 70° at 93.7 ft.
93.7–95.2	Quartz-mica-sillimanite schist. Composed of quartz (45 percent), muscovite (35 percent) sillimanite (10 percent), biotite (8 percent), and tourmaline (2 percent). Foliation is 90° to the drill core.
95.2–104.8	Quartzite. Contains quartz (87 percent), biotite (5 percent), muscovite (5 percent) and tourmaline (3 percent). Hard fine-grained compact rock; thin schist layers at 98.9 and 100.2 ft.

TABLE 19.—*Logs of diamond-drill holes, Elkhorn pegmatite*—Continued

Hole 3—Continued

Interval (feet)	*Description*
104. 8–132. 0	Quartz-mica schist. Contains quartz (58 percent), muscovite (20 percent), biotite (10 percent), sillimanite (8 percent), garnet (2 percent), and tourmaline (2 percent). Sillimanite is conspicuous as white blebs ¼ in. long, especially in the last 10.0 ft of the interval. Foliation is 83° to drill core at 111 ft, 65° at 116.4 ft, 85° at 118.0 ft, 83° at 120.0 ft, 66° at 122.4 ft, 75° at 126.0 ft, 75° at 128.0 ft, and 55° at 136.0 ft.
132. 0–134. 0	Quartz vein.
134. 0–137. 0	Quartz-mica schist. Similar to rock at 104.8 to 132.0 ft.
End of hole.	

Hole 4

[pl. 16]

Location: 196 ft N. 70° W. of hole 3.
Altitude of collar: 5,199.1 ft
Inclination: Minus 50°.

Bearing: S. 4° E.
Total length: 160 ft

Interval (feet)	*Description*
0–12. 3	Overburden. No core.
12. 3–35. 0	Quartzite. Hard, gray to tannish-gray; contains quartz (93 percent), apatite (4 percent), tourmaline (2 percent), muscovite (1 percent), and kaolin (trace). Translucent grayish-white interlocking anhedral quartz crystals are 1/32 in. or less in diameter. Dark bluish-green anhedral apatite grains average slightly less than 1/32 in. in size; many exceed 1/16 in. in maximum diameter. Tourmaline occurs as disseminated anhedral grains less than 1/64 in. in size.
35. 0–45. 0	Quartz-mica schist. Only 2.4 ft of core recovered. Recovered rock contains quartz (55 percent), muscovite (39 percent), tourmaline (2 percent), apatite (1 percent), garnet (1 percent), biotite (1 percent), and sillimanite (1 percent). In the lower 2 ft, quartz is more abundant and muscovite is sparse. Quartz is in anhedral grains less than 1/64 in. in diameter uniformly mixed with muscovite flakes. The muscovite flakes average 1/32 in. in the upper part of the unit, but become smaller with depth. Foliation is 89° to the drill core at 37 ft, 75° at 44 ft.
45. 0–49. 0	Quartzite. Medium-gray hard and well-indurated rock. Contains quartz (88 percent), hornblende (10 percent), tourmaline (1 to 2 percent), muscovite ($<$1 percent), and kaolin (trace). The grain size averages less than 1/64 in. Grades downward into quartz-mica schist.
49. 0–66. 3	Quartz-mica schist. Fine-grained; contains quartz (64 percent), muscovite (20 percent), biotite (10 percent), sillimanite (3 percent), tourmaline (2 percent), garnet (1 to 2 percent), and apatite ($<$1 percent). Mineral grains are anhedral and have an average grain size of 1/64 in. Two quartz veins ¼ in. thick were cut in this interval. Foliation is 65° to the drill core at 51 ft, and 80° at 54 ft.
66. 3–70. 0	Quartzite. Well-indurated; contains quartz (93 percent), muscovite (4 percent), tourmaline (1 to 2 percent), biotite (1 percent), and a trace of garnet. Quartz is in anhedral grains 1/64 in.
70. 0–78. 5	Quartz-mica schist. Similar to rock between 49.0 and 66.3 ft.
78. 5–82. 4	Quartzite. Similar to quartzite between 66.3 and 70 ft.
82. 4–118. 7	Quartz-mica schist. Similar to quartz-mica schist between 49.0 and 66.3 ft. Quartzite beds between 85.5 and 86.7 and between 119.0 and 119.7 ft. Foliation is 85° to the drill core at 82.7 ft, 59° at 83.2 ft, 90° at 85 ft, 67° at 109.3 ft, 51° at 111.5 ft, and 85° at 118 ft.
118. 7–135. 5	Pegmatite. The lower contact is 58° to the drill core.
118. 7–130. 0	Albite-quartz-perthite pegmatite. Wall zone. Average grain size is 1 in. Yellowish-white limonite-stained anhedral albite crystals, intergrown with irregular grains of quartz and muscovite average about 1 in. in length; some are as much as 2 in. long. Grayish-white translucent irregular quartz grains are slightly more abundant in the lower half of this core interval. Perthite occurs in crystals as much as 8½ in. across. Accessory muscovite occurs as silvery-white books as much as 1½ in. long and ½ in. wide. Beryl in 16 small yellowish-white to white anhedral crystals ranged in exposed area from 0.00005 to 0.00033 sq ft, and have a total area of 0.00198 sq ft. The margins of the crystals are very irregular and some are corroded; a few were soft and highly altered. Some of the smaller beryl crystals contain inclusions of albite.
130. 0–135. 5	Muscovite-albite-tourmaline pegmatite. Wall zone. Muscovite is in felted aggregates of silvery-white books intergrown with albite and quartz. The mica books average about ⅛ in. in size, and are most abundant between 132.0 and 135.5 ft. Tannish-white anhedral albite crystals are as much as 1 in. in length; the average is ½ in. Tourmaline in grains 1/64 in. in size are common in irregular patches and crude irregular bands at about 133 ft. Tourmaline also occurs as disseminated grains. Accessory quartz is in irregular anhedral grains as much as 1 in. long; the average is less than ⅛ in.

TABLE 19.—*Logs of diamond-drill holes, Elkhorn pegmatite*—Continued

Hole 4—Continued

Interval (feet)	*Description*
135. 5–136. 0	Quartz-muscovite granulite. Contains quartz (68 percent), muscovite (25 percent), biotite (5 percent), and tourmaline (2 percent). The rock is not foliated.
136. 0–136. 2	Quartz vein.
136. 2–136. 7	Quartzite. Contains quartz (80 percent), biotite (8 percent), muscovite (8 percent), tourmaline (4 percent). Grain size 1/32 in. or less.
136. 7–141. 6	Quartz-mica schist. Contains quartz (58 percent), muscovite (20 percent), biotite (15 percent), sillimanite (5 percent), tourmaline (1 percent), and garnet (<1 percent). Well foliated; foliation about 90° to the drill core.
141. 6–160	Quartzite with thin interbeds of quartz-mica schist. Quartzite contains quartz (73 percent), biotite (15 percent), muscovite (10 percent), garnet (1 percent), and tourmaline (1 percent). Average grain size between 1/64 and 1/32 in. Quartz-mica schist forms 4- to 8-in. well-foliated layers at 142.7, 144, 154.2, 156.4 and 159.4 ft. At 150.5 ft there is a 1.7 ft bed. Foliation is 90° to the drill core.
End of hole.	

Hole 5

[pl. 16]

Location: 99 ft, S. 49° W. of hole 4
Altitude of collar: 5,180.7 ft
Inclination: Minus 65°

Bearing: S. 4° E.
Total length: 135.0 ft

Interval (feet)	*Description*
0–16. 6	Overburden. No core.
16. 6–48. 4	Quartzite. Light-gray, fine-grained; consists of quartz (98 percent), apatite (1 percent), tourmaline (1 percent), muscovite (<1 percent), garnet (<1 percent), and biotite (<1 percent). Average grain size is 1/64 in. No banding or bedding is visible. Between 40.0 and 43.0 ft is an opaque to translucent white quartz vein containing about 1 percent of biotite and tourmaline
48. 4–72. 8	Quartz-mica schist. This interval contains several varieties of quartz-mica schist. From 48.4 to 59.0 ft the quartz-mica schist is a light greenish gray and contains quartz (60 percent), muscovite (34 percent), biotite (2 percent; as much as 15 percent locally), tourmaline (2 percent), garnet (1 percent), and apatite (<1 percent). Limonite coats quartz grains and mica flakes. Elliptical "blebs" of fine-grained muscovite between 1/8 to 3/16 in. long and 1/16 to 1/8 in. thick make up 20 percent of this interval between 48.4 and 51.0 ft. No sillimanite was identified in these blebs, though they are believed to have been originally composed entirely of sillimanite. From 59.0 to 65.4 ft muscovite is less abundant and the foliation is not as pronounced. Biotite (5 percent) and tourmaline (3 percent) are more abundant. Kaolin, which occurs as white or greenish patches between quartz grains, may represent an alteration of a feldspar. Garnet constitutes less than 1 percent of the rock. From 65.4 to 66.0 ft, 75 percent of the rock is composed of bands of white mica 1/4 in. thick alternating with bands of quartz and accessory minerals. From 70.5 to 72.3 ft muscovite constitutes as much as 60 percent and biotite 10 percent of the rock. From 72.3 to 72.8 ft the rock is a quartz-mica schist containing quartz (67 percent), biotite (20 percent), muscovite (10 percent), tourmaline (2 percent), and garnet (1 percent). Tourmaline makes up 30 percent of the rock at the contact of schist with the pegmatite. Bedding is 60° to the drill core at 48.4 ft, and foliation is 75° to the drill core at 49.0 ft and 38° at 59.0 ft.
72. 8–95. 5	*Pegmatite.* Upper contact is 75°, and the lower gradational contact is approximately 60° to the drill core.
72. 8–83. 1	Albite-tourmaline pegmatite. Wall zone. White to yellowish-white anhedral bladed albite crystals range to as much as 1½ in. in size; the average is ¾ in. Minor pale yellowish-green mica occurs along fractures in and between albite crystals. Aggregates of equidimensional anhedral tourmaline crystals each averaging 1/64 in. or less in diameter are found in irregular patches and streaks.
83. 1–93. 8	Albite-quartz pegmatite. Wall zone. Average grain size is ¾ in. White to yellowish-white, anhedral bladed albite crystals range up to 4 in.; the average is ¾ in. Quartz is in clear grayish-white rounded to very irregular anhedral crystals averaging 1 in. in diameter. Accessory muscovite occurs as clear to greenish-white irregular heavily ruled books that range to as much as 2 in. in length; the average is ¾ in. for the length and ½ in. for the thickness. Muscovite constitutes 35 to 40 percent of the drill core between 86.0 and 88.0 ft. Minor tourmaline is most common as black subhedral crystals averaging ¼ in. across and having a maximum length of 1 in. They are most abundant between 89.0 and 93.0 ft. Beryl occurs as small white to yellowish-white anhedral crystals ranging in exposed area from 0.00003 to 0.0007 sq ft, and having a total area of 0.00538 sq ft. One beryl crystal was identified at 75.4 ft and 25 other crystals occurred between 82.1 and 90.6 ft. All beryl crystals are altered crumbly and had indistinct outlines, except where they were surrounded by a yellow-stained corroded rim. Most commonly they occur in a matrix of interlocking albite. N_ω of the beryl ranged from 1.578 to 1.592; the average is 1.583.

TABLE 19.—*Logs of diamond-drill holes, Elkhorn pegmatite*—Continued

Hole 5—Continued

Interval (feet)	*Description*
72.8–95.5	93.8–95.5 Muscovite-albite-quartz pegmatite. Wall zone. Yellowish-green books of muscovite average slightly less than ⅛ in. in size and are intimately mixed in felted aggregates with albite. White to yellowish-white anhedral albite is as much as ¼ in. across; the average is about 3/16 in. Quartz occurs as clear to opaque-white anhedral crystals as much as ½ in. across; the average is ¼ in. Accessory tourmaline occurs as aggregates and streaks of finely divided anhedral to subhedral crystals, averaging about 1/32 in. in diameter. Tourmaline is commonly included in quartz, garnet, and albite. Accessory garnet is found in weathered reddish-brown anhedral crystals that average about 3/16 in. in diameter and are most abundant between 94.1 and 94.5 ft. Minor dark bluish-green apatite occurs as a single large anhedral crystal, ⅜ in. long, and as scattered grains, as much as ⅛ in. long.
95.5–97.3	Quartz-muscovite-tourmaline granulite. Consists of quartz (47 percent), muscovite (40 percent), tourmaline (10 percent), albite (2 percent), and garnet (<1 percent). Average grain size is ¼ in. Irregularly shaped grains of quartz averaging about ⅛ in. in diameter comprise most of the fine-grained nonfoliated groundmass. Quartz also occurs as large highly fractured anhedral crystals as much as ¾ in. long. Silvery-white unoriented books of muscovite range in maximum diameter from ⅛ to ¾ in.; the average is slightly more than ¼ in. Several large conspicuous patches and bands of muscovite books ½ in. long cut across the core. These books have a very slight greenish tint, but the fine-grained muscovite disseminated rather evenly throughout the interval is a decided yellowish-green. Tourmaline occurs chiefly as disseminated black grains less than 1/64 in. in diameter, but a few blocky subhedral crystals are about ½ in. in diameter. Anhedral albite crystals range up to 1 in. in maximum diameter. Inclusions of fine-grained muscovite are common. Garnet is in scattered reddish-brown grains from 1/32 to 1/64 in. across.
97.3–104.5	Quartz-mica schist. Contains quartz (57 percent), muscovite (25 percent), biotite (15 percent), tourmaline (2 percent), and garnet (<1 percent). Quartz grains are 1/16 in. and smaller in size. Books of muscovite are as much as ¼ in. in length except from 97.6 to 98.3 ft and 101.0 to 101.3 ft where some books range up to 1 in. long and nearly 1 in. thick. Foliation is 75° to the drill core at 97.4 ft; 85° at 99.0 ft; 73° at 101.0 ft; and 57° at 102.0 ft.
104.5–135.0	Mica-quartz schist. Consists of quartz (48 percent), muscovite (45 percent), biotite (5 percent), and tourmaline (2 percent). Porphyroblasts of mica averaging ⅛ by 3/16 in., are common and are roughly parallel to the foliation. A very irregular highly fractured quartz vein occurs at 115.2 to 116.0 ft, cutting transversely across the core.
End of hole.	

Hole 6

[pl. 16]

Location: 180 ft, S. 87° W. of hole 5.	Bearing: S. 4° E.
Altitude of collar: 5,192.0 ft.	Total length: 135.0 ft.
Inclination: Minus 62°.	

Interval (feet)	*Description*
0–11.0	Overburden. No core.
11.0–38.5	Quartzite with layers of quartz-mica schist between 31.0 and 32.6 feet. Quartzite contains quartz (96 percent), biotite partly altered to chlorite (2 percent), liminite (1 percent), apatite (<1 percent), garnet (<1 percent), muscovite (<1 percent), tourmaline (<1 percent), and opaque black mineral (trace). Hard medium- to dark-gray fine-grained rock. Irregular anhedral quartz grains or masses as much as ¾ in. in diameter occur from 35.9 to 36.5 ft associated with biotite and garnet. Dark-green anhedral apatite and unidentifiable black opaque mineral grains are disseminated in this core interval. Garnet occurs as small euhedral to subhedral crystals, or as larger granular masses. Biotite altered to chlorite gives the rock a slightly greenish tint. Quartz-mica schist layer contains about 40 percent muscovite and 1 percent biotite. No core was recovered between 16.0 and 24.0 ft. Rough banding is 90° to drill core at 30 ft, and foliation is 71° to the drill core at 32 ft.
38.5–56.3	Quartz-mica schist. Contains quartz (73 percent), muscovite (25 percent), garnet (1 percent), limonite (1 percent), sillimanite (<1 percent), and biotite (trace). Schist is well foliated and has coarse muscovite flakes between 45 and 55 ft. Quartz is in anhedral grains 1/64 in. in average diameter, and muscovite flakes average 1/32 in. Sillimanite blebs make up as much as 15 percent of a few 1-in. beds. Garnet is in scattered subhedral crystals and larger granular masses. One quartz vein ¼ in. thick occurs at 54 ft. The foliation is 67° to the drill core at 39.2 ft, 52° at 54 ft, 84° at 55 ft, and 83° at 56 ft.
56.3–65.0	Quartzite. Contains quartz (96 percent), tourmaline (2 percent), muscovite (1 percent), biotite (<1 percent), and apatite (trace). Proportions of quartz vary from 90 to 100 percent.
65.0–70.0	Quartz-mica schist. Similar to quartz-mica schist layer between 38.5 and 56.3 ft. Poor foliation is 71° to the drill core.

TABLE 19.—*Logs of diamond-drill holes, Elkhorn pegmatite*—Continued

Hole 6—Continued

Interval (feet)	*Description*
70. 0–80. 0	Quartzite. Similar to quartzite between 56.3 and 65.0 ft. A 0.1-ft quartz vein occurs at 75.4 ft.
80. 0–88. 0	Quartz vein. Only 1.0 ft of core recovered. Vein consists of white to gray quartz.
88. 0–90. 5	Quartz-muscovite pegmatite. Wall zone. Contacts of this unit with vein above and granulite below were not recovered. Average grain size is ¼ in. Quartz is in gray to white very irregular anhedral grains. Silvery-white to pale greenish-yellow muscovite books are as much as ¾ in. long by ½ in. thick; the average is ¼ in. by ⅛ in. The largest books are in the upper 1 to 2 ft. Finer-grained muscovite is distributed fairly uniformly through the rest of the unit. Accessory tourmaline is found in small disseminated subhedral to anhedral grains, although two patches ¾ to 1½ in. in maximum diameter were observed at 89.1 ft and at 89.9 ft. Apatite occurs in accessory dark bluish-green anhedral crystals averaging 1/16 in. White to yellowish-white anhedral albite grains are rare. Several black opaque cassiterite grains having a maximum size of 1/16 in. were noted.
90. 5–90. 6	Mica-quartz granulite. Contains muscovite (41 percent), biotite (30 percent), quartz (25 percent), tourmaline (2 percent), apatite (1 percent), garnet ($<$1 percent), and limonite ($<$1 percent). Average grain size is 1/32 in. Biotite and muscovite are in small equidimensional books and flakes oriented parallel to the foliation. Apatite and garnet occur as disseminated anhedral grains. Foliation is 56° to the drill core.
90. 6–115. 5	Pegmatite. Upper contact was not recovered; lower contact is gradational.
	90. 6–91. 1 Quartz-muscovite-albite pegmatite. Wall zone. Average grain size of about ⅛ in. Quartz in translucent white to smoky-gray anhedral crystals as much as ½ in. in diameter. Silvery-white muscovite is common as aggregates consisting of flakes 1/32 in. in diameter and as isolated books averaging ⅜ in. in diameter. Light-tan anhedral albite crystals average ¼ in. in size. Accessory garnet is conspicuous as reddish-brown anhedral grains between 1/16 and ⅛ in. in diameter, but is most abundant between 90.6 and 90.7 ft.
	91. 1–91. 6 Muscovite-tourmaline-quartz pegmatite. Wall zone. Average grain size is 1/16 in.
	91. 6–95. 0 Quartz-muscovite-albite pegmatite. Wall zone. About 0.8 ft. of core recovered. Average grain size is less than ¼ in. Milky-white to yellow-brown stained anhedral quartz crystals are intergrown with muscovite and albite. Silvery-white to pale yellowish-green muscovite is in flakes or books, as much as ½ in. thick, and albite is in roughly bladed anhedral crystals. Albite becomes more abundant with depth and constitutes nearly 60 percent of the rock at 94.9 ft.
	95. 0–95. 6 Quartz-albite pegmatite. Wall zone. Average grain size is 1 in. Quartz is translucent, grayish white, and highly irregular in shape. White to yellowish-white albite is in veinlike masses between large quartz crystals. Albite crystal borders are very irregular where in contact with quartz.
	95. 6–97. 0 Quartz pegmatite. Core. Contains quartz (98 percent), albite (1 percent), muscovite (1 percent), and beryl (0.058 percent). The rock is dominantly translucent grayish-white to white massive quartz. Muscovite and albite occur in a 2-in. aggregate of crystals at 95.2 ft. The muscovite flakes average 1/16 in. in size, but are as large as ⅜ in. Albite averages ¼ in., but is as large as ½ in. Three beryl crystals at 96. 5 ft range in exposed area from 0.00006 to 0.00012 sq ft, and have a total area of 0.00026 sq ft. N_ω of each grain is 1.579, 1.581, and 1.580. The beryl is yellowish white and intensely altered. These anhedral grains have indistinct outlines and occur inconspicously in a matrix of quartz, albite, and muscovite.
	97. 0–115. 5 Albite-quartz pegmatite. Wall zone. White to yellowish-white anhedral albite crystals average ¾ in. Irregular anhedral quartz crystals range up to 1 in. in length. Silvery-white books of accessory muscovite, ⅛ to ¼ in. in diameter, are scattered throughout the albite and quartz matrix, and exceedingly fine grained yellowish-green muscovite occurs as a thin coating along fracture surfaces and between crystals of quartz and albite. Accessory perthite occurs at 105.0 and 106.5 ft as two yellowish-white crystals at least 2 in. long. Minor tourmaline is in aggregates of small black subhedral crystals. Dark bluish-green anhedral crystals of minor apatite are disseminated through the rock, but are most common in upper foot. Six yellowish-white anhedral beryl crystals occur between 98.2 and 104.3 ft They range in exposed area from 0.00002 to 0.00105 sq ft, and have a total area of 0.00233 sq ft.

TABLE 19.—*Logs of diamond-drill holes, Elkhorn pegmatite*—Continued

Hole 6—Continued

Interval (feet)	*Description*
115. 5–120. 5	Muscovite-albite granulite. Fine-grained rock; contains muscovite (75 percent), albite (15 percent), quartz (4 percent), apatite (3 percent), and tourmaline (3 percent). The upper 0.7 foot of this core interval consists of intergrowths of rock containing albite (48 percent), muscovite (42 percent), and quartz (10 percent). The average grain size is less than ⅛ in. There is no foliation. Albite and quartz decrease in abundance downward and muscovite becomes more dominant. Muscovite books and flakes, about ⅛ in., form felted aggregates of silvery-white units in which white to yellowish-white anhedral albite is scattered. Few anhedral albite crystals, about ¼ in. in size, have a random distribution. N'_{α} is 1.531 at 116 ft. Quartz occurs in anhedral translucent grains ⅛ to ¼ in. in diameter. Apatite is present as scattered dark bluish-green anhedral ⅛ in. grains in a matrix of felted muscovite books.
120. 5–135. 0	Quartz-mica schist. Contains quartz (50 percent), muscovite (30 percent), biotite (15 percent), tourmaline (3 percent, and sillimanite (2 percent). Average grain size is 1/32 in. Sillimanite occurs as white fibrous "blebs" ⅛ in. long and 1/16 in. wide. These blebs have been altered, for the most part, to muscovite. Foliation is pronounced and is 80° to the drill core at 122 ft., 85° at 124 ft., and 72° at 127 ft.
End of hole.	

Data from drill hole 1 and the surface suggested the possibility that the plunges of the main part of the Elkhorn pegmatite and the northwestward-trending segment diverged at depth. This in turn suggested that the area of this intersection was favorable for a wider core with a possible large deposit of beryl at its outer edge. Drill hole 2 was drilled to intersect this junction at depth, determine its direction and amount of plunge, and explore for beryl. The drill hole actually passed under the junction of the two segments of the Elkhorn pegmatite and cut albite-quartz-muscovite pegmatite of the main segment (pl. 16) from 118.7 to 130.4 ft. Below this, thin schist layers alternate with thin pegmatite stringers to 150.4 ft. (table 19). This hole gave the approximate position of the keel of the pegmatite and indicated that the plunge of the intersection of the two pegmatites, which was measured at the surface as 60° to the west (pl. 15), flattens within a short distance at depth. The westward-trending segment plunges about 10° to the west, and the two segments probably join as shown in plate 16, though it is possible that no junction exists in this section.

The flattening of the plunge of the pegmatite, as shown in holes 1 and 2, indicated that the pegmatite was much shallower than it was originally thought to be; hence, the chance for a wider pegmatite core with depth with possible peripheral beryl deposits was less. Drill holes 3, 4, 5, and 6 were put in to delineate the actual size of the pegmatite. Holes 4 and 5 were also drilled to determine the extent of the pegmatite core below the West pit, where it thickens. Owing to rapid thinning of the pegmatite the core was not intersected in either holes 4 or 5. With the data obtained from the first five holes, the bottom of the core was intersected in hole 6 about 50 feet below the outcrop (pl. 16). The drilling showed that the plunge of the keel of the pegmatite was shallow and variable between the drill holes, although it tends to steepen to the west. Between drill holes 2 and 3 the plunge was nearly horizontal, S. 60° W., between holes 3 and 4 it was about 7°, W., and between holes 4 and 5 it was about 14° S. 80° W.

Cores and sludges from the pegmatite, slivers of country rock between the pegmatite stringers, and in some drill holes the country rock that was immediately adjacent to the outer pegmatite contact were analyzed quantatively by spectrograph for BeO. The results of these individual analyses for each hole are given in table 20. The table summarizes the BeO content, beryl content—assuming all the BeO to be in beryl—and the amount of beryl visible on the drill core for each rock type.

MINERAL DEPOSITS

The Elkhorn pegmatite contains beryl, feldspar, and mica of potential ecomonic value.

BERYL

Beryl is most abundant in the outer parts of the core, but also is scattered throughout the wall zone. Most of the beryl in the outer part of the core is in the form of rather clear, light-green crystals as much as 1 foot in length. Most of the crystals are 0.1 to 0.2 foot in diameter, and approximately 90 percent of all the beryl from this zone is recoverable by hand cobbing (cross-sectional area of 0.01 sq ft or greater). The beryl is most abundant in the outer 3 to 10 feet of the core. Along the sides of the two large opencuts and in the Bureau of Mines sample cuts, 260 crystals were measured in 1,659 square feet of outcrop—a grade of 0.59 percent beryl (table 21). Locally, beryl crystals are found associated with late biotite. These crystals are yellow in color and usually less than an inch long. Microscopically the beryl shows numerous gas and liquid inclusions.

Two types of beryl occur in the wall zone: coarser grained beryl adjacent to the core and finer grained beryl away from the core. The coarser grained beryl closest to the core is commonly similar in color, shape, and size to the beryl in the core. This beryl, however, ranges from blue through green to white in color, occurs in euhedral crystals, and its average size decreases outward from the core. In mineral measurements made on 176.3 square feet of wall zone adjacent to the core the rock contained 0.08 percent of coarser grained beryl. In hand-sorting tests of material from 10 sample cuts by the U.S. Bureau of Mines both in the outer part of the core and in the inner part of the wall zone a total of 1,466.5 pounds of beryl was recovered from 731,016 pounds of rock, a recoverable beryl content of 0.21 percent (Tullis, 1952, p. 17).

The second type of beryl found in the wall zone is colorless to yellowish-white anhedral grains about one-eighth inch in diameter, and approximately the same color as the adjacent albite. Many of these small crystals are partially kaolinized and some of these have been altered in part to svanbergite ($2SrO \cdot 3Al_2O_3 \cdot 2SO_3 \cdot P_2O_5 \cdot 6H_2O$). Kaolinized beryl was found in all drill cores except those from drill hole 3. In mineral measurements of the drill cores, 89 crystals were noted in 86 feet of drill core and none of these crystals was over ¾ inch across. The drill cores had an average grade of 0.067 percent beryl based on mineral counts.

The maximum index of refraction (N_ω) was determined on 105 beryl specimens of both types from surface exposures and drill cores. The N_ω of beryl on 91 specimens from the wall zone ranges from 1.578 to 1.594; the large range in index from this zone may be partly the result of alteration of some of the beryl to kaolin. The N_ω of beryl on 14 specimens from the pegmatite core ranges from 1.578 to 1.581. The average of the N_ω of beryl in the Elkhorn decreases from 1.583 in the wall zone to 1.579 in the core. The average of the N_ω of beryl in the Helen Beryl and Tin Mountain pegmatites, however, showed an increase towards the core.

This variation in N_ω indicates according to Schaller's and Steven's graph (Norton, Griffitts, and Wilmarth, 1958, p. 23) that the beryl ranged from 11.2 to 13.2 percent BeO in the wall zone and from 12.9 to 13.2 percent BeO in the core. Conversely the alkali content of the beryl would range from about 2.8 to 0.8 percent in the wall zone and from 1.1 to 0.8 percent in the core. This large range in composition of the beryl within a single unit is likely to effect the recoverages of beryl in any flotation process.

The question of whether the change in composition of the beryl crystals was due mainly to a change in beryllia or alkali content of the pegmatite fluids was tested by measuring the alkali content of albite crystals adjacent to beryl crystals. The alkali content of the albite was also obtained indirectly by measuring the index of refraction ($N_{\alpha'}$), which decreases with an increase of Na_2O. The $N_{\alpha'}$ of albite in the Elkhorn pegmatite (tables 17 and 18) has a relatively small range and showed no recognizable variation to that of the beryl. A large increase in the N_ω of one beryl crystal over another might be parallelled by increase, decrease, or no change in N_α of albite crystals adjacent to these beryl crystals. Hence, the variation in the composition of beryl in various parts of the pegmatite most likely reflects the BeO content rather than the alkali content of this part of the pegmatite.

FELDSPAR

Perthite was mined from the perthite-quartz core in the East and West pits (pl. 15) during 1938, 1939, and 1940. The perthite occurs as white blocky crystals and commonly is graphically intergrown with quartz. Impurities in the feldspar increase towards the outside of the perthite-quartz core, and the best commercial feldspar occurs in the wider parts of the pegmatite, in the two large opencuts. Small amounts of potassium feldspar in small crystals also occur in the wall zone, and adjacent to the core perthite makes up 6.6 percent of the rock (table 21). If the rock were milled for beryl, a sodium-potassium feldspar product might be a byproduct.

MICA

Muscovite is estimated to compose 4 percent of the quartz-albite pegmatite wall zone and 2 percent of the perthite-quartz pegmatite core. In the wall zone it occurs as irregular books, three-quarters of an inch in diameter, and is commonly intergrown with quartz. The muscovite is too small to be recovered by hand cobbing and is associated with biotite that would interfere with its recovery by milling. The muscovite in the core commonly occurs in radiating sheaves as much a 1 foot long that are most abundant in the outer part of the zone. Most of the mica is white and highly reeved, has abundant mineral stains, and is useful only as scrap mica.

TIN MOUNTAIN PEGMATITE

The Tin Mountain pegmatite is in the central part of sec. 35, T. 3 S., R. 3 E., Black Hills principal meridian, Custer County, S. Dak. (fig. 71). The pegmatite is on a patented mining claim of 8.75 acres, which is 1,450 feet long and 300 feet wide. The claim was patented in 1889 by the Tin Mountain Co.; after passing through several hands it was acquired in July 1928 by the Maywood Chemical Co. of Maywood, N.J.

TABLE 20.—BeO *and beryl content, diamond-drill holes 1–6, Elkhorn pegmatite, Custer County, S. Dak.*

Rock unit	Depth (feet)	Average BeO and beryl content of rock units							Drilling data from—						Weighted-average percent BeO
		Percent BeO—			Percent beryl—				Core samples			Sludge samples			
		From core	From sludge	From average of assays	From core	From sludge	From average of assays	Observed on core	No.	Length (feet)	Percent BeO	No.	Length (feet)	Percent BeO	
Diamond-drill hole 1 [See rock-unit numbers, pl. 16]															
1. Wall zone (albite-quartz pegmatite)	60.1– 65.0	0.005	0.006	0.006	0.040	0.047	0.047		C 273	0.2	0.021	----	----	----	0.021
								0	C 274	4.7	.004	S 99	5.0	0.0059	0.005
															.006
2. Quartzite	65.0– 66.9	.019	.000	.003	.15	.000	.024	0	----	1.5	----	S 100	5.0	.000	.000
									C 275	.4	.019				.009
3. Wall zone (muscovite-quartz-tourmaline pegmatite)	66.9– 67.3	----	.000	.000	----	.000	.000	0	----	.4	----				.000
4. Quartzite and quartz-mica schist	67.3– 70.9	----	.000	.000	----	.000	.000	0	----	3.6	----				.000
5. Wall zone (albite-quartz-tourmaline-muscovite pegmatite)	70.9– 79.7	.013	.000	.005	.10	.000	.040	.10	C 276	8.8	.013	S 101	10.0	.000	.005
6. Quartz-muscovite-tourmaline granulite	79.7– 80.0	.002	.000	.001	.016	.000	.008	0	C 277	.3	.002				.001
7. Wall zone (albite-quartz,tourmaline-muscovite pegmatite) and quartz-muscovite granulite	80.0– 84.5	.004	.000	.002	.032	.000	.016	0	C 278	.3	.004				.001
									C 279	5.0	.004	S 102	5.0	.000	.002
8. Wall zone (albite-quartz pegmatite)	84.5– 87.9	.007	.000	.003	.055	.000	.024	0	C 280	2.6	.007	S 103	5.0	.000	.003
															.000
9. Quartz-mica schist and quartz-mica-sillimanite schist	87.9– 95.0	----	.000	.000	----	.000	.000	0	----	7.1	----	S 104	4.7	.000	.000
Diamond-drill hole 2 [See rock-unit numbers, pl. 16]															
1. Quartzite, quartz-mica-sillimanite schist, and mica-quartz schist	109.0–118.7	----	0.002	0.002	----	0.016	0.016	0	----	9.7	----	S 105	5.0	0.0015	0.002
												S 106	5.0	.0017	.002
2. Wall zone (albite-quartz-muscovite pegmatite)	118.7–129.3	0.015	.012	.014	.12	.098	.11	.16	C 226	.3	0.015				.005
									C 227	5.0	.006	S 107	5.0	.0064	.006
									C 228	5.0	.030	S 108	5.0	.016	.021
									C 229	.3	.003	S 109	5.0	.030	.017
3. Wall zone (tourmaline-albite-quartz pegmatite)	129.3–130.4	.006	.030	.019	.049	.24	.15	0	C 230	1.1	.006				.019
4. Muscovite-quartz schist	130.4–132.3	.008	.030	.019	.065	.24	.15	0	C 231	1.9	.008				.019
5. Wall zone (albite-tourmaline-garnet-muscovite-quartz pegmatite)	132.3–133.5	.010	.030	.020	.031	.24	.16	0	C 232	1.2	.010				.020
6. Wall zone (albite-quartz-muscovite pegmatite) with 0.2 foot stringer of muscovite-quartz schist	133.5–134.6	.24	.022	.13	1.95	.18	1.06	0	C 233	.5	.51				.261
									C 234	.6	.022				.019
												S 110	5.0	.016	

															.016
7. Mica-quartz schist	134.6–149.0	----------	.011	.011	----------	.089	.089	0	--------	14.4	----------	S 111	5.0	.0096	.010
												S 112	5.0	.0074	.007
8. Wall zone (muscovite-quartz-tourmaline pegmatite)	149.0–150.4	.008	.006	.007	.065	.049	.057	0	C 235	1.4	.008	S 113	5.0	.0062	.007
															.006
9. Quartz-mica schist, quartz-mica-sillimanite schist, and quartzite	150.4–164.0	----------	.006	.006	----------	.049	.049	0	--------	13.6	----------	S 114	5.0	.010	.010
												S 115	5.0	.0023	.002

Diamond-drill hole 3

[See rock-unit numbers, pl. 16]

1. Quartz vein	69.0– 69.1	0.007	0.013	0.011	0.055	0.10	0.086	0	C 265	0.1	0.007				0.011
2. Quartzite	69.1– 69.3	.010	.013	.012	.078	.10	.094	0	C 266	.2	.010				.012
3. Wall zone (quartz-albite pegmatite)	69.3– 69.6	.009	.013	.012	.070	.10	.094	0	C 267	.3	.009				.012
4. Quartzite	69.6– 72.0	.005	.013	.010	.039	.10	.078	0	C 268	2.4	.005	S 125	5.0	0.013	.010
5. Wall zone (tourmaline-quartz-albite pegmatite)	72.0– 72.4	.005	.013	.010	.039	.10	.078	0	C 269	.4	.005				.010
6. Wall zone (quartz-albite pegmatite)	72.4– 73.8	.011	.013	.012	.086	.10	.094	0	C 270	1.4	.011				.012
7. Wall zone (albite-tourmaline-muscovite-quartz pegmatite)	73.8– 75.4	.006	.006	.006	.047	.047	.047	0	C 271	.2	.010				.012
									C 272	1.4	.006	S 126	5.0	.0054	.006
															.005
8. Quartzite and quartz-mica-sillimanite schist	75.4– 84.0	----------	.002	.002	----------	.008	.008	0	--------	8.6	----------	S 127	5.0	.000	.000

Diamond-drill hole 4

[See rock-unit numbers, pl. 16]

1. Wall zone (albite-quartz-perthite pegmatite)	118.7–130.0	0.024	0.13	0.11	0.18	0.99	0.84	0.043	C 258	1.3	0.011	S 129	1.3	0.74	0.607
									C 259	5.0	.024	S 130	5.0	.041	.036
									C 260	3.0	.040	S 131	3.0	.062	.053
									C 261	2.0	.011	S 132	3.0	.054	.042
2. Wall zone (muscovite-albite-tourmaline pegmatite)	130.0–135.5	.009	.020	.016	.069	.15	.12	0	C 262	1.0	.010				.041
									C 263	4.0	.009	S 133	4.0	.013	.011
									C 264	.5	.009	S 134	.5	.006	.007

TABLE 20.—BeO *and beryl content, diamond-drill holes 1–6, Elkhorn pegmatite, Custer County, S. Dak.*—Continued

Rock unit	Depth (feet)	Average BeO and beryl content of rock units							Drilling data from—						Weighted-average percent BeO
		Percent BeO—			Percent beryl—				Core samples			Sludge samples			
		From core	From sludge	From average of assays	From core	From sludge	From average of assays	Observed on core	No.	Length (feet)	Percent BeO	No.	Length (feet)	Percent BeO	
Diamond-drill hole 5															
[See rock-unit numbers, pl. 16]															
1. Wall zone (albite-tourmaline pegmatite)	72.8– 83.1	0.029	0.023	0.025	0.23	0.18	0.20	0.081	C 250	7.2	0.035	S 135	2.0	0.000	0.002
												S 136	5.2	.0098	.015
									C 251	3.1	.020	S 137	5.0	.038	.032
									C 252	1.9	.000				.026
2. Wall zone (albite-quartz pegmatite)	83.1– 93.8	.032	.068	.053	.25	.53	.42	.072	C 253	4.0	.002	S 138	4.0	.066	.048
									C 254	4.8	.070	S 139	6.0	.066	.068
3. Wall zone (muscovite-albite-quartz pegmatite)	93.8– 95.5	.067	.051	.058	.53	.40	.45	0	C 255	1.2	.090				.077
									C 256	.5	.010				.012
4. Quartz-muscovite-tourmaline granulite	95.5– 97.3	.050	.014	.030	.39	.31	.35	0	C 257	1.8	.050	S 140	5.0	.014	.030
5. Quartz-mica schist	97.3–105.0	--------	.011	.011	--------	.086	.086	0	--------	7.7	--------				.014
												S 141	5.0	.010	.010
Diamond-drill hole 6															
[See rock-unit numbers, pl. 16]															
1. Wall zone (quartz-muscovite pegmatite)	88.0– 90.5	0.007	0.009	0.008	0.54	0.70	0.062	0	C 236	2.0	0.005	S 142	2.0	0.0081	0.007
									C 237	.5	.040				.019
2. Mica-quartz granulite	90.5– 90.6	.010	.016	.015	.077	.12	.12	0	C 238	.1	.010				.015
3. Wall zone (quartz-muscovite-albite pegmatite)	90.6– 91.1	.007	.016	.015	.054	.12	.12	0	C 239	.5	.007	S 143	5.0	.016	.015
4. Wall zone (muscovite-tourmaline-quartz pegmatite)	91.1– 91.6	.005	.016	.015	.039	.12	.12	0	C 240	.5	.005				.015
5. Wall zone (quartz-muscovite-albite pegmatite)	91.6– 95.0	.003	.016	.014	.023	.12	.11	0	C 241	3.4	.003				.014
6. Wall zone (quartz-albite pegmatite)	95.0– 95.6	.000	.027	.018	.000	.21	.14	0	C 242	.6	.000				.018
7. Core (quartz pegmatite)	95.6– 97.0	.000	.027	.018	.000	.21	.14	.068	C 243	1.4	.000	S 144	5.0	.027	.018
									C 244	3.0	.012				.022
									C 245	5.0	.025	S 145	5.0	.026	.026
8. Wall zone (albite-quartz-pegmatite)	97.0–115.5	.026	.014	.015	.20	.11	.12	.076	C 246	5.0	.035	S 146	5.0	.0042	.008
									C 247	5.0	.030	S 147	5.0	.0045	.008
									C 248	.5	.000	S 148	5.0	.0051	.004
9. Muscovite-albite granulite	115.5–120.0	.015	.005	.007	.12	.039	.054	0	C 249	4.5	.015				.007

TABLE 21.—*Summary of mineral measurements on surface exposures by zones, Elkhorn pegmatite*

Zone	Mineral	Number of separate areas measured	Total area measured (sq ft)	Total crystals			Percent mineral	Cobbable crystals		Percent cobbable mineral
				Number	Size range (sq ft)	Area (sq ft)		Number	Area (sq ft)	
Wall	Beryl	8	176. 3	14	0. 0004–. 0480	0. 1471	0. 083	5	0. 1150	0. 065
	Perthite	3	102. 0	32	. 010–1. 26	6. 742	6. 61	32	6. 742	6. 61
Core	Beryl	10	1659. 4	260	. 0004–1. 4	9. 8242	. 591	138	9. 3921	. 57
	Tourmaline	2	82. 8	101	. 0001–. 0520	. 2507	. 30	(1)	(1)	(1)

[1] Not applicable.

The early exploration was for tin and consisted of excavating three pits along the top of the pegmatite. Later, spodumene, amblygonite, beryl, and pollucite were mined from underground workings in the center of the pegmatite. At this time considerable perthite was taken from an upper stope and thrown over the dump, where it was later recovered by one of the local miners.

The deposit has been described briefly by Connolly and O'Harra (1929, p. 245, 261), Schwartz (1930), Hess (1933), and W. C. Stoll (Page and others, 1953, p. 197–201).

MINE WORKINGS

The Tin Mountain pegmatite was prospected and mined from three surface pits, the largest of which in 1948 was 40 feet long, 20 feet wide, and 8 feet deep (pl. 17), two underground levels at altitudes of 5,637 feet and 5,609 feet (pl. 18) and three stopes at altitudes of 5,670 feet, 5,637 feet, and 5,614 feet. The main adit (pl. 18) was driven in pegmatite N. 82° W. for 170 feet. It has several branches including an 80-foot southwestward-trending crosscut. At its western end a large stope 105 feet long, 30 feet wide, and about 14 feet high extends to the north. This stope is connected by raises to the surface. Approximately 35 feet above the 80-foot crosscut on the main level is a second stope, 80 feet long, 25 feet wide, and 20 feet high. The lower level, which is 23 feet below the main level, is connected to the 80-foot crosscut on the main level by a vertical winze, to the main stope by a vertical raise and small stope, and to the surface by an inclined winze and short adit. The lower level has 210 feet of workings.

By 1948, 5,000 tons of pegmatite had been mined from the main level stope, 3,200 tons from the upper stope, and 4,800 tons from the levels, shaft, and raises—a total of 13,000 tons from the underground workings.

GEOLOGY

METAMORPHIC ROCKS

Quartz-mica schist and amphibolite are the country rock that surrounds the Tin Mountain pegmatite. Amphibolite, which was intruded into the quartz-mica schist (J. A. Redden, 1957, oral communication), forms the greater part of the rock in the vicinity of this pegmatite. The metamorphic rocks have a foliation that strikes N. 75°–85° E. and dips 55°–88° SE.

QUARTZ-MICA SCHIST

Two layers of quartz-mica schist were cut on the hanging wall and one layer on the footwall side of the pegmatite in drill holes 1 and 2. A thick band of quartz-mica schist appears to have been intruded by the westward-trending part of the pegmatite (pl. 17), and remnants of schist are left along the south side and top of this part of the pegmatite. This schist is fairly uniform in mineral composition and consists of quartz and feldspar (65 to 75 percent), muscovite (15 to 25 percent), biotite (5 to 15 percent), chlorite (0 to 3 percent) and garnet (0 to 1 percent). Where the schist is close to the contact of the pegmatite, as between 64 and 64.8 feet in drill hole 1 (table 26), cassiterite and tourmaline may be present. In other places, as at 65.4 to 88 feet in drill hole 1 (table 26), the rock may be bleached and biotite altered to chlorite. The average grain size is less than one thirty-second of an inch. The largest grains are round pink porphyroblasts of garnet as much as an eighth of an inch across. The schistosity and laminations are parallel to the contact of the amphibolite.

AMPHIBOLITE

The amphibolite forms broad prominent outcrops on the ridge in the north-central part of the Tin Mountain property and adjacent to the southeast side of the pegmatite (pl. 17). It was also found interfingering with quartz-mica schist in drill holes 1 and 2 (pl. 20). The amphibolite consists chiefly of hornblende (65 to 90 percent), andesine (1 to 35 percent), and biotite (1 to 12 percent). In some localities the amphibolite also contains small amounts of muscovite, garnet, and magnetite; and adjacent to quartz veins the rock commonly contains some quartz. The average grain size of the amphibolite is one-sixteenth of an inch. This rock is commonly layered, and some layers consist of elongate dark-green hornblende grains separated by layers of white andesine. The andesine (An_{32}) has minimum index of refraction on cleavage fragments ($N_{\alpha'}$) of 1.545±0.002.

Adjacent to the pegmatite the amphibolite is altered to kaolin in hole 3. The biotite-quartz-garnet schist in hole 1 may also represent altered amphibolite.

PEGMATITE

The Tin Mountain pegmatite is a well-zoned pegmatite intruded into interlayered Precambrian amphibolites and quartz-mica schists. On the surface (pl. 17) its outcrop is L-shaped; the larger leg of the L trends N. 75° W. for 300 feet and has a maximum width of 78 feet; the smaller leg trends N. 7° W. for 150 feet and has a maximum width of 55 feet. The two legs of the pegmatite plunge in nearly opposite directions; the larger leg has a very flat plunge to the east and the smaller leg a fairly steep plunge to the northwest. The three-dimensional picture of the Tin Mountain pegmatite is of a long rod-shaped body slanting downwards which has a right-angle bend near its upper end.

The present top of the west limb of the pegmatite is essentially the crest of the pegmatite, as can be seen from the maps and cross sections (pls. 17, 19, and 20). The plunge of rolls exposed on the under side of the pegmatite varies from place to place; the range is 15°–37° N. 75° E. to S. 65° E. In the pit at the west end of the body, the plunge of the keel is 28° S. 84° E.; the plunge determined from the drill holes is 3° S. 85° E.

The north limb of the Tin Mountain pegmatite is highly irregular: the upper contact dips 15°–82° westward, and the irregularities or "rolls" plunge 4° to 40° N. 64° W. to S. 43° W.

A bowing out of internal units on the east side of the main adit indicates that the pegmatite has an irregular extension downward to the east. This projection is fairly steep and probably connects with the isolated outcrop 95 feet to the east of the portal (pl. 17).

On the northern part of the Tin Mountain property, where the pegmatite intrudes chiefly amphibolite, the pegmatite is fracture controlled and is quite irregular in detail. On the southern part of the property, where the pegmatite intrudes quartz-mica schist interlayered with some amphibolite, the pegmatite follows the foliation and is much less irregular. The bend in the pegmatite occurs where the country rock changes from predominant amphibolite to predominant quartz-mica schist.

Six well-developed zones and a small fracture-filling unit have been mapped at the Tin Mountain pegmatite (pls. 17 and 18). In addition two of the zones have been subdivided into three or more units. All the zones except the albite-quartz-spodumene third intermediate zone and the quartz-spodumene-lithia mica core are exposed at the surface. The zones from the outside inward are (1) a thin border zone of muscovite-albite-quartz pegmatite; (2) a wall zone of variable thickness, which has been divided into four units; (3) a first intermediate zone of perthite-quartz-albite pegmatite; (4) a second intermediate zone of perthite pegmatite; (5) a third intermediate zone of albite-quartz-spodumene pegmatite; and (6) a core of quartz-spodumene-lithia mica pegmatite. A small fracture-filling unit of quartz-spodumene pegmatite is exposed on the surface where it cuts the wall zone and first intermediate zone.

The border and wall zones are almost continuous shells of varying thickness that are parallel to the pegmatite contact in detail. The shapes of the first two intermediate zones in plan are similar to the upper part of the irregular pegmatite, but they pinch out in depth. Hence, at depth in the northern branch of the pegmatite the core is in direct contact with the wall zone, but in the shallow westward-extending branch the first two intermediate zones make up most of the pegmatite. Along the under side of the pegmatite the third intermediate zone forms a trough-like structure that pinches out upward. This zone is only found in the northern branch of the pegmatite.

The core is in two parts: the main segment exposed in the main level (pl. 18), lower level (pl. 18), and drill hole 3 (pl. 20), and a smaller segment lying below and to the east of the main one and exposed only at the foot of the inclined winze on the lower level (pl. 18). This smaller segment pinches out in a short distance above this level and probably does not extend to a great depth. Both parts are irregular because they follow the irregular shape of the wall zone and third intermediate zone whose shape, in turn, is controlled by the very irregular pegmatite-amphibolite contact.

A small normal fault cuts across the pegmatite near the junction of the north and west limbs (pl. 17). It has a strike of N. 46° W. and dips 87° SW. Two small subsidiary normal faults branch off from this fault. These faults have displacements of several feet.

MUSCOVITE-ALBITE-QUARTZ PEGMATITE

[Border zone]

The border zone consists of a fine-grained selvage, generally about one-tenth but as much as eight-tenths of a foot thick, at the contact of the pegmatite. In most places, because of its thinness, this unit is mapped with the wall zone (pls. 17 and 18); it is shown only when, owing to flattening of dip, the outcrop width is at least 1 foot. The rock has an average grain size of an eighth of an inch. Samples from the drill holes vary in composition, as shown in table 22. The

TABLE 22.—*Modes of the border zone cut in the drill holes, Tin Mountain pegmatite*

[Modes given in percent]

Location (distance in feet)	Quartz	Albite	Muscovite	Cassiterite	Beryl	Apatite
Drill hole 1:						
63.6–64	2	30	68	<1	----	----
64.8–65.4 (probably stringer from border zone)	2	63	35	Tr.	----	----
Drill hole 2:						
54.5–54.6	69	1	30	----	----	----
96.7–97	65	----	35	Tr.	----	Tr.
Drill hole 3:						
182.4–183.2	2	40	58	----	0. 071	----
Average	11	38	51	Tr.	. 026	Tr.

albite from drill holes 1 and 3 had a minimum index of refraction on cleavage fragments ($N_{\alpha'}$) of 1.529 and 1.530, respectively (table 23).

ALBITE-QUARTZ-MUSCOVITE PEGMATITE

[Wall zone]

The wall zone of the Tin Mountain pegmatite is composed of four mineralogic units: (1) albite-quartz pegmatite, (2) quartz-albite-muscovite pegmatite, (3) albite-muscovite pegmatite, and (4) albite-quartz-muscovite pegmatite. Unit 4 has been noted on the surface; units 1 and 4 on the main adit level, unit 1 on the lower level, and units 2, 3, and 4 in the drill holes.

The average mineral composition of the wall zone in the drill holes consists of albite (54 percent), quartz (32 percent), muscovite (12 percent), and accessory minerals (2 percent). (See table 24.) Each of the following accessory minerals is present in amounts of less than 1 percent: Spodumene, kaolin, perthite, tourmaline, cassiterite, light-green mica, lepidolite, apatite, beryl, amblygonite, columbite-tantalite, and loellingite.

The albite-quartz pegmatite is a unit in which the muscovite content is low. This unit, which is exposed near the main adit portal, is as much as 7 feet thick and has an average grain size of about three-quarters of an inch.

The quartz-albite-muscovite pegmatite is a variety of wall zone richer in quartz than albite. It occurs on

TABLE 23.—*Indices of refraction of albite and beryl from drill core in the pegmatite units, Tin Mountain pegmatite*

Location (distance in feet)	Pegmatite unit	Essential minerals (in order of abundance)	$N'\alpha$ of albite	N_ω of beryl
Diamond-drill hole 1:				
39.0–41.0	Wall zone	Quartz-albite-muscovite	1. 529	1. 584
			1. 528	1. 585
				1. 585
				1. 585
41.0–49.4	First intermediate zone	Quartz-albite-perthite	1. 526	
			1. 529	
			1. 528	
49.4–63.6	Wall zone	Albite-quartz-muscovite	1. 529	1. 591
			1. 528	1. 585
			1. 530	1. 585
				1. 585
				1. 586
				1. 592
63.6–64.0	Border zone	Muscovite-albite	1. 529	
64.8–65.4	Border zone	Albite-muscovite	1. 529	
Diamond-drill hole 2:				
54.6–96.7	Wall zone	Albite-quartz-muscovite	1. 527	1. 586
			1. 528	1. 586
			1. 529	1. 586
			1. 532	1. 586
			1. 529	1. 588
			1. 529	1. 585
			1. 528	1. 589
			1. 529	1. 585
			1. 528	1. 587
			1. 529	1. 591
Diamond drill hole 3:				
51.0–72.2	Wall zone	Quartz-albite-muscovite	1. 528	1. 586
			1. 527	1. 585
			1. 527	
72.2–136.5	Core	Quartz-albite-spodumene	1. 527	
			1. 528	
			1. 528	
			1. 529	
136.5–151.8	Third intermediate zone	Quartz-albite-spodumene	1. 529	1. 587
151.8–182.4	Wall zone	Albite-muscovite	1. 529	
			1. 529	
			1. 529	
			1. 530	
182.4–183.2	Border zone	Muscovite-albite	1. 530	

TABLE 24.—*Modes of the wall zone, Tin Mountain pegmatite*

[Modes given in percent]

Location (distance in feet)	Quartz	Albite	Muscovite	Perthite	Spodumene	Kaolin	Tourmaline	Cassiterite	Lithia mica	Apatite	Beryl	Amblygonite	Columbite-tantalite	Lepidolite	Loellingite
Drill hole 1:															
39–41	49	35	15	----	----	----	Tr.	1	----	----	0.39	----	----	----	----
49.4–63.6	40	50	10	----	----	<1	<1	<1	<1	Tr.	.052	0.022	----	----	----
Drill hole 2:															
54.6–80	47	40	10	1	<1	1	<1	Tr.	----	<1	.077	.374	Tr.	----	----
80.0–89.8	42	45	10	----	----	2	<1	----	----	<1	.084	.090	----	----	----
89.8–96.7	3	84	12	----	----	----	Tr.	<1	----	----	.099	.008	Tr.	----	----
Drill hole 3:															
51–72.2	50	38	12	----	----	<1	----	Tr.	----	<1	.037	.040	Tr.	----	----
151.8–182.4	3	77	20	----	----	----	----	<1	----	Tr.	----	.004	Tr.	<1	<1
Weighted average [1]	32	54	12	<1	0.7	<1	<1	<1	<1	<1	.12	.07	Tr.	<1	<1
Weighted average [1] for—															
1. Quartz-albite-muscovite	48	39	11	<1	<1	<1	<1	<1	0	<1	.07	.17	Tr.	0	0
2. Albite-quartz-muscovite	41	47	10	0	0	<1	<1	<1	<1	<1	.07	.05	0	0	0
3. Albite-muscovite	3	77	19	0	0	Tr.	Tr.	<1	0	Tr.	.02	.02	Tr.	<1	<1

[1] Weighted against core lengths.

the hanging-wall side of the pegmatite and ranges from 2 to 25.4 feet in thickness. This unit of the wall zone is easily separated in the drill cores, but has not been mapped separately and it is included with the albite-quartz-muscovite pegmatite. The quartz-albite-muscovite pegmatite has an average grain size of about half an inch, although muscovite books may be as much as 1 inch in size. Of particular interest is the presence of small amounts of spodumene, perthite, beryl and amblygonite (table 24). Albite in this unit has a minimum index of refraction on cleavage fragments ($N_{\alpha'}$) of from 1.527 to 1.529 (table 23).

The albite-muscovite pegmatite is a quartz-poor variety of wall zone. It was found on the footwall side of the pegmatite where the outer part of the wall zone was cut by drill holes 2 and 3. This pegmatite is 6.9 and 30.6 feet thick where intersected in the two drill holes, and has an average grain size of about half an inch. In drill hole 3 this rock contained numerous vugs as much as three-quarters of an inch in diameter. This unit differs from the other wall zone units, besides having an unusually low proportion of quartz, in that it has only traces of tourmaline and apatite, is richer in columbite-tantalite, and contains lepidolite and loellingite associated with the vugs (table 24). The $N_{\alpha'}$ on four specimens of albite ranges from 1.529 to 1.530 (table 23).

The albite-quartz-muscovite pegmatite is the most abundant unit in the wall zone. It has been noted (1) on the footwall side of the pegmatite in drill hole 1, (2) in the central part of the wall zone in drill hole 2, (3) inside of albite-quartz pegmatite on the main level, and (4) adjacent to schist on the surface and lower level of the mine. This unit is as much as 14 feet thick in the drill holes and 15 feet in the exposed parts of the pegmatite. The albite-quartz-muscovite pegmatite has an average grain size of about half an inch; some of the muscovite, however, is as much as several inches in diameter. On the lower level the muscovite increases in diameter inward from the contact, and also gradually changes from a deep ruby or brown flat mica to a greenish-brown curved mica with many of the characteristics of lepidolite. Of particular note (table 24) is the presence of greenish aggregates of fine-grained lithia mica associated with vugs, the relatively high apatite and kaolin contents, and the presence of small amounts of beryl, amblygonite, and columbite-tantalite. The $N_{\alpha'}$ on 13 specimens of albite ranges from 1.527 to 1.532 (table 23).

PERTHITE-QUARTZ-ALBITE PEGMATITE

[First intermediate zone]

The first intermediate zone forms a hood in the upper part of the pegmatite and is best exposed on the surface. This zone narrows and pinches out with depth, so that in drill hole 3 and on the lower level, the wall zone is directly in contact with the core. The main constituent is perthite (50 percent) in large blocky cream-colored crystals, as much as 4 feet by 6 feet in size; these are in a fine-grained matrix of quartz (33 percent), albite (10 percent), and muscovite (7 percent), with an average grain size of three-quarters of an inch. Accessory minerals are spodumene ($<$1 percent), kaolin ($<$1 percent), lithium-iron-manganese phosphate minerals ($<$1 percent), beryl (trace), tourmaline (trace), lithia mica (trace), and cassiterite (trace). Perthite ranges from less than 15 percent to 80 percent of the rock in different parts of the unit. The white to yellowish albite having $N_{\alpha'}$ of 1.526 to 1.529 (table 23) forms irregular streaks in quartz. Spodumene is most conspicuous on the east side of the pegmatite.

PERTHITE PEGMATITE

[Second intermediate zone]

The second intermediate zone, consisting mainly of perthite, is best exposed on the surface and in the upper stope; it was not cut by the drill holes. The bottom of this unit is present in the stope on the main level. This hood-shaped unit caps the spodumene-bearing core and pinches out downward along the sides of the pegmatite.

The second intermediate zone is as much as 40 feet thick, and has an average composition of perthite (89 percent), quartz (6 percent), albite (2 percent), spodumene (1 percent), lithium-iron-manganese phosphate minerals (1 percent), muscovite (<1 percent), beryl (0.4 percent), apatite (trace), amblygonite (trace), and columbite-tantalite (trace). Perthite crystals are pink in color and as much as 15 feet in diameter. Some perthite from this zone was studied by Miss Jewell Glass who found the microcline to have a $2V$ near 68°, $N_\alpha=1.517$, $N_\beta=1.521$, and $N_\gamma=1.524$. Small anhedral crystals of quartz are commonly included in the perthite; quartz is also found in large milky white masses as much as 4 feet in diameter. Albite occurring as cream-colored crystals intergrown with perthite has $N_{\alpha'}$ of from 1.528 to 1.529. Spodumene occurs along the contact of the second and the third intermediate zones.

ALBITE-QUARTZ-SPODUMENE PEGMATITE

[Third intermediate zone]

The third intermediate zone forms an incomplete shell along the under side of the pegmatite. The upper end of this zone is exposed on the main level about 50 feet from the entrance of the adit. On the lower level the third intermediate zone encloses two segments of the core and forms subsidiary fracture fillings in the wall zone; it also was found in drill hole 3 just below the core. In the central and lower parts of the pegmatite this zone is as much as 15 feet thick; the fracture filling on the lower level averages about 3 feet in thickness. This rock is a medium- to coarse-grained pegmatite with crystals as much as 2 feet long. The composition of this zone, as obtained from mineral counts on the lower level, is albite (43 percent), quartz (27 percent), spodumene (26 percent), muscovite (1.3 percent), beryl (1.2 percent), amblygonite (1.0 percent), and lithia mica (0.5 percent). In drill hole 3 this zone contains more quartz (50 percent), and less albite (39 percent), and spodumene (5 percent) (table 26). Although the composition as indicated by the mineral content of the pegmatite in the drill core is considerably different from that obtained on the lower level, the two rocks are believed to be in the same zone. The pegmatite measured in the drill core is probably not representative of the zone as a whole because the area of the drill core measured is small compared to the grain size of the unit, and spodumene, which is fibrous, tended to be ground out of the core. Spodumene in the third intermediate zone is commonly in irregular partly altered crystals, which are smaller than those found in the adjacent core. Beryl is found chiefly in white euhedral crystals in the matrix between spodumene and mica crystals.

QUARTZ-SPODUMENE-LITHIA MICA PEGMATITE

[core]

The core of the pegmatite is not exposed on the surface, but it is exposed on the main level where it has been outlined by the workings. Its top is at an elevation of 5,662 feet, just above the main level. On this level it is entirely quartz-spodumene-lithia mica rock. On the lower level this zone is generally richer in albite and leaner in spodumene, and the lithia mica content shows considerable variability. In the stope on this level some layers in the core rich in lithia mica are adjacent to others that are rather lean. The core in general consists of very coarse grained pegmatite; individual white spodumene crystals are as much as 16 feet long and 2 feet across. The parts rich in lithia mica, however, are somewhat finer grained, but aggregates and individual crystals of the component minerals are several feet across. The variations in some of the minerals in the core are given in table 25. The average composition of the core is quartz (55 percent), spodumene (23 percent), lithia mica (14 percent), albite (6 percent), muscovite (1 percent), beryl (0.47 percent) and anblygonite (0.36 percent). Apatite, cassiterite, columbite-tantalite, microlite, and pollucite are each less than 1 percent.

The quartz is in large white anhedral masses except adjacent to microlite, where it is smoky. The fine-grained lithia mica is in large part brown, yellow, and gray to greenish gray, but some is clear and colorless; and some is pink to purple lepidolite. The lepidolite has flat laminae; the other lithia micas are in brittle curved laminae. Albite is in white platy crystals; commonly in mammillary aggregates encasing part or all of a spodumene crystal. The $N_{\alpha'}$ ranges from 1.527 to 1.529. Amblygonite occurs in masses several feet across and as graphic intergrowths with albite near the outer edge of the core. The beryl is in white to pinkish crystals as much as 3 feet in diameter. It occurs chiefly with quartz interstitial to spodumene. Cassiterite, columbite-tantalite, microlite, apatite, and lepidolite are intergrown with the albite masses between spodumene crystals and quartz. The surface of these aggregates is flat adjacent to spodumene; adjacent to quartz it is gently curved in general appearance but very irregular in detail. Microlite is in dark brownish to black grains and octahedral crystals as much as 1 inch in diameter and is closely associated with lepidolite and columbite-tantalite.

QUARTZ-SPODUMENE PEGMATITE

[Fracture-filling]

Quartz-spodumene pegmatite occurs in a fracture filling along the east side of the largest opencut on the top of the ridge (pl. 17). The outcrop has a T-shaped

TABLE 25.—*Mineral measurements made on the pegmatite core in the two levels, Tin Mountain pegmatite*

[N.D., not determined]

Location	Total area measured (sq ft)	Mineral	Area of mineral (sq ft)	Number of crystals	Percent mineral
Main level					
74 ft west of entrance	63	Spodumene	25.89	26	41.1
		Beryl	.01	1	.016
		Amblygonite	.32	8	.51
		Muscovite	.37	29	.59
		Lithia mica	6.14	ND	16.9
		Albite	6.0	ND	9.6
		Quartz	19.7	ND	31.3
Center of west wall of main stope	91	Spodumene	3.13	3	3.4
		Beryl	2.84	9	3.1
		Amblygonite	20.17	86	22.2
		Lithia mica	15.14	ND	16.6
		Albite	5.95	ND	6.5
		Quartz	43.63	ND	48.0
		Cassiterite	.144	9	.15
118 ft west of entrance	184	Spodumene	52.15	31	28.4
		Beryl	.58	2	.31
		Amblygonite	5.85	5	3.2
		Lithia mica	8.31	9	4.5
		Albite	2.65	12	1.4
		Quartz	114.46	ND	62.2
South end of east side of main stope	232	Spodumene	94.35	64	40.6
		Lithia mica	30.70	10	13.2
		Albite	12.66	20	5.5
		Quartz	94.29	ND	40.7
22 ft south on west wall of crosscut, which is 108 ft west of entrance.	112	Spodumene	38.55	20	34.4
		Beryl	2.58	10	2.3
		Amblygonite	.91	6	.81
		Lithia mica	14.93	8	13.3
		Albite	1.74	7	1.6
		Quartz	53.29	ND	47.6
Lower level					
South side of inclined winze for 20 feet from level	100	Spodumene	22.10	39	22.1
		Beryl	.207	5	.21
		Amblygonite	.69	7	.69
		Lithia mica	4.56	2	4.6
		Albite	14.94	24	14.9
		Phosphate minerals	.268	4	.27
		Quartz	ND	ND	[1]57.2
130 ft north of main winze, west wall	112	Spodumene	7.84	1	7.0
		Lithia mica	19.00	5	16.9
End of adit, 155 ft north of main winze	49	Spodumene	10.23	2	20.9
		Lithia mica	2.25	1	4.6
140 ft north of main winze, east wall	96	Spodumene	2.80	1	2.9
		Beryl	.02	1	.021
		Amblygonite	.52	2	.54
		Lithia mica	18.3	3	19.1
		Quartz	45.49	3	47.4
120 ft north of main winze, west wall	114	Spodumene	12.58	5	11.0
		Beryl	.05	1	.043
		Amblygonite	.04	1	.035
		Lithia mica	32.53	4	28.5
12 ft north of main winze, east wall	114	Spodumene	8.69	4	7.6
		Amblygonite	1.75	13	1.5
		Lithia mica	9.90	1	8.7

[1] Obtained by subtraction of the total measured constituents from 100.

pattern, and is approximately 17 feet in its longest dimension and 4 feet thick. Where exposed, the fracture filling is in part between the wall zone and first intermediate zone, and in part cuts across the first intermediate zone. It contains predominantly quartz (55 percent), and spodumene (37 percent). Muscovite (5 percent), albite (2 percent), lithia mica (<1 percent), and apatite (<1 percent) are accessory minerals. The rock has an average grain size of 5 inches. The spodumene is in gray or greenish-gray crystals 2 to 5 inches in diameter and 1 to 1½ feet long that are commonly oriented with their long axes perpendicular to the contact of the fracture filling. The muscovite is in light-colored flakes as much as 2 inches in diameter, and the albite is in white platy grains associated with 1/16-inch light-green books of lithia mica. The albite has a minimum index of refraction on cleavage fragments of ($N_{\alpha'}$) 1.528.

DIAMOND-DRILLING

Both limbs of the Tin Mountain pegmatite were explored by diamond-drilling. The first two holes prospected the westward-trending limb to determine its shape and internal structure. A third hole was drilled on the north limb to determine the probable shape and extension of the core of the pegmatite. The data pertinent to drilling and detailed logs of the cores are given in table 26.

TABLE 26.—*Detailed logs of diamond-drill holes, Tin Mountain pegmatite*

[Logged by M. H Staatz. Modes of the pegmatite border zone and wall zone are given in tables 22 and 24; indices of refraction of albite and beryl for the entire pegmatite are given in table 23]

Hole 1

[pl. 20]

Location: 78 ft N. 52 ½° E. of northeast corner of small shaft at west end of pegmatite (pl. 17)
Altitude of collar: 5,676.8 ft
Inclination: Minus 31°

Bearing: S. 5° W.
Total length: 120 ft

Interval (feet)	*Description*
0–18.0	Overburden. No core.
18.0–34.2	Quartz-mica schist. Rock consists chiefly of quartz, muscovite, and biotite. About 3 percent chlorite is also present. Composition of the schist varies from place to place with the upper 11 ft quartz-rich. The drill core contains a fine network of fractures filled with chlorite and sericite; fractures increase in number toward the surface. Foliation is at an angle of 15° to the drill core at 20.6 ft, 30° at 26 ft, and 28° at 33.6 ft.
34.2–37.8	Schistose amphibolite. Rock is dark green and has a matted appearance. Contains hornblende (87 percent), biotite (8 percent), quartz (4 percent), garnet (1 percent), andesine (<1 percent), and muscovite (<1 percent). The biotite occurs as fine black flakes disseminated in hornblende. Quartz is in clear white grains, usually near small quartz veins. Red-brown garnet is in porphyroblastic euhedral crystals about 1/16 in. in diameter. Between 36.2 and 37 ft are several small (<1 in. thick), extremely irregular quartz veins that do not completely cross the drill core; they have no apparent structural control. Obscure foliation is at 30° to the drill core at 35 ft.
37.8–39.0	Biotite-quartz-garnet schist. Rock contains biotite (81 percent), quartz (10 percent), garnet (8 percent), and muscovite (1 percent). Garnet is in reddish-brown to pink porphyroblasts 1/16 to ⅛ in. in diameter. Bedding is at 11° to the drill core at 38.8 ft.
39.0–64.0	Pegmatite. Upper contact not recovered; lower contact is at 67° to the drill core.
39.0–41.0	Quartz-albite-muscovite pegmatite (wall zone). Average grain size is ½ in. White to cream anhedral albite is interstitial to clear anhedral quartz. Albite forms a fine network around and between quartz and muscovite crystals. Extremely irregular muscovite books as much as 1 in. across are light colored and heavily reeved. Accessory cassiterite is in black subhedral to euhedral crystals as much as ¼ in. across, cassiterite is in part altered to limonite on its outer edge. Sixteen white to whitish-yellow anhedral to subhedral beryl crystals range in exposed area from 0.00002 to 0.00107 sq ft; they total 0.00394 sq ft. They are the same color and are difficult to distinguish from albite.
41.0–49.4	Quartz-albite-perthite pegmatite (first intermediate zone). Contains quartz (40 percent), albite (36 percent), perthite (18 percent), muscovite (5 percent), kaolin (1 percent), green mica (<1 percent), cassiterite (<1 percent), and tourmaline (<1 percent). Average grain size is about 1 in. Streaks of white to whitish-yellow albite enclose clear anhedral quartz grains; yellowish euhedral lathlike albite crystals occur as interlocking mats or individual crystals in perthite; and at 41.3 ft pink fine-grained albite is intergrown with fine-grained books of a light-green mica. White perthite crystals are as much as 8 in. long. Their edges are corroded and cut by the finer grained albite-quartz matrix. Muscovite is in light-colored irregular books ¼ to ½ in. across. Kaolin occurs as soft light-green to greenish-black irregular areas ⅛ to ½ in. in length that probably are pseudomorphous after spodumene. Kaolin is platy and biaxial negative and has a $2V$ between 20 and 40°, a positive elongation, and indices of refraction between 1.560 and 1.565. Light-green mica flakes, about 1/64 in. across are intimately mixed with pink albite between 41.2 and 41.6 ft where the mica makes up about 5 percent of the rock. Black anhedral to subhedral cassiterite crystals range up to ⅛ in. in diameter. They are associated with albite and quartz. Tourmaline occurs in dark-blue anhedral crystals as much as 1/16 in. across.

TABLE 26.—*Detailed logs of diamond-drill holes, Tin Mountain pegmatite*—Continued

Hole 1—Continued

Interval (feet)		*Description*
39.0–64.0	49.4–63.6	Albite-quartz-muscovite pegmatite (wall zone). Average grain size is 1/2 in. Albite occurs as white to yellowish-white anhedral crystals, commonly filling in between quartz crystals. In the lower part of the drill core pink albite is associated with light-green mica in grains about 1/16 in. in diameter that contains small vugs or cavities 1/32 in. across. Quartz is in clear to white anhedral grains. Light-colored muscovite is in extremely irregular books as much as 1 in. across. Minor kaolin occurs in irregular dark-green patches ranging up to 1/4 in. long. Minor cassiterite is in scattered dark-brown, anhedral to subhedral crystals as much as 1/8 in. across. Minute amounts of dark-blue anhedral apatite and tourmaline are in grains from 1/16 to 3/8 in. across. Sixteen white to yellowish-white, anhedral beryl crystals were identified. They range from 0.00030 to 0.00076 sq ft in exposed area; the total was 0.00374 sq ft. This beryl was very difficult to distinguish from the surrounding albite. Amblygonite occurs as three small white anhedral crystals ranging in exposed area from 0.00007 to 0.00141 sq ft; the total is 0.00155 sq ft.
	63.6–64.0	Muscovite-albite pegmatite (border zone). Average grain size is 1/8 in. Light-colored muscovite forms irregular interlocking books 1/16 to 1/2 in. in diameter. Pink anhedral albite occurs in 1/8-in. crystals. Accessory quartz is in small, clear anhedral crystals. Minute amounts of dark-brown subhedral crystals of cassiterite occur in the muscovite.
64.0–64.8		Quartz-mica schist. Consists chiefly of quartz, biotite, and muscovite but near the upper contact it also contains cassiterite (<1 percent) and tourmaline (trace). Cassiterite is in dark-brown anhedral crystals as much as 1/8 in. across and tourmaline is in fine-grained dark-blue grains. Rock has an obscure schistosity.
64.8–65.4		Albite-muscovite pegmatite (border zone). Average grain size is 1/8 in. Albite is in pink anhedral crystals. Muscovite is in light-colored, irregular, 1/16- to 1/4-in. interlocking books. Accessory quartz is found in small clear anhedral crystals about 1/16 in. in diameter.
65.4–88.0		Quartz-mica schist. The rock is a light brown to gray and has a prominent compositional layering. Some layers contain as much as 60 percent mica, others as little as 15 percent. Muscovite is the most common mica, but biotite and chlorite also are present. Garnet occurs in small patches as pink porphyroblastic crystals 1/16 in. in diameter. From 65.4 to 74 ft the rock has a bleached appearance and thin films of iron oxide are on some foliation planes. Bedding is parallel to the schistosity and cuts the drill core at an angle of 9° at 67 ft, 15° at 73.5 ft, 35° at 82.5 ft, 30° at 86 ft, and 25° at 87.2 ft.
88.0–120.0		Amphibolite. Rock is dark green, has good foliation, and contains hornblende (75 percent), andesine (15 percent), and biotite (10 percent). Andesine is in white blebs 1/16 to 1/8 in. long interstitial to the hornblende and has a $N_{\alpha'}$ of 1.545 at 103 ft. Biotite is in thin black layers. A well-developed foliation cuts the drill core at an angle of 15° at 91 ft, of 35° at 107 ft, of 20° at 111 ft, and of 25° at 119 ft. The amphibolite is cut by a few quartz veins, ranging from 1/8 to 1/2 in. in thickness, that are parallel to the foliation.
End of hole.		

Hole 2

[pl. 20]

Location: 85.5 ft S. 80° E. from drill hole 1 (pl. 17)
Altitude of collar: 5,717.3 ft
Inclination: Minus 50°
Bearing: S. 5° W.
Total length: 110 ft

Interval (feet)	*Description*
0–3.5	Overburden. No core.
3.5–27.1	Amphibolite. The average composition of this rock is hornblende (64 percent), andesine (33 percent), biotite (2 percent), garnet (1 percent), and muscovite (trace). The upper 18 ft, however, contain as much as 80 percent hornblende. Below 18 ft the rock is banded; some bands contain more andesine than hornblende and some bands contain biotite and garnet. Hornblende is in dark-green irregular elongate grains surrounded by white andesine ($N_{\alpha'}$ at 7.8 ft is 1.546). Biotite is in narrow laminae in the lower part of the drill core; garnet occurs in pink porphyroblastic crystals as much as 1/8 in. in diameter. The hornblende in the upper part of the drill core has an obscure orientation and elongation which at 7.2 and 16.2 ft is at an angle of 15° to the drill core. The well-defined banding is at an angle of 32° to the drill at 20 ft and 25° at 26 ft.
27.1–38.1	Quartz-mica schist. Rock is light gray and finely banded. The lower part of the section is slightly richer in micas, especially biotite, and contains garnet. At 28.8 to 30.2 ft muscovite occurs both as 1/16-in. porphyroblasts and as fine-grained flakes oriented parallel to the foliation. Foliation is parallel to the bedding and at 28.1 ft is at an angle of 25° to the drill core, at 32.8 ft 40°, and at 37.8 ft 42°.

TABLE 26.—*Detailed logs of diamond-drill holes, Tin Mountain pegmatite*—Continued

Hole 2—Continued

Interval (feet)	*Description*
38. 1–46. 5	Amphibolite. Dark-green hornblende and thin black layers of biotite make up most of this unit. Amphibolite contains hornblende (83 percent), biotite (12 percent), andesine (4 percent), and garnet (1 percent). Garnet is found chiefly in the upper and lower parts of the core as round pink porphyroblasts as much as ⅛ in. in diameter. Quartz veins make up about 6 percent of the core and range from 1/32 to ½ in. in thickness. Many of them are conformable to the foliation, whereas others are crosscutting. Foliation is 38° to the drill core at 39.3 ft and 33° at 45.4 ft. The lower contact is parallel to the foliation and is at 42° to the drill core.
46. 5–54. 5	Quartz-mica schist. Same as 27.1 to 38.1 ft. Between 54.0 and 54.5 ft the muscovite is in unoriented porphyroblastic crystals as much as 1.8 in. across. Foliation is parallel to bedding and is 30° to the drill core at 49.0 ft, 40° at 52.0 ft, and 36° at 54.3 ft.
54. 5–97. 0	Pegmatite. Upper contact is 42° to the drill core; the lower contact is 75°.
54. 5–54. 6	Quartz-muscovite pegmatite (border zone). Average grain size is 1/16 in. Clear whitish quartz occurs in 1/32- to 1/16-in. anhedral crystals; muscovite is in extremely irregular books as much as ½ in. long.
54. 6–96. 7	Albite-quartz-muscovite pegmatite (wall zone). This zone contains the following three compositional units: quartz-albite-muscovite pegmatite from 54.6 to 80.0 ft, albite-quartz-muscovite pegmatite from 80.0 to 89.8 ft, and albite-muscovite pegmatite from 89.8 to 96.7 ft. (See table 24.) The quartz-albite-muscovite pegmatite has an average grain size of ¾ in. The quartz and albite content varies widely; parts of this unit contain more albite than quartz. White or yellowish-white streaks or platy crystals of albite occur in clear white, anhedral quartz. Muscovite occurs in irregular light-colored books as much as 1 in. across. Two white perthite crystals, about 3 in. long, contain subhedral quartz crystals and long blades of albite. One fresh and several altered specimens of spodumene in white fibrous 2-in. crystals were cut between 60.0 and 60.8 ft. Minor kaolin is in irregular dark-green patches as much as ¼ in. in diameter. Minor blue tourmaline and apatite are in anhedral to subhedral crystals 1/16 in. and ¼ in. in diameter, respectively. A total of 27 white anhedral amblygonite crystals in groups of two to four were disseminated throughout the drill core. They ranged in exposed area from 0.00007 to 0.00500 sq ft; the total is 0.03118 sq ft. Several white to yellowish-white anhedral beryl crystals, that very closely resemble albite range in exposed area from 0.00004 to 0.00320 sq ft; the total is 0.00643 sq ft. Cassiterite is found in 1/32-in. dark subhedral grains. Columbite-tantalite occurs in small dark flat platy crystals. The albite-quartz-muscovite pegmatite has an average grain size of ½ in. Very fine grained, dark-gray patches, that resemble schist in color and grain size, are composed of albite, muscovite, and kaolin. These patches are a light green where kaolin is absent. The remainder of pegmatite is similar to the quartz-albite-muscovite pegmatite. Albite is interstitial to quartz and is in white to yellowish-white anhedral grains. Muscovite is in light-colored heavily reeved, irregular books as much as ¾ in. in length. Accessory kaolin occurs in dark-green patches as much as ¼ in. across and as a dark coating on feldspar in the dark fine-grained patches of muscovite and albite. Ten white anhedral crystals of amblygonite range in exposed area from 0.00007 to 0.00118 sq ft; the total is 0.00287 sq ft. The three white, anhedral to subhedral beryl crystals noted closely resembled amblygonite. They range in exposed area from 0.00024 to 0.00215 sq ft; the total is 0.00267 sq ft. Minor blue tourmaline and apatite occur in grains as much as ⅛ in. across. In the albite-muscovite pegmatite the albite occurs in yellowish to pinkish white, fine-grained, platy crystals, irregularly intergrown with muscovite. Muscovite is found in light-colored, heavily reeved irregular books ranging from 1/16 to 1 in. across. Accessory quartz in ¼-in. grains is most abundant near the upper and lower edges of this unit. Sixteen small yellow-white, anhedral beryl crystals range in exposed area from 0.00007 to 0.00038 sq ft; the total is 0.00185 sq ft. Small amounts of dark black subhedral to euhedral cassiterite grains range up to ⅛ in. in size. One white, anhedral amblygonite grain with an area of 0.00014 sq ft was noted. Fine thin black plates of columbite-tantalite and blue anhedral tourmaline crystals are rare.
96. 7–97. 0	Quartz-muscovite pegmatite (border zone). Average grain size is ⅛ in. Clear anhedral quartz and light-colored irregular-shaped muscovite are the two chief constituents. Cassiterite occurs as rare black specks less than 1/32 in.
97. 0–110. 0	Quartz-mica schist. Light-gray, highly foliated rock with some variance in mineral composition. Between 101.5 and 110 ft some of the muscovite is as much as 1/16 in. long. Foliation is at an angle of 18° to the drill core at 97.2 ft, 10° at 101.8 ft, and 12° at 108 ft.

End of hole.

TABLE 26.—*Detailed logs of diamond-drill holes, Tin Mountain pegmatite*—Continued

Hole 3

[pl. 20]

Location: 117.3 ft. N. 13 1/2° E. of drill hole 1 (pl. 17)
Altitude of collar: 5688.3 ft.
Inclination: Minus 70°

Bearing: N. 63° E.
Total length: 195 ft.

Interval (feet)		*Description*
0–15. 0		Overburden. No core.
15. 0–48. 0		Amphibolite. Contains hornblende (65 percent), andesine (25 percent), biotite (10 percent), garnet ($<$1 percent), and pyrite (trace). Dark-green elongate hornblende crystals give the rock its color and a weak foliation. Andesine occurs in white lenticulars blebs interstitial to the hornblende. At 39 ft it has a minimum index of refraction on a cleavage fragment ($N_{\alpha'}$) of 1.545. Black flakes of biotite, less than 1/32 in. in diameter, form a fine network. Garnet occurs in round pink porphyroblasts as much as ⅛ in. in diameter, and pyrite is in tiny anhedral grains sparsely disseminated in the gneiss or along fractures. The foliation is 32° to the drill core at 28.0 ft, 35° at 32.5 ft, 28° at 38 ft, and at 31° at 44.5 ft. The foliation of the amphibolite is cut by several quartz veins; the smaller ones are extremely irregular. Prominent veins are at 27.1 ft, where a ½-in. vein cuts across the core at a 62° angle; at 28.7 ft, where a 2-in. quartz vein cuts the core at 90°; and at 31.0 ft, where a 1-in. vein cuts the core at 80°.
48. 0–51. 0		Altered amphibolite. Rock varies from dark green through light green to brown; the brown color is caused by intense iron oxide stain. The rock is soft and friable; core recovery was poor. Hornblende, biotite, and andesine occur only in the upper end of the drill core, where they are partly altered to a kaolin. Small round brown garnetlike grains are scattered through the drill core, but are now kaolin. Banding noted at 50.9 ft is at 50° to the drill core.
51. 0–183. 2		Pegmatite. Upper contact not recovered; lower contact is at an angle of 65° to the drill core.
	51. 0–72. 2	Quartz-albite-muscovite pegmatite (wall zone). Average grain size is ½ in. White, yellowish white or pinkish albite commonly forms a network of thin streaks in milky anhedral-quartz. Albite also occurs as distinctive lath-like plates. Muscovite occurs in light-colored irregular books ranging from ⅛ to 1½ in. across. Minute amounts of apatite are in light-blue to dark-blue anhedral grains ranging up to ¼ in. in diameter. Minor kaolin is in a few soft dark-green, irregular patches. Six white anhedral amblygonite crystals range in exposed area from 0.00003 to 0.00122 sq ft; the total is 0.00196 sq ft. Seven small yellowish anhedral beryl crystals range in exposed area from 0.00005 to 0.00056 sq ft; the total is 0.00178 sq ft. Beryl was most abundant in the upper part of this unit between 51.0 and 53.0 ft. Columbite-tantalite occurs as fine (less than one thirty-second of an inch), black platy crystals and cassiterite as wedge-shaped black crystals. Both are rare.
	72. 2–136. 5	Quartz-albite-spodumene(?) pegmatite (core). The rock is badly fractured and the core recovery was only 25 percent. Recovered core contains quartz (76 percent), albite (20 percent), muscovite (2 percent), spodumene (1 percent), amblygonite (0.56 percent), lepidolite ($<$1 percent), apatite ($<$1 percent), and cassiterite (trace). Average grain size is greater than 4 in. Quartz occurs in large milky white masses interspersed with areas containing a mixture of finer grained quartz, albite, and muscovite. Albite occurs in white to pinkish-white crystals, some of which form a network or platy mass in the quartz. Albite in this unit is the cleavelandite variety. Muscovite is found in light-colored, irregular books ⅛ to ½ in. long and filling fractures in the quartz and the associated albite. Gray-white spodumene crystals are in part altered to a clay mineral. This alteration, combined with a splintery cleavage, makes recovery of this mineral poor in drill cores. Sixteen white anhedral amblygonite crystals range in exposed area from 0.00031 to 0.00310 sq ft; the total is 0.03844 sq ft. Amblygonite is intimately associated with a mixture of albite, muscovite, and quartz. Lepidolite forms gray crystals with curved laminae as much as 1 in. across, and brittle irregular, light-green crystals as much as ¾ in. across; both types are common in the albite-rich part of the pegmatite. Light-blue to dark-blue anhedral apatite crystals range from 1/32 to ⅛ in. in diameter. Rare cassiterite is in black diamond-shaped subhedral to euhedral grains ranging from 1/16 to ¼ in. in diameter.

TABLE 26.—*Detailed logs of diamond-drill holes, Tin Mountain pegmatite*—Continued

Hole 3—Continued

Interval (feet)		*Description*
51. 0–183. 2	136. 5–151. 8	Quartz-albite-spodumene pegmatite (third intermediate zone). Contains quartz (50 percent), albite (39 percent), spodumene (5 percent), muscovite (3 percent), apatite (2 percent), amblygonite (0.24 percent), kaolin (<1 percent), lepidolite (<1 percent), beryl (0.56 percent), and cassiterite (trace). Average grain size is ¾ in. White and yellowish-white albite occurs as streaks in clear anhedral quartz. Spodumene has a splintery cleavage and the core recovery of this mineral is poor; only one greenish-gray crystal was noted. This crystal is 1½ ft long and contains about 20 percent of included quartz and albite. Light-colored irregular muscovite books range from ⅛ to 1½ in. in size. Fine specks of dark-blue anhedral apatite is scattered throughout the unit. Between 150 and 151 ft is a fracture filled with an iron-oxide cemented breccia of albite and minor apatite. Bordering the fracture are large apatite crystals. Six white anhedral amblygonite crystals range in exposed area from 0.00008 to 0.00308 sq ft; the total is 0.00703 sq ft. Kaolin occurs in light-green to dark greenish-black soft anhedral grains as much as ¼ in. across. Lepidolite is in dark-gray chunky books with curved laminae as much as ¼ in. wide. One yellowish-white anhedral beryl crystal, 0.00160 sq ft in size, was found. A few small black crystals of cassiterite are present.
	151. 8–182. 4	Albite-muscovite pegmatite (wall zone). Average grain size is ½ in. Rock is white to pinkish and contains numerous vugs from 1/16 to ¾ in. long. Many of these are coated with iron oxide and some of them are lined with small clear euhedral albite crystals. Most of the albite is in white to yellowish or white to pink, anhedral crystals. In places it is platy. Muscovite occurs in light-colored, extremely irregular books from ⅛ to 1 in. in length. Accessory clear anhedral quartz is most abundant in the upper part of this unit where it is associated with a small amount of dark-gray lepidolite in ⅛ in. books. Amblygonite was noted in two small white anhedral grains 0.00009 and 0.00030 sq ft in exposed area; the total is 0.00039 sq ft. A few small, brown-black, euhedral cassiterite crystals occur near the top of the unit. Two 1/16-in. columbite-tantalite crystals were observed at 172 ft. Gray-black metallic loellingite is found veining albite near 181 ft.
	182. 4–183. 2	Muscovite-albite pegmatite (border zone). Average grain size is ¼ in. Muscovite is in numerous interlocking books (1/16 to ½ in.) and white to pinkish-white anhedral albite is interstitial to the muscovite. Quartz occurs in a few small milky anhedral crystals in upper part of the unit. Two yellowish-white anhedral beryl crystals at 182.5 ft are 0.00006 and 0.00009 sq ft in exposed area; the total is 0.00015 sq ft.
183. 2–195. 0		Amphibolite. Contains hornblende (69 percent), andesine (30 percent), magnetite (1 percent) and biotite (<1 percent). Dark-green elongate hornblende crystals give the rock its foliation. White andesine is interstitial to the hornblende and at 189 ft has a N'_α of 1.546. Magnetite occurs in fine grains in the hornblende. The foliation is 42° to the drill core at 185.5 ft, of 89° at 188.4 ft, and 50° 193.1 ft. Between 192.5 and 192.7 ft a prominent quartz-calcite vein cuts the amphibolite. It contains quartz (65 percent), and calcite (35 percent). Its upper contact is irregular, and approximately 12° to the drill core; the lower contact is at 26°.
End of hole.		

Hole 1 was located to cut the pegmatite 86 feet east of the extreme western end, primarily to determine the plunge of the keel of this part of the pegmatite. The hole apparently passed about 16 feet above the keel, allowing its position to be determined within a few feet by projection.

Hole 2 (pls. 17 and 20), 47 feet from the north side of the pegmatite, was drilled to determine accurately the internal structure of the westward-trending limb and to prospect for the quartz-spodumene-lithia mica core. The hole cut only the wall zone (table 26) and passed about 39 feet above the keel (pl. 20). The trend of the keel as determined from holes 1 and 2 is 3° S. 85° E.

Hole 3 (pls. 17 and 20), 156 feet northwest of the northernmost outcrop on the north limb, was drilled to explore the pegmatite downplunge, and to determine the probable size and extension of the quartz-spodumene-lithia mica core. Pegmatite was cut between 51 feet and 183.2 feet (pl. 20 and table 26), and the core of the pegmatite was cut between 72.2 and 136.5 feet. In addition the wall zone and third intermediate zone were also cut. Further drilling is needed to completely outline the shape and continuation of this branch of the pegmatite.

Cores and sludges from pegmatite and in some places country rock immediately adjacent to the pegmatite were analyzed quantitatively by spectrograph for BeO. The results of these individual analyses for each hole are given in table 27. This table summarizes the BeO content, beryl content (assuming all the BeO to be in beryl), and amount of beryl visible on each drill core for each rock type.

654869—62——5

TABLE 27.—BeO *and beryl content, diamond-drill holes 1–3, Tin Mountain pegmatite, Custer County, S. Dak.*

Rock unit	Depth (feet)	Average BeO and beryl content of rock units							Drilling data from						Weighted average percent BeO
		Percent BeO—			Percent beryl—				Core samples			Sludge samples			
		From core	From sludge	From average of assays	From core	From sludge	From average of assays	Observed on core	No.	Length (feet)	Percent BeO	No.	Length (feet)	Percent BeO	
Diamond-drill hole 1 [See rock-unit numbers, fig. 20]															
1. Wall zone (quartz-albite-muscovite pegmatite)	39.0– 41.0	0.081	----------	0.081	0.65	----------	0.65	0.39	C 160	2.0	0.081	--------	----------	----------	0.081
2. First intermediate zone (quartz-albite-perthite pegmatite)	41.0– 49.4	.024	0.051	.045	.19	0.41	.36	0	C 161	5.0	.023	S 149	5.0	.069	.058
									C 162	3.4	.026	S 150	5.0	.024	.025
3. Wall zone (albite-quartz-muscovite pegmatite)	49.4– 63.6	.048	.059	.055	.39	.48	.45	.08	C 163	1.6	.021				.023
									C 164	5.0	.0067	S 151	5.0	.032	.021
									C 165	5.0	.054	S 152	5.0	.091	.080
									C 166	2.6	.13				.093
4. Border zone (muscovite-albite pegmatite)	63.6– 64.0	.043	.071	.061	.35	.58	.50	0	C 167	.4	.043	S 153	5.0	.071	.061
5. Quartz-mica schist	64.0– 64.8	.003	.071	.046	.024	.58	.37	0	C 168	.8	.0031				.046
6. Border zone (albite-muscovite pegmatite)	64.8– 65.4	.005	.071	.047	.041	.58	.38	0	C 169	.6	.0048				.047
7. Quartz-mica schist	65.4– 74.0	.003	.019	.013	.024	.15	.11	0	C 170	.6	.0027				.046
									C 171	8.0	.0027	S 154	8.0	.015	.011
Diamond-drill hole 2 [See rock-unit numbers, pl. 20]															
1. Quartz-mica schist	53.0– 54.5	0.002	----------	0.002	0.016	----------	0.016	0	C 172	1.5	0.0022				0.002
2. Border zone (quartz-muscovite pegmatite)	54.5– 54.6	.049	----------	.049	.40	----------	.40	0	C 173	.1	.049	--------	3.0	----------	.049
3. Wall zone (albite-quartz-muscovite pegmatite)	54.6– 96.7	.042	0.049	.047	.34	0.40	.38	.05	C 174	1.4	.11				.11
									C 175	3.0	.039	S 155	3.0	0.062	.053
									C 176	2.5	.076	S 156	2.5	.036	.048
									C 177	3.5	.0026	S 157	3.5	.0047	.004
									C 178	5.0	.010	S 158	5.0	.068	.042
									C 179	5.0	.0028	S 159	5.0	.0038	.004
									C 180	3.0	.0035	S 160	3.0	.014	.010
									C 181	2.0	.0031	S 161	4.0	.024	.019
									C 182	2.0	.0027				.019
									C 183	5.0	.13	S 162	5.0	.14	.136
									C 184	2.8	.12	S 163	5.0	.060	.083
									C 185	2.2	.068				.063
									C 186	4.7	.013	S 164	5.0	.041	.033
4. Border zone (quartz-muscovite pegmatite)	96.7– 97.0	.064	.041	.047	.52	.33	.38	0	C 187	.3	.064				.047
5. Quartz-mica schist	97.0–102.0	.001	.007	.005	.008	.057	.041	0	C 188	5.0	.0009	S 165	5.0	.0073	.005

Diamond-drill hole 3

[See rock-unit numbers, pl. 20]

									C 189	5.0	0.068	S 166	5.0	0.080	0.075
									C 190	5.0	.038	S 167	5.0	.33	.288
									--------	1.0	----------	--------	1.0	----------	----------
1. Wall zone (quartz-albite-muscovite pegmatite)	51.0– 72.2	0.028	0.118	0.103	0.23	0.95	0.83	0.04	C 191	1.0	.0047	S 168	5.0	.038	.028
									C 192	4.0	.0032				.025
									C 193	3.0	.0031	S 169	4.0	.028	.025
									C 194	1.0	.0023				.022
									C 195	1.2	.003	S 170	5.0	.035	.008
									C 196	3.8	.0011				.008
									C 197	5.0	.024	S 171	5.0	.020	.020
									C 198	4.0	.0014	S 172	4.0	.041	.040
									C 199	5.0	.0016	--------	5.0	----------	.002
									C 200	5.0	.0010	S 173	5.0	.0063	.006
									C 201	4.0	.000	S 174	4.0	.0067	.006
									C 202	1.0	.000	--------	6.0	----------	.000
									C 203	5.0	.000				.000
2. Core (quartz-spodumene-albite pegmatite)	72.2–136.5	.003	.015	.012	.025	.12	.10	0	C 204	5.0	.0019	S 175	5.0	.0026	.003
									C 205	4.0	.000	S 176	4.0	.0029	.002
									C 206	5.0	.000	S 177	5.0	.0016	.001
									C 207	1.5	.000	S 178	1.5	.0013	.001
									C 208	4.5	.0044	S 179	4.5	.0039	.004
									C 209	5.0	.0011	S 180	5.0	.033	.027
									C 210	1.5	.004	S 181	1.5	.022	.021
									--------	2.5	----------	S 182	2.5	.048	.048
									C 211	2.5	.0015	S 183	5.0	.021	.019
									C 212	2.5	.034				.023
3. Third intermediate zone (quartz-albite-spodumene pegmatite).	136.5–151.8	.0311	.021	.023	.25	.17	.20	.06	C 213	5.0	.022	S 184	5.0	.019	.020
									C 214	5.0	.024	S 185	5.0	.006	.010
									C 215	2.8	.056	S 186	3.0	.051	.053
									C 216	.2	.22				.122
									C 217	5.0	.097	S 187	5.0	.056	.063
									C 218	5.0	.056	S 188	5.0	.082	.075
4. Wall zone (albite-muscovite pegmatite)	151.8–182.4	.232	.225	.227	1.87	1.81	1.83	0	C 219	6.0	.17	S 189	6.0	.38	.304
									C 220	5.0	.37	S 190	5.0	.25	.293
									C 221	5.0	.41	S 191	5.0	.27	.318
									C 222	4.4	.31	S 192	5.0	.30	.304
5. Border zone (muscovite-albite pegmatite)	182.4–183.2	.280	.229	.248	2.26	1.84	2.00	.06	C 223	.6	.24				.279
									C 224	.2	.40	S 193	5.0	.017	.155
6. Amphibolite	183.2–188.0	.005	.017	.013	.040	.14	.11	0	C 225	4.8	.005				.013

MINERAL DEPOSITS

Beryl, spodumene, amblygonite, feldspar, and pollucite have been produced from the Tin Mountain pegmatite. Fairly large resources of all these minerals except pollucite were known in the pegmatite in 1950. Smaller quantities of muscovite, columbite-tantalite, microlite, and cassiterite also are present.

BERYL

Beryl has been found in all zones of the Tin Mountain pegmatite. In the border zone, the outer part of the wall zone, and the first intermediate zone, it cannot be recovered except by milling. In the inner 1 foot of the wall zone, in the second and third intermediate zones, and in the core, much of the beryl can be obtained by hand-sorting. The waste rock from hand-sorting operations would also be an additional source of feed to a mill.

Within each zone, beryl has an irregular distribution. In the second intermediate zone, for example, the beryl is found chiefly in the quartz-rich parts interstitial to the very large perthite crystals and masses. Such quartz-rich areas may contain many times the average beryl content of the entire zone (table 28). Likewise, most of the beryl in the core is in the outer 10 feet of this unit (table 28).

The beryl crystals of the border zone are white to greenish white, and as much as one-quarter of an inch in diameter. They are associated with quartz, muscovite, albite, apatite, and cassiterite.

The beryl of the wall zone is in white anhedral to euhedral crystals that closely resemble the associated albite in color and shape. Individual beryl crystals measured on surface exposures ranged from 0.00002 to 0.24 square feet in area; those adjacent to the core were larger, and as much as 1.0 square feet in area. The maximum index of refraction (N_ω) of 24 crystals was measured and found to range from 1.581 (13.0 percent BeO) to 1.592; (11.6 percent BeO) the average is 1.586 (12.4 percent BeO). (See table 29.)

TABLE 28.—*Summary of grade data on beryl, Tin Mountain pegmatite*

Unit	Percent beryl by grain measurement	Average refractive index (N_ω)	BeO determined—		Calculated beryl content (percent)
			From index of refraction	By spectrographic analysis of rock (percent)	
Border zone	0. 022	N.D.[1]		0. 112	[2] 0. 90
Wall zone	. 61	1. 586	12. 4	. 124	1. 00
First intermediate zone	. 37	[3] 1. 587	12. 3	. 045	. 37
Second intermediate zone	. 40	[3] 1. 586	12. 4	N.D.	
Third intermediate zone	1. 15	[3] 1, 587	12. 3	. 023	. 19
Core:					
Quartz-spodumene-lithia mica pegmatite	. 76			. 012	. 10
Quartz-lithia mica pegmatite	. 014	1. 589	12. 0		
Weighted average	0. 47			0. 012	0. 10

[1] N.D. stands for "not determined."
[2] Assumes BeO content of the beryl in the border zone is the same as that of the wall zone.
[3] Only one determination.

TABLE 29.—*Maximum index of refraction (N_ω) of beryl in the various zones, Tin Mountain pegmatite*

Pegmatite unit	Number of determinations	Average N_ω	Range of N_ω
Wall zone	24	1. 586	1. 581–1. 592
First intermediate zone	1	1. 587	1. 587
Second intermediate zone	1	1. 586	1. 586
Third intermediate zone	1	1. 587	1. 587
Core	6	1. 589	1. 587–1. 593

The beryl of the first intermediate zone is in white anhedral to euhedral crystals associated with masses of finer grained quartz, albite, and muscovite interstitial to the large perthite crystals. The beryl grains are difficult to distinguish from feldspar grains. A crystal of beryl from this zone has a N_ω of 1.587, indicating a BeO content of 12.3 percent.

Beryl of the second intermediate zone is in white semivitreous subhedral to euhedral crystals and is most abundant in quartz interstitial to perthite. The beryl crystals range in area from 0.01 to 2.2 square feet. Only one specimen of beryl from this zone was examined optically; it had N_ω of 1.586, corresponding to 12.4 percent BeO.

Beryl of the third intermediate zone is chiefly in white euhedral crystals and is most commonly associated with spodumene and muscovite. The beryl crystals in this zone ranged from 0.01 to 1.0 square feet in area. One beryl crystal had a N_ω of 1.587 (12.3 percent BeO).

Most of the beryl in the core is in the outer 10 feet of the unit where it forms large crystals. These crystals occur chiefly as anhedral masses interstitial to spodumene logs. They are white to vitreous and commonly have a faint iron stain along fractures and contacts, which makes them distinguishable from the feldspar and amblygonite of the unit. The 22 crystals measured on the two levels ranged in area from 0.005 to 24 square feet; one mass weighing 5 tons is reported to have been mined. (Charles Evans, 1948, oral communication). The N_ω of 6 beryl specimens ranged from 1.587 (12.3 percent BeO) to 1.593 (11.4 percent BeO); the average was 1.589 (12.0 percent BeO) (table 29).

The grade data pertinent to the beryl deposits are summarized in table 28.

SPODUMENE

Spodumene has been found in all zones of the Tin Mountain pegmatite except the border zone, but the main deposit includes only the third intermediate zone and the core.

The main deposit does not crop out but is exposed on the main level as a body at least 160 feet long and 85 feet wide. It has been mined out above the main level except for a small area between the stopes. The workings on the lower level are not sufficiently extensive to outline more than a part of the spodumene-bearing pegmatite, but the deposit on this level is at least 100 feet long by 60 feet wide. The deposit is known to extend 60 feet downplunge (10°–20° N. 25° W.) from these workings to drill hole 3.

The average grade of spodumene in this deposit is between 20 and 30 percent; the average grade of the core is 23 percent and the average grade of the third intermediate zone is 26 percent. The fracture-filling unit, although small, is estimated to contain 37 percent spodumene.

Most of the fresh spodumene is white to gray; some is pale green. Some of the spodumene has been altered to a dull white to gray soft friable claylike material. The spodumene is in euhedral to subhedral or rounded crystals that range in size from 0.1 foot in diameter and 0.3 foot long to 2.0 feet in diameter and 16 feet long. Schwartz (1930, p. 280) reported seeing a crystal more than 30 feet long during his visit in 1927. The larger crystals occur near the center of the core and form an intersecting crisscross pattern. The spodumene in the third intermediate zone rarely exceeds 1.0 foot in diameter and 5 feet in length.

Miss Jewell Glass studied the fresh parts of three specimens of spodumene and found them to have the following optical properties:

Color	Colorless	$N\alpha$	1.658–1.660
Optic sign	+	$N\beta$	1.664–1.666
$2V$	59°–63°	$N\gamma$	1.675–1.676

These specimens showed incipient alteration; the most altered parts showed the greatest range of indices of refraction. Five specimens collected from the core on the main level were analyzed for Li_2O, K_2O, and Na_2O (table 30).

Alteration decreases the Li_2O content of the spodumene; in places and in parts of some crystals the Li_2O content is too low for the spodumene to be marketable. The percentage of altered to total spodumene, as determined from mineral measurements, ranges from 16 to 75 percent. The most common alteration product is a white chalklike material with variable optical properties that resembles some of the clay minerals. Similar material from altered spodumene at the Helen Beryl pegmatite was identified as halloysite-kaolinite. A second alteration product of spodumene looks and feels like talc, but has optical properties similar to those of sericite. Alteration is commonest on the outside and ends of crystals, and consequently, this powdery material can be removed during mining.

TABLE 30.—*Alkali content of fresh and altered spodumene from core of Tin Mountain pegmatite*

[Analysts, W. W. Brannock and E. A. Nygaard]

Specimen	Description	Alkali content (percent)		
		Li_2O	K_2O	Na_2O
MHS-33-48	Altered spodumene from exterior of same crystal as MHS-32-48.	0.15	1.16	0.14
MHS-31-48	Altered spodumene from same crystal as MHS-31a-48.	.29	1.61	.18
MHS-32-48	Fresh spodumene from central part of crystal.	7.22	.16	.38
MHS-30-48	Fresh spodumene from 16-ft crystal	7.31	.13	.36
MHS-31a-48	Fresh spodumene from crystal in core near contact with wall zone.	7.57	.09	.43

AMBLYGONITE

Amblygonite was observed in the wall zone, second intermediate zone, third intermediate zone, and core; the main deposit, however, is in the third intermediate zone and the outer 20 feet of the core.

The grade of the amblygonite, as determined from grain measurements, is 1.00 percent in the third intermediate zone, 0.36 percent in the core, and 0.14 percent in the wall zone.

The amblygonite occurs in white anhedral crystals ranging in size from 0.0025 to 4.8 square feet in exposed area. In places amblygonite forms a graphic intergrowth with albite. The amblygonite probably varies in composition, even in the same crystal. Optical data on two specimens determined by Miss Jewell Glass show it has a $2V$ near 90°; some grains are optically positive and others negative; $N\alpha$ is near 1.595 and $N\gamma$ ranges from 1.618 to 1.635. The mineral is thus at the montebrasite end of the amblygonite-montebrasite series (Winchell, 1947, p. 152).

Two specimens of amblygonite from the core were analyzed by W. W. Brannock and E. A. Nygaard and were found to contain 8.81 and 9.37 percent Li_2O.

FELDSPAR

Perthite is mainly in the first and second intermediate zones; small quantities are also found in the wall zone of the Tin Mountain pegmatite. The two perthite-bearing intermediate zones form hood-shaped bodies that extend throughout most of the exposed length of the north and west limbs of the pegmatite. They have a combined length at the surface of 370 feet, a maximum thickness of 70 feet, and a maximum extension downplunge of 240 feet. They comprise most of the interior of the west limb (see pls. 19 and 20). About two-thirds of the perthite is in the first intermediate zone and about one-third in the second intermediate zone.

Perthite occurs in blocky pink to cream-colored subhedral to euhedral crystals as much as 15 feet in diameter. It is slightly iron stained at the surface. In the second intermediate zone the perthite contains few admixed minerals, but in the first intermediate zone the edges of the crystals are intergrown in a few places with quartz, muscovite, and albite. Tourmaline or other dark minerals rarely occur in the perthite.

POLLUCITE

One carload of pollucite was shipped from the Tin Mountain pegmatite, but this mineral was not observed in any of the exposures studied in 1948. The pollucite mined is reported to have occurred in the core on the north wall of the main level at its junction with the large stope. According to Charles Evans (1948, oral communication) the mineral was in two large masses, but Francis McKenna (1948, oral communication) states that one large mass contained most of the ore. The pollucite when first exposed was reported to be glassy, hard, and very difficult to drill. After it had been exposed awhile, however, it hydrated and was easily mined with a pick. Material saved by McKenna was isotropic and had an index of refraction of 1.515.

Connolly and O'Harra (1929, p. 261) report the following analysis of pollucite made at the Mining Experiment Station of the South Dakota School of Mines:

Constituent	*Percent*	*Constituent*	*Percent*
SiO_2	47.88	Na_2O	3.58
Fe_2O_3	.14	Li_2O	.12
Al_2O_3	17.96	Moisture at 110°C	.37
CaO	1.04	Ignition loss	3.45
MgO	.38		
Cs_2O	23.46	Total	99.44
K_2O	1.06		

MUSCOVITE

Muscovite is abundant only as scrap mica in the border zone, the wall zone, and the first intermediate zone, where it was estimated to make up 12 percent of the total rock. Probably it can be recovered only by milling.

NIOBIUM AND TANTALUM MINERALS

Both columbite-tantalite and microlite have been found at the Tin Mountain pegmatite. Columbite-tantalite was observed in the wall zone, the second intermediate zone, and the core. In the first two zones the grains are scarce, platy, and small. They have an average thickness of about one thirty-second of an inch. In the core the columbite-tantalite is more abundant and grains as much as 0.04 square foot in exposed area were found. On the lower level this unit was visually estimated to contain 4 pounds of columbite-tantalite per ton of rock.

Microlite was found only in the core of the pegmatite on the main level, where it is in anhedral to euhedral grains as much as 1 inch in diameter. The microlite grains are generally in narrow bands of pale-purple lepidolite, greenish lithia mica, and albite that separate large spodumene crystals from black to smoky quartz. The small unmined part of the core on the south side of the main adit contains the only known microlite, but additional microlite-rich areas probably will be found in mining the core. The columbite-tantalite and microlite can be recovered only as a byproduct of milling operations.

CASSITERITE

Cassiterite was observed in the border zone, the wall zone, the first intermediate zone, and the core. It occurs in dark-brown to black anhedral to euhedral crystals with a diameter of from less than one-thirty second to one-quarter of an inch. The distribution of the cassiterite is quite erratic, although it appears to be commonest on the underside of the pegmatite. At no place is it as abundant as one percent of the rock; at most places only a trace is present.

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