Geology and Mineral Deposits of Some Pegmatites in the Southern Black Hills South Dakota

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By JAMES J. NORTON *and others*

PEGMATITES AND OTHER PRECAMBRIAN ROCKS IN THE SOUTHERN BLACK HILLS

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This report is based on work done jointly with Lincoln R. Page, John B. Hanley, Douglas M. Sheridan, David B. Stewart, Roy E. Roadifer, John W. Adams, and others

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By JAMES J. NORTON and others

ABSTRACT

This report is primarily a description of the geology of 17 zoned pegmatites in the southern Black Hills that have not previously been adequately described in published reports. In many ways this is an extension of work by Page and others reported in Geological Survey Professional Paper 247, published in 1953.

All these pegmatites have wall zones rich in plagioclase and quartz, generally accompanied by abundant muscovite. Two also have perthite as an essential mineral of the wall zone. Perthite is most abundant, however, in intermediate zones, where it is accompanied by quartz or by quartz and albite. Spodumene-bearing intermediate zones, which also carry quartz and feldspar, are important in the Etta pegmatite, but spodumene is sparse or absent in the other pegmatites described in this report. All but six of the pegmatites have quartz cores.

Potash feldspar (perthitic microcline) has been mined in large quantity from perthite-rich intermediate zones in the Big Chief, Dan Patch, and Hot Shot pegmatites and from a perthite-quartz zone that forms the apparent core of the White Cap pegmatite. A perthite-quartz-albite intermediate zone in the Pine Top pegmatite is a potentially important source of potash feldspar.

Beryl is concentrated in several different parts of these pegmatites—in so many parts, in fact, that all the known important kinds of beryl concentrations are represented in this small group of pegmatites. Wall zones carrying albite, quartz, and commonly muscovite are rich in beryl at the Barker-Ferguson, Sitting Bull, and Dan Patch West pegmatites. Aggregates of iron-manganese phosphates carry beryl in the wall zone of the White Cap and along the inner border of perthite-quartz-albite intermediate zones at the Hot Shot and Dan Patch pegmatites. Other important concentrations of beryl are in a perthite-quartz-spodumene intermediate zone in the Etta pegmatite and at the border of the quartz core in the Big Chief pegmatite.

Many of the deposits described in this report were diamond drilled, chiefly by the U.S. Bureau of Mines, and the geologic work accompanying the drilling illustrates the use of geologic techniques in the exploration of zoned pegmatites. The techniques, simply described, consist of making detailed geologic maps, constructing geologic sections or other diagrams to make a three-dimensional interpretation of the geology, and then drilling the pegmatite and modifying the previous interpretations as necessary. The most clear-cut example of these techniques is at the Barker-Ferguson mine, where the only two pegmatite outcrops were on either side of a hill. Geologic mapping and subsequent drilling showed that the two outcrops belong to a single pegmatite that extends through the hill and has its top a few feet below the crest of the hill. At the Monte Carlo prospect, geologic mapping indicated that only the outer part of the pegmatite is exposed at the surface and that concealed inner zones might be found by drilling; such a zone was found, though it proved to be very small. At the Buster Dike mica mine, an inference based on the geologic maps suggested that mica-rich pegmatite could be found south of the old mine workings. Though contrary to reports that the mine workings had reached the south end of the pegmatite, the inference was confirmed by subsequent drilling. Drilling elsewhere had more modest objectives, but it was equally successful in supporting geologic mapping as a means of evaluating zoned pegmatites.

INTRODUCTION

The purpose of this report is to present a detailed account of the geology of some pegmatites in the southern Black Hills, Custer and Pennington Counties, South Dakota, that hitherto have not been described in the geologic literature or have been described incompletely. In a sense, this report is a sequel to the study of Black Hills pegmatites reported by Page and others (1953) in U.S. Geol. Survey Prof. Paper 247. That publication contains an extended treatment of the geology of many Black Hills pegmatites, and describes their economic utilization at some length. The reader should refer to it if he needs a fuller background than is supplied in the abbreviated text of the present report.

The pegmatites of the southern Black Hills are distributed over an area of about 340 square miles surrounding Harney Peak (fig. 107). All the pegmatites described in this report are near Keystone (fig. 108A) or near Custer (fig. 108B).

The pegmatite area lies about 25 miles southwest of Rapid City, which is the economic center of western South Dakota. The principal towns are on the flanks of the mountainous area around Harney Peak, where

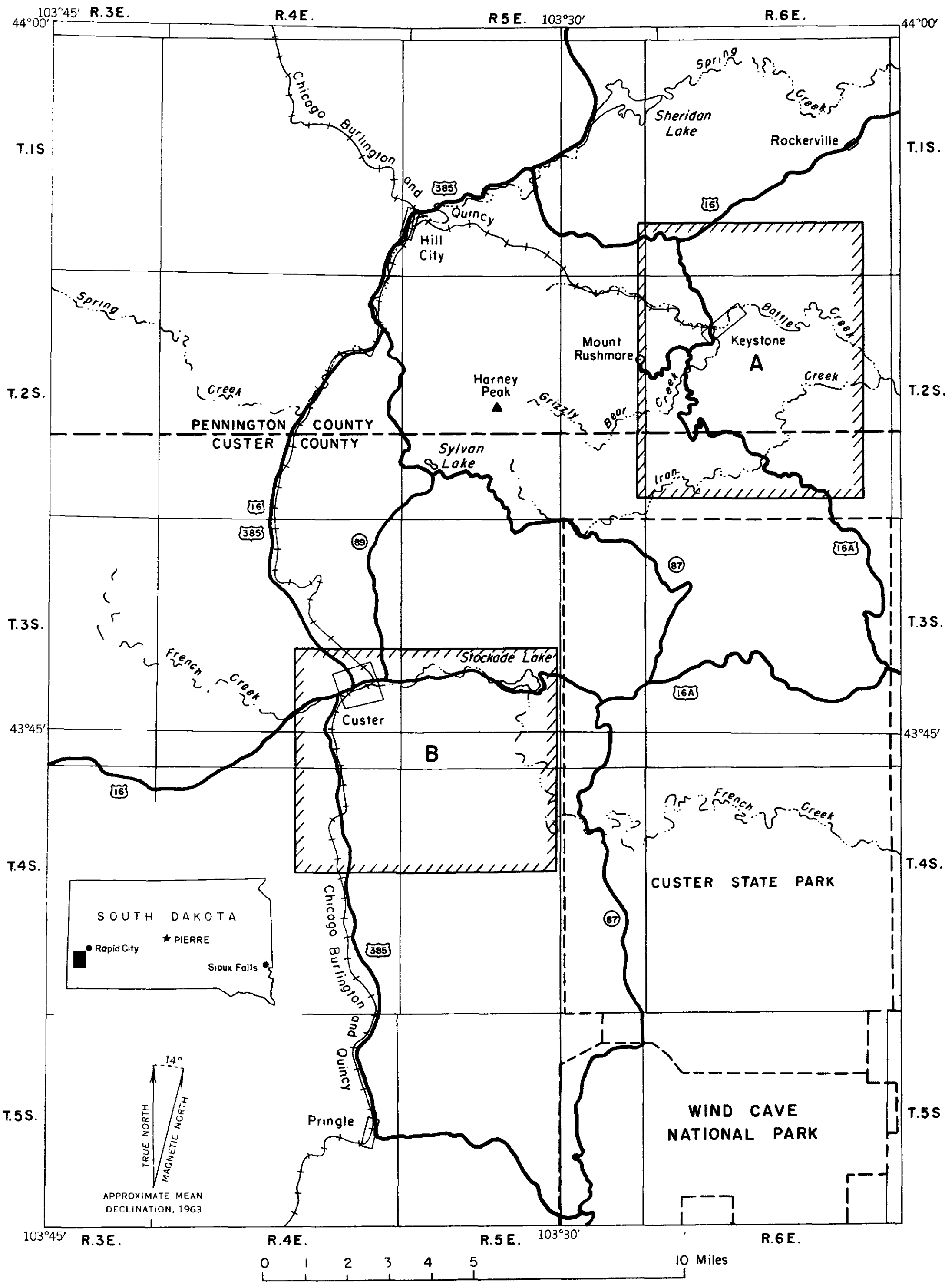

FIGURE 107.—Index map, southern Black Hills, Pennington and Custer Counties, S. Dak. Insets A and B are shown in figure 108.

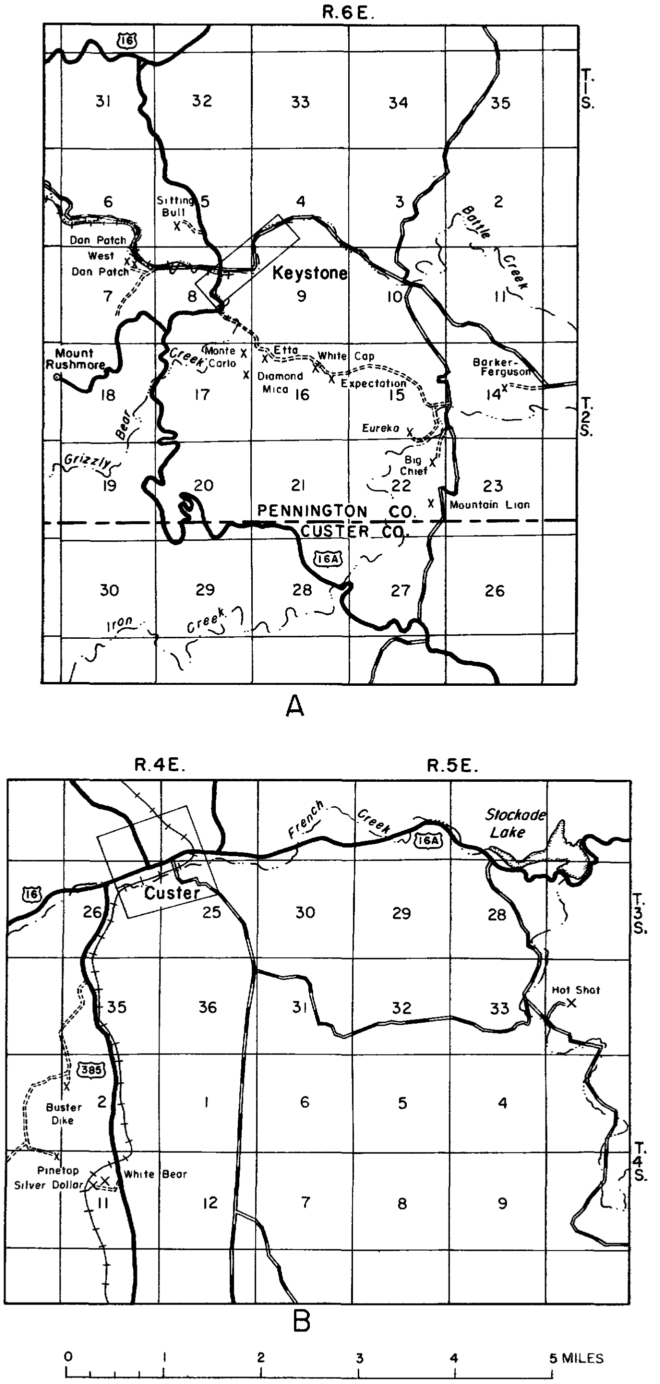

FIGURE 108.—Insets A and B of figure 107. Inset A shows pegmatites near Keystone and inset B shows pegmatites near Custer that are described in this report.

the dominant rock is a pegmatitic granite, called the Harney Peak Granite. Custer lies to the southwest, Hill City to the northwest, and Keystone to the northeast of this mountainous area. A branch line of the Chicago, Burlington & Quincy Railroad serves all three towns. The main roads in the region are U.S. Highways 16 and 385, but there are so many graveled highways, unimproved dirt roads, and fire trails that nearly every point in the region, except in the most rugged areas, is easily accessible. The greater part of the pegmatite-bearing area is in Custer County, which has Custer as its county seat. The Keystone district, which is of small size but has a record of large production, is in Pennington County. The several thousand persons who live in the southern Black Hills are supported mainly by the lumbering, mining, and tourist industries. The major tourist attraction is the Mount Rushmore National Memorial, 2 miles west-southwest of Keystone.

The entire area has a maturely dissected topography dominated by forested slopes. Ponderosa pine is far more abundant than any other tree. Spruce and scrub oak grow in a few parts of the area, and aspen and birch are common along valley floors.

The area is drained only by small streams that either go outward from the vicinity of Harney Peak or flow around it. The largest is French Creek, which passes through Custer and goes east and southeast. Spring Creek, passing through Hill City, flows generally to the northeast. Battle Creek and its main tributary, Iron Creek, flow eastward through the Keystone district. All these streams ultimately enter the Cheyenne River, which flows northeast to its junction with the Missouri.

HISTORY

The earliest recorded entry of white men into the central part of the Black Hills was an expedition led by General George A. Custer in 1874. Placer gold was discovered near the site of the present city of Custer by Horatio N. Ross, one of the members of the Custer expedition, and a rush to the Black Hills began shortly thereafter. The first pegmatite mining was in 1879 for sheet mica at the McMackin (now Crown) mine, 3 miles northwest of Custer.

The history of mining during succeeding years in the southern Black Hills has been described in many publications. Connolly and O'Harra (1929) wrote the principal general reference. Sterrett (1923, p. 289–302) described the early mica mining, especially for the years 1906–11. Page and others (1953, particularly p. 4–6) summarized the history of all pegmatite mining in the Black Hills through 1945.

As a consequence of the stimulus to pegmatite mining caused by industrial needs during World War II, the Black Hills was an important source of mica, feldspar, beryl, and lithium minerals. The height of this mining activity was in 1943 and 1944, and a decline was apparent in 1945, chiefly as a result of the drop in demand for sheet mica. The course taken by pegmatite mining from 1945 to 1958 in the Black Hills is shown by the production figures in table 1. Production prior to 1945 is given in Page and others (1953, table 1).

Throughout these postwar years, potash feldspar was the backbone of the industry. Annual production was ordinarily between 40,000 and 60,000 tons, and average value was $5.50 per ton. The most productive years were just after the war: 68,374 tons were mined in 1945 and 74,540 tons in 1946. The lowest production was 23,229 tons in 1958, but this was a temporary effect caused by the lack of grinding facilities that resulted from the destruction by fire of the mill at Keystone in 1957 and the mill at Custer in 1958. The Custer mill was rebuilt and resumed production within a few months. The Consolidated Feldspar Corp. does all the feldspar milling and most of the mining. In 1952 this company was purchased by the International Minerals & Chemical Corp., and became a department in that organization.

Mica mining decreased greatly after 1945, when the Federal Government's wartime program of buying sheet mica came to an end. Custer Mining Account, which had been one of the principal mica-mining companies in 1944 and 1945, continued mining and also engaged in mica processing and fabrication. This company ceased operating at the end of 1947, and no mica except scrap was produced in the Black Hills during the following year. Though scrap mica was mined at the rate of 1,000 to 2,000 tons per year, as in nearly all the years between 1945 and 1958, sheet mica did not again become an important product until a new Government mica-buying program began in 1952. Under the stimulus of this program, several thousand pounds of sheet mica were produced annually in the succeeding years.

Spodumene was mined in every year from 1945 to 1958, but like mica, it had its ups and downs. The main producers were the Maywood Chemical Co., which operated the Etta mine during all these years, and the Lithium Corp. of America, which obtained spodumene concentrates from a sink-float plant at the Edison mine near Keystone, chiefly in the late 1940's, and from a flotation plant at the Mateen mine in Hill City, mainly in the early 1950's. When the Hill City plant was closed in 1955, the Lithium Corp. of America ceased mining in the Black Hills.

The greatest spodumene production during World War II was 4,303 tons in 1943 (Page and others, 1953, table 1), which also was the greatest production in the Black Hills in any one year since the beginning of mining for lithium minerals. Production dropped to only 749 tons in 1945, but from there it climbed more or less steadily until the gross value of the industry's output reached $392,764 in 1952, when 7,421 tons of spodumene were produced. Though production figures for the following years are not available, it may be presumed that there was a great decrease after 1955, when the operation by the Lithium Corp. of America came to an end.

The Black Hills has been the most consistent, and in many years the largest, source of beryl in the United States. The greatest production during World War II was 306 tons in 1944 (Page and others, 1953, table 1),

TABLE 1.—*Production of pegmatite minerals, Black Hills, S. Dak., 1945–58*

[From U.S. Bureau of Mines yearbooks unless otherwise indicated]

Year	Potash feldspar		Beryl		Sheet mica		Punch mica		Scrap mica		Spodumene [1]		Columbite-tantalite	
	Long tons	Value	Tons	Value	Pounds	Value	Pounds	Value	Tons	Value	Tons	Value	Pounds	Value
1945	68,374	$314,787	38	[2] 6,000	24,064	$168,969	32,506	$9,727	1,192	$21,534	749	$28,32[illegible]	[3] 85	[3] $21
1946	74,540	299,852	95	[2] 17,000	3,516	6,284	13,884	2,148	2,806	63,692	1,190	35,655	1,703	3,246
1947	58,959	284,378	70	[2] 12,000	26,000	6,240	162,380	22,464	1,499	37,225	1,718	51,24[illegible]	[3] 0	[3] 0
1948	54,037	270,889	45	[2] 12,000	0	0	0	0	988	28,515	2,729	81,87[illegible]	500	([4])
1949	32,272	156,548	139	[2] 45,000	1,161	2,542	7,206	846	1,125	31,285	6,349	141,67[illegible]	0	0
1950	43,875	249,176	96	[2] 29,000	458	309	12,560	1,375	1,902	24,989	5,821	142,94[illegible]	[3] 837	[3] 1,256
1951	48,559	290,520	138	46,007	0	0	0	0	2,292	42,714	8,568	274,70[illegible]	[3] 1,630	[3] 3,670
1952	40,163	220,954	334	166,251	4,308	32,034	0	0	915	24,148	7,421	392,764	[3] 150	[3] 465
1953	50,601	321,026	392	157,656	11,174	77,352	0	0	1,687	27,388	([4])	([4])	4,431	9,022
1954	[3] 44,498	[3] 281,810	337	139,663	16,299	65,222	0	0	1,510	26,943	([4])	([4])	25,447	43,260
1955	42,164	267,286	294	157,056	4,854	21,383	0	0	1,322	26,853	([4])	([4])	5,638	9,584
1956	45,226	288,843	195	94,830	12,494	67,053	0	0	1,268	31,224	([4])	([4])	237	403
1957	41,316	266,780	268	[5] 145,000	9,093	45,507	0	0	1,626	43,142	([4])	([4])	2,311	[5] 6,000
1958	23,229	[5] 145,000	240	[5] 129,000	16,772	67,882	0	0	1,003	24,241	([4])	([4])	4,294	[5] 10,000
Totals	667,813	[5] 3,658,000	2,681	[5] 1,156,000	130,193	560,777	228,536	36,560	21,135	453,893	[6] 34,545	[6] 1,149,174	47,263	[5,6] 87,000

[1] From South Dakota Inspector of Mines Annual Reports. Includes a small quantity (probably less than 200 tons) of amblygonite and lepidolite.
[2] Estimated.
[3] From South Dakota Inspector of Mines Annual Report.
[4] Not available.
[5] Rounded to nearest thousand.
[6] Total of available years.

and this was also the greatest production ever attained in the Black Hills up to that time. Production dropped to 38 tons in 1945, and it averaged slightly less than 100 tons annually from 1946 through 1951. The stimulus of a beryl-purchasing program by the Federal Government caused renewed activity beginning in 1952; from 1952 to 1958 the annual output ranged from 195 to 392 tons.

The total value of minerals produced through 1958 from Black Hills pegmatites amounted to about $13 million. Though this production is large in relation to many other pegmatite districts, it is small in comparison with the production of important metal-mining districts. The mines themselves are also small and are operated by relatively simple techniques. Open-pit methods predominate, and such underground mines as do exist are rarely more than 200 feet deep. Few mines employ more than 10 men. Hand cobbing is the chief concentrating method; the main exception has been the milling techniques used by the Lithium Corp. of America to concentrate spodumene.

GEOLOGIC INVESTIGATIONS

The earliest geologic investigations of the Precambrian core of the Black Hills was in 1875 by Newton and Jenney (1880). Among the many later reports describing the general geology of the southern Black Hills, the most useful are those by Darton and Paige (1925), Connolly and O'Harra (1929), and Runner (1943).

The pegmatites have been the object of many studies. In papers published during the early years, the emphasis was on descriptive mineralogy and on the mining activities, as in Blake (1885a, b), Headden (1890; 1906), Hess (1911), O'Harra (1902), Schaller (1916; 1919), Sterrett (1923, p. 289–302), and Ziegler (1914). The first fairly complete geologic investigations of the pegmatites came in the 1920's. Hess (1925) and Landes (1928) used examples from the southern Black Hills in expounding their views that pegmatites formed largely by replacement processes. Schwartz (1925) published a description of the Etta pegmatite accompanied by a map that, even though it lacks the detail shown in more recent maps of pegmatites, has successfully withstood the test of time.

A program of detailed study of the structural and economic geology of pegmatites in the southern Black Hills were carried out in 1942–45, and the results were published by Page and others (1953). Additional detailed studies, some with more emphasis or petrology, were done between 1945 and 1954. The results of many of these studies have been published by Sheridan (1955), Sheridan and others (1957), Lang (1955), Redden (1959), Orville (1960), Norton and others (1962), and Staatz and others (1963); the remainder are in the present report. At the same time, comprehensive regional studies of pegmatite areas near Custer, Hill City, and Keystone have been underway; the first of these was published by Redden (1963).

Most of the fieldwork at the 17 pegmatites described in this report was done between 1945 and 1954. Only four of these pegmatites—the Buster Dike, Hot Shot, Silver Dollar, and White Bear—had previously been mapped and described in detail by Page and others (1953). The four were all favorable places to explore for sheet mica, and the new geologic work was in conjunction with a U.S. Bureau of Mines diamond-drilling project in 1947 that was designed for this purpose (Needham, 1950). Five other pegmatites—the Barker-Ferguson, Big Chief, Eureka, Expectation, and Mountain Lion—were drilled in 1953 and 1954, during a U.S. Bureau of Mines project that was mainly for beryl. Of these five deposits, only the Mountain Lion (or Soda Spar) had previously been described in the geologic literature, and then but briefly by Page and others (1953, p. 192–3). Another pegmatite—the Monte Carlo—was drilled in 1950 by the U.S. Geological Survey in an effort to demonstrate that it contains unexposed inner zones.

The Etta, Dan Patch, and White Cap pegmatites were described only briefly by Page and others (1953); inasmuch as these pegmatites are all important mines, they were later studied in detail, and the results are reported here. The Pine Top and Sitting Bull prospects, described briefly by Page and others (1953), have also been studied in more detail. The Diamond Mica and Dan Patch West deposits are small pegmatites, of moderate promise as mining properties, that are described here for the first time.

ACKNOWLEDGMENTS

Many geologists participated in the fieldwork at these mines and prospects. This report is based largely on manuscript reports and notes supplied by L. R. Page, J. B. Hanley, D. M. Sheridan, D. B. Stewart, R. E. Roadifer, and J. W. Adams; however the text was written entirely by J. J. Norton, and he assumes responsibility for its content.

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Party chiefs and associates in the study of the individual pegmatites are listed below:

Party chief(s)	*Associate(s)*	*Pegmatite*
J. W. Adams	H. G. Stephens	Dan Patch West.
J. B. Hanley		White Cap.
	C. H. Chao	Sitting Bull.
	L. R. Page	Dan Patch.
J. J. Norton		Silver Dollar.
	R. E. Burns	Diamond Mica.
	J. E. Roadifer, J. A. Redden.	Barker-Ferguson, Big Chief.
L. R. Page	C. H. Chao	Mountain Lion (Soda Spar).
	J. B. Hanley, J. J. Norton.	Etta.
	J. J. Norton	Buster Dike, Pine Top, White Bear.
L. R. Page, H. G. Stephens.	D. B. Stewart, J. J. Norton.	Hot Shot.
J. A. Redden	J. E. Roadifer	Expectation.
R. E. Roadifer	do	Eureka.
D. M. Sheridan	R. E. Roadifer, J. J. Norton, Carl Ulvog, W. A. Anderson.	Monte Carlo.

This work has been greatly aided by the mine operators and the U.S. Bureau of Mines. The Consolidated Feldspar Department of the International Minerals & Chemical Corp., owner or leaser of several of the deposits described here, has been helpful in many ways. The Maywood Chemical Co., owner of the Etta mine, and Dewey Peterson, foreman at this mine, have been similarly helpful. We owe special thanks to the Bureau of Mines engineers who, by virtue of their participation in the various exploration projects, had a direct part in obtaining some of the data in this report. They include A. B. Needham, Paul Pesonen, E. O. Binyon, D. H. Mullen, Glen Walker, and Stuart Ferguson.

Much of the work at the Monte Carlo pegmatite and some of the work at other localities described in this report was done in behalf of the Division of Raw Materials, U.S. Atomic Energy Commission.

GENERAL GEOLOGY

Precambrian rocks form the core of the Black Hills, both in the pegmatite area surrounding Harney Peak and in areas to the north. The geology of the entire area has been described by Darton and Paige (1925), and detailed data for some of the pegmatite-bearing areas has been given by Redden (1963) and Norton (1960).

The predominant rocks in the region as a whole are metasedimentary schists consisting mainly of quartz, biotite, muscovite, and plagioclase. Less common metasedimentary rocks include quartzite and amphibole and graphitic schists. All these rocks are isoclinally folded, and in places they are deformed by cross folds. Masses of amphibolite, some of which extend over several square miles, cut isoclinally folded schist beds and are clearly of intrusive igneous origin; other bodies of amphibolite follow the structure of the enclosing rocks and are not necessarily of intrusive origin. Several faults, some with a displacement of many miles, cut the metamorphic rocks.

The pegmatitic and granitic rocks surrounding Harney Peak dominate the geology of the southern Black Hills. The schist dips outward in all directions from Harney Peak to form a domal structure; smaller but otherwise similar domes have been recognized in outlying areas. The metamorphic grade is highest in pegmatite-rich areas south of Harney Peak, where sillimanite is an abundant constituent of the schist. To the north the grade decreases through a staurolite zone and a garnet zone to relatively low grade rocks that are exposed beyond the area shown on the index map (fig. 107).

The Harney Peak Granite is the most abundant intrusive rock in the area containing pegmatites. As Orville (1960), Kupfer (1963) and Redden (1963) have shown, it is a leucocratic rock that ordinarily consists of alternating, but vaguely defined, layers of coarse-grained material clearly pegmatitic in character and of finer grained rock that can be called granite. The coarse-grained layers consist mainly of plagioclase, perthite, and quartz, and the finer grained layers consist largely of plagioclase and quartz.

Many of the pegmatites are virtually homogeneous bodies; such pegmatites lack conspicuous zoning, layering, or other internal structure, but the grain size ordinarily increases inward from the contact, and very thin fine-grained border and wall zones may be recognizable. Most of these bodies consist of plagioclase-quartz-perthite pegmatite in which the perthite occurs as coarse crystals in a fine- to medium-grained [1] groundmass that is chiefly plagioclase and quartz. A few homogeneous pegmatites have only sparse perthite, and consist predominantly of plagioclase and quartz, commonly accompanied by abundant muscovite.

Neither the homogeneous pegmatites nor the layered intrusives have been economically important. A few are rich enough in potash feldspar to have been prospected or mined, but not with great success. Still other prospects and small mines are in fracture fillings that cut these pegmatites. The dominant minerals of such

[1] The grain-size categories are those suggested by Cameron and others (1949, p. 16):

	Inches
Fine	<1
Medium	1-4
Coarse	4-12
Very coarse	>12

fracture fillings are quartz and perthite, accompanied in places by plagioclase and muscovite, either homogeneously distributed or segregated into zones. These fracture fillings have been minor sources of potash feldspar, mica, beryl, and other minerals.

ZONED PEGMATITES

Zoned pegmatites have been the main sources of industrial minerals in the Black Hills, and they have also been the subject of most of the pegmatite literature, though they constitute only about 1 percent of all the pegmatites in the region. The economic importance of the zonal structure is that it gives rise to concentrations of industrial minerals in certain parts of a pegmatite, and only these parts of the pegmatite need be mined to obtain a salable product. All the pegmatites here described are best classified as zoned pegmatites except possibly the Mountain Lion, in which most of the mining has been in fracture-filling units.

The geology of zoned pegmatites has been so extensively treated in the literature that only the aspects that bear specifically on the pegmatites described in this report need to be presented here. Virtually the entire monograph by Cameron and others (1949) is on zoned pegmatites, and the work in the Black Hills reported by Page and others (1953) was also mainly on zoned pegmatites.

Pegmatites of this kind were shown by Cameron and others (1949, p. 14) to have three categories of internal structural units—zones, fracture fillings, and replacement bodies. Of these, zones are by far the predominant type of unit in the Black Hills as well as elsewhere. Examination of the maps and sections will confirm that the pegmatites described in this report consist mainly of zones, which form shells having contacts approximately parallel with the outer border of the pegmatite. Some of the zones are incomplete; they appear as crescent-shaped units that either form hoods in the upper part of the pegmatite or form inverted counterparts of the hoods along the bottom of the pegmatite. Fracture-filling units are best illustrated in the Big Chief pegmatite (fig. 4), but also have been recognized elsewhere. None of the 17 pegmatites studied here has a firmly demonstrated replacement body, but the Etta, Hot Shot, and Barker-Ferguson pegmatites have units rich in mica and albite that may be of replacement origin.

Contacts between pegmatite units may be sharp, but more commonly are gradational over a few inches or even several feet. Comparison of plate 28, showing the mineral distribution in underground workings at the Hot Shot pegmatite, with plate 29, showing the contacts between units in these same workings, indicates the problems and the degree of subjectivity involved in mapping a contact. A contact such as the inner border of the wall zone, where muscovite changes from an essential mineral to a minor accessory over the space of a few inches, can be precisely located. On the other hand, the inner border of the perthite-quartz-albite zone, which is supposed to be where the perthite content drops below 5 percent, cannot possibly be exact because the perthite is in crystals several feet long and the line drawn between the zones has to be highly generalized. Though errors may be made in this process, they are too small to give rise to difficulties when the data from the maps and drill holes are projected into geologic sections for use in interpreting the geology of the pegmatite as a whole.

The maps and sections accompanying this report show that the pegmatites are in many respects similar to each other in their overall form and in their internal structure. Most of the pegmatites have a lenticular shape, though they range from nearly tabular, as at the White Cap, to the inverted teardrop shape of the Etta, which is nearly circular in plan. The pegmatites are thickest near the top, which generally has a rounded form; they thin gradually at depth and take on the shape of a keel, as at the Silver Dollar (pl. 32). The many rolls in the outer contact of some pegmatites ordinarily affect the structure only in detail, not in the gross relations.

Similarities in the internal structure of these pegmatites are brought out not only by the maps and sections but also by table 2, showing the sequence of mineral assemblages. This table follows the form originally used by Cameron and others (1949, p. 59–70) and by Page and others (1953, p. 15–16). No pegmatite contains all 11 of the assemblages shown in the table, and in some pegmatites a single assemblage has been mapped as two or more zones. Nevertheless, this table and others published previously demonstrate the remarkable correspondence in the sequence from one pegmatite to another, not only in a single district but also in widely separated districts.

The border and wall zones of most of the pegmatites consist of quartz, plagioclase, and muscovite (assemblage 1) having a fine- to medium-grained pegmatitic texture. In a few pegmatites the outermost zone belongs to assemblage 2 (quartz and plagioclase) or assemblage 3 (quartz, plagioclase, and perthite). The plagioclase is almost entirely albite in all units of all the pegmatites except the Silver Dollar, which carries oligoclase and perhaps sodic andesine in its wall zone. The muscovite content of wall zones is generally greatest near the contact with the country rock, where it

TABLE 2.—*Sequence of mineral assemblages*

[Form of table after Cameron and others (1949, p. 59–70)]

Sequence (from contact inward)	Assemblage	Pegmatite																
		Barker-Ferguson	Big Chief	Buster Dike	Dan Patch	Dan Patch West	Diamond Mica	Etta	Eureka	Expectation	Hot Shot	Monte Carlo	Mountain Lion (Soda Spar)	Pine top	Silver Dollar	Sitting Bull	White Bear	White Cap
1	Quartz, plagioclase, muscovite	×	×[1]	×	×		×[1]	×	×	×	×	×				×		
2	Quartz, plagioclase					×					×	×	×			×		×
3	Quartz, plagioclase, perthite [2]	×	×	×	×		×		×	×	×	×	×	×	×		×	×[1]
4	Quartz, perthite	×			×	×			×		×	×	×		×	×	×	×
5	Quartz, plagioclase, with or without muscovite, perthite, amblygonite, spodumene.	×						×					×					
6	Quartz, plagioclase, spodumene							×			×							
7	Quartz, spodumene							×		×								
8	Plagioclase, lepidolite, quartz																	
9	Quartz, microcline or perthite																	
10	Plagioclase, lithia mica, microcline, quartz.																	
11	Quartz		×	×	×	×	×	×	×	×			×	×			×	

[1] A zone of this composition is present, but too thin to map.
[2] Commonly grades downward and inward to a unit consisting of quartz, plagioclase and minor perthite.

may be more abundant than either quartz or feldspar, and it decreases sharply toward the inner part of the pegmatite. Where the decrease in muscovite content is especially great, an intermediate zone of quartz and albite (assemblage 2) succeeds the wall zone. Such zones generally have a medium-grained pegmatitic texture, as in the Hot Shot and Sitting Bull pegmatites, but in the Monte Carlo pegmatite assemblage 2 consists largely of sugary albite and quartz.

The most common variety of intermediate zone contains the quartz, plagioclase, and perthite of assemblage 3. Many of these zones are very large. They are ordinarily in contact with wall zones containing muscovite, and the perthite of assemblage 3 takes the place of muscovite in assemblage 1 as the main potassium-bearing mineral. Most of the crystals of perthite are several feet long, and some are several tens of feet long; they are set in a matrix of quartz and albite that is medium grained at most localities. The richest concentrations of perthite are in the upper part of a pegmatite; the abundance decreases downward and inward. Perthite becomes so sparse at depth in many pegmatites that quartz, albite, and perhaps muscovite are the only abundant minerals occupying the structural position belonging to assemblage 3. Geologic sections (for example, at the Dan Patch, fig. 111) show that the upper part of such a pegmatite has a hood-shaped unit of perthite-rich rock that is succeeded at depth by a similarly shaped, but inverted, unit consisting mainly of quartz and albite.

Many of the pegmatites contain an inner zone of very coarse grained quartz and perthite. The perthite crystals are for the most part several feet long, and the matrix is chiefly massive quartz.

The spodumene-bearing assemblages 5–7 are not common. Among the pegmatites described in this report, they are conspicuous only in the Etta. The modest quantity of spodumene-bearing pegmatite at the Expectation, Hot Shot, and Mountain Lion pegmatites has much the same lithologic character as the units in the Etta mine. The plagioclase of these assemblages is invariably platy albite or cleavelandite, in contrast to the generally more blocky albite (or rarely oligoclase) of assemblages 1–4.

The core of 11 of the 17 pegmatites in table 2 consists of massive quartz, and some of the others may have unexposed quartz cores. Four pegmatites have cores of quartz and perthite belonging to assemblage 4.

The geology of these zoned pegmatites has not required any significant changes in the concepts of origin described in earlier reports (especially Page and others, 1953, p. 17–24; Sheridan and others, 1957, p. 18–21; and Norton and others, 1962, p. 107–124), and as a consequence, this subject needs no lengthy discussion here. The evidence presented in these earlier reports favors an origin from a magma-like liquid rich in SiO_2, Al_2O_3, Na_2O, and K_2O, but also carrying unusual amounts of lithium, beryllium, boron, H_2O, and other volatile constituents. Injection of this liquid was followed by crystallization from the contact inward, accompanied by fractionation that gave rise to the segregation into zones. The presence of small replacement bodies in some of the Black Hills pegmatites indicates that a fluid rich in volatiles was active at a late stage of crystallization.

MINERAL DEPOSITS

The chief economic products of the pegmatites described here have been sheet and scrap mica, potash feldspar, spodumene, and beryl. Only very small quantities of other pegmatite minerals, such as amblygonite, columbite-tantalite, and cassiterite, have been produced.

An extensive account of the economic geology and related aspects of these minerals was published by Page and others (1953, p. 24–60), and the discussion below treats only highlights that apply particularly to the pegmatites described in this report.

MICA

The Buster Dike mine has been one of the largest sources of sheet mica in the Black Hills, and the Silver Dollar, White Bear, White Cap, and Hot Shot mines have also been important. The Pine Top is promising as a prospect.

Sheet mica is obtained mainly from wall zones, but some of the mica at the Silver Dollar has come from the outer part of the perthite-quartz core, along its contact with the wall zone. Mica books that yield sheet mica are ordinarily several inches across, but books 1 to 3 feet long have been obtained. The mica is ruby in color and generally moderately to heavily air stained.

POTASH FELDSPAR

The Dan Patch, White Cap, Hot Shot, and Big Chief mines have all been important as sources of potash feldspar. All the other pegmatites described in this report have also been mined or prospected for feldspar.

The potash feldspar is perthitic microcline. It occurs mainly in the hood-shaped units of perthite, quartz, and albite, and in inner zones consisting of perthite and quartz.

Perthite is a conspicuous rock-forming constituent of all these pegmatites, but it can be profitably mined only where it is especially abundant and where it is in large crystals, free of impurities, that can be readily hand sorted. The very coarse grained, nearly pure perthite (pl. 28) in the shaft at the Hot Shot mine is an especially good example meeting these conditions. Similarly coarse-grained and rich concentrations of perthite were obtained from the perthite-quartz-albite zone in the Dan Patch pegmatite and the perthite-quartz zone in the White Cap pegmatite.

SPODUMENE

Of the spodumene deposits described here, only the one at the Etta mine is known to be important, but small quantities of spodumene also exist in the Expectation, Hot Shot, Mountain Lion, and perhaps the Barker-Ferguson pegmatite. The spodumene of all these deposits is coarse enough to be hand sorted.

BERYL

The White Cap, Big Chief, and Barker-Ferguson pegmatites have all been mined largely for beryl. The Dan Patch, Etta, and Hot Shot mines have also been sources of beryl, though other minerals have been the main products. The Eureka, Dan Patch West, and Sitting Bull are prospects in which beryl has been the chief mineral of interest.

Concentrations of beryl are in a variety of places in these pegmatites. Norton and others (1958, p. 26–29) showed that several of the mineral assemblages characteristic of zoned pegmatites are likely to be rich in beryl, and all the important types of beryl deposits cited by them are represented in this small group of pegmatites. Assemblage 5, which in many places contains beryl associated with quartz, feldspar, and lithium minerals, is represented at the Etta mine, where most of the beryl probably was in the perthite-quartz-spodumene zone. Assemblage 1, in wall zones containing beryl with quartz, plagioclase, and muscovite, is represented especially well by the Barker-Ferguson and Sitting Bull pegmatites; a similar beryl-rich wall zone in the Dan Patch West pegmatite has only sparse muscovite, and thus belongs to assemblage 2. Association of beryl with aggregates rich in iron-manganese phosphates is evident in the White Cap pegmatite, where beryl is concentrated in the inner part of the cleavelandite-quartz wall zone, and in the Dan Patch and Hot Shot pegmatites, where the phosphates and beryl are mainly along the inner border of perthite-quartz-albite zones. At the Big Chief mine, most of the beryl is at the margin of the quartz core. Several of these pegmatites also carry an appreciable quantity of beryl in perthite-rich zones belonging to assemblages 3 and 4, in which beryl can be a byproduct of feldspar mining. The White Cap, Hot Shot, and Eureka pegmatites are the best examples; the Barker-Ferguson also has beryl in a perthite-rich zone, but the perthite is so heavily iron stained that it is unlikely to be mined.

The beryl of these deposits ranges from greenish yellow to pure white. Much of it is in subhedral to euhedral crystals that are several inches to several feet long and easily recovered by hand cobbing. Crystals at some localities have such a high content of mineral impurities that the beryllium oxide content of the hand-sorted product may be below acceptable limits. White beryl is ordinarily associated with lithium minerals, as in the Etta mine where some of it has a well-developed basal cleavage. The beryl at the Barker-Ferguson mine is noteworthy for its heavy iron stain and for a close resemblance to quartz that makes it very difficult to recognize.

EXPLORATION TECHNIQUES

Much of the work reported here was associated with exploration. Though geologic methods and diamond drilling have not commonly been used in zoned pegmatites, and though their utility has at times been denied, they have been successfully applied at several of the deposits.

The techniques are actually fairly simple, and sufficiently reliable and precise for most purposes. The basis for this work is a detailed geologic map, of the sort shown in the illustrations accompanying this report. These maps show the distribution and shape of the pegmatite and of its internal units, and they also contain structural data from which the strike, dip, and plunge of the body can be determined. The most useful information, and often the most difficult to obtain, is accurate knowledge of the plunge. Rolls in the pegmatite contact, especially the large rolls, commonly are well enough exposed to permit measurement of their plunge, and the data thus obtained can be used to project these rolls into geologic sections, though the plunge may change somewhat from place to place. The plunge of large rolls is ordinarily parallel to the plunge of the ends of the pegmatite, which themselves are really only large rolls. Consequently, even where the ends of the pegmatite are not exposed, their plunge can be inferred.

Working from these data, one can construct vertical or horizontal geologic sections, structure-contour maps, isopach maps, or other diagrams that are used in conjunction with the maps to show the geology of the pegmatite in three dimensions. Though the interpretations thus obtained may be in part debatable, they are at least consistent with the available information, and wherever checked by diamond drilling, they have proved to be correct in their essential elements. At the Silver Dollar pegmatite (pl. 32), where the geology is relatively simple, drill hole 2 passed through both the hanging wall and footwall within 1 foot of the predicted depth. At the Monte Carlo pegmatite, on the other hand, the geology is more complex and was incompletely understood at the outset of drilling. Nevertheless, as shown in section *B–B′* of plate 30, the outline of the pegmatite predicted prior to drilling is not significantly different from that indicated by the drilling data. Gross errors can, of course, be made in the geologic interpretations, but experience in the Black Hills with more than 50 holes drilled by the Bureau of Mines and the Geological Survey indicates that such errors should be rare. Only one of these drill holes missed the pegmatite entirely; that was hole 1 at the Eureka prospect (pl. 26), and it was expected to pass beneath the pegmatite.

The entire procedure is illustrated in a simple and clearcut way by the work at the Barker-Ferguson property (fig. 109). At this locality the pegmatite was exposed in two places on either side of a small hill, and it was generally assumed that these two exposures were of separate pegmatites. Geologic mapping showed, however, that the exposures belong to a single pegmatite that extends through the hill and has its crest just beneath the top of the hill. Diamond drilling confirmed this interpretation.

The geologic map of the Monte Carlo pegmatite (pl. 30) showed that the surface exposures are all near the top of the pegmatite; it followed that unexposed inner zones might be found at depth. Furthermore, a guess was made as to the composition of the concealed units because fracture fillings exposed at the surface presumably are offshoots of these inner zones. The predictions were confirmed by diamond drilling, but the unexposed zone discovered in this way was smaller than had been hoped, and much too small to mine.

At the Buster Dike mica deposit, the mine workings had long been thought to have reached the southern end of the pegmatite. The circumstances were such that, if the southern end of the pegmatite had been reached, it has a different plunge than the large rolls exposed in the mine workings. Reexamination of this structural inconsistency led to the conclusion that additional mica-rich pegmatite might be found south of the old workings. The results from diamond drilling confirmed this conclusion, but no one has yet attempted the costly effort necessary to develop and mine this part of the pegmatite.

The most productive part of the mica zone in the Buster Dike and several other Black Hills pegmatites lay beneath the surface, below the base of a perthite-rich hood. This relation opens the possibility that in an otherwise similar pegmatite, such as the Pine Top (fig. 118), a minable concentration of mica can be found by subsurface exploration. Drilling has not ordinarily been used for this purpose, mainly because an inclined shaft is commonly cheaper and provides a more adequate sample. In some degree, however, the drilling at the Hot Shot served this purpose, though the geology of the mica zone was already fairly well known prior to the drilling.

A more prosaic outcome of the use of diamond drilling as a supplement to geologic mapping has been simply to insure that subsurface data do not require that the geologic interpretations be greatly modified. The Eureka pegmatite, for example, lies on a dip slope, and the drilling was mainly to substantiate the belief that the keel is at shallow depth and that the total tonnage of rock in this pegmatite is not as great as its broad surface exposure might suggest to the casual examiner. The Big Chief pegmatite also is exposed over a wide area and has a gentle dip that was confirmed by drilling. At the Silver Dollar pegmatite, drilling was mainly to establish the predicted extensions of the mica deposit at depth.

BARKER-FERGUSON BERYL MINE

The Barker-Ferguson beryl property is of particular interest as an example of the use of geologic data in successfully predicting the existence of a concealed body of minable pegmatite. The interpretations were based on two small exposures of pegmatite on either side of the top of a small hill. The geologic mapping indicated a very great likelihood that these two exposures belong to a single pegmatite that extends through the hill, and two U.S. Bureau of Mines diamond-drill holes showed that they do.

The Barker-Ferguson pegmatite is in the SW1/4-NE1/4 sec. 14, T. 2 S., R. 6 E., about 3 miles east-southeast of Keystone. It is partly on property owned by C. P. Barker and partly on property owned by C. W. Ferguson. At the time the pegmatite was mapped, the only mining had been in two small pits near the north end (fig. 109). Subsequently the Consolidated Feldspar Department of the International Minerals and Chemical Corp. mined the deposit from a new and much larger pit located near the top of the hill in the vicinity of sections *A–A′* and *B–B′*, figure 109. The main product was beryl, but potash feldspar and scrap mica were also produced. Another pegmatite located just to the west of the area shown on the geologic map has been mined chiefly for potash feldspar.

The geologic map was made by J. J. Norton and J. E. Roadifer in October 1953. The drilling was done later in 1953 under the supervision of E. O. Binyon of the Bureau of Mines. The geologic work for the drilling was done mainly by Norton, but in part by J. A. Redden.

The pegmatite is intrusive into steeply dipping metamorphic rocks consisting of quartz-mica schist and a metamorphosed iron formation. The dominant rock immediately adjacent to the surface exposure of the pegmatite is the iron formation, which forms a layer 80 to 100 feet wide crossing the property in a northwesterly direction. The iron formation consists of amphibole schist with layers and lenses of glassy quartzite that are mostly less than 1 inch thick. The amphibole schist is so heavily weathered and iron stained at this locality that no precise description of it is possible; similar rock elsewhere in the Keystone district is known to consist largely of grunerite, but also contains other amphiboles, quartz, garnet, iron oxides, and a variety of minor accessory minerals.

Quartz-mica schist is exposed on either side of the layer of iron formation. The rocks are isoclinally folded, and the exposures are not adequate for drawing the contacts at the scale of the map (fig. 109). Minor folds here and to the northwest and southeast are such that the contacts have a zigzag pattern, in which the long limbs of folds strike north-northwest and the short limbs strike north. At the Barker-Ferguson mine this pattern is further complicated by local distortion adjacent to the pegmatite.

Pegmatite is exposed in three places. The exposure near the northeast corner of the map is a homogeneous body consisting mainly of quartz, albite, and perthite. The other two exposures are the two ends of the Barker-Ferguson pegmatite, which, as the geologic sections indicate, are joined to each other beneath the top of the hill.

The exposure at the northwest end of the Barker-Ferguson pegmatite has a wall zone of fine- to medium-grained albite-quartz-muscovite pegmatite and an inner zone of perthite-quartz-albite pegmatite. Many of the perthite crystals in the inner zone are more than 1 foot long, but the quartz and albite of the matrix are ordinarily less than 2 inches across. The albite in both of the zones is largely cleavelandite. Tourmaline and beryl are common accessory minerals, especially in the wall zone, and iron-manganese phosphates (probably mainly heterosite) appear in the inner zone.

The crest of the pegmatite, where exposed 70 feet north of the collar of hole 1, is very nearly flat; the geologic sections show that to the southeast the crest is only a few feet beneath the surface. The exposure of pegmatite in the southeast part of the map area is all near the crest. The wall zone is the main unit exposed here, but the perthite-quartz-albite zone and a very small exposure of quartz-perthite pegmatite have also been mapped. This is the only surface exposure of quartz-perthite pegmatite, and it is not even clear whether this exposure is a zone or a fracture filling. The drill holes show that there is a zone

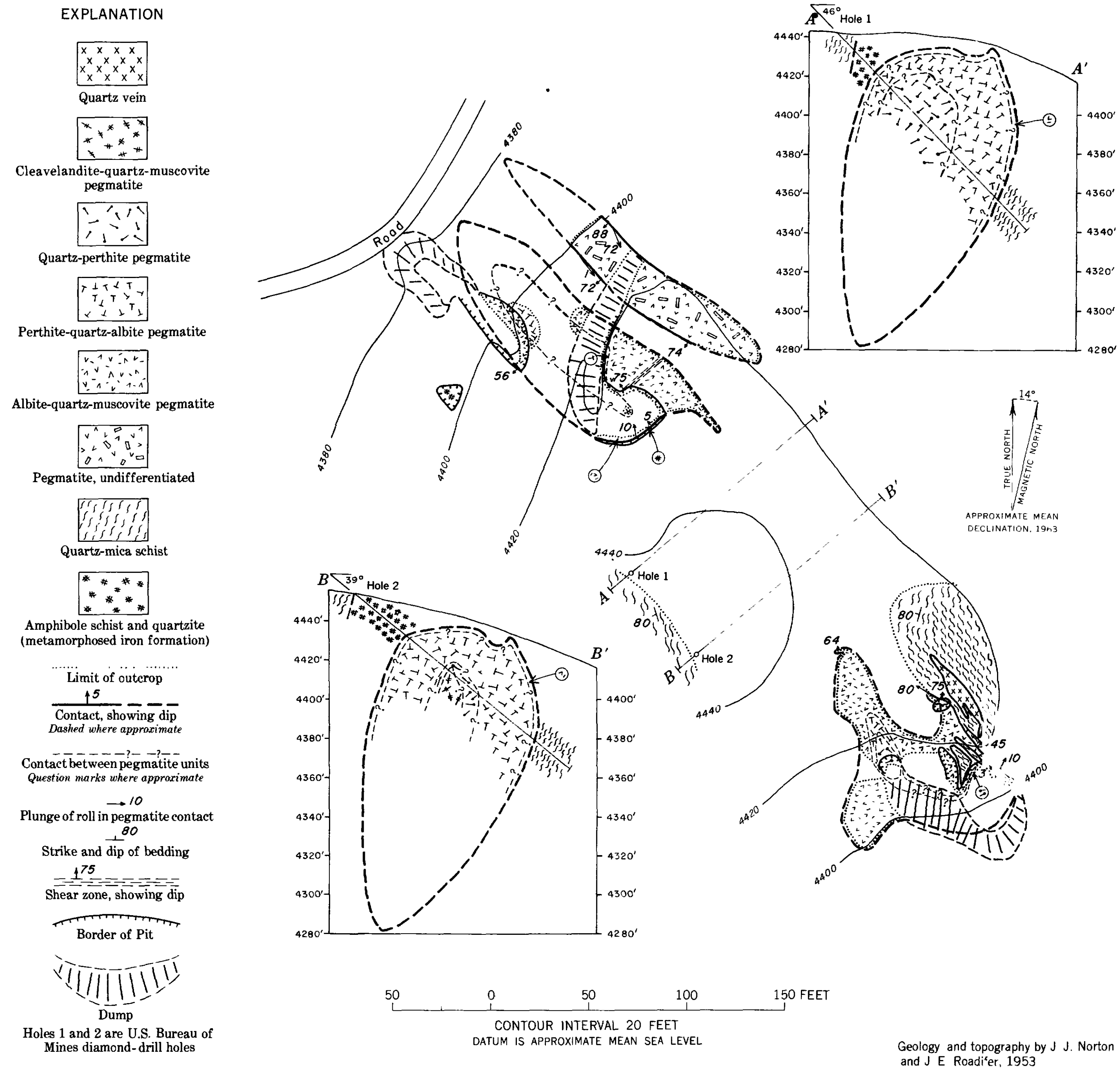

FIGURE 109.—Geologic map and sections of the Barker-Ferguson pegmatite, Pennington County, S. Dak.

consisting mainly of quartz and perthite. The grain size is unusually coarse: hole 1 was in a single crystal of perthite for a distance of 14 feet and it was in massive quartz for as much as 7 feet. The only other unit recognized is cleavelandite-quartz-muscovite pegmatite, which was found only in hole 2 in a position that suggests it is the core of the pegmatite. Albite occurs as sugary masses and as aggregates of 1/2-inch plates of cleavelandite. Quartz is for the most part interstitial to the cleavelandite, but one 5-inch mass of quartz was recovered; muscovite was found mainly near this quartz.

The drill holes established the continuity of the deposit. During the subsequent mining, beryl was the chief economic product. Most of it came from the wall zone, but some was from the perthite-quartz-albite zone, and some may have been from the quartz-perthite zone. The potash feldspar is stained with iron minerals that have been introduced in fractures throughout the pegmatite during the weathering of the iron-rich country rock. Scrap mica is the only other known economic product. Accessory spodumene was identified near the center of the pegmatite in hole 1, and it is possible that a small concealed spodumene-bearing unit will ultimately be found.

BIG CHIEF FELDSPAR MINE

The Big Chief pegmatite, also known as the Johnson pegmatite, is a feldspar mine in which beryl has been an important byproduct. It is 3 miles southeast of Keystone in NE1/4 sec. 22, T. 2 S., R. 6 E., and may be reached by a gravel road that goes east and then south from Keystone. The mine is on a group of patented claims held by J. A. Johnson, who resides nearby. Mining has been done by a succession of leasers, but mainly by the Consolidated Feldspar Corp. and the Vickers Feldspar Corp.

The Big Chief pegmatite was mapped by Norton and J. E. Roadifer in December 1953 (fig. 110). Shortly thereafter the U.S. Bureau of Mines explored the deposit by means of two diamond-drill holes. Geologic work during the drilling was done by Norton and J. A. Redden.

The pegmatite is a large one, but it crops out along a dip slope in such a way as to appear even larger than it really is. The surface exposure extends for 650 feet in a northeasterly direction. The width of exposure is about 250 feet, but because the dip is only about 30° to the southeast (fig. 110), the true thickness of the pegmatite is at the most 90 feet.

In shape the pegmatite is lenticular, and it is approximately concordant with the schistosity of the quartz-mica schist that forms the country rock. The few minor rolls in the contact plunge gently to the east, and the overall structure indicated by the diamond drilling is consistent with a plunge of 15° to 20° almost due east.

The internal structure is uncomplicated. The wall zone consists of quartz-albite-muscovite pegmatite that for the most part is only 1 to 2 feet thick, too thin to be shown separately on the maps and sections. It is succeeded by a perthite-quartz-albite intermediate zone, which forms most of the pegmatite. A quartz core is in the center of the pegmatite, and many quartz fracture-fillings cut the outer units.

The average grain size in the wall zone is about one-fourth inch and in the intermediate zone it is only about one-half inch for all the major minerals except perthite. The perthite crystals are ordinarily 1 to 2 feet long, and some are as much as 10 feet long. Much of the perthite is graphically intergrown with quartz. Beryl has been found mainly in the inner part of the intermediate zone, especially along the upper side of the quartz core, where for a thickness of 10 feet the beryl content is about 1 percent and the muscovite content is also high. The beryl crystals vary greatly in size, but the average is about 0.5 foot in diameter. Beryl is also abundant, but as smaller crystals, in places where iron-manganese phosphates appear.

The quartz core consists almost entirely of massive quartz, some of which has a rose color. Perthite crystals as much as 10 feet long are also in this unit.

Quartz fracture fillings are unusually abundant in the Big Chief pegmatite, and at least some of them are offshoots from the quartz core (fig. 110). Most of the fracture fillings have a strike approximately parallel to the strike of the pegmatite and a dip normal to the dip of the pegmatite.

The diamond drilling was mainly for the purpose of determining the size and structure of the pegmatite at depth, so that the probable extent of the beryl-bearing unit could be predicted. The two holes, as shown by sections *A–A′* and *B–B′*, confirm the gentle dip of the pegmatite. Hole 1 passed beneath the quartz core, but the geometry of section *A–A′* suggests that it is not far beneath the core. Hole 2 cut what appears to be the quartz core from 39.6 to 44.0 feet below the collar. These data indicate that the quartz core extends 100 to 250 feet down dip, and the map shows that the strike length is at least 300 feet. The beryl unit along the hanging-wall side of the quartz probably has the same extent, and it may be expected to contain several hundred tons of beryl.

BUSTER DIKE MICA MINE

The Buster Dike pegmatite was the largest source of sheet mica in the Black Hills from 1942 to 1944, during its only period of intensive mining. The location is in the SW1/4NW1/4 sec. 2, T. 4 S., R. 4 E., about 2-1/2 miles south-southwest of Custer. The deposit is on an unpatented claim that, during the principal period of mining, was owned and operated by the Black Hills Mining Co., but there have been several other owners and operators. The underground workings were backfilled with waste rock at the conclusion of mining in 1944, and have been inaccessible since then.

The Buster Dike pegmatite is very well zoned and quite different from the homogeneous pegmatites exposed elsewhere in the immediate vicinity. Nevertheless, the exposures available during early studies suggested to Norton (1953a, p. 87, pl. 8) and to Fisher (1945, p. 24, fig. 6) that the Buster Dike grades laterally into homogeneous pegmatite.

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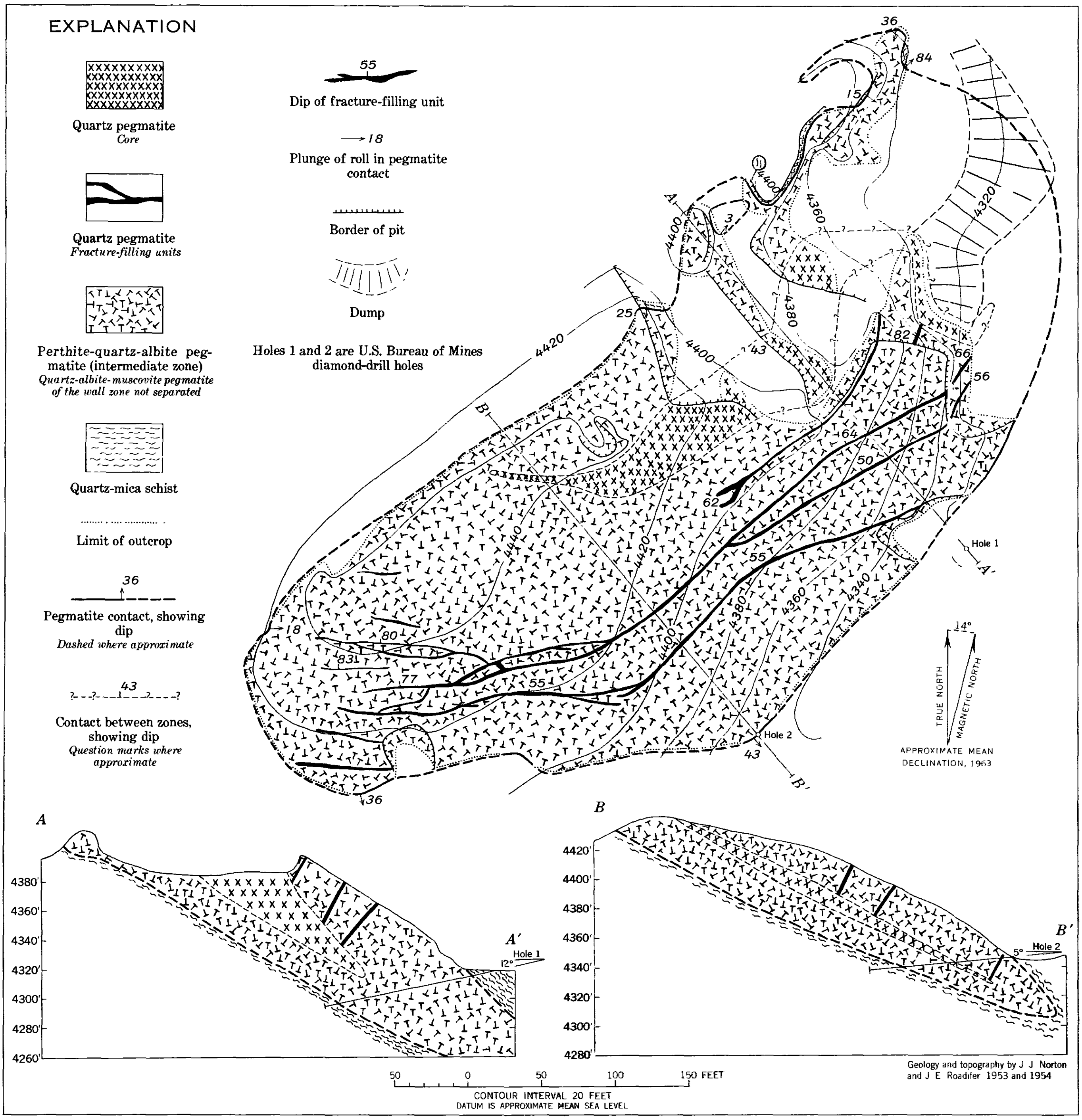

FIGURE 110.—Geologic map and sections of the Big Chief pegmatite, Pennington County, S. Dak.

The maps of the underground workings (Norton, 1953a, pl. 9) showed that most of the mica mining was in rolls that plunge 50° to 60° S. 30° to 35° W. The plunge of rolls like these in most other Black Hills pegmatites is parallel to the plunge of the ends of the pegmatite. In the Buster Dike, however, the south end of the pegmatite, although it could not be located precisely, was thought to plunge 60° S. 80° W. (Norton, 1953a, p. 87, pl. 9) along the south border of the mine workings.

Both of these conclusions—that the Buster Dike grades into homogeneous pegmatite and that the plunge of the rolls is discordant with the plunge of the pegmatite—became increasingly suspect as knowledge of Black Hills pegmatites became greater. It seemed more likely that the Buster pegmatite should be a discrete body separated from the other pegmatites of the area and that its plunge should be parallel to the plunge of the rolls. These suppositions carried two important implications: First, they suggest a likelihood that additional mica shoots lie to the north of the old workings, either in previously unknown rolls or at the very end of the pegmatite; second, they point to the possibility that mining was stopped to the south where sharp rolls of the schist were encountered in the drifts and that these rolls were mistaken for the south end of the pegmatite. The mine maps (Norton, 1953a, pl. 9) show nothing to rule out these views, and the inference was clear that additional mica-rich pegmatite might be found.

In order to test these possibilities, the U.S. Bureau of Mines explored the deposit in 1947. The surface was stripped by a bulldozer so it could be mapped in detail by L. R. Page and Norton (pl. 24). On the basis of information acquired from this mapping and from the earlier work, the deposit was explored by three diamond-drill holes. Two of the holes are to the north and one is south of the underground workings. Needham (1950, p. 26–36) published an account of this work that contains a summary of the geology and also has detailed logs of the drill holes prepared by L. R. Page.

The stripping of surficial material exposed the Buster pegmatite for its entire length of 200 feet beneath the nearly flat ground surface. The results confirmed the expectation that the pegmatite terminates to the north and does not grade into a body of homogeneous quartz-albite-perthite pegmatite. The maximum thickness of the Buster pegmatite is about 50 feet. The strike is N. 15° W., and the dip is for the most part between 60° and 70° W., though it is somewhat steeper near the north end. The wall rock is chiefly quartz-mica schist and quartz-mica-sillimanite schist, but feldspar-rich granulite is common immediately adjacent to pegmatite.

At the surface the pegmatite consists mainly of a central zone of perthite-albite-quartz pegmatite surrounded by a wall zone of albite-quartz-muscovite pegmatite. Along the north border of the pegmatite the position of the wall zone is occupied by a crescent-shaped unit of quartz-albite-biotite pegmatite containing relicts of schist.

The perthite decreases greatly in abundance at a shallow depth, and the central zone becomes albite-quartz pegmatite. The albite is partly cleavelandite. The inner part of the zone may have more cleavelandite than blocky albite, and may have more quartz than feldspar. The body of quartz encountered in hole 2 suggests that the pegmatite has a small quartz core, perhaps consisting of a series of discontinuous, centrally located pods.

The wall zone, which is less than 5 feet thick at the surface, became as much as 12 feet thick along the hanging wall in the underground workings. It also became extraordinarily rich in muscovite; 558 tons of crude mica were produced from approximately 5,700 tons of rock between July 1, 1942, and the end of December 1943 (Norton, 1953a, p. 88). Mining was stopped to the north where the wall zone becomes thin and mica is sparse; through most of the mine workings, this point was at the north border of a large roll. The drilling showed, however, that the wall zone can be traced farther north. Fragments of muscovite as much as 3 inches long recovered in hole 1 (Needham, 1950, p. 28) substantiate the existence of sheet mica in this part of the pegmatite. Furthermore, the surface map (pl. 24) shows rolls that have been projected to section *B–B′* and to the plan at altitude 5,450 feet, and these rolls may be the site of mica-rich shoots.

To the south, hole 2 (section *C–C′*, pl. 24) eliminates any doubt that mica-rich pegmatite actually does exist beyond the limits of the underground workings. The largest fragment of mica recovered was 2-1/2 inches long and 1 inch thick (Needham, 1950, p. 33). The drill hole cut the wall zone in two places near the apparent center of the pegmatite. These circumstances suggest the presence of rolls, which in the form shown in section *C–C′* and on the geologic plan can be correlated with rolls near the south end of the pegmatite on the surface. The rolls may well be sharp enough to account for the impression that the pegmatite ended at the south edge of the underground workings. Whether they are accompanied by a shoot of mica pegmatite rich enough for mining can be shown only by entering this body of rock with new mine workings.

DAN PATCH FELDSPAR MINE

The Dan Patch feldspar mine is about 1 mile west of Keystone in the NE1/4NE1/4 sec. 7, T. 2 S., R. 6 E. The owner is the Consolidated Feldspar Department of the International Minerals & Chemical Corp. Most of the mining was done by this organization, but part was done by other operators. Though complete production figures have not been compiled, it is clear that several tens of thousands of tons of potash feldspar have been mined and that this product has been by far the most important from the deposit. The scrap mica recovered probably amounts to a few hundred tons. The beryl output is uncertain, but probably is between 50 and 100 tons.

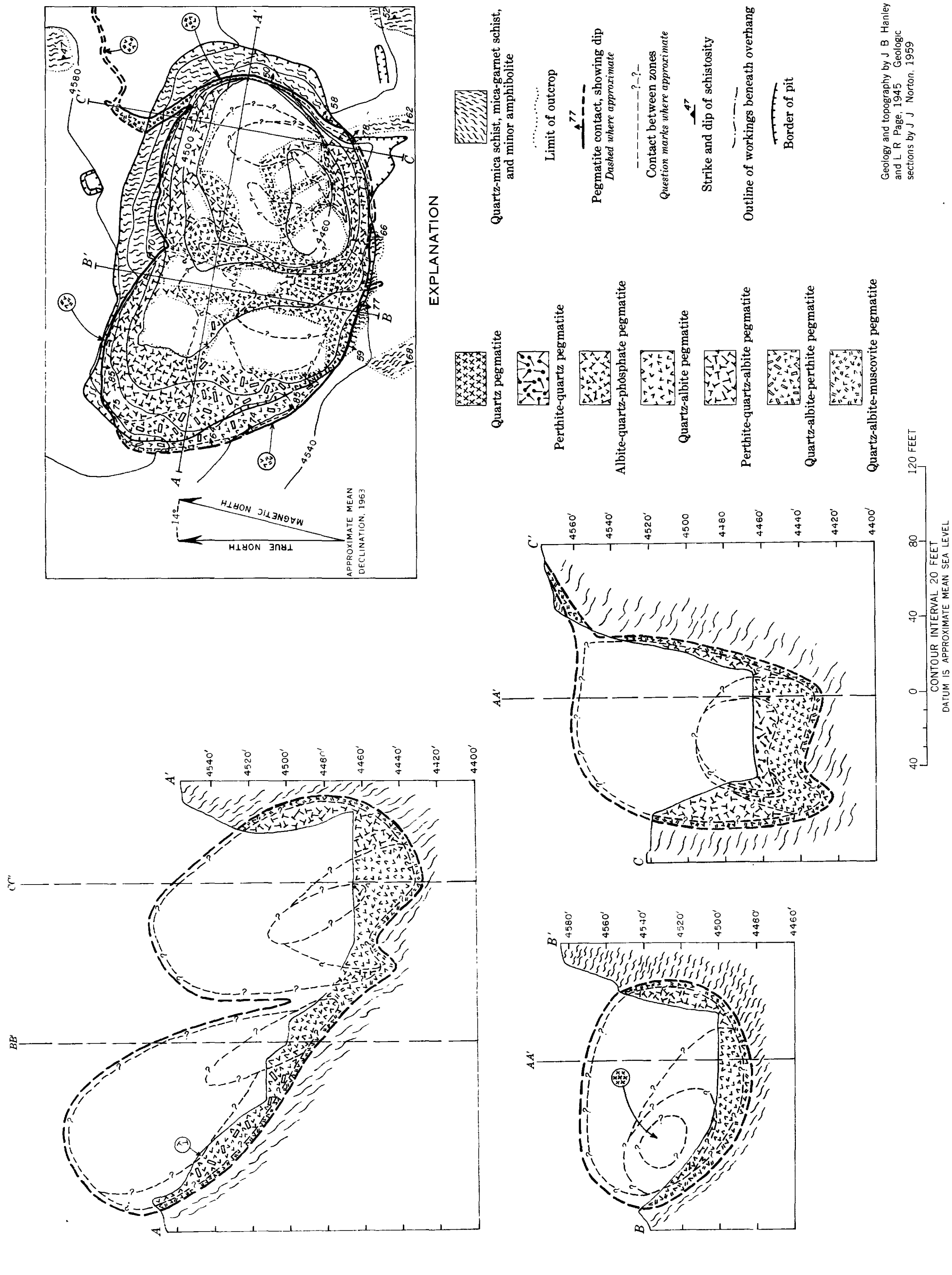

Figure 111.—Geologic map and sections of the Dan Patch pegmatite, Pennington County, S. Dak.

The main period of mining was between 1940 and 1946. The geologic map (fig. 111) was made by J. B. Hanley and L. R. Page in October 1945, near the end of mining. At that time the pit had a maximum length of 215 feet and a width of 135 feet, and its average depth was about 75 feet. Guiteras (1940, p. 25–26) stated that in September 1938 the mine had two pits: one was 50 feet long, 20 feet wide, and 10 to 30 feet deep and the other was 25 feet long, 20 feet wide, and 25 feet deep.

The Dan Patch pegmatite is intrusive into metamorphic rocks that consist in the main of micaceous schists in which the schistosity and bedding have a northerly strike and an average dip of about 55° to the east. The chief lithologic variety is a quartz-mica schist containing accessory garnet, but a distinctive unit of mica-garnet schist with euhedral garnet crystals one-eighth inch in diameter is exposed in the pit. This unit has been traced far to the north and south of the mine. In many places amphibolite separates it from quartz-mica schist on one or both sides. The greatest thickness of amphibolite near the mine is about 25 feet.

The pegmatite appears as an oval body on the geologic map. A key element of the structure, however, is the sharp roll on the north contact (fig. 112), which extends at least halfway across the pegmatite at an altitude of 4,520 feet. The geologic sections show that the roll divides the pegmatite into two nearly spherical bodies. A statement of the strike, dip, and plunge of a pegmatite of this shape has little meaning. In a broad sense, however, the pegmatite may be said to strike N. 80° W., dip 75° S., and plunge southeast at a moderate to steep angle, perhaps 70° S. 30° E.

FIGURE 112.—Schist roll in the north border of the Dan Patch pegmatite.

The dominant units in this pegmatite are three perthite-rich zones. Other units include a quartz-albite-muscovite wall zone, a quartz-albite zone that appears only in the lower part of the pegmatite, an albite-quartz-phosphate zone, and a small body of massive quartz that may be the core of the pegmatite.

The wall zone surrounds the entire pegmatite. It is only 2 to 3 feet thick in most of the surface exposure, but it may be somewhat thicker at depth. The essential minerals are gray quartz (45 percent), white to pale-pink albite (45 percent), and light-ruby muscovite (8 percent). Accessory minerals include black tourmaline, beryl, apatite, perthite, and columbite. For most of these minerals the average grain size is about 2 inches, but muscovite and perthite are commonly as much as 6 inches in the longest dimension.

In most parts of the pegmatite the wall zone is succeeded by a hood-shaped zone of perthite-quartz-albite pegmatite having an average content of about 60 percent perthite. In the west part of the open pit, the geologic map shows that this unit is separated from the wall zone by a gradational phase consisting of quartz-albite-perthite pegmatite carrying 10 to 50 percent perthite. The perthite crystals are subhedral in outline and have a pale-pink color; many contain graphic quartz. The interstitial material between perthite crystals consists mainly of quartz and albite, but muscovite and black tourmaline are also fairly common.

A zone of quartz-albite pegmatite is exposed in many places along the floor of the pit. Its outer border is mostly in contact with the wall zone, but it is also in contact with the perthite-quartz-albite and quartz-albite-perthite units. The inferred relations with these units are illustrated in the geologic sections. The perthite content probably decreases downward and inward until it forms such a small part of the rock that quartz and albite are the only abundant minerals. The perthite-rich material at the top of the pegmatite thus forms a hood, and the quartz-albite unit at the bottom of the pegmatite has a similar, but inverted, shape.

These units rich in quartz and in the two feldspars are succeeded by a zone of albite-quartz-phosphate pegmatite, in which the most distinctive feature is the presence of abundant iron-manganese phosphates in heavily stained dark-brown altered masses. The maximum observed thickness of this zone is about 10 feet. The dominant phosphate minerals are probably triphylite and heterosite, but there also are a variety of other minerals that it has not been feasible to identify. The phosphates, in aggregates and perhaps crystals as much as 3 feet across, are distributed irregularly through the zone; the intervals between are occupied mainly by quartz and albite having much the same character as in outer zones. Beryl, which commonly is associated with the phosphates, is in euhedral or nearly euhedral crystals as much as 6 feet long and 3-1/2 feet in diameter. Intergrowths of quartz, albite, and muscovite are abundant in the central part of many of the crystals. Minor minerals include muscovite, loellingite(?), pyrite, and uraninite.

Dark-brown sphalerite, intimately intergrown with small plates of muscovite, was abundant in a large pod-shaped body exposed in 1943 within the phosphate unit; some tons of the sphalerite went into the dump, and several tens of tons was sold for its scrap-mica content. This sphalerite is unusual in its extraordinarily high content of cadmium. An analysis reported by Skinner (1961, table 8) indicates that it contains, in weight percent, 1.70 cadmium, 3.12 iron, 0.02 manganese.

The phosphate-rich zone surrounds a body of quartz in the west part of the pegmatite and a body of perthite and quartz in the east part. Each of these units is centrally located, as the geologic sections show, and though their exposures are insufficient for ascertaining their shape and size in detail, they apparently are two entirely independent cores of the two segments of this pegmatite. It is likely, however, that the quartz pegmatite unit extended to the east just above the floor of the pit, that the perthite-quartz unit is a core-margin zone, and that the quartz unit is the core of the pegmatite.

The perthite-quartz zone contains about 75 percent pink perthite in subhedral to euhedral crystals as much as 5 feet wide and 18 feet long. Quartz, albite, and muscovite are the only other minerals observed in this unit. The quartz core consists almost entirely of massive milky quartz.

The potash feldspar, in all the units from which it has been mined, is nearly free of impurities, except where it carries graphic quartz. Iron stain is common only in the immediate vicinity of clay-filled fractures that cut the pegmatite. Four analyses of typical samples showed results (table 3) unexceptional in most respects. The analyses indicate that the perthite consists of about one-fourth $NaAlSi_3O_8$ and three-fourths $KAlSi_3O_8$ in molecular proportions. The 1.14 percent calcium oxide in two of the samples is far too high to be explained by the presence of anorthite or even of contaminating apatite, and it is ascribed tentatively to analytical error.

The only other minerals abundant enough to be commercially important are muscovite and beryl. The muscovite is mainly of scrap quality, though some sheet may be obtained. Some of the beryl associated with muscovite in the wall zone is recoverable by hand methods, but the large crystals in the phosphate unit are more promising as a source of beryl, though where they have abundant mineral inclusions the overall beryllium oxide content is low.

TABLE 3.—*Chemical composition of perthite from the Dan Patch pegmatite*

[Analyses by Charles Bentley, Engineering and Mining Experiment Station, South Dakota School of Mines and Technology]

Constituent	Quartz-albite-perthite zone (near center of west half of pit)	Perthite-quartz-albite zone: From north wall near center of pit	Perthite-quartz-albite zone: From north wall near east end of pit	Perthite-quartz zone (from southeast part of pit)
SiO_2	64.00	63.78	63.76	63.62
Al_2O_3	19.40	20.94	19.74	20.38
Fe_2O_3	.09	.07	.09	.09
MgO	.32	.28	.38	.20
CaO	1.14	.18	1.14	.18
Na_2O	2.76	2.74	2.92	2.90
K_2O	12.46	12.44	12.24	12.04
Total	100.17	100.43	100.27	99.41
Loss on ignition	.31	.36	.35	.38
Total	100.48	100.79	100.62	99.79

The Dan Patch feldspar mine had been nearly mined out at the time it was mapped, and even the small amount of perthite-rich pegmatite shown in the geologic sections was largely removed before the mine closed. Much of the mica and beryl, however, remains to be extracted.

DAN PATCH WEST PEGMATITE

A deposit here called the Dan Patch West pegmatite is about 400 feet west-northwest of the Dan Patch mine, in NW1/4NE1/4, sec. 7, T. 2 S., R. 6 E. At the time the pegmatite was mapped in 1947 by J. W. Adams and H. G. Stephens, it was a virtually unexplored prospect containing notable quantities of potash feldspar and beryl. Since then it has been mined at a small scale under lease from the Consolidated Feldspar Department of the International Minerals & Chemical Corp.

The pegmatite is 165 feet long, and its maximum thickness is only about 20 feet. The map and sections (fig. 113) indicate that a thin schist screen crosses the pegmatite about 50 feet from the south end and separates it into two independent segments. Each segment has a strike of about N. 10° W. and a dip of about 55° E., very nearly the same as the strike and dip of schistosity in the enclosing quartz-mica schist.

The south segment of the Dan Patch West pegmatite is a tabular body having an average thickness of only 4 feet. Throughout most of its length it consists of a

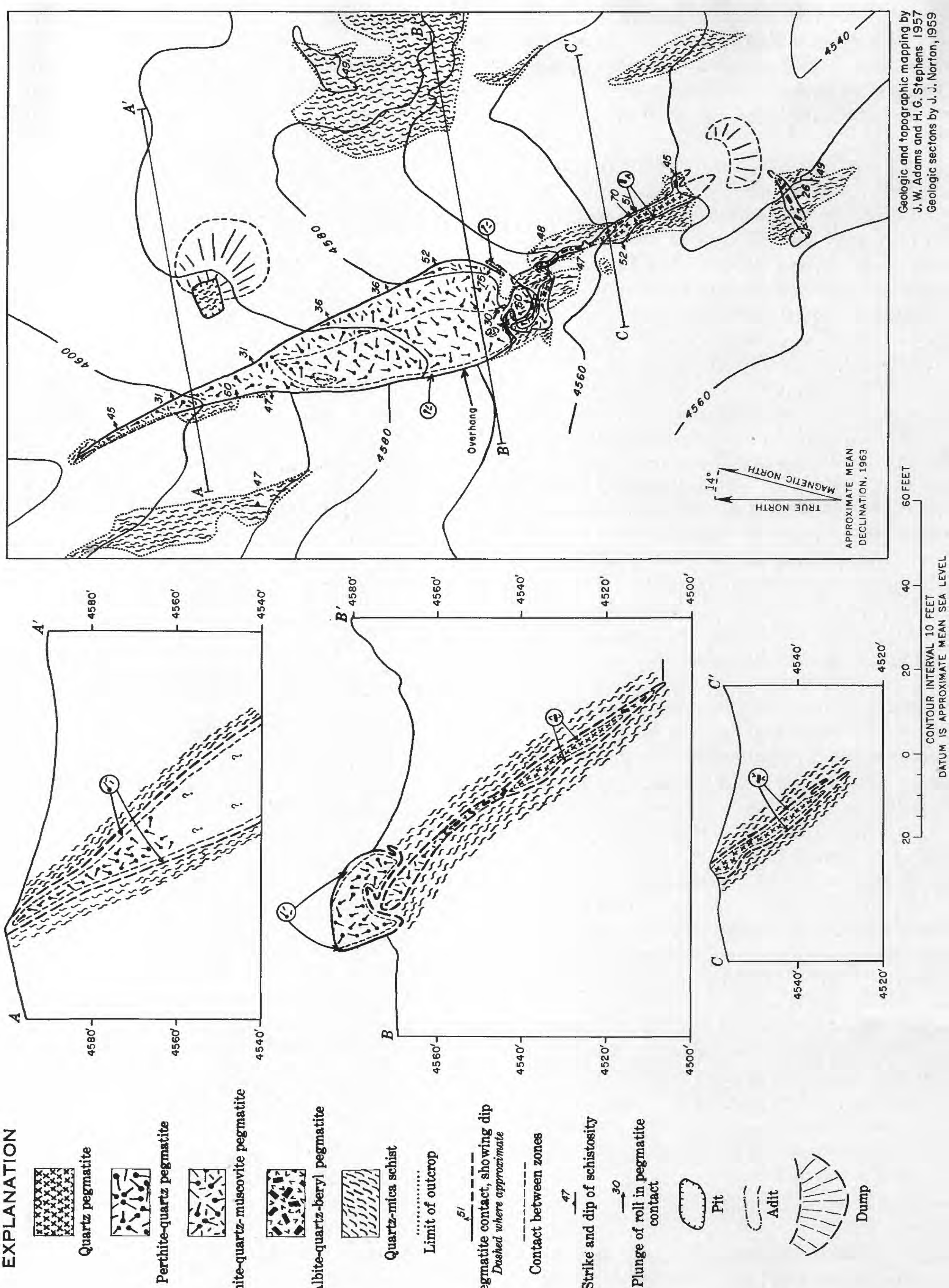

FIGURE 113.—Geologic map and sections of the Dan Patch West pegmatite, Pennington County, S. Dak.

wall zone of albite-quartz-beryl pegmatite and a quartz core. To the north, however, the albite-quartz-beryl zone grades into perthite-quartz-muscovite pegmatite. The north end of this segment plunges 30° N. 17° E., and this is presumably the plunge of the entire segment.

The north segment has a teardrop shape, the blunt end to the south and the thin end to the north. It consists predominantly of perthite-quartz pegmatite, but it also has a wall zone of perthite-quartz-muscovite pegmatite about 1 foot thick. This thin wall zone covers most of the outcrop, and the geologic sections show that the top of the outcrop is virtually the top of the pegmatite. The plunge of the top of the pegmatite, therefore, is at a gentle angle to the south-southeast, almost parallel to the existing surface. Where the north segment abuts against the north end of the south segment, its plunge presumably swings around from south-southeast to north-northeast, an attitude that is parallel to the top of the south segment.

The albite-quartz-beryl wall zone consists mainly of albite, but also has about 15 percent quartz and 4 percent beryl. Beryl forms as much as 20 percent of the rock over areas of 2 to 3 square feet. The principal accessory mineral is muscovite, but others include perthite, tourmaline, columbite-tantalite, iron-manganese phosphates, and amblygonite. The grain size is generally 1 to 2 inches.

The perthite-quartz-muscovite unit that forms the wall zone in the north segment and in the north part of the south segment contains about 20 percent muscovite; the rest is divided equally between perthite and quartz. Albite and beryl are accessory minerals.

Perthite-quartz pegmatite, appearing only in the north segment, contains about 65 percent light-buff perthite, 30 percent white quartz, and 5 percent muscovite. Most of the perthite crystals are 0.5 to 2 feet across, and the quartz is also in fairly large masses. Muscovite books, however, have an average size of only 1 to 2 inches. The few isolated crystals of beryl are less than 2 inches in diameter.

The quartz core is exposed only in the south segment, but it may also be present, though concealed, in the north segment in the locality shown with question marks in section *A–A′* (fig. 113). The quartz core contains accessory muscovite, perthite, albite, beryl, and iron-manganese phosphates in crystals and aggregates as much as 6 inches across.

Potash feldspar and beryl are the only economic products of significant value recoverable from this pegmatite. A moderate quantity of high-grade potash feldspar can be obtained by hand sorting from the perthite-quartz zone of the north segment.

Beryl is mainly in the wall zone of the south segment. This unit is small in size, and much of the beryl is in crystals that are too small for hand cobbing. As table 4 shows, however, the percentage of beryl is unusually high, especially on the hanging-wall side of the pegmatite.

Whether a significant quantity of beryl can be found in the north segment is uncertain. Only about 0.1 percent beryl was observed in existing exposures.

TABLE 4.—*Beryl content of the albite-quartz-beryl wall zone of the south segment, Dan Patch West pegmatite*

[Determined from grain measurements by J. W. Adams and H. G. Stephens]

Location	Area measured (sq ft)	Beryl crystals	Area of beryl (sq ft)	Percent beryl
Hanging-wall side	8.1	60	0.657	8.1
	1.8	9	.059	3.3
	1.5	7	.039	2.6
	1.0	17	.309	30.9
Subtotal or average	12.4	93	1.064	8.6
Footwall side	12.0	11	0.095	0.8
Both sides (at places where quartz core is absent)	17.0	53	0.354	2.1
	16.0	41	.541	3.4
	3.8	11	.288	7.6
Subtotal or average	36.8	105	1.183	3.2
Total or average	61.2	209	2.342	3.8

DIAMOND MICA PROSPECT

The small pegmatite here called the Diamond Mica is one of several 1 mile south of Keystone to which this name has been applied. Diamond-shaped crystals of muscovite, abundant at the margin of the quartz core of the pegmatite, presumably were the reasons for the name. The geologic map in figure 114 was made by pace and compass methods during the course of a brief examination of the property by Norton and R. E. Burns in 1948.

Prospecting and mining at this locality have been so meager that only a few very small openings have been made. Scrap mica has probably been the chief economic product.

The pegmatite is an irregularly lenticular body about 145 feet long and as much as 55 feet thick. Despite the many rolls in the contact, which give an appearance of complexity, the pegmatite is a structurally simple body that strikes N. 45° E. and dips steeply to the west. The overall plunge is probably about 60° N. 30° E., but the exact amount is difficult to infer, because most of the rolls shown on the map are near the top of the body, where the plunges are unusually low, or they are in places where the contact dips to the southeast and the plunge swings around eastward.

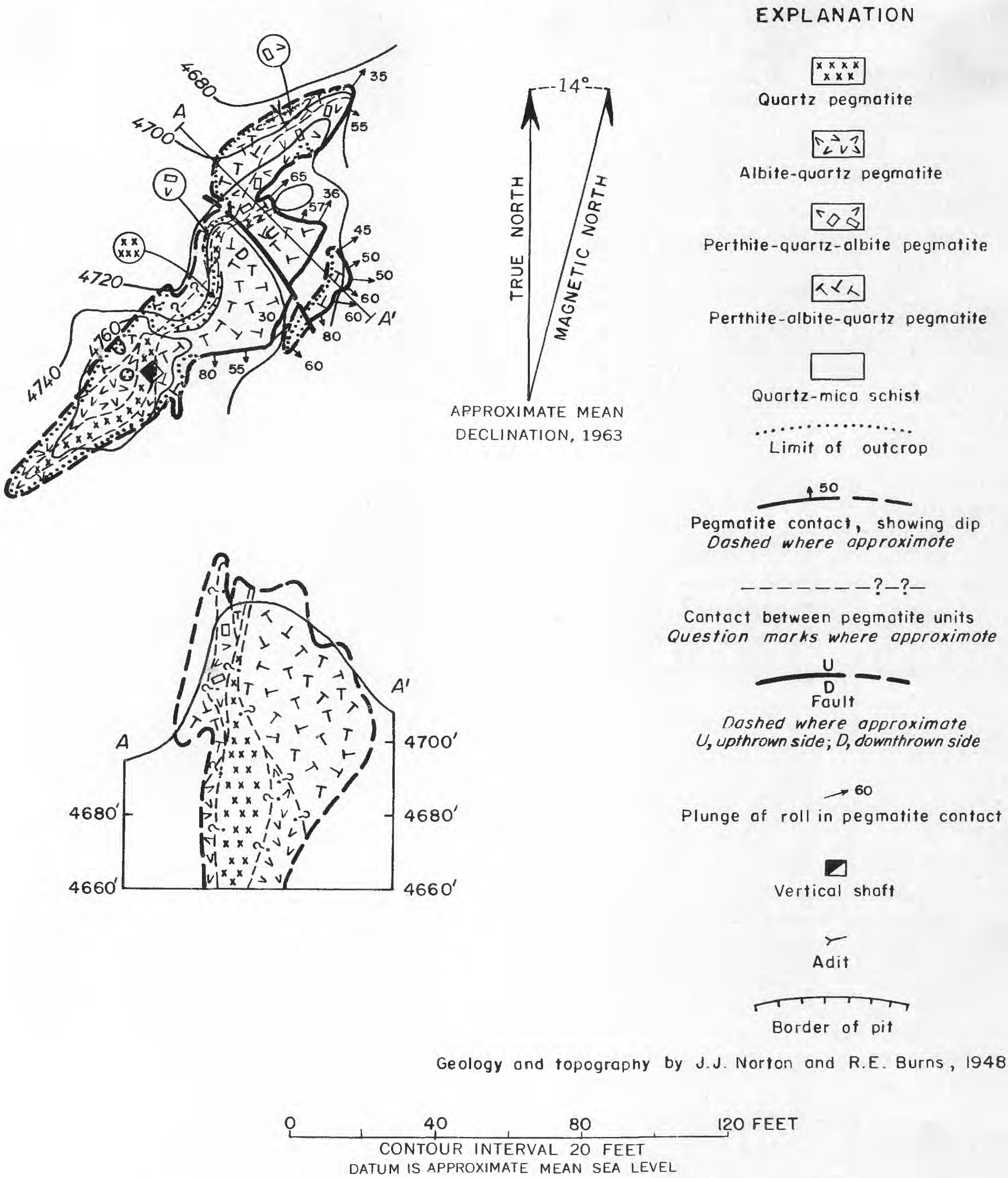

FIGURE 114.—Geologic map and section of the Diamond Mica pegmatite, Pennington County, S. Dak.

The country rock exposed in nearby areas is entirely quartz-mica schist similar to that at the Monte Carlo prospect to the north and the Etta mine to the northeast. No schist is exposed in the area shown on the map except where it appears as a veneer along the border of pegmatite outcrops.

The outermost unit of the Diamond Mica pegmatite is a border or very thin wall zone of albite-quartz-muscovite pegmatite less than 0.5 foot thick. Next is a perthite-albite-quartz pegmatite unit that is exposed mainly in the northeast half of the pegmatite, where it is hood-shaped and lies above the inner zones. Toward the inner part of this hood, the increase in the quartz content and the decrease in the albite content give rise to the perthite-quartz-albite zone exposed near the northeast end of the pegmatite. Toward the southwest, in the structurally lower parts of the pegmatite, the perthite content diminishes greatly, and albite-quartz pegmatite can be mapped as a separate unit underlying the perthite-rich hood. The quartz core exposed in the center of the pegmatite has a maximum thickness of about 5 feet at the surface, but it may be thicker at depth. Muscovite is very abundant adjacent to the core; it forms 90 percent of the rock for a thickness of 4 inches at the edge of the quartz core in the main pit.

A small fracture filling of quartz extends from the core north to the contact of the pegmatite. It is displaced, however, by the small, steeply dipping fault that crosses the pegmatite near the north end of the core, and the structural relations in the faulted area are not clearcut in all respects.

The concentration of muscovite at the margin of the quartz core seems to have been the chief stimulus to prospecting in this pegmatite. The muscovite is suitable mainly for scrap mica; the yield of sheet from this mica would be very small. Potash feldspar probably could be mined from the perthite-rich hood exposed in the northeast part of the pegmatite.

ETTA SPODUMENE MINE

The Etta pegmatite, through the fame of its unusually large spodumene crystals (fig. 115) and its standing for many years as the chief source of the world's lithium, is the most widely known of the Black Hills pegmatites. It is in the NW1/4 sec. 16, T. 2 S., R. 6 E., about 1 mile south of Keystone.

Though the earliest mining of the Etta pegmatite seems to have been for sheet mica shortly after 1880, the first important stimulus to work at this pegmatite was a consequence of the discovery in 1883 that it contains tin (Headden, 1890, p. 347; 1906, p. 169; O'Harra, 1902, p. 66). In the years immediately thereafter, this pegmatite was one of the chief properties worked during the unsuccessful effort to establish a tin-mining industry in the Black Hills (Connolly and O'Harra, 1929, p. 263; South Dakota State Planning Board, 1936, p. 1, 4). The presence of spodumene was known at least by 1884 (Blake, 1885a, p. 606), and the start of mining for it in 1898 is regarded as the beginning of lithium mining in the United States (Schaller, 1919, p. 7). Reinbold & Co. of Omaha, Nebr., worked the property until 1905, when it was purchased by the Maywood Chemical Co. of Maywood, N.J. (Connolly and O'Harra, 1929, p. 240), which was still the owner in 1960. Spodumene mining continued

FIGURE 115.—Large spodumene crystals (*S*) in a matrix that is mainly quartz (*Q*), Etta pegmatite. Hammer in lower left is on a spodumene crystal.

for 62 years with only short interruptions during periods of low demand. For a great part of this time the Etta mine was the main source of spodumene in the world, but when much larger deposits came into production, especially in the 1950's, its importance waned. The mine was closed on April 29, 1960, though reserves of spodumene still remain below the main adit level.

The Etta pegmatite has been mentioned widely in geologic literature. The chief references are by Schwartz (1925), Landes (1928, especially p. 525–527), Connolly and O'Hara (1929, p. 240–245), and Stoll and Page (1953, p. 118). No one, however, has made a complete study of its structure, mineralogy, and petrology. Fieldwork in 1945 by L. R. Page and J. B. Hanley, on which the present description is based, was intended to be the beginning of extensive detailed work, including periodic remapping of the mine workings. Unfortunately, however, there was no opportunity to complete this work, and the account of the geology contained herein is based only on the field study in 1945 and on brief, though frequent, visits to the mine between 1939 and 1960, especially by Page and Norton.

Mining was mainly by the glory-hole method by way of the main adit at an altitude of 4,585 feet (pl. 25) and in early years from adits at higher levels. Open-pit methods doubtless were also used at the start of mining, when the pegmatite projected above the surrounding ground surface to form what was known as the Etta Knob. The dumps shown on plate 25 were made during mining at these higher levels; the later dumps lie to the west of the area shown in this plate.

Development work on the level at an altitude of 4,520 feet, 65 feet below the floor of the glory hole, apparently was done sporadically in the 1920's and 1930's (Schwartz, 1925, fig. 2; 1937, p. 303). Not much ore was extracted from these workings until 1944, but in the years since then, a great part of the spodumene-rich pegmatite between the two levels has been mined. Furthermore, nearly all the spodumene that remained above the adit level has been extracted. In order to develop another level, 65 feet greater in depth, a second inclined shaft (not shown on pl. 25) was sunk in 1957–58. This shaft, collared in the southwest part of the glory hole, is in the footwall of the pegmatite. Though the shaft was completed, no further work to develop the new level was ever done.

GEOLOGY

The Etta pegmatite has approximately the shape of an inverted teardrop plunging steeply to the north (pl. 25). The country rock is quartz-mica schist, in large part massive and rich in quartz, but in places carrying enough mica to be noticeably schistose. Both bedding and schistosity strike for the most part between north and northeast and dip steeply to the east, but immediately adjacent to the pegmatite the schistosity and the contact are commonly parallel to each other.

Much of the schist near pegmatite has been altered to a granulite having a more or less equigranular texture but containing relicts showing the schistosity. The granulite consists predominantly of feldspar and quartz, but also has varying amounts of mica and minor apatite and tourmaline. The most extensive granulite is along the south border of the pegmatite, where a thickness of 10 feet is common and the maximum thickness may exceed 20 feet. At other Black Hills pegmatites, it has been noted that altered wall rock is most abundant along crosscutting contacts, where fluids presumably had ready access to the country rock along planes of schistosity (Page and others, 1953, p. 17; Sheridan and others, 1957, p. 5). At the Etta one further step is apparent: the intricate structural relations with schist along the south contact of the pegmatite, where many offshoots of pegmatite cut the country rock as fracture fillings or more irregular bodies, show that the formation of thick granulite at this locality was accompanied by extensive invasion of the schist by pegmatite fluids. Relicts of deformed schistosity are well preserved in granulite exposed in the uppermost adit.

Even where granulite is absent, the schist may be in part altered. The most common effect is the addition of abundant tourmaline. Less common is the presence of microcline metacrysts as much as 1 inch long, as in the schist outcrop 85 feet south of the Etta pegmatite.

Altered relicts of schist are present even in the outermost unit of the Etta pegmatite itself and in the exposed parts of the dike 60 feet to the south. The mixed rock thus formed, which consists of both microcline-rich pegmatite and remnants of schist, is unlike any other rock previously reported in the Black Hills.

The mixed rock in the dike of microcline-quartz-biotite pegmatite that lies to the south carries abundant granulitic material accompanied by metacrysts of biotite and coarse pegmatitic microcline and quartz. In general the pegmatite material is more abundant in the central part and along the north side of this body, and the granulitic relicts of schist are more abundant along the south side. The rock as a whole is similar to some of the granulite that is cut by pegmatitic streaks in the footwall of the Etta pegmatite.

A somewhat different variety of mixed rock forms the unit of microcline-biotite pegmatite that lies along the north and east sides of the Etta pegmatite. The maximum thickness is about 12 feet. Though this unit varies greatly in composition and texture, it generally contains abundant microcline surrounding irregular patches of granulitic material in which biotite is a conspicuous constituent. Microcline is by far the most abundant mineral (table 5). Crystals are as much as 6 inches long, and they are nonperthitic in the surface exposures. In contrast, they rarely exceed 2 inches in length and commonly are perthitic on the lower level, though one crystal on this level had dimensions of 5 by 6 feet. Quartz is generally a minor constituent, but a few parts of the unit with sparse biotite have more quartz than feldspar. Muscovite and tourmaline are accessory minerals.

TABLE 5.—*Modes, in percent, Etta pegmatite*

[By visual estimate of surface exposures, supplemented by the measurements of spodumene content reported in table 6]

Unit	Quartz	Albite	Perthite and microcline	Spodumene	Muscovite	Biotite	Tourmaline
Microcline-biotite pegmatite	10	-------	70	-------	2	15	3
Quartz-muscovite-albite pegmatite	60	15	2	3	20	------	<1
Perthite-quartz-spodumene pegmatite	25	10	50	10	5	------	-------
Quartz-cleavelandite-spodumene pegmatite	35	35	1	25	3	------	-------
Quartz-spodumene pegmatite	70	1	3	25	1	------	-------
Quartz pegmatite	99	<1	-------	<1	<1	------	<1

The second unit of the Etta pegmatite is a medium-grained quartz-muscovite-albite zone that is ordinarily between 1 and 5 feet thick, but ranges from as little as 0.5 to as much as 10 feet. It resembles the wall zones of many Black Hills pegmatites, but is unusual in that it carries more muscovite than albite and is very rich in quartz (table 5). Accessory minerals include perthite, spodumene, iron-manganese phosphates, beryl, and tourmaline. The phosphates were observed mainly on the north wall of the glory hole.

A series of three large spodumene-bearing zones, which contain most of the rock in the pegmatite, succeed the quartz-muscovite-albite zone. The first of the three is perthite-quartz-spodumene pegmatite. On the maps this zone is shown only along the north wall of the glory hole and near the east end of the adit, but apparently it originally formed a hood-shaped unit lying, for the most part, above the adit level and extending upward to the outcrop of the pegmatite. Beneath the hood lies the quartz-cleavelandite-spodumene zone, which is trough shaped in form. These two zones, in which feldspar accompanies the quartz and spodumene, surround a zone of quartz-spodumene pegmatite, and it in turn surrounds the quartz core.

Perthite is the dominant mineral in the perthite-quartz-spodumene zone, and it also forms the largest crystals—some as much as 15 feet long. Perthite surrounds spodumene crystals, and the matrix enclosing the perthite is mainly quartz. Spodumene crystals, commonly several feet long, make up about 10 percent of the zone (table 5). Beryl, though rare in present exposures, is so abundant in the old dumps that it may have formed as much as 3 percent of the upper part of this unit.

The quartz-cleavelandite-spodumene zone is widely exposed in the mine workings. The spodumene forms a network in which each spodumene crystal seems to be attached to one or more of the nearby spodumene crystals. Crystals that are not attached at both ends commonly have crystal faces on the end toward the center of the pegmatite. Sheaths of cleavelandite surround the spodumene crystals, and the remaining space not filled by these minerals is occupied by quartz. Similar textural relations have been interpreted at the Hugo pegmatite (Norton and others, 1962, p. 76–77) as meaning that the spodumene crystallized first, the cleavelandite then formed around the spodumene crystals, and finally the quartz filled the interstices. This interpretation requires the supposition that the network of spodumene, surrounded by fluid, was able to support itself (Jahns, 1953, p. 594). A contrary view—that this texture means that the spodumene formed by replacement in a solid media—has been expressed by Hess (1925, p. 295).

The average spodumene content of the quartz-cleavelandite-spodumene zone is about 25 percent (table 5). A content of 75 percent is common in the southeast part of the pegmatite above the adit level, where for a 9-month period the average ratio of spodumene to waste was 3:1 (Dewey Peterson, oral communication, 1945). On the other hand, detailed measurements of exposures in the lower level indicate a content of 22.1 percent spodumene (table 6).

TABLE 6.—*Spodumene content, in percent, east half of lower level (altitude 4,520 feet), Etta pegmatite*

[Determined by measuring exposed spodumene crystals and casts of crystals]

Spodumene	North drift	East drift	South drifts	Total or weighted average
Quartz-cleavelandite-spodumene zone				
Area .... square feet	323	756	820	1,899
Fresh spodumene	17.0	14.8	22.3	18.4
Altered spodumene	.4	.7	.2	.4
Casts of spodumene	5.4	3.1	2.5	3.2
Total spodumene content	22.8	18.6	25.0	22.1
Quartz-spodumene zone				
Area .... square feet	866	539	338	1,743
Fresh spodumene	17.0	15.6	12.0	15.6
Altered spodumene	1.5	.3	1.8	1.2
Casts of spodumene	3.2	8.1	4.2	4.9
Total spodumene content	21.7	24.0	18.0	21.7

Among the other minerals of this zone, quartz and cleavelandite are by far the most abundant, each forming about 35 percent of the rock. The cleavelandite plates in the sheaths surrounding spodumene crystals are perpendicular to the crystal borders of the spodumene; at their other ends the cleavelandite plates project into the interstitial quartz and have crystal faces against the quartz. Additional minerals include microcline and muscovite, and small quantities of beryl, tourmaline, apatite, cassiterite, tantalite, uraninite, and torbernite. Muscovite is most abundant along contacts between spodumene and cleavelandite. The beryl is yellowish white to pure white; in some of it the cleavage can be detected megascopically.

The quartz-spodumene zone, which is the innermost of the spodumene-bearing units, has many similarities to the feldspar-bearing spodumene zones, but it contains less than 5 percent of either cleavelandite or perthite. Measurements in the lower level of the mine indicate a content of 21.7 percent spodumene (table 6), but elsewhere the zone is somewhat richer. Probably the average content is about 25 percent spodumene (table 5). The largest spodumene crystals now exposed in the mine are in this zone: one crystal is at least 23 feet long, and the ends are not exposed; many crystals are more than 2 feet thick. The largest recorded crystal, having an exposed length of 47 feet (Schaller, 1916, p. 138), and other crystals reported to be nearly as large (Blake, 1885b; Hess, 1911, p. 651; Ziegler, 1914, p. 655; and Schaller, 1919, p. 8–9) probably also came from this unit. Quartz is virtually the only mineral occupying the interstices of the spodumene network. In a few places quartz veinlets cut across spodumene crystals. Accessory minerals include microcline, cleavelandite, muscovite, and very small quantities of cassiterite and stannite. The stannite forms masses as much as 2 feet across.

Part of the spodumene in each of the spodumene-bearing zones is altered to white, green, or red aggregates of clay and micaceous minerals. This alteration is more common in the outer units, where some crystals have been almost entirely replaced. A sample of such material contained only 0.19 percent Li_2O according to an analysis by Charles Bentley of the Mining Experiment Station, South Dakota School of Mines. In the larger crystals, which commonly have oval cross sections, the outer part for a thickness of as much as 6 inches consists of altered material, and the center is fresh spodumene with only a few veinlets of alteration products, mostly along cleavage planes. Alteration is generally less evident in the quartz-spodumene zone than in the other units, yet the outer borders of nearly all crystals have been partly replaced, and the ends of crystals that project into the quartz core have been almost entirely altered. The chemistry and mineralogy of the various alteration products were discussed by Schwartz and Leonard (1926), who ascribed the origin chiefly to meteoric solutions, and later by Schwartz (1937), who then favored a hydrothermal origin. The highly selective nature of this process, affecting only spodumene, and the universal presence of its effects in other Black Hills spodumene pegmatites suggest that the process is a normal part of the crystallization of these rocks, and not a separate episode involving solutions formed at a later time. The observations at the Etta are in accord with a process in which the spodumene is altered by reaction with the rest liquid during the primary crystallization of the pegmatite. The lithium given up during the alteration may have been used again in making spodumene crystals that formed later in other parts of the pegmatite.

The spodumene-bearing zones surround the quartz core of the pegmatite. The core consists of massive quartz and only minor accessory minerals, including muscovite, cleavelandite, spodumene, and tourmaline. The quartz is slightly iron stained.

The unit of muscovite pegmatite exposed on the northwest wall of the glory hole may be of replacement origin. The evidence is inconclusive, for it contains no readily identifiable relicts of previously solidified rock. Nevertheless, it contrasts markedly with the surrounding quartz-cleavelandite-spodumene pegmatite. The dominant mineral is muscovite, occurring as aggregates of yellowish flakes as much as 1-1/2 inches wide, associated with albite and quartz. Cassiterite and tantalite are common accessory minerals; Blake (1885a, p. 606–610) described rock of this sort as being the source of the tin obtained from this pegmatite in the 1880's.

MINERAL DEPOSITS

Spodumene has been much the most important economic mineral in the Etta mine. Other products, all minor, have been potash feldspar, scrap mica, and beryl. Despite the early interest in the cassiterite in this deposit, only a few tons were produced (South Dakota State Planning Board, 1936, p. 4).

The spodumene has been recovered entirely by hand sorting, made possible by the extraordinarily large size of the crystals. Figure 116, showing the dimensions of crystals exposed in the east part of the lower level, indicates the great abundance of crystals that are 1 to 2 feet long, and it also shows that crystals 2 to 7 feet long are fairly common. Larger crystals are only occasionally observed. Figure 10 also shows a very great similarity in the pattern of size distribution of crystals in the quartz-cleavelandite-spodumene and the quartz-spodumene zones.

The diamond-drill holes logged in table 7 indicate that the spodumene-rich units extend downward at least to an altitude of 4,455 feet (pl. 25). The size of the pegmatite diminishes at such a rate, however, that the spodumene-rich units are unlikely to extend more than 100 feet below this depth.

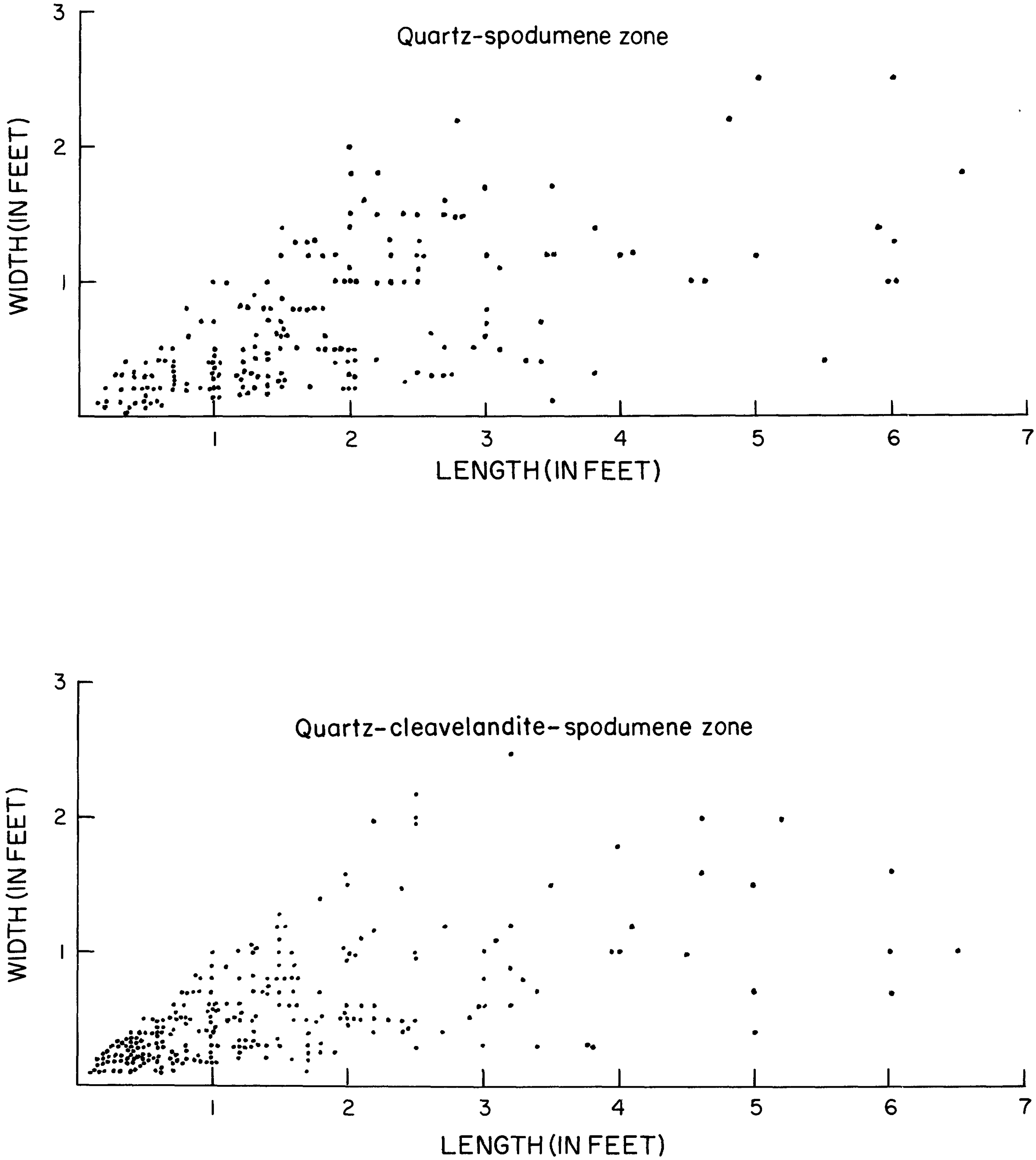

FIGURE 116.—Dimensions of exposed spodumene crystals in the east half of the lower level (alt. 4,520 ft), Etta pegmatite.

TABLE 7.—*Logs of diamond-drill holes, Etta pegmatite*

[Locations of holes are shown on the map of the lower level in pl. 25. Core recovery very low in all holes]

HOLE 1

[Direction: N. 11° E.; inclination: −43½°]

Depth (feet)	*Description*
0–25	Very coarse quartz and spodumene.
25–50	Quartz, albite, and spodumene.
50–55	Albite, quartz, and muscovite.
55–60	Muscovite, spodumene, quartz, and albite.
60–63	Albite and microcline.
63–66	Granulite.
66–67	Microcline-biotite pegmatite.
67–68	Granulite.
68–88	Microcline-biotite pegmatite.
88–96	Granulite.

HOLE 1s

[Direction: S. 1° E.; inclination: 0°]

Depth (feet)	*Description*
0–46	Granulite grading into quartz-mica schist.
46–80	Quartz-mica schist with metacrysts of biotite and microcline.

HOLE 2

[Direction: N. 39° E.; inclination: −45°]

Depth (feet)	*Description*
0–52	Quartz and spodumene.
52–62	Albite, spodumene, and quartz.
62–69	Muscovite and quartz.
69–81	Microcline-biotite pegmatite.
81–83	Granulite.
83–89	Quartz, microcline, and cleavelandite.
89–102	Mainly microcline, but 5 to 10 percent albite and quartz, and minor tourmaline and muscovite.
102–110	Biotite-quartz schist.

HOLE 2s

[Direction: S. 50° W.; inclination: −2°]

Depth (feet)	*Description*
0–5	No core.
5–11. 5	Granulite with thin pegmatite stringers.
11. 5–17. 5	Microcline, biotite, and muscovite.
17. 5–53	Granulite.
53–70	Quartz-mica schist with metacrysts of biotite and microcline.
70–74	Microcline-quartz-biotite pegmatite as on the surface southeast of the open cut.
74–80	Quartz-mica schist with metacrysts of biotite and microcline.

HOLE 3

[Direction: N. 55° W.; inclination: −43°]

Depth (feet)	*Description*
0–4	Quartz.
4–13.5	Quartz and albite.
13. 5–30	Quartz.
30–40	Albite, spodumene, and quartz.
40–75	Quartz (60–70 percent), albite and muscovite.
75–90	Granulite.
90–95	Quartz-mica schist.

HOLE 3A

[Direction: N. 56° W.; inclination: 0°]

Depth (feet)	*Description*
0–3	Spodumene, albite, and quartz
3–8	Granulite.

TABLE 7.—*Logs of diamond-drill holes, Etta pegmatite*—Continued

HOLE 4

]Direction: S. 65° E.; inclination: −45°]

Depth (feet)	*Description*
0–7	Quartz.
7–94	Quartz (35 percent), albite (35 percent), and spodumene (30 percent).
94–102	Albite, quartz, and muscovite.
102–109	Granulite.

HOLE 5

[Direction: S. 18° E.; inclination: −46½°]

Depth (feet)	*Description*
0–48	Quartz, albite, spodumene, and minor muscovite.
48–52	Quartz, albite, and muscovite.
52–53	Granulite.
53–64	Muscovite, albite, and tourmaline.
64–70	Quartz and spodumene.
70–71	Granulite.
71–89. 8	Quartz, muscovite, and tourmaline.
89. 8–90	Granulite.

EUREKA FELDSPAR AND BERYL PROSPECT

The Eureka pegmatite is a small but promising prospect for potash feldspar and beryl in the SW1/4-SE1/4 sec. 15, T. 2 S., R. 6 E., about 2-1/2 miles southeast of Keystone. The property is held by the heirs of George M. Madill of Keystone. The geology was mapped by R. E. Roadifer and J. E. Roadifer in the fall of 1953 in conjunction with a diamond-drilling program of the U.S. Bureau of Mines. At the time of this work, the pegmatite contained only a few prospect pits, but a small amount of mining has been done since then.

The country rock consists of quartz-mica schist, which is rarely exposed in the immediate vicinity of the pegmatite (pl. 26) but forms many outcrops in the surrounding area. The attitudes of foliation and bedding are variable; generally the dip is at a low or moderate angle to the southeast, but less commonly it is to the southwest. The schist contains small quantities of garnet, staurolite, sillimanite, and tourmaline, but much of the staurolite and sillimanite have been pseudomorphically altered to aggregates consisting largely of muscovite. At many places within 1 to 3 feet of the pegmatite, the wall rock contains abundant albite, tourmaline, and apatite.

High-level gravel, like that mapped southwest of the pegmatite, is uncommon in this area. This gravel is presumably of Quaternary age.

The pegmatite is a pipe-shaped body having a plunge of about 20° east-southeast, which is very nearly parallel to the present surface. In cross section the pegmatite has a thick lenticular form, and it dips to the northeast (sections *A–A′*, *B–B′*, and *C–C′*, pl.

26). In a direction parallel to the plunge, however, the shape resembles a teardrop (section *D–D′*, pl. 26). The maximum length of the exposure is 420 feet. In cross section, the greatest dimensions are about 80 by 125 feet.

The pegmatite is surrounded by a fine-grained border zone, ordinarily only about 1 foot thick, that consists of albite-quartz-muscovite pegmatite. Accessory constituents include tourmaline, apatite, garnet, and beryl.

The wall zone is a 4-foot-thick unit of quartz-albite-muscovite pegmatite. It covers nearly all the southeastern part of the outcrop, forming a veneer that conceals the inner units of the pegmatite. The dominant minerals are quartz (45 percent), albite (40 percent), and muscovite (10 percent). Other minerals include perthite (2 percent), beryl (0.2 percent), apatite, garnet, tourmaline, graphite, and pyrite. Tourmaline is much more sparse than in wall zones of most other Black Hills pegmatites. The perthite of this zone is mostly near the northwest end of the pegmatite. Most of the minerals of the wall zone have an average grain size of about one-half inch, but perthite and beryl are as much as 3 inches long.

An intermediate zone of perthite-quartz-albite pegmatite is conspicuous in the eastern part of the pegmatite, but lenses out to the west. It contains pink to grayish-pink perthite crystals, 2 to 6 inches across, in a finer grained matrix consisting mainly of quartz and albite but also having muscovite, tourmaline, graphite, and beryl. Some of the perthite contains abundant inclusions or intergrowths of muscovite.

The innermost exposed zone is of perthite-quartz pegmatite, which is mainly in the thick western part of this body (section *D–D′*, pl. 26). In addition to perthite (65 percent) and quartz (30 percent), the zone contains muscovite, albite, beryl, tourmaline, and graphite. The average length of perthite crystals is about 2 feet, but some are as much as 6 feet long. Graphite and muscovite are distributed along cleavage planes in the perthite. Several white to green beryl crystals, ranging from 6 to 18 inches in length, have been found during mining.

A small pod or fracture filling of quartz pegmatite cuts the wall zone near the footwall of the pegmatite just east of section B–B′. Perhaps it is an offshoot of a concealed quartz core.

The diamond drilling was designed mainly to determine whether the pegmatite extends downward any farther than could reasonably be inferred from the structure mapped at the surface. Hole 1 (section *C–C′*) was drilled with the hope that, despite the evidence to the contrary, it would cut the pegmatite rather than pass beneath it. Inasmuch as the hole missed the pegmatite entirely, even though drilled at an angle of only 30°, it effectively dispelled any likelihood that the bottom of the pegmatite is far beneath the surface. Holes 2 and 3 cut the keel of the pegmatite. These in conjunction with hole 1 indicate that the keel has a very gentle plunge and that the pegmatite thins greatly to the east, in the manner shown in section *D–D′*. The pegmatite is so unlikely to continue down plunge a significant distance to the east of present exposures that no further drilling seemed warranted. Additional drilling could also have been done to establish the size and nature of the inner units of the pegmatite, but more precise data than that contained in the geologic sections would be of little value. Analogy with other Black Hills pegmatites indicates that the unpatterned areas in the geologic sections are probably inner zones consisting mainly of quartz and albite, but possibly containing small quantities of minerals of economic value.

The chief economic mineral is the potash feldspar in the perthite-quartz zone. Much of the potash feldspar has inclusions of graphite, which may adversely affect its value. Beryl crystals large enough for hand sorting can also be recovered from the perthite-quartz zone, but the beryl crystals in outer units are too small to be recovered in this way. The muscovite of the Eureka pegmatite is marketable mainly as scrap mica.

EXPECTATION FELDSPAR AND SPODUMENE PROSPECT

The Expectation pegmatite, in the SE1/4NE1/4 sec. 16, T. 2 S., R. 6 E., has been worked on a small scale for feldspar, and it also contains spodumene. Most of the mining was in a pit 75 feet long and 25 feet wide on the east side of the pegmatite. The owners are Mrs. Mary H. Champion and Mrs. Olive M. Brown of Rapid City.

This deposit was mapped by J. A. Redden and J. E. Roadifer in 1954, and at that time the U.S. Bureau of Mines drilled one diamond-drill hole (fig. 117).

The pegmatite exposure has a length of 210 feet and an average width of 50 feet. The contact has a moderate to steep dip wherever it is exposed: the only dip measured on the east side is 78° E. and the dip on the west side ranges from 54° to 65° W. The plunge is unknown, but the rounded form of the pegmatite indicated in section *A–A′* (fig. 11) suggests that it may be a nearly horizontal pipelike body.

The wall zone consists of quartz-albite-muscovite pegmatite that for the most part is 3 to 5 feet thick. In surface exposures this zone is succeeded by an intermediate zone of quartz-perthite-albite pegmatite. At depth, however, the drill hole cut a thick unit of

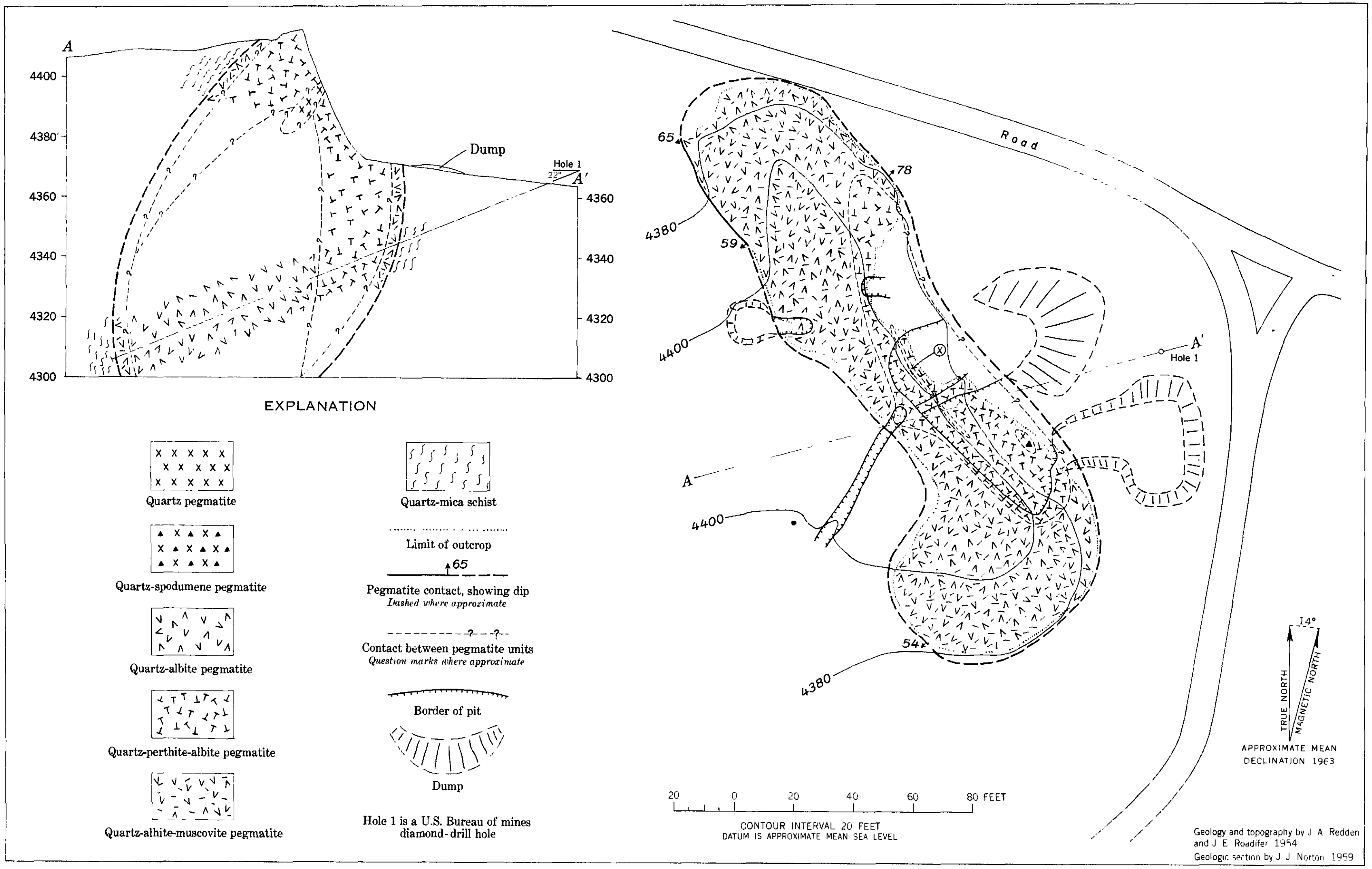

FIGURE 117.—Geologic map and section of the Expectation pegmatite, Pennington County, S. Dak.

quartz-albite pegmatite in a position that suggests that the perthite is in a hood-shaped unit overlying quartz-albite pegmatite in the manner shown in section *A–A′* (fig. 117). The main open pit also contains a thin unit of quartz pegmatite and a small exposure of quartz-spodumene pegmatite. Each of these may be a fracture filling rather than an inner zone, but even so there may well be inner zones of the same composition in the area shown unpatterned on section *A–A′*.

The diamond-drill hole had two purposes: to find the position of the pegmatite at depth and to search for a spodumene-bearing zone. Unfortunately, the core recovery was so low that any conclusions from this hole must be regarded as tentative. Even the position of the east contact of the pegmatite is in some doubt, because from 0 to 55 feet only small fragments of core were obtained. Spodumene was not found anywhere in the hole, but inasmuch as in some places no core was recovered for distances of as much as 6 feet, some spodumene may well be present. A more important point is that no evidence from the drilling indicates the presence of a large unit of spodumene-bearing pegmatite. The drilling does, however, demonstrate that the quartz-perthite-albite zone extends downward as a sizable unit that may be mined for potash feldspar.

HOT SHOT FELDSPAR AND MICA MINE

The Hot Shot pegmatite, about 4 miles east-southeast of Custer, near the center of the W1/2 sec. 34, T. 3 S., R. 5 E., has been a significant source of both potash feldspar and sheet mica. The only published description of the geology is by Norton (1953b), who made a brief study of the deposit in 1943 in conjunction with more intensive work on the nearby Elkhorn pegmatite. Mining prior to that time had been chiefly for feldspar. Probably most of the mining in the open pits shown on the geologic map (pl. 27) was done in the 1930's. Subsequently the sheet mica in the deposit attracted the interest of the Custer Mining Account. In 1945 this company leased the property from Robert McRobbie, and in 1947 purchased it outright. Custer Mining Account worked the deposit for mica in 1946 and 1947, partly in the open pits, but mainly in the vertical shaft, which was sunk to a depth of 55 feet, and in the underground workings at an altitude of 5,090 feet. After the end of mica mining in 1947, the property was again mined for potash feldspar, chiefly in the early 1950's by the Consolidated Feldspar Department of the International Minerals & Chemical Corp.

The U.S. Bureau of Mines diamond drilled the Hot Shot pegmatite in 1947, and in 1948 explored it further by deepening the shaft 50 feet and driving crosscuts from the base of the shaft to each wall of the pegmatite (section *B–B′*, pl. 27). A published description of this work (Needham, 1950, p. 37–54) contains preliminary geologic sections and logs of the drill core prepared by L. R. Page.

The report on the Hot Shot pegmatite presented here is mainly an account of the geologic work that accompanied the Bureau of Mines exploration. The geologic map in plate 27 is a moderately revised version of a previously published map (Norton, 1953b, pl. 16). The geologic sections of the drill holes are based on Page's drill logs. D. B. Stewart and H. G. Stephens made the detailed studies of the geology and mineral distribution in the underground workings that are the basis for plates 28 and 29.

GEOLOGY

The Hot Shot pegmatite as exposed at the surface (pl. 27) has a slender elliptical form; the length is about 620 feet, and the maximum thickness is about 90 feet. The strike is N. 85° E., and the average dip is about 55° N. Sections *B–B′* and *C–C′* indicate a steepening of the dip near the surface, which gives the pegmatite a crescent shape, concave upward. Plunges are for the most part between 15° and 30° ENE.

The main body of the Hot Shot pegmatite is joined near its east end by another pegmatite, a narrow northwest–trending body that dips about 60° to the southwest. This narrow pegmatite crosscuts the enclosing quartz-mica and quartz-mica-sillimanite schist, whereas the main pegmatite is virtually conformable. To the northwest, the crosscutting body joins the Elkhorn pegmatite, as shown by Norton (1953b, pl. 16). The crosscutting body consists throughout its length of an almost homogeneous aggregate of perthite, quartz, and albite, having no apparent commercial value.

The Hot Shot pegmatite contains six zones and it also has aggregates of cleavelandite-lithia mica-quartz pegmatite that may belong to a replacement unit. The average mineral composition of these units in the underground workings is shown in table 8, and similar data from the drill holes are in table 9.

The wall zone consists of albite-quartz-muscovite pegmatite that in many places is only 1 to 3 feet thick, but attains a maximum thickness of at least 8 feet. Medium-grained platy to blocky albite and irregularly shaped quartz are intimately interlocked. Muscovite is in books as much as 12 inches long, 10 inches wide, and 4 inches thick. The content of muscovite is greatest adjacent to the schist contact, and decreases sharply toward the inner part of the zone.

An intermediate zone of albite-quartz pegmatite appears at the inner edge of the wall zone where the

TABLE 8.—*Calculated mineral content of the pegmatite units in the lower part of the shaft and in the crosscuts, Hot Shot pegmatite*

[Based on data in pls. 28, 29]

Unit	Volume (cubic feet)	Mineral content (volume percent)							
		Perthite	Albite	Quartz	Muscovite	Lithia mica	Spodumene	Iron-manganese phosphates	Tourmaline
Albite-quartz-muscovite pegmatite	200		57	23	18				2
Albite-quartz pegmatite	1, 500		59	37	3				1
Perthite-quartz-albite pegmatite	3, 800	65	12	21	1			1	
Quartz-albite-muscovite pegmatite	1, 300	4	22	68	5			<0. 5	<0. 5
Quartz-spodumene-albite pegmatite	100		12	70	1		17		
Cleavelandite-lithia mica-quartz pegmatite	100		48	9		42		1	

TABLE 9.—*Mineral content of pegmatite units in the diamond-drill holes, Hot Shot pegmatite*

[Calculated from logs by L. R. Page]

Unit	Length in drill holes (feet)	Mineral content (volume percent)						
		Perthite	Albite	Quartz	Muscovite	Spodumene	Amblygonite	Tourmaline
Albite-quartz-muscovite pegmatite	32. 1		49	25	21			5
Albite-quartz pegmatite	49. 9		55	40	4			1
Perthite-quartz-albite pegmatite	20. 9	62	18	19	1			
Quartz-albite-muscovite pegmatite	65. 5		39	53	7			1
Quartz-spodumene-albite pegmatite	25. 8	10	13	42	7	14	14	

muscovite content becomes insignificant, yet the rock is otherwise similar to the wall zone. On the maps and sections this unit is shown only beneath the surface, where it has a maximum thickness of 16 feet. Though similar rock can also be found along the inner edge of the wall zone at the surface, it is too thin to be mapped separately.

Albite-quartz pegmatite is succeeded by a zone of perthite-quartz-albite pegmatite that was by far the most abundant rock exposed when the mapping was done. In many places it extends over virtually the entire thickness of the pegmatite, and even where it forms an envelope surrounding the perthite-quartz unit, as shown in the geologic sections (pl. 27), its thickness commonly is as much as 20 feet. The perthite-quartz-albite zone is hood shaped and overlies a zone of quartz-albite-muscovite pegmatite, which in turn surrounds the quartz-spodumene-albite core of the pegmatite.

The perthite-quartz-albite zone characteristically has abundant large crystals of perthite. Some of these crystals are 10 feet long, and aggregates consisting almost entirely of perthite are as much as 30 feet long. The chief minerals of the matrix are intergrown albite and quartz having a grain size of less than 3 inches. In many places, however, the matrix is rich in phosphate minerals, mainly triphylite-lithiophilite and heterosite. Most of the known beryl in the Hot Shot pegmatite is in these phosphate-rich aggregates.

Large pods that form a discontinuous perthite-quartz zone occur in the central part of the pegmatite near the surface. The longest of these extends for a distance of 135 feet and has a maximum thickness of about 50 feet. Like other such pods, it is entirely surrounded by perthite-quartz-albite pegmatite, and is separated from the inner zones in the lower part of the pegmatite. Among the two dominant minerals, perthite is only slightly more abundant than quartz. Accessory minerals include albite, muscovite, and iron-manganese phosphates.

The quartz-albite-muscovite zone, lying beneath the perthite-rich hood, has much the same character as the matrix of the perthite-quartz-albite zone and is the down-dip equivalent of that zone. Perthite, however, is only an accessory mineral, and the iron-manganese phosphates are less abundant than in the perthite-rich rock. The maximum thickness of this zone is probably about 25 feet.

A quartz-spodumene-albite unit that appears to be the core of the Hot Shot pegmatite has been recognized mainly in the drill holes, but the top of the core is exposed at the base of the shaft. The minerals are medium to very coarse grained. An aggregate of spodumene crystals exposed in the shaft is 6 feet long, but individual spodumene crystals are generally not more than 1 foot long. Most of the spodumene in the shaft has been altered to clay and micaceous minerals, but fresh spodumene was obtained in the drill core from inner parts of this zone. The matrix surrounding the spodumene is predominantly massive quartz, but it also contains white cleavelandite as much as 5 inches long. Amblygonite was found in the drill core, which cut one crystal that is at least 2 feet long. Probably the maximum thickness of the quartz-spodumene-albite zone is about 25 feet.

The aggregates of cleavelandite-lithia mica-quartz pegmatite are so poorly exposed that their structural relations with the rest of the pegmatite cannot be determined. They are surrounded by pegmatite belonging to the perthite-quartz-albite and quartz-albite-muscovite zones. The irregular boundaries of this unit do not conform structurally with the boundaries of the zones, and it is reasonable to suspect that the unit is a replacement body formed after crystallization of the zones. The dominant minerals are cleavelandite and lithia mica, which are known to be abundant in replacement bodies elsewhere in the Black Hills (for an example, see Sheridan and others, 1957, p. 15). Cleavelandite is in aggregates as much as 1-1/2 feet long. These aggregates are intimately intergrown with aggregates of a gray lithia mica in which the individual grains are generally less than one-eighth inch wide. Irregular masses of quartz are interstitial to the other minerals.

MINERAL DISTRIBUTION

The detailed data (pl. 28) on mineral distribution in the underground workings were acquired for three purposes: (a) to estimate the quantity of each economic mineral contained in each round in the shaft and crosscuts, so that after hand sorting each sample to obtain these minerals, the percent recovery could be calculated, (b) to compare the composition of the pegmatite units in the underground workings with the composition of these same units in the diamond-drill cores, and (c) to illustrate, by means of plates 28 and 29, the generalizations required in drawing contacts between pegmatite units. This information could also be used in conjunction with the data on the other maps and sections to estimate the composition of the entire pegmatite.

Plate 28, showing the mineral content of exposures in the shaft and crosscuts, contains the chief data on which the mineral-distribution studies are based. Where possible, similar data were also obtained at the successive faces of the crosscut as the workings were advanced. The fieldwork was at 1 inch equals 3 feet, a scale which made it possible to outline large crystals and large aggregates consisting of a single mineral. Even at this scale, however, the finer grained minerals making up most of the pegmatite cannot be shown separately. For this reason, aggregates of these minerals were outlined, and the mineral content of each aggregate, expressed in percent, recorded on the illustration. Though the figures for the aggregates are for the most part visual estimates, they were checked from time to time by actually measuring the area of all minerals in a small part of an aggregate.

During the Bureau of Mines work in the shaft and crosscuts, the data on mineral distribution were used to calculate the quantity of perthite, muscovite, and iron-manganese phosphates contained in each round. The procedure consisted of drawing a block diagram of a round, and projecting the data from each side of the block into its interior. By thus converting the areal percentages into volume percentages, the approximate quantity of perthite, muscovite, and iron-manganese phosphates in the round was calculated. When subsequently the rock was hand sorted, the quantity recovered of each mineral and the estimated total quantity available were used to calculate the percentage recovered. Inasmuch as tables showing the results of this work have been published and discussed (Needham, 1950, table 5; Norton and Page, 1956, table 4, p. 409–411), a complete account is not needed here. In general, the data show that high recoveries were obtained where the mineral sought was both coarse grained and abundant: the maximum recoveries were 99 percent for perthite, 40 percent for muscovite, and 44 percent for phosphates. Under less favorable conditions, recoveries of less than 20 percent of the perthite and less than 10 percent of the other minerals were common.

The same method of calculation was used to find the volume percentage of each mineral in each of the pegmatite units in the underground workings. The results, shown in table 8, provide modes for each of these units that can be compared with modes from the drill logs, shown in table 9. Differences between the two tables can have several causes: (a) changes in composition of a unit from one place to another, (b) inadequate sample size, especially in the very coarse grained units, and (c) errors of judgment introduced by the several persons who participated in this work—D. B. Stewart and H. G. Stephens, who did the work on mineral distribution in the underground workings; L. R. Page, who logged the drill core; and Norton, who drew contacts on the basis of work by the others.

Actually the figures in the two tables are so similar that none of these causes of error has great influence. The drill holes and the underground workings are in structurally similar parts of the pegmatite, and one may assume, in the absence of evidence to the contrary, that changes in the composition of any unit are unlikely to be found. The compositions of the wall zone of albite-quartz-muscovite pegmatite and of the first intermediate zone of albite-quartz pegmatite are virtually the same in the underground workings and in the drill holes; the greatest difference is in the content of albite of the wall zone, which is 49 percent in the drill holes and 57 percent in the underground workings. The perthite-quartz-albite zone also shows no large differences, perhaps largely by chance because the 20.9 feet of drill core is hardly an adequate sample of a unit containing 10-foot crystals of perthite. The quartz-spodumene-albite core also is very coarse grained and is represented only by small samples in both the underground workings and the drill hole. As expectable in the circumstances, the data for this unit show large discrepancies, mainly the presence of 14 percent amblygonite and 42 percent quartz in the drill holes, but no amblygonite and 70 percent quartz in the underground workings.

The modes of the quartz-albite-muscovite zone are less simple to reconcile. The unit contains 22 percent albite and 68 percent quartz in the underground workings, yet it has 39 percent albite and 53 percent quartz in the drill holes. The underground workings, however, cut this unit near its crest, where it lies between the perthite-rich hood and the spodumene-bearing core; both the hood and the core carry more quartz than albite, and it is hardly surprising that the interval between them is also rich in quartz. The drill holes, on the other hand, cross the flanks of the core, where perthite-bearing pegmatite is thin or absent, and the quartz-albite-muscovite unit can be expected to be rich in albite because it grades into the albite-rich rock of the albite-quartz zone.

The data for mineral distribution on plate 28 were used to draw the contacts between pegmatite units on plate 29. Comparison of one plate with the other brings out the nature of these ordinarily gradational contacts, and shows the generalizations involved in selecting the locations of such contacts during the geologic mapping of a pegmatite at scales of 1:240 or 1:480. Though the scale of 1:36 used in the mineral-distribution studies may seem to permit greater refinement than provided on plate 29, this refinement ceases to be feasible when the same geology is plotted at a scale of 1:480 and projected into unexposed pegmatite in the geologic sections (pl. 27).

The inner contact of the wall zone is the most sharply defined of all the contacts in the underground workings. It is based mainly on muscovite, which is abundant in the wall zone and very sparse in the adjacent albite-quartz zone. In general, the contact marks the boundary between rock with more than 5 percent and rock with less than 5 percent muscovite, though areas of a few square feet in the wall zone may be slightly below 5 percent in muscovite content.

The contact between the albite-quartz and the perthite-quartz-albite zone is fairly closely defined by the presence of perthite, which appears abruptly and in such abundance that the location of the contact is rarely questionable. The matrix between perthite crystals, however, consists of quartz and albite that are much the same as in the albite-quartz zone, and thus in small areas lacking perthite the contact has rock of virtually the same character on either side. If the contact were drawn only at the edges of perthite, the map would be nothing more than a diagram showing the outline of perthite crystals.

The inner edge of the perthite-quartz-albite zone, where it grades into quartz-albite-muscovite pegmatite, is a more effective illustration of this point. The contact, as drawn in plate 29, is approximately where the perthite content drops below 5 percent. All the exposures of quartz-albite-muscovite pegmatite in the underground working are within 7 feet of the zonal contact, and inasmuch as a single perthite crystal may be more than 7 feet long, the generalized nature of the contact is evident. That the contact really exists, however, is assured by the fact that the 1,300 cubic feet of this unit in the underground workings contained only about 4 percent perthite (table 8), and the 65.5 feet of the unit in the drill holes at greater depths contained no perthite at all (table 9). A point worth noting is that the contact, as drawn, cuts across perthite crystals in a few places in the underground workings.

The contact of the quartz-spodumene-albite core is at the place where spodumene first appears. The spodumene crystals and aggregates are large, and crystals concealed in the walls may extend 2 feet or more beyond the contacts as now drawn.

The patches of cleavelandite-lithia mica-quartz pegmatite have contacts that are gradational over such a few inches that, in any practical sense, the contacts drawn in the underground workings are sharp.

MINERAL DEPOSITS

Potash feldspar, constituting about 65 percent of the perthite-quartz-albite zone, is the principal mineral resource of the Hot Shot pegmatite. The upper 31 feet of the part of the shaft shown in plates 28 and 29 was almost entirely in the feldspar unit. The total volume of 2,170 cu ft mined here contained an estimated 1,345 cu ft, or 62 percent, potash feldspar. This quantity of feldspar would weigh about 108 tons; 58.4 tons, or 54 percent, of this total was recovered by hand sorting. Similar recoveries may be expected elsewhere in the main body of this zone.

Muscovite occurs throughout the pegmatite, but aside from the small quantities of scrap mica that might be recovered as a byproduct of feldspar mining, the only mica likely to be mined is in the wall zone.

Muscovite large enough for punch and sheet mica is an abundant constituent of this zone, especially along the hanging wall. The mica is ruby in color and commonly flat, but is air stained and in places stained with black mineral inclusions.

Tables 8 and 9 show the muscovite content of the wall zone at 18 and 21 percent. These high percentages may be misleading, partly because the few very rich samples included in the calculations may have distorted the results, but mainly because only a part of the muscovite is in books large enough to provide punch or sheet mica. An estimate of the amount of mica actually recoverable was made possible by hand sorting of the rock mined in the underground workings by the Bureau of Mines. Unfortunately, the round at the end of each crosscut, containing some of the best mica, was not sorted, but in five other rounds the wall zone was a large enough constituent to contribute most of the recoverable mica. The five rounds contained about 100 cubic feet of wall zone, carrying an estimated 26.9 percent by volume, or 26.9 cubic feet, of mica. This quantity of muscovite would weigh about 4,700 pounds. If all the 1,296 pounds of mica obtained from these rounds by hand sorting came from the wall zone, the recovery was 27.6 percent; actually, however, as much as 200 or even 300 pounds may have come from other units, and the percentage recovery should be reduced accordingly. These figures indicate that in the five rounds at least 5 percent or perhaps as much as 7.4 percent of the wall zone consisted of recoverable mica.

A second approach to the same problem is used in table 10. All muscovite crystals in a part of the wall

TABLE 10.—*Measured muscovite content of parts of the albite quartz-muscovite wall zone at the north and south ends of the crosscuts, Hot Shot pegmatite*

	North crosscut	*South crosscut*
Exposure measured square feet	26.6	16.8
Muscovite, total quantity:		
Square feet	3.27	1.11
Percent of the exposure	12.3	6.6
Muscovite, quantity in crystals more than 0.2 foot in longest dimension:		
Square feet	2.70	.94
Percent of the exposure	10.2	5.6
Percent of the total muscovite	83	85

zone at the north end and in another part at the south end of the crosscuts were measured; the muscovite content of the wall zone was 12.3 percent along the north contact and 6.6 percent along the south contact. Although these figures are somewhat lower than percentages recorded from elsewhere in the wall zone, the proportion of muscovite coarse enough for hand sorting was very high. Muscovite crystals having a length of more than 0.2 foot formed 10.2 percent of the north exposure and 5.6 percent of the southern one. These figures, in conjunction with those in the previous paragraph, suggest that about 7 percent of the Hot Shot wall zone is recoverable block mica.

Beryl is not a conspicuous constituent of the Hot Shot pegmatite, but small quantities have been obtained both on the surface and in the underground workings. The beryl is white and anhedral; where associated with iron-manganese phosphates, it is commonly stained. The beryl is easily overlooked; in the underground workings it was observed in only one place in the shaft.

The analyses in table 11 indicate that parts of the pegmatite do carry a significant proportion of beryl. The analyses are of samples taken from the rejects after hand sorting of the rock mined in the underground workings. To convert these analyses to actual beryllium oxide (BeO) content of the rock, it would be necessary to correct for the quantity of material removed by hand sorting, but as the table shows, the quantity removed was ordinarily so small where the beryllium oxide content is high that the correction would not be significant.

Among the 31 samples analyzed for beryllium oxide, 11 had less than 0.004 percent, which was the threshold for the analytical method, and 9 others had less than 0.012 percent, which is equivalent to 0.1 percent beryl; the remaining 11 samples are the only ones for which the analyses yield high values. Most of these are in the perthite-quartz-albite and quartz-albite-muscovite zones, but two samples from the albite-quartz zone contain 0.012 and 0.014 percent beryllium oxide. The greatest concentration is near the base of the shaft and in adjacent parts of the north crosscut. Of 8 samples from this area, 5 range from 0.085 to 0.165 percent beryllium oxide (equivalent to 0.7 to 1.3 percent beryl), and the other 3 samples have 0.0087, 0.027, and 0.052 percent beryllium oxide (equivalent to 0.07 to 0.4 percent beryl). These high values are associated with the phosphate-rich pegmatite along the inner contact of the perthite-quartz-albite zone. It is likely that much of whatever beryl is produced from this pegmatite in the future will be obtained from phosphate-rich rock of this kind.

Among other minerals in the Hot Shot mine, both spodumene and amblygonite are potentially minable from the core of the pegmatite, though the core is small. Traces of purple lepidolite have been observed in the underground workings, but there is no evidence that this pegmatite contains a sizable unexposed unit rich in lepidolite.

Table 11.—*Beryllium oxide (BeO) content of samples from lower part of the shaft and from the crosscuts, Hot Shot pegmatite.*

[The samples were first hand sorted for potash feldspar, mica, and phosphate minerals, and the BeO content of the remainder was determined by quantitative spectographic analyses. Analyses by Saratoga Laboratories, Inc., Saratoga Springs, N.Y.]

Sample location (feet)	Zone(s) sampled [1]	Sample	BeO content of material remaining after hand sorting	Percent of entire sample represented
Shaft				
Depth				
60.3–64.1	Perthite-quartz-albite	567	0.017	84
64.1–69.5	do	568	.0049	80
69.5–73.1	do	569	>.004	64
73.1–76.0	do	570	>.004	52
76.0–79.7	do	571	.061	52
79.7–83.4	do	572	>.004	58
83.4–88.2	do	573	.0041	64
88.2–91.6	do	574	>.004	54
91.6–94.4	Quartz-albite-muscovite and perthite-quartz-albite zones.	575	.052	74
94.4–97.9	Quartz-albite-muscovite zone.	576	.11	95
97.9–100.4	do	577	.0087	97
100.4–101.9	do	584	.085	89
101.9 to 104.7	Not sampled			
North crosscut				
Distance from shaft (0–7.0, see South crosscut, 0–6.8)				
7.0–11.7	Perthite-quartz-albite zone	579	0.165	96
11.7–15.2	do	581	.12	96
15.2–20.5	do	582	.13	93
20.5–25.7	Albite-quartz and perthite-quartz-albite zones.	585	.0056	94
25.7–31.7	Albite-quartz zone	586	.014	99
31.7–37.0	do	587	.0065	100
37.0–41.1	do	589	.0042	98
41.1–46.5	do	590	.0072	99
46.5–51.0	Perthite-quartz-albite and albite-quartz zones.	591	<.004	97
51.0–56.2	Perthite-quartz-albite zone	592	<.004	90
56.2–62.5	Albite-quartz zone	594	<.004	96
62.5–65.0	Albite - quartz - muscovite and albite-quartz zones.	596	<.004	98
65.0–69.5	Not sampled			
South crosscut				
Distance from shaft				
0–6.8 (includes North crosscut, 0–7.0)	Quartz - albite - muscovite. and perthite-quartz-albite zones.	578	0.027	89
6.8–11.0	Quartz - albite - muscovite zone.	580	.0058	98
11.0–17.0	Perthite-quartz-albite and quartz - albite - muscovite zones.	583	<.004	96
17.0–22.5	Perthite-quartz-abilite zone	588	<.004	95
22.5–27.3	do	593	<.004	94
27.3–30.0	Albite-quartz and perthite-quartz-albite zones.	595	.0047	97
30.0–38.7	Albite-quartz zone	597	.012	100
38.7–42.0	Not sampled			

[1] Only the pegmatite units that are a large part of the sample are listed.

MONTE CARLO PROSPECT

The Monte Carlo prospect is in a very large pegmatite, about 1,100 feet long and an average of 120 feet wide, located in the NE1/4NE1/4 sec. 17, T. 2 S., R. 6 E., 1 mile south of Keystone. It lies between the Hugo mine (Norton and others, 1962) to the west and the Etta mine to the east.

Potash feldspar is the only industrial mineral that is abundant enough in the surface exposures to be of economic interest. Structural analysis of the pegmatite shows, however, that the surface exposures are all very near the top of the intrusive and that only the outermost zones are exposed. Once these facts were firmly established by geologic mapping, the inference was obvious that there may be concealed inner zones that could be found by diamond drilling. The exploration undertaken for this purpose was geologically successful, in the sense that a quartz-perthite core was found, but the unit is much too small to be economically attractive.

The first examination of the Monte Carlo pegmatite was by Norton and L. R. Page in 1947. The geologic mapping was done mainly by D. M. Sheridan and R. E. Roadifer at various times in 1948 and 1949 (pl. 30). The diamond drilling was done in 1950 under contract with Millard Filmore of Deadwood, S. Dak. The geologic work accompanying the drilling was done by Norton aided by Carl Ulvog and W. A. Anderson.

At the time of this investigation, the only mining had been in a few small pits. Subsequently, potash feldspar was mined from near the northwest end of the pegmatite by the Consolidated Feldspar Department of the International Minerals & Chemical Corp., which owns claims covering this part of the body. The Maywood Chemical Co. also owns part of the deposit, and the rest was unclaimed in 1950.

The main body of the Monte Carlo pegmatite strikes north-northwest and dips about 60° N. Near its east end, however, a branch extends to the southwest and dips 65° SE. Though this branch merges with the main body, it is substantially independent in a structural sense and has a somewhat different lithology than the rest of the pegmatite. Its surface exposures consist almost entirely of quartz-albite-perthite pegmatite, which is surrounded by a quartz-albite-muscovite wall zone that is ordinarily less than 1 foot thick. In the main body, the wall zone is mostly between 5 and 15 feet thick, and much of it is separated from the quartz-albite-perthite zone by intermediate zones containing aggregates of aplitic albite and quartz associated with various quantities of coarser quartz, albite, perthite, and muscovite.

The country rock is quartz-mica schist, in which the schistosity ordinarily strikes between N. 25° E. and N. 50° E. and has a steep dip, mostly to the southeast. This attitude is very nearly concordant with the southwest-trending segment, but discordant with the main body of the pegmatite. Immediately adjacent to the contact, however, the schistosity swings around to a parallel position. The schist also changes in lithology near the pegmatite: much of it within 5 feet of the contact is heavily impregnated with tourmaline, and in places the alteration is so intense that the rock is a granulitic aggregate of albite, quartz, and tourmaline.

The top of the pegmatite outcrop has scattered exposures of schist and a thin veneer of wall zone in many places, and it is clear that the crest of the pegmatite was nowhere more than about 20 feet above the top of the present exposures. Plunges of rolls in the pegmatite contact are for the most part between 20° and 50° to the east and northeast, but there are many exceptions. The overall pattern of the geologic map indicates that the crest of the pegmatite is nearly flat over most of the outcrop, but at the east end it plunges beneath the surface at an angle of about 40° NNE. The underside of the intersection between the two segments of the pegmatite is an arch-shaped structure (section *B–B′*) that plunges about 55° NNE.

The wall zone consists of relatively fine grained quartz-albite-muscovite pegmatite. Quartz (45 percent) and albite (35 percent) predominate over muscovite (15 percent). The accessory minerals are tourmaline (3 percent), perthite, apatite, garnet, and very sparse beryl. Near the pegmatite contact the wall zone becomes increasingly rich in muscovite and lean in albite, and in the outer 1/2 to 2 inches a border zone of quartz-muscovite-albite pegmatite can be distinguished. Much of the muscovite in the border zone is oriented in such a way that the cleavage is perpendicular to the contact. At many places along the crest of the pegmatite, the border and wall zones together have a thickness of only 0.2 foot. The wall zone is very thin, even in the drill core, in the southwest-trending segment, but along the sides of the main body of the pegmatite it thickens at depth to as much as 15 feet.

The distinctive feature of the three zones succeeding the wall zone is the presence of sugary aggregates consisting of albite (70 percent) and quartz (25 percent) accompanied by accessory muscovite, tourmaline, and apatite. The first of the three zones is albite-quartz-muscovite pegmatite, in which 10 to 90 percent of the rock is sugary material and the remainder is similar to the wall zone. The second is albite-quartz pegmatite containing more than 90 percent sugary material. The third is albite-quartz-perthite pegmatite, which carries 10 to 90 percent of the sugary rock intermixed with aggregates having the same composition as the next succeeding zone, quartz-albite-perthite pegmatite. All three of these zones are discontinuous units that appear only along the footwall side and the top of the main body of the pegmatite. The maximum thickness of the albite-quartz zone is about 6 feet, and though the other two units ordinarily are no larger, they probably reach a maximum thickness of about 15 feet.

Quartz-albite-perthite pegmatite forms the innermost zone exposed at the surface. Evidence from diamond drilling indicates a thickness of 50 feet in some places, and for the most part the thickness is at least 30 feet, though it decreases to as little as 7 feet along the footwall of the main body of the pegmatite. The only abundant minerals are quartz (35 percent), albite (30 percent), and perthite (25 percent). Muscovite and tourmaline are the main accessory minerals, but apatite, garnet, biotite, and beryl have also been observed. Perthite crystals are as much as 10 feet across, but the grain size of the accompanying minerals is invariably less than 2 inches. Perthite is most abundant in the southwest-trending segment and near the west end of the main body of the pegmatite, where it forms as much as 50 percent of the rock.

Many small fracture fillings of coarse-grained quartz-perthite pegmatite cut the surface exposures, especially in the quartz-albite-perthite zone. The fracture-fillings have an average thickness of 1-1/2 feet, and the greatest length is 40 feet. Quartz (50 percent) is only slightly more abundant than perthite (45 percent). Part of the potassic feldspar is so nearly free of perthitic albite that it can be called microcline. The main accessory mineral is muscovite, which is concentrated along the borders of fracture fillings. Fine-grained aggregates of cleavelandite and a gray mica, similar to the so-called lithia mica of the Peerless and Hugo pegmatites (Sheridan and others, 1957; Norton and others, 1962), have been found in two places. An analysis indicating 1.90 percent Li_2O in this mica was made by Charles Bentley of the Engineering and Mining Experiment Station, South Dakota School of Mines and Technology. Beryl and apatite, though sparse, are widely distributed in the fracture fillings.

The diamond drilling showed that each segment of the pegmatite has a quartz-perthite core of almost the same composition as the fracture-filling units. The maximum thickness of the core is probably no greater than 10 feet.

The purpose of the drilling was to search for unexposed inner units. By analogy with the fracture fillings, which were presumed to be offshoots of inner zones or at least contemporaneous with inner zones, it followed that quartz and perthite should be the dominant constituents of unexposed inner units. The presence of lithium-rich mica in the fracture fillings suggested that lithium-bearing inner zones might be found, as in the nearby Hugo and Etta pegmatites. Beryl is commonly mined from zones of the composition anticipated (Norton and others, 1958, p. 28–29), and inasmuch as beryl is also a constituent of the fracture fillings, there was a possibility that a significant beryl deposit would be discovered.

Holes 1 and 2 (section *B–B′*, pl. 30) were planned to explore the vicinity of the intersection of the southwest-trending segment and the main body, where the inner part of the pegmatite was likely to be large enough to contain sizable inner zones. The contacts of the southwest-trending segment dip outward at the surface, and if these dips were to continue at depth for a significant distance, the pegmatite would be very large. The actual expectation, however, was that the northwest contact of this segment would change dip at shallow depth from northwest to southeast (as, for example, in section *C–C′*), and, prior to the drilling of hole 1, the outline of the pegmatite was predicted to have the form shown by the dotted line in section *B–B′*. Holes 1 and 2 demonstrated this structural interpretation to be approximately correct, and they also established that a concealed inner zone of quartz-perthite pegmatite is present, though very small in size. At this stage in the exploration it seemed clear that neither segment of the pegmatite was likely to thicken appreciably at depth or to have large inner units, and these conclusions were verified beyond reasonable doubt by holes 3, 4, and 5 (sections *A–A′*, *C–C′*, and *D–D′*, pl. 30).

Beryl was sparse in the drill core, and the largest observed crystal had an exposed area of only one-half square inch. The low beryl content was verified by analyses of samples obtained between 128.5 and 333.7 feet in hole 1 (table 12); only a few of the samples contain more than 0.01 percent beryllium oxide, which is approximately equivalent to 0.1 percent beryl. Another noteworthy aspect of these analyses is that for the sludge samples, which were analyzed where the core recovery was less than 90 percent, all but 3 of the 20 analyses indicate more beryllium oxide than in the accompanying core samples. The sludge samples were analyzed at the same time and by the same method as the core samples, and the only evident explanation for this discrepancy is that beryl crystals tend to break free from the core and go into the sludge. That this may have happened in some of the sample intervals in which the sludge was not analyzed suggests that the grade indicated by the analyses is lower than the true grade, but the analyses are so uniformly low that the error is not likely to be economically significant.

Whatever economic value the Monte Carlo pegmatite has is based almost entirely on the potash feldspar. The richest exposures are in the southwest-trending segment and in the west part of the main body.

MOUNTAIN LION (SODA SPAR) SPODUMENE PROSPECT

The Mountain Lion or Soda Spar prospect is in a large body of pegmatite that contains small fracture-filling units carrying coarse-grained quartz, perthite, or spodumene. This property is about 3 miles southeast of Keystone, S. Dak., in the NE1/4SE1/4 sec. 22. T. 2 S., R. 6 E. It was described by Stoll (1953b), and a map and section of one of the pits was published by Cameron and others (1949, fig. 20). The geologic map presented here as plate 31 was made by L. R. Page and C. H. Chao in 1946.

The Mountain Lion pegmatite is 700 feet long and has a maximum width of 400 feet. The strike is northerly, and the dip in most places is steep to the west. The plunge of rolls is generally 60° to 75° N.W.

Albite-quartz-perthite pegmatite is by far the most abundant rock in this intrusive. Along the west side it is separated from the contact by a unit of pegmatitic granite that consists mainly of albite and quartz, but also contains perthite, muscovite, and tourmaline. The variable grain size and compositional differences of this rock give rise to a layered structure having a strike and dip approximately parallel to the hanging wall of the pegmatite.

The inner part of the intrusive has coarse-grained fracture fillings and irregularly shaped units that cut the albite-quartz-perthite unit. The small units are most abundant in the southeast part of the pegmatite, where most of the mine workings are located. Graphic granite is so abundant in parts of this area that units of albite-quartz-graphic granite pegmatite have been shown separately on the geologic map. The same area has several large fracture fillings containing quartz pegmatite, perthite-quartz pegmatite, and perthite-quartz-spodumene pegmatite. All these fracture fillings have wall zones consisting of albite, quartz, and muscovite, but because the wall zones are rarely more than 1 foot thick, they are not shown separately on the map.

Economic interest has been mainly in spodumene-bearing pegmatite exposed in the two largest pits, which are near the center of the pegmatite south of section *A–A′*. The very coarse grained pegmatite in these pits has, for the most part, a fracture-filling

TABLE 12.—*Beryllium oxide (BeO) content of samples from diamond-drill hole 1, Monte Carlo pegmatite*

[Quantitative spectrographic analyses by Strock Laboratories, Inc., Saratoga Springs, N.Y. Sludge samples were analyzed only where the core recovery was less than 90 percent; analyses indicating 0.0005 percent BeO were described as approximate by the analyst]

Depth in drill hole (feet)	Rock	Length of sample interval (feet)	Core recovery (percent)	Core sample No.	Core sample BeO (percent)	Sludge sample No.	Sludge sample BeO (percent)
128.5–133.9	Quartz-mica schist	5.4	90	MCC-1	0.0085	MCS-26	0.0031
133.9–134.8	Quartz-albite-muscovite wall zone	.9		2	.12		
134.8–213.4	Quartz-albite-perthite intermediate zone	2.9	79	3	.042	27	.10
		2.0	100	4	.0062		
		2.1	100	5	.024		
		5.0	76	6	.012	MCS-30	.023
		3.8	79	7	.0015	31	.0050
		2.5	56	8	.0009	32	.0026
		1.8	100	9	.0014		
		5.1	100	10	.0027		
		4.9	94	11	.13		
		1.6	94	12	.0025		
		3.9	74	13	.0020	MCS-37	.0035
		2.6	77	14	.0010	38	.0039
		1.4	100	15	.0015		
		3.4	76	16	.0015	MCS-40	.0008
		4.1	95	17	.0011		
		4.8	98	18	.0013		
		2.6	100	19	.0008		
		2.2	86	20	.0011	MCS-44	.0028
		2.3	100	21	.0020		
		4.9	84	22	.0012	MCS-46	.0015
		2.6	85	23	.0008	47	.052
		3.7	86	24	.0005	48	.011
		4.8	90	25	.0013		
		3.6	100	26	.0005		
213.4–230.1	Quartz-perthite core	1.6	100	27	.0008		
		3.0	73	28	.0008	MSC-51	.0018
		2.0	95	29	.0014		
		1.9	89	30	.0007	MSC-53	.0026
		3.8	76	31	.0010	54	.0023
		2.5	64	32	.0035	55	.0016
		1.9	100	33	.0016		
230.1–255.3	Quartz-albite-perthite intermediate zone	2.0	100	34	.0028		
		2.6	88	35	.0018	MSC-57	.0060
		3.3	100	36	.0015		
		3.8	100	37	.0018		
		3.0	97	38	.014		
		4.9	100	39	.0013		
		2.9	100	40	.018		
		2.7	90	41	.0028		
255.3–256.1	Quartz-perthite core	.4		42	.0020		
		.4	77	43	.0005	MSC-64	.0034
256.1–332.4	Quartz-albite-perthite intermediate zone	4.4		44	.0006		
		3.3	85	45	.0015	65	.0032
		5.9	90	46	.0011		
		2.9	100	47	.0005		
		3.4	97	48	.0005		
		2.7	100	49	.0009		
		4.2	98	50	.0005		
		3.0	93	51	.0030		
		3.0	100	52	.0029		
		3.6	100	53	.0029		
		1.7	65	54	.0005	MSC-74	.0034
		2.0	95	55	.0020		
		4.6	100	56	.0024		
		5.2	100	57	.0015		
		1.0	100	58	.0007		
		1.0	100	59	.0005		
		5.0	100	60	.0026		
		5.3	94	61	.0023		
		4.0	98	62	.0012		
		3.4	100	63	.0013		
		5.0	98	64	.032		
		1.7	100	65	.024		
332.4–332.7	Quartz-albite-muscovite wall zone	.3	100	66	.0069		
332.7–333.7	Quartz-mica schist	1.0	100	67	.0005		

relationship to the host rock, but a part of the exposures may be at the outer edge of the core of the entire pegmatite. In any event, the fracture filling is well zoned. Its wall zone, consisting dominantly of cleavelandite, muscovite and quartz, is generally between 1 and 2 feet thick, but reaches a maximum thickness of 5 feet. This wall zone cannot be shown separately on plate 31, but it does appear on the larger scale map by Page and Hanley (Cameron and others, 1949, fig. 20). The central part of the fracture-filling unit near its southwest end is quartz pegmatite containing minor spodumene, and near the northwest end it is perthite-quartz pegmatite. The area in between has perthite-quartz-spodumene pegmatite as the dominant rock, but Page and Hanley also recognized small bodies of quartz-spodumene and cleavelandite-spodumene pegmatite. Amblygonite has been observed as an accessory mineral.

The surface evidence suggests that the spodumene-bearing fracture filling may be an offshoot of inner zones that are largely or entirely unexposed. In order to test this possibility, the U.S. Bureau of Mines drilled one diamond-drill hole through this pegmatite in 1951. The collar of the hole was about 50 feet southwest of the east end of section *A–A′*, and the hole was drilled N. 74° W. at a shallow angle so as to pass about 60 feet beneath the mine workings. Nothing was found, however, except quartz-albite-perthite pegmatite and small quartz fracture fillings (E. O. Binyon, oral communication, 1953), and it is unlikely that spodumene-bearing units significantly larger than the ones now known will be discovered in this pegmatite.

PINE TOP FELDSPAR AND MICA PROSPECT

The Pine Top pegmatite is a virtually undeveloped prospect offering promise as a source of potash feldspar and sheet mica. Its location is 3 miles south-southwest of Custer in the NE1/4NE1/4 sec. 10, T. 4 S., R. 4 E. The Consolidated Feldspar Department of the International Minerals and Chemical Corp. owns the property, and probably has excavated the few pits on it during assessment work.

The Pine Top pegmatite was examined by W. C. Stoll and W. E. Hall in 1942, and the description written at that time is still virtually complete (Page and others, 1953, p. 177). The only significant new contribution that can be presented here is the geologic map made by Page and Norton in January 1947 (fig. 118).

The pegmatite is exposed for a distance of 260 feet, and its maximum thickness is about 35 feet. The strike is for the most part N. 15° to 20° W., and the average dip is about 60° W. The pegmatite is generally concordant with the bedding of the enclosing quartz-mica schist. Rolls in the contact plunge generally south-southwest at angles ranging from 34° to 65°, and probably the plunge of the pegmatite as a whole is very close to 50° S. 26° W.

The wall zone of albite-quartz-perthite-muscovite pegmatite is exposed mainly along the dip slope on the west side of the pegmatite, where the thickness of the zone is commonly less than 2 feet. The thickness may be somewhat greater to the south where the zone extends over the top of the outcrop in the southward-plunging upper part of this pegmatite.

The chief inner unit is a perthite-quartz-albite intermediate zone containing perthite crystals many feet in diameter. The quartz core, in which most of the quartz is rose colored, is the only other mappable unit. The quartz core crops out in two places, on either side of the pinch in the pegmatite that is just south of section *A–A′*.

The character of the pegmatite at depth can only be surmised from analogy with other Black Hills pegmatites. The perthite content of the intermediate zone probably decreases so much that the rock becomes quartz-albite pegmatite, and the wall zone may become thicker and rich enough in coarse muscovite to be mined for sheet mica. In this regard, the Pine Top pegmatite may be very similar to the nearby Buster Dike pegmatite.

Potash feldspar is the only industrial mineral that can be mined in quantity from the presently exposed parts of this pegmatite. The flat ruby mica of the wall zone may be abundant enough at depth to have economic importance.

SILVER DOLLAR MICA MINE

The Silver Dollar pegmatite, NW 1/4 sec. 11, T. 4 S., R. 4 E., Custer County, S. Dak., has been a small but significant source of high-quality ruby sheet mica. The geology has been described by Joralemon (1953a), and the work reported here is concerned mainly with the geologic aspects of diamond drilling that was done by the U.S. Bureau of Mines in 1947 (Needham, 1950 p. 18–25). Logs of the drill holes made by Norton have been published (Needham, 1950, p. 20–25).

The Silver Dollar claim was originally located in 1942 by S. T. Gamber of Custer, S. Dak., and he was also the first to mine the deposit. The mine had various operators during succeeding years. The last of these was the Custer Mining Account, which purchased the property in 1946 and mined it during June and July of that year. The mine workings consist of a shallow opencut 125 feet long and 15 feet wide, a 70-foot shaft inclined 60° to the west, a drift near the base of the shaft that extends 30 feet north and 50 feet south, and several small stopes and raises.

The recorded production for 1942–44 was 2,998.87 pounds of sheet mica and 9,496 pounds of untrimmed punch (Joralemon, 1953a, p. 191). The production by Custer Mining Account in 1946 was 194 pounds of untrimmed sheet mica 1-1/2 by 2 inches and larger, and 821 pounds of untrimmed washer and punch mica.

The main elements of the structure of both the pegmatite and the country rock are fairly simple. The pegmatite is a thinly lenticular body, 268 feet long and as much as 15 feet thick (pl. 32). Its average strike of N. 24° W. and dip of 52° W. are approximately the same as the strike and dip of both schistosity and bedding in the enclosing quartz-mica schist.

The dominant minerals of the schist are quartz and biotite, but feldspar, muscovite, and garnet are also common. Sillimanite aggregates as much as one-fourth inch long are abundant in drill core from within 10 feet of the pegmatite contact, but were not observed elsewhere. Minor constituents of the schist include staurolite, kyanite, amphibole, pyrite, and pyrrhotite.

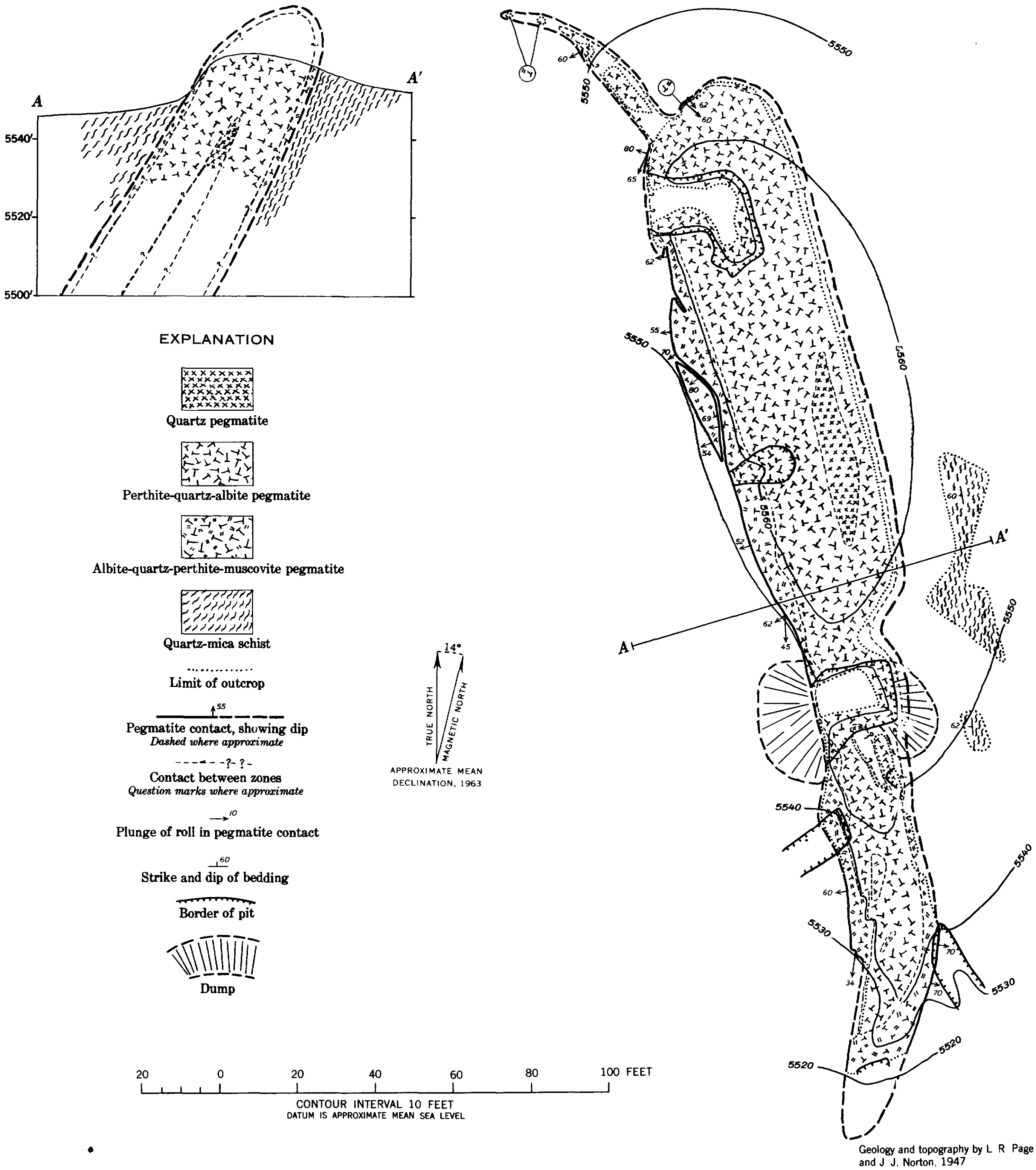

FIGURE 118.—Geologic map and section of the Pine Top pegmatite, Custer County, S. Dak.

The schist contains a few beds of lime-silicate rock consisting mainly of plagioclase, dark-green amphibole, and garnet. The greatest thickness of these beds in the drill holes is 7 inches.

The pegmatite as mapped consists of two zones: a quartz-plagioclase-perthite-muscovite wall zone and a perthite-quartz core. The thickness of the wall zone is ordinarily between 2 and 4 feet and of the core between 4 and 6 feet, but each unit may have a maximum thickness of as much as 8 feet. Coarse muscovite that can be mined and processed to yield sheet mica is concentrated in a 2-foot-thick layer that straddles the contact between the two zones. This muscovite-rich unit, despite its small size, can be regarded as an intermediate zone.

The wall zone consists dominantly of a fine-grained intergrowth of quartz and plagioclase. Perthite crystals are commonly more than 1 foot long except adjacent to the schist contact, where much of the perthite is as fine grained as the surrounding quartz and plagioclase. Muscovite crystals are ordinarily less than one-half inch in diameter in the outer part of the zone, and many of them are oriented such that the cleavage is normal to the schist contact. The grain size of muscovite increases inward and reaches a maximum of about 6 inches near the contact with the core of the pegmatite. Muscovite intergrown with biotite also occurs as thin sheets or blades that fill fractures cutting other minerals of the zone; these blades first appear about 4 inches from the contact with schist, and they extend to within about 1 foot of the contact with the core. The accessory minerals of the wall zone include tourmaline, apatite, and garnet.

The indices of refraction of the plagioclase in the Silver Dollar wall zone have a greater range and are somewhat higher than usual in zoned pegmatites of the Black Hills. The index of α' (the minimum index of 001 cleavage fragments) of plagioclase at both the footwall and hanging-wall contacts is as high as 1.544, which according to Emmons and others (1953, fig. 6) indicates sodic andesine; the indices decrease abruptly away from the contact, and throughout most of the wall zone α' are between 1.529 and 1.535, or approximately An_0 to An_{10}.

The perthite-quartz core is a very coarse grained unit in which the largest crystals are several feet long. The perthite contains graphic inclusions of quartz and also inclusions of muscovite and tourmaline. The perthitic structure commonly is not well developed. The outer part of the zone, where book mica is a conspicuous constituent, contains more albite (α'1.529 to 1.532) than the inner part, and it also has accessory beryl, apatite, and large masses of tourmaline.

Mica mining in this deposit has been successful in places where the barren part of the core is less than 3 feet thick, and the mica-rich rock on either side can be extracted without the necessity of mining an excessive thickness of unproductive rock from the core. In such places the book mica recovered was about 3.3 percent of the central 6 to 7 feet of the pegmatite (Joralemon, 1953a, p. 191).

The most profitable underground mining was in a narrow part of the pegmatite that crosses the shaft just below its collar and plunges about 40° S. 18° W. This pinch in the pegmatite is shown in the southern part of the drift on the underground map of Joralemon (1953a, pl. 37). Undoubtedly the pinch continues to greater depths, but mining was discontinued because at the drift level the pegmatite is cut by so many gently dipping fractures that much of the mica is deformed and of low value. Though this condition presumably does not persist, the marginal nature of the deposit has prevented the mine operators from extending the underground workings beyond the fracture zone.

The purpose of the drilling was to determine the size and position of the pegmatite and to establish the continuity of the mica unit beyond the limits of the mine workings. Hole 1 (section *A–A'*, pl. 32) was aimed to cut the pinch in the pegmatite body at a point 40 feet below the drift level, and it did, in fact, pass through pegmatite much resembling material that has been mined. Fragments of mica from books that are at least as much as 3-1/2 inches long and 1-1/2 inches thick were recovered in the drill core. Hole 2 was drilled to obtain evidence supporting a belief that the pegmatite as a whole plunges 40° S. 18° W., parallel to the pinch and to the few rolls observed along the contact. The hole (section B–B', pl. 32) is south of the southern end of the pegmatite on the surface, and if the plunge is to the west or northwest, the hole would have missed the pegmatite entirely. Actually, however, it not only passed through the pegmatite, but it cut each contact within 1 foot of where it was anticipated; there is, therefore, little doubt that the structure has been correctly interpreted.

The block of pegmatite outlined by the drilling is 125 feet long and its extent down the dip is everywhere at least 100 feet. Additional mica pegmatite lies to the north, to the south, and beneath the drill holes. The mica content of the unmined parts of the pegmatite, to judge from the drill core, is probably about the same as in the previously mined rock. Because the mica-bearing unit is narrow and has a relatively low mica content, future attempts at mining will be most effective if the main efforts are in places where the pegmatite is thin and where only part of the barren core need be extracted.

SITTING BULL BERYL PROSPECT

The Sitting Bull pegmatite is a small body that has long been of interest as a potential source of beryl, but the only mining has been in small opencuts put in by the Black Hills Keystone Corp., which owns the property. This prospect is at the crest of a ridge, three-fourths mile northwest of Keystone and just southwest of the center of the SW1/4 sec. 5, T. 2 S., R. 6 E.

The first geological study of this pegmatite was by W. C. Stoll and W. E. Hall in 1942 (Stoll, 1953a). The present report is based on detailed mapping done by J. B. Hanley and C. H. Chao in 1946 (fig. 119).

The Sitting Bull pegmatite is a lenticular body having a length of 180 feet and a maximum thickness of about 30 feet. The strike is N. 20° W.; the dip is 65° E., and the plunge, so far as can be determined from the few rolls exposed at the surface, is about 60° N. 35° E. The adjacent country rock is quartz-mica schist containing staurolite that is pseudomorphically altered to mica and chlorite. Bedding and schistosity have a strike approximately parallel to the strike of the pegmatite, but the dip is steeper, generally between 80° E. and vertical. Similar schist, but with unaltered staurolite, extends to the east and north, without change in attitude. About 100 feet west of the pegmatite, however, quartzite and garnet-rich mica schists become abundant, and the strike turns to the northwest. though the dip does not change significantly.

A small normal fault crossing the southern part of the pegmatite has a northeasterly strike and a 54° dip to the southeast. The displacement, measured horizontally, is only 6 feet. The fault is sharply defined where it cuts the west contact of the pegmatite, but it forms many parallel fractures at the east contact.

The pegmatite, as mapped, consists of three zones: (a) an albite-quartz-muscovite wall zone, (b) a quartz-cleavelandite intermediate zone, and (c) a quartz-perthite core. A border zone of fine-grained quartz-muscovite pegmatite has a maximum thickness of only 2 inches, and cannot be mapped as a separate unit.

The wall zone is generally between 2 and 4 feet thick; it consists, for the most part, of albite (55 percent) and quartz (35 percent), but also carries muscovite (6 percent) as an essential mineral. All three minerals have an average grain size of 2 inches. Accessory perthite, however, is in subhedral crystals having an average size of about 1 foot. The only other conspicuous accessory mineral is white beryl, which is in subhedral to euhedral crystals as much as 3 inches in diameter. Beryl is most abundant in exposures along the footwall side of the pegmatite, where the average content is about 1 percent of the rock; one area of 18 square feet was found by Stoll (1953a, p. 192) to contain 5 to 6 percent beryl. Black tourmaline is a minor accessory mineral. A few minute grains of columbite-tantalite can be found in the inner part of the wall zone.

The quartz-cleavelandite intermediate zone is ordinarily about 7 feet thick, but it is somewhat thicker near the north end of the pegmatite and it lenses out entirely at the south end. It contains 60 percent quartz, 30 percent white cleavelandite, and accessory perthite, muscovite, beryl, lithiophilite-triphylite, apatite, and amblygonite. The grain size is generally about 3 inches, but perthite crystals as much as 3 feet long are in the inner part of the zone and euhedral beryl crystals as much as 10 inches in diameter are exposed near the contact with the wall zone. The average beryl content is no more than 0.5 percent and may be as low as 0.2 percent. The beryl is white, subhedral to euhedral, and generally associated with lithiophilite-triphylite, pink cleavelandite, and yellowish muscovite.

An offshoot from the quartz-cleavelandite zone forms a small fracture filling cutting the wall zone on the footwall side of the pegmatite just north of section *A–A′* (fig. 119).

The core consists dominantly of quartz (65 percent) and white to pale-gray perthite (30 percent) along the top of the pegmatite outcrop, where the thickness of the unit is as much as 15 feet. Along the base of the outcrop on the east side, in the thin lower part of this zone, perthite is less abundant and cleavelandite is a significant constituent. The average grain size of the core is 2 feet, but crystals of perthite and masses of quartz are as much as 10 feet across.

Muscovite is a common alteration product of perthite in the Sitting Bull pegmatite. The alteration is most evident near the fault, where bright-yellow muscovite forms veinlets that commonly follow the feldspar cleavages but also cut across the cleavage. Elsewhere, throughout the core, perthite crystals are commonly coated with a rim of 1/8-inch muscovite plates oriented normal to the crystal border.

Beryl is surely the most promising of the potential mineral products in this pegmatite. Though the percentage of beryl is fairly high in the footwall part of the wall zone, the deposit is so small that the tonnage of beryl cannot be great. Scrap mica will be an additional product of any mining in the wall zone. A small tonnage of potash feldspar can be mined from the core.

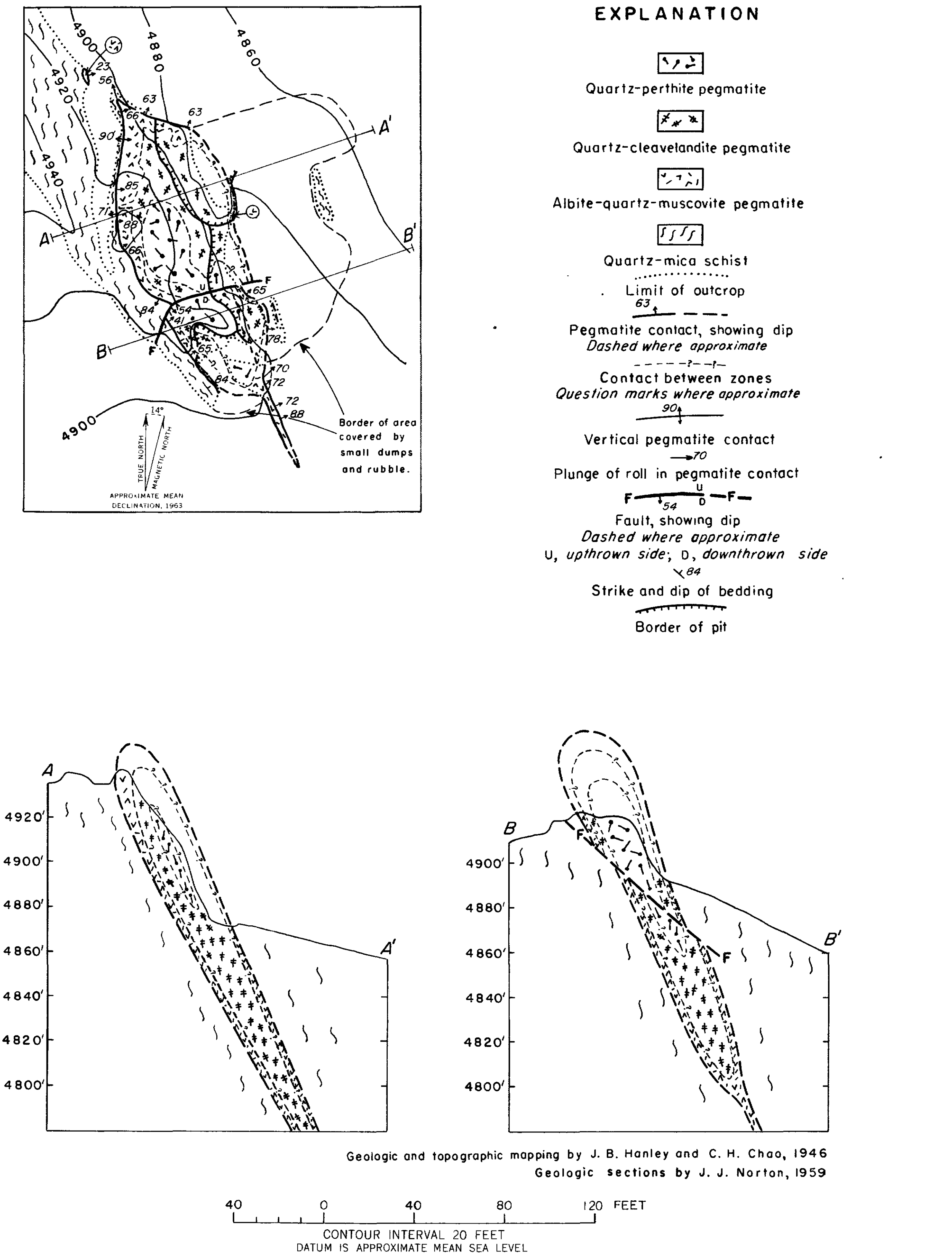

FIGURE 119.—Geologic map and sections of the Sitting Bull pegmatite, Pennington County, S. Dak.

WHITE BEAR MICA MINE

The White Bear pegmatite, 3.5 miles south of Custer in the NW1/4 sec. 11, T. 4 S., R. 4 E., is of commercial interest mainly as a source of sheet mica, but it has also been mined for potash feldspar. Virtually all the sheet mica has been obtained from a southwest plunging shoot at the south end of the pegmatite.

The geology of the mica-rich shoot was studied in detail by Joralemon (1953b) in 1944, when the mine was in operation. His surface map of the pegmatite and the adjacent area was necessarily somewhat generalized, for evidence bearing on certain critical aspects of the overall structure of the pegmatite was not readily available from the existing exposures. The reasons for the localization of the mica-rich shoot could not be thoroughly ascertained, nor was it clear where, or if, other mica-rich shoots could be found beneath the surface in this pegmatite.

As a consequence of these uncertainties, the U.S. Bureau of Mines diamond drilled the pegmatite in 1947, and at the same time the geology was restudied by Page and Norton (pl. 33). A published description of this work (Needham, 1950, p. 4–18) contains Page's logs of the drill core.

GEOLOGY

The White Bear pegmatite crops out as a broadly lenticular body, about 200 feet long and as much as 70 feet thick. The strike is almost directly north; the dip is 60° W.; and the plunge is generally 40° to 55° SW. The pegmatite is generally conformable to the enclosing quartz-mica schist, which consists mainly of quartz and biotite but also contains feldspar, muscovite, garnet, graphite, and pyrite. Lime-silicate rock carrying amphibole, feldspar, and garnet is a minor constituent recognized in the drill core.

The pegmatite at the surface forms a small hill in which the predominant rock is quartz-albite-perthite pegmatite. A discontinuous wall zone of albite-quartz-perthite-muscovite pegmatite was also mapped (pl. 33), though it rarely is as much as 1 foot thick in the surface exposure. A veneer of schist covering much of the outcrop indicates that very little of the pegmatite has been removed by erosion.

The mica-rich shoot that has been mined from the shaft at the south end of the pegmatite seemed from the early studies (Joralemon, 1953b) to be most readily interpreted as a thickened part of the wall zone plunging southwest along the crest of the pegmatite. This simple concept, though correct in several respects, fails to explain some notable aspects of the geology. Joralemon's underground maps and sections show that the underside of the mica shoot is not, as one might expect, in contact with coarse-grained pegmatite of the inner zone, but with a mixed rock consisting of both pegmatite and schist. This mixed rock separates the mica shoot from the main body of pegmatite. The schist in the mixed rock may well be remnants of a schist screen separating two pegmatites of slightly different age, the older being the main body of the pegmatite and the younger a muscovite-rich body that followed the crest of the earlier intrusive. An alternative interpretation, which is consistent with the same structural arrangement, is that the mica shoot formed largely through replacement of schist by fluids emanating from the main body of pegmatite. The amount of schist that would be completely replaced in this process need not be large; its mafic constituents would reappear in the pegmatite as biotite and tourmaline, which are notably abundant in the mixed rock and in muscovite-rich parts of the pegmatite.

In the northern part of the surface exposures, two structurally separate pegmatites have been mapped. The larger one, lying to the east, is the main body. As elsewhere, it consists chiefly of quartz, albite, and perthite, but it has a narrow mica-bearing wall zone and it also has a large quartz-perthite fracture filling. The smaller pegmatite has a wall zone that is not greatly different from the wall zone of the larger one, but the wall zone is succeeded not by a feldspathic unit, as in the larger pegmatite, but by a well-developed quartz core. The area between the two pegmatites has unaltered schist for the most part, but in addition it has an extensive exposure consisting of biotite-bearing pegmatite that includes remnants of schist, similar to the mixed pegmatite and schist in and near the shaft, where uncontaminated pegmatite also exists on the two sides.

A problem that immediately arises is whether the small pegmatite to the northwest and the mica-rich pegmatite in the shaft are actually a single intrusive that follows the upper side of the main pegmatite. The geologic map shows that at the surface they are separate bodies, each coming to an end near section *A–A′*. The available exposures, however, do not provide conclusive evidence on this point. Even if they did, the possibility would by no means be excluded that these two apparently separate bodies join at a shallow depth to form a single pegmatite; the absence of this pegmatite at the surface near section *A–A′* may mean only that the top has plunged downward for a short distance.

DIAMOND DRILLING

The evidence from the diamond drilling is in accord with an interpretation that a single small body of pegmatite follows the hanging wall and wraps around the crest of the larger pegmatite. All three drill holes cut the mixed rock in places where it is most readily explained as separating the smaller pegmatite from the larger one.

Hole 1 passed beneath the underground workings; the drill core greatly resembles the rock in the mine workings and in nearby surface exposures. The drill hole first penetrated pegmatite at a depth of 185.7 feet, where it passed through 2.3 feet of albite-quartz-perthite-muscovite pegmatite having virtually the same character as that in the mine workings. The drill hole next passed through 18.5 feet of mixed pegmatite and schist that is much the same as the rock along the floor of the inclined shaft. Finally, it cut 6.4 feet of pegmatite rich in perthite, albite, quartz, and muscovite; this rock is interpreted as corresponding to the wall zone of the main body of pegmatite exposed at the surface.

Hole 2 was planned to cut the pegmatite down plunge from the southernmost exposures on the surface. It passed first through the small pegmatite lying above the main body, and then through pegmatite mixed with schist. The hole cut only 8 feet of uncontaminated pegmatite that appears to belong to the main body, which at this depth consists only of a quartz core surrounded by a narrow garnet-bearing wall zone. Though no quartz core is exposed at the surface, there is a quartz fracture filling, and the discovery of a quartz core at depth should cause no surprise. Along the footwall, pegmatite is in contact with 3.8 feet of altered schist, which, as drawn in section *C–C′* (pl. 33), is in the same structural position as the schist inclusions on the surface north-northeast of the shaft.

Hole 3 was drilled north of the other holes to intersect the keel of the pegmatite down plunge from the northernmost surface exposures. The evidence from this drill core, as from those of the other holes, indicates the existence of two pegmatites. The main rock found in hole 3 was albite-quartz-perthite pegmatite containing a few remnants of schist and carrying abundant accessory muscovite, biotite, and tourmaline. As section *A–A′* (pl. 33) and the geologic plan show, this rock probably lies between the small upper pegmatite and the main body. It presumably is continuous with the mixed pegmatite and schist found in holes 1 and 2. Furthermore, its structural position near the keel of the main pegmatite indicates that it is the down-plunge extension of lithologically similar rock exposed where the keel of the pegmatite comes to the surface.

The drilling indicates that the small pegmatite is continuous, or virtually continuous, along the entire extent of the hanging wall of the main body. The two pegmatites are separated largely by a mixed rock consisting of both pegmatite and schist, but fragments of schist are more abundant in the rock near the shaft than they are to the north.

MINERAL DEPOSITS

Muscovite is a conspicuous constituent of the wall zone of both the main body of the White Bear pegmatite and the small upper pegmatite. The only mining, however, has been from the smaller pegmatite in the mica-rich shoot exposed in the shaft, where the wall zone has a high percentage of coarse-grained muscovite and a fairly great thickness of minable rock. Though elsewhere in this pegmatite the content of coarse-grained muscovite is ordinarily not as high nor the thickness as great as in the mine workings, its potentialities as a source of sheet mica have by no means been exhausted. Additional mica certainly can be obtained down plunge from the old workings. The most favorable locality, however, may be to the north along the keel of the two pegmatites. Hole 3 cut large mica books not only in the wall zones but also in the biotite-bearing pegmatite that presumably corresponds to the mixed pegmatite and schist in the shaft, where similar rock was a source of sheet mica.

The diamond drilling, as a consequence of being directed primarily at obtaining data about sheet mica, provides only a small quantity of new information regarding the large body of potash feldspar-bearing rock in the main pegmatite. The structural relations, as shown in the geologic sections, are somewhat better defined than previously. The main potash feldspar unit was not cut by any of the drill holes, and though it may be expected that the percentage of contained potash feldspar will decrease at depth as it does in many other Black Hills pegmatites, the magnitude of this decrease is not known.

WHITE CAP MINE

The White Cap pegmatite, 1 mile southeast of Keystone in the NE1/4 sec. 16, T. 2 S., R. 6 E., has been mined by several operators for potash feldspar, beryl, and mica. Though the pegmatite is of modest size, it has been a significant source of all these minerals. It was mined sporadically by Clark and Watson Butts from 1939 to 1945. It was being mined by the Lor Mining Co. (Lithium Corp. of America) in 1946 when J. B. Hanley mapped the deposit. Subsequently, it was mined by Baldwin Sagdalen, Dale McDermand, and the Consolidated Feldspar Corp. In the late 1950's the operator was McCarthy-Pullen Mines. The aggregate production by all these operators is probably at least 15,000 tons of potash feldspar, 200 tons of beryl, and 200 tons of crude mica. The mica has been sold as sheet and punch as well as scrap mica.

At the time the geologic map (fig. 120) was made, the mine was still in an early stage of development. Nearly all the mining at that time had been done by the Butts brothers. The map shows two large pits separated by an area in which the top of the pegmatite plunges beneath the surface. A saddle-shaped feature was thus formed in the crest of the pegmatite, but at depth the pegmatite is continuous from one pit to the other. During the Lor Mining Co. operation, which was primarily to obtain potash feldspar from the central part of the pegmatite, the two pits were greatly deepened and joined to form a single large pit. The rock in the vicinity of the saddle was left as a large arch over the top of the pit. The Consolidated Feldspar Corp. subsequently removed this arch; the company obtained several tons of beryl in the process, and also mined feldspar from the northwest end of the pit. Work by other operators has consisted partly of deepening the pit to obtain feldspar and beryl from the central part of the pegmatite and partly of scaling the walls of the pit to obtain beryl and scrap mica from the wall zone.

GEOLOGY

The White Cap pegmatite is a lenticular body that is 350 feet long and has a maximum thickness of about 60 feet. The strike is N. 50° W. through the southeast pit, but it turns to N. 60° W. in the northwest pit (fig. 120). The average dip is about 85° NE. The plunge of the crest and also the plunge of rolls in the contact is for the most part between 10° and 14° to the southeast, except where the top of the pegmatite is depressed in the structural saddle between the two pits. The low plunge keeps the crest near the original surface throughout the length of the mine workings. At the south end of the pegmatite the plunge steepens greatly, and the crest plunges beneath the surface at 50° S. 55° E.

The country rock is quartz-mica schist having the form of a southeast-plunging syncline in which the axial region is occupied by the pegmatite, as shown in the geologic sections. The strikes of bedding and schistosity are generally to the northwest, and the dips are steep. A thin-bedded schistose rock consisting of quartz, biotite, muscovite, and feldspar is predominant in the area, but near the south end of the pegmatite much of the schist is quartz-rich and massive. The schist changes both in structure and composition within a distance of 2 feet or less from the pegmatite contact. The schistosity turns until it is parallel to the contact, even in such places as the saddle between the two pits, where the contact is markedly discordant with the regional structure. Muscovite is unusually abundant in schist within 2 to 4 inches of the contact, and tourmaline is abundant beyond the muscovite-rich rock, but within 1 to 2 feet of the contact.

The pegmatite, as shown on the geologic map, consists of a wall zone of cleavelandite-quartz pegmatite and a core of perthite-quartz pegmatite. A fine-grained border zone of quartz-muscovite pegmatite is also recognizable, but it is only about 1 inch thick.

The wall zone, 5 to 10 feet thick, not only has abundant cleavelandite and quartz, but in places it also carries significant quantities of iron-manganese phosphates, perthite, muscovite, and beryl. Minor accessory minerals include tourmaline, apatite, columbite-tantalite, and arsenic minerals. Within the wall zone, three subunits can easily be recognized; the only reason these are grouped as a single unit is that the subunits are so thin and they are exposed on such steep walls at the edge of the pit that they cannot be shown separately at the scale of the map. The outermost of these subunits consists mostly of fine-grained cleavelandite (80 percent) and quartz (15 percent), but it also has muscovite and tourmaline in crystals that commonly are as much as 3 inches long. The next subunit differs from the first mainly in the abundance of muscovite (10 to 15 percent), which forms books having an average size of 4 inches, but it also has more quartz (30 percent) and less cleavelandite (50 percent). The innermost subunit is much coarser grained and is marked by the presence of abundant iron-manganese phosphates and perthite, associated with quartz, cleavelandite, and beryl. This innermost subunit is generally somewhat thicker than either of the other two, but for the most part the thickness of each of the subunits is between 2 and 4 feet.

The only other exposed zone is one that forms the apparent core, which probably is the true core; it consists mainly of perthite (60 percent) and quartz (25 percent), but also carries cleavelandite, muscovite, apatite, beryl, and iron-manganese phosphates. The perthite is in subhedral crystals having an average length of 10 feet. These are surrounded by a fine- to medium-grained matrix consisting of all the other minerals of the zone. Perthite forms as much as 80 percent of the rock in the upper parts of this zone, but it decreases to as little as 40 percent in the deepest exposure visible at the time the mine was mapped. According to Baldwin Sagdalèn (oral communication, 1955), the perthite content decreases even more at greater depths, and the quartz and cleavelandite of

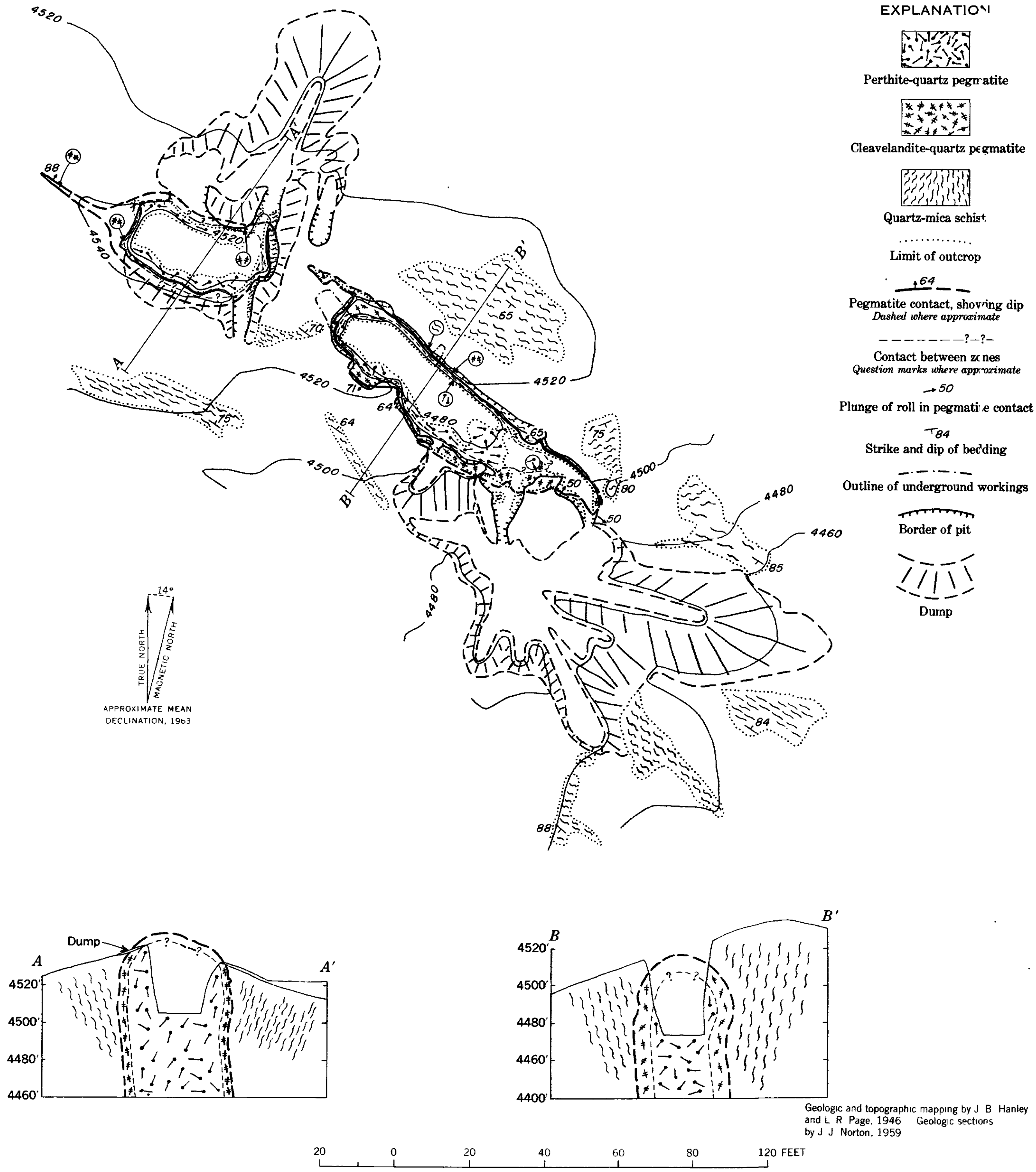

FIGURE 120.—Geologic map and sections of the White Cap pegmatite, Pennington County, S. Dak.

the matrix become the predominant minerals. The average thickness of the core is about 30 feet.

The core is cut in several places by small quartz-rich fracture-filling units that are as much as 15 feet long and 8 inches thick. Felted aggregates of yellow muscovite form about 5 percent of these fracture fillings. Amblygonite has also been found.

MINERAL DEPOSITS

At the time this mine was mapped, it contained significant reserves of potash feldspar, beryl, and mica. During subsequent mining, potash feldspar and beryl were the main products. Most of the potash feldspar had been mined out by 1959, but beryl and scrap mica were still being extracted.

The main source of feldspar is the core, where the large and abundant crystals of perthite are especially adaptable to hand sorting. The smaller and less abundant perthite crystals in the inner part of the wall zone have not been important.

Beryl is most abundant in the phosphate-rich inner part of the wall zone, where crystals several inches long are fairly common. Much larger crystals—some as much as 6 feet long and 4 feet in diameter—have been obtained from the core.

Mica appears in all units of the pegmatite, but the only place where it is abundant enough and coarse enough to be commercially important is in the central part of the wall zone. Here mica forms 10 to 15 percent of the rock over a thickness of about 2 feet. Some muscovite books are as much as 5 inches wide and 8 inches long, but more commonly they are so small that none larger than punch-size can be obtained. The mica is ruby in color and generally of adequate quality, except that it is air stained.

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