SEQUENCE OF MINERALIZATION IN THE KEYSTONE, SOUTH DAKOTA, PEGMATITES

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CONTENTS

SUMMARY

The pegmatites described are the Etta, Hugo, Peerless, and Bob Ingersoll in Pennington County in western South Dakota. The deposits are pipe or dike-like intrusions into pre-Cambrian schist which forms the central part of the Black Hills uplift. Nearby, and genetically related, is the Harney Peak batholith which is itself pegmatitic. The minerals in the Keystone pegmatites were deposited in three stages. In the first stage black tourmaline, muscovite, beryl, triphylite, apatite, microcline, and quartz crystallized out from the pegmatite magma. The very abundant mineralizers were largely rejected during this mass crystallization. In the second or intermediate period they soaked through the pegmatite and replaced the older minerals with large crystals of spodumene, amblygonite, and beryl. In the third period the

hydrothermal solutions replaced earlier minerals and filled fissures, making veins. Minerals typical of this phase are albite (cleavelandite), lepidolite, yellow and green muscovite, tourmaline (indicolite), quartz, and a number of metallic minerals such as cassiterite and löllingite.

INTRODUCTION

Keystone is a small mining town located in Pennington County, South Dakota, about twenty miles southwest of Rapid City. A mail stage connects it with both Rapid City and Hill City, the latter a town ten miles to the west on the Burlington railroad. A spur runs from Hill City to Keystone, which is now used but once a week and then for freight only. Keystone is in a most rugged part of the Black Hills consequently there are no highways other than the stage routes. The town itself is surrounded by abandoned gold mines, but close by are a number of very interesting granite pegmatites. Four of these have been worked for many years and offer magnificent exposures to the visiting mineralogist. The Etta mine, long famous for its spodumene crystals, lies a mile south of Keystone. In the same vicinity are the Hugo and Peerless pegmatites which are of lesser note but of equal interest. To the northwest is the Bob Ingersoll mine which has supplied many cabinet specimens of lepidolite and columbite. The exact location of these pegmatites is given on the accompanying map. There are a number of other pegmatites in the Keystone district, but none are as well exposed.

The writer spent four weeks in this region in the summer of 1927, studying the pegmatites and making a representative collection which includes about thirty species. He is indebted to Mr. E. E. Hesnard, Superintendent of the Hugo and Peerless mines, for assistance both in the collecting of specimens and in the supplying of data which aided materially in the theoretical considerations. The writer is also grateful to his father, Prof. Henry Landes, for helpful advice in the field.

The specimens collected have been studied in the laboratory and the observations incorporated in the present paper. However, this phase of the investigation is not yet complete and it is hoped to publish a later paper giving optical, chemical, and X-ray data for a number of the more unusual minerals. The writer wishes to thank Mr. Emmett Beach of the Chemistry Department of

the University of Kansas for making analyses of several of the minerals.

General Geology

The Keystone district lies near the center of the southern Black Hills. The general geology of the Hills has been described

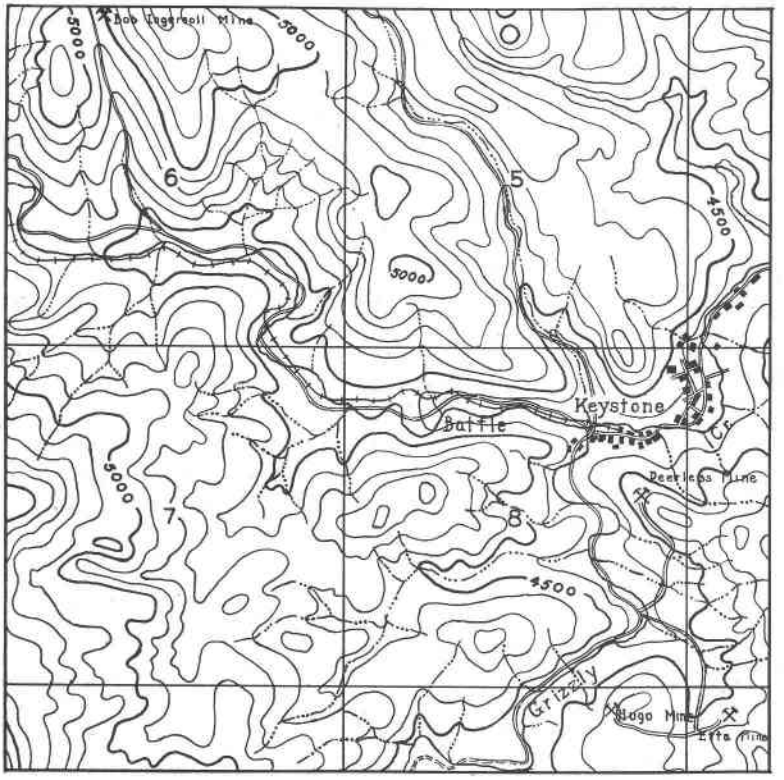

Fig. 1

Map of Keystone Area (modified after the Forest Service working plan map), T. 2S., R. 6E., Pennington County, South Dakota. Contour interval 100 ft. Sections one mile square.

by a number of writers[1] and a recent folio of the U. S. Geological Survey contains in addition to descriptive matter topographic and geologic maps of the major part of the area.[2] The Black Hills are

[1] O'Harra, C. C. A bibliography of the geology and mining interests of the Black Hills Region. *S. Dakota School of Mines, Bull.* **11**, 1917.

[2] Darton, N. H. and Paige, Sidney. *U. S. Geol. Survey, Folio* **219**, 1924.

erosional remnants resulting from a domical uplift at the time of the Laramide revolution. The dome is elliptical in plan with the major axis trending a little west of north. Erosion has stripped off the rocks lying across the top of the dome so that pre-Cambrian schists and granite crop out in the center and an outward dipping series of successively younger sedimentary formations, representing parts of every period from the Cambrian to the Cretaceous, except the Silurian and Devonian, are exposed between the pre-Cambrian rocks and the outer margin of the uplift. The northern Hills, where the Homestake gold mine is located, has been the scene of considerable Tertiary igneous activity. The southern Hills center in Harney Peak which has an elevation of 7242 feet. It and other peaks in the immediate vicinity are carved out of pre-Cambrian granite which is intrusive into schist. The Keystone pegmatites lie in the schist area seven miles northeast of the summit of Harney Peak, and about two miles from the nearest granite outcrop. The nearest Paleozoic rocks are over four miles eastward, so the only country rock involved in a study of these pegmatites is the pre-Cambrian.

Schist and Slate.—Schist, slate and granite form the core of the Black Hills, cropping out over an area of several hundred square miles. The plan of the general outcrop is elliptical. Ziegler[3] has compiled a list of rock varieties found in the metamorphic complex in the Harney Peak region which includes actinolite, garnet, mica, staurolite, tourmaline, graphite, and quartz schists, slates, graywackes, and amphibolites. The commonest rock observed by the writer around the Keystone pegmatites was biotite schist. Newton and Jenny[4] have described the microscopic petrography of the schists occurring to the south and southeast of Harney Peak. Van Hise[5] notes a transition in the rocks between the margin of the pre-Cambrian and the intrusive granite. Slates lie the farthest out, but they become schists as the granite is approached and the schists in turn become coarser, more foliated, and much more crystalline immediately adjacent to the granite. Furthermore

[3] Ziegler, Victor. The differentiation of a granitic magma. *Econ. Geol.*, **9**, No. 3, p. 265, 1914.

[4] Newton, Henry and Jenny, W. P. Report on the Geology and Resources of the Black Hills of Dakota. *U. S. Geog. and Geol. Survey, Rocky Mt. Region*, **1880**.

[5] Van Hise, C. R. The pre-Cambrian Rocks of the Black Hills. *Bull. Geol. Soc. Am.*, Vol. **1**, pp. 203-244.

the schists in the vicinity of Harney Peak strike parallel to and dip away from the granite contact. The principal metamorphic rocks were originally sedimentary. In regard to the age Paige[6] concludes "that the pre-Cambrian rocks of the Black Hills are probably older than Keweenawan and younger than lower Huronian and may therefore be either middle or upper Huronian."

Granite.—The Harney Peak granite is exposed in the southeastern portion of the pre-Cambrian outcrop. It produces a much more rugged topography than does the surrounding schist. The largest exposure includes Harney Peak and is about ten miles across. Many smaller outcrops occur, some of them irregular in outline while others are dike-like. These latter are especially numerous about the main granite mass. They are usually conformable to the schistosity and, therefore, strike parallel to the granite-schist contact. As the granite is approached lit-par-lit injection of dike into country rock may become so common as to obscure the actual contact. Furthermore xenoliths of schist are abundant within the granite, especially about its outer margins.

Most of the dikes are pegmatitic rather than granitic in texture, often containing quartz and feldspar individuals several feet across. Some of the rock in the larger masses is a true granite, but most of it is exceedingly coarse grained and minerals are present which are characteristic of pegmatites. On the trails ascending Harney Peak this coarse granite is well exposed. Not only are feldspar, quartz, and muscovite present in individuals measuring several inches, but also rose quartz and black tourmaline are of common occurrence. According to Paige[7] the feldspars in the Harney Peak granite are microcline, orthoclase, albite, and oligoclase. Microcline is often combined with albite to form perthite which in turn may be intergrown graphically with quartz. Apatite, magnetite, zircon, titanite, and garnet are accessory minerals which may be observed in thin sections.

The method of emplacement of the Harney Peak granite is a problem of such magnitude that time did not permit its inclusion in the present investigation. Both Paige and Ziegler[8] discuss this problem. Hypotheses as to the mechanics of intrusion must take into account the size of the rock body, the metamorphism and de-

[6] *U. S. Geol. Survey, Folio* **219**, p. 4.
[7] *Op. cit.*
[8] *Op. cit.*

formation of the country rock, the number and character of apophyses, the contact phases of the granite, and the very unusual pegmatitic character of the main mass. Ziegler believes that the granite represents the marginal zone of a batholith, probably its upper surface laid bare by erosion. Usually the margin of a batholith is of finer texture than the interior, so if this assumption is correct the Harney Peak batholith might become a truly gigantic pegmatite at depth. Paige[9] concludes that "The relation of the rocks indicate that the granite of the Black Hills came into its present position in the main by distension of the older rock body under great pressure. The schists, deformed by the advance of the magma, were forced into closely appressed recumbent folds. The schistosity produced during this folding favored further injection by the magma through great numbers of parallel dikes and by intricate intrusion "bed by bed." The batholithic magma must have contained an unusual if not unique abundance of water and other mineralizers.

PEGMATITES

Pegmatites are found in the Black Hills in the vicinity of Harney Peak and in the Tinton district (Wyoming) at the northern end of the Hills. Probably the best known pegmatites are those lying northeast of Harney Peak, which are described in the present paper. A great number of articles have been written on these pegmatites, but most are confined to a single phase. A bibliography of the more important general articles is given below:

Blake, W. P. Tin ore veins in the Black Hills. *Trans. Am. Inst. Mining Eng.*, **13,** 691-696, 1885.

Carpenter, F. R. Notes on the geology of the Black Hills. *Trans. Am. Inst. Mining Eng.*, **17,** 588-598.

Connolly, J. P. The Etta Mine. *Black Hills Engineer*, Jan. **1925,** pp. 18-23. Geology and Mineralogy of the Keystone District, *loc. cit.*, pp. 11-18.

Darton, N. H., and Paige, Sidney. Central Black Hills folio, South Dakota. *U. S. Geol. Survey, Folio* **219.**

Hess, Frank L. Tin, tungsten and tantalum deposits of South Dakota. *Min. and Sci. Press,* **100,** 822, 1910. *U. S. Geol. Survey, Bull.* **380,** 131-161, 1909. The Natural History of the Pegmatites. *Eng. and Min. Journal-Press,* **120,** No. 8, 289-298, 1925.

Lincoln, Francis Church. Pegmatite mining in the Black Hills. *Eng. and Min. Jour.*, June 18, **1927,** 1003-1006.

Schwartz, G. M. Geology of the Etta spodumene mine. *Econ. Geol.*, **20,**

[9] *Op. cit.*, page 5.

646-659, 1925. The Black Hills Mineral Region. *Am. Mineral.* Feb. **1928,** 56-63.

Sterrett, D. B. Mica deposits of South Dakota. *U. S. Geol. Survey, Bull.* **380,** 382-397, 1909.

Ziegler, V. The Minerals of the Black Hills. *S. Dakota School of Mines, Bull.* **10,** 1914. The differentiation of a granitic magma. *Ec. Geol.,* **9,** No. 3, 264-277, 1914. Lithia deposits of the Black Hills. *Eng. and Min. Jour.,* **96,** 1053-1056, 1913.

Pegmatite dikes have been intruded into schists on all sides of Harney Peak. Next in importance to the Keystone district is the Custer area, southwest of the peak. Several important mica deposits and the famous Scott rose quartz mine are found in this locality. The geographical relationship of the pegmatites with the Harney Peak granite forces the conclusion that the two are genetically related. They probably connect at depth. Van Hise[10] notes the occurrence of dikes radiating out from the granite which near-by are granitic and farther away pegmatitic until, by a lessening of the feldspar, they grade into ordinary quartz veins.

Duncan[11] states that the strike of the pegmatites and the cleavage of the schists are in general parallel, but they may differ up to 40 degrees. Because the cleavage of the schist is usually parallel to the periphery of the granite the general trend of the pegmatites will be tangent to the contact. However, the Keystone pegmatites exhibit such irregularity in form (some are cylindrical) that this generalization is difficult of application. Brief descriptions of the pegmatites follow.

Etta

The Etta pegmatite has been sporadically exploited for about 50 years. Previous to 1883 it was worked for mica. In that year cassiterite was first recognized in the deposit and extensive tin mining operations were started. These proved unsuccessful and about 1898 spodumene mining began and has continued until the present day, producing a large share of the domestic lithium. The presence in the Etta pegmatite of about sixty mineral species and the unusual size of the spodumene crystals attracted many geologists and mineralogists to the mine which resulted in the publication of a large number of papers. One of the most complete

[10] Van Hise, C. R. Principles of North American pre-Cambrian geology. *U. S. Geol. Survey, 16th Annual Report,* **1894-5,** p. 813.

[11] Duncan, G. S. Contribution to the study of the pre-Cambrian rocks of the Harney Peak district. *Trans. Am. Inst. Mining Eng.,* **43,** 207-218, 1913.

of these was written by G. M. Schwartz[12] in 1925. Other recent papers have been written by Connolly[13] and Lincoln.[14] Among the older writers Blake[15] deserves special mention.

The Etta pegmatite is more resistant than the schist into which it is intruded. Consequently it forms a hill or "knob" which at one time stood about 300 feet above the nearby stream valleys. The top of the knob has been removed by mining operations and a large glory hole now occupies the center. A tunnel has been driven 125 feet below the rim. The pegmatite is a nearly vertical plug, elliptical in plan, with the maximum dimensions at the level of the tunnel. The diameters here are 200 and 250 feet. The convergence above the tunnel is slight, but below the deposit pinches rapidly and diamond drilling has indicated that it closes in at 100 feet.[16] In all probability it does not completely pinch out with depth, but is connected with the Harney Peak granite by a narrow feeder dike or neck.

The country rock into which the pegmatite has been intruded is a gray schist, containing quartz, biotite, muscovite, and a little garnet. Contact metamorphism has destroyed the schistosity for a short distance outward from the pegmatite creating instead a fine granular aggregate of quartz, feldspar, garnet, tourmaline, and biotite. Proceeding inward from the contact there is first encountered what Schwartz terms the "mica selvage" zone. This is from five to fifteen feet thick and consists of large quantities of muscovite with lesser amounts of quartz and feldspar. The remainder of the pegmatite consists largely of spodumene, quartz, and feldspar (microcline, microcline-perthite and albite). The spodumene crystals are very prominent on the walls of the glory hole because of their size and abundance. Some form radial aggregates while others are scattered through the mass like jackstraws. At the time of Blake,[17] before mining reached its present level, four concentric zones were discernable. The outermost

[12] Geology of the Etta Spodumene Mine. *Econ. Geol.*, **20,** 646-659, 1925.

[13] Connolly, J. P. The Etta Mine. *Black Hills Engineer*, **13,** No. 1, 18-23, 1925.

[14] Lincoln, Francis Church. The Etta Mine—A Unique Lithia Producer in the Black Hills. *Eng. and Min. Jour.*, **124,** No. 6, 213-214, 1927.

[15] Blake, W. P. Tin Ore in the Black Hills of South Dakota. *U. S. Geol. Surv., Mineral Resources,* **1883-4,** pp. 602-613. Tin Ore Veins in the Black Hills. *Trans. Am. Inst. Min. Eng.*, **13,** 691-696, 1885.

[16] Schwartz, G. M. *Loc. cit.* p. 651. Cross section on p. 653.

[17] *Op. cit.*

contained both muscovite and biotite. Then came spodumene and greisen followed by a zone consisting of greisen only. The central core contained quartz with subordinate feldspar and spodumene. At the present stage of operations there seems to be little or no difference in the amount of spodumene between the mica zone and the center of the deposit. Another change which has been observed with increasing depth is a decrease in the amount of cassiterite.

Hugo

Although larger than the Etta and magnificently exposed by open cut mining operations the Hugo pegmatite has been described in detail only by Ziegler[18] A briefer description was recently published by Schwartz.[19] The pegmatite outcrop lies near the top of a high ridge about a third of a mile west of the Etta mine (see map). The deposit is a tabular body dipping about 79 degrees northward. It extends over 200 feet east and west and it is 650 feet from the foot wall schist northward to where the pegmatite passes under alluvium.

The country-rock adjacent to the Hugo mine is a very fine biotite schist which has been intruded for some distance from the pegmatite by thin dikes of granitic texture. Some dikes contain quartz only while others consist largely of pink feldspar with small needles of black tourmaline scattered along the contact. The dominant mineral of the schist is quartz with feldspar (orthoclase plus a little albite) and biotite subordinate. A few small grains of garnet are visible in thin section. The schist along the pegmatite contact has been metamorphosed. The quartz and feldspar have recrystallized into a coarser textured rock and varying amounts of tourmaline and muscovite have been introduced. One specimen collected from the contact apparently consisted largely of black tourmaline crystals. When sectioned and viewed under the microscope it was seen that each tourmaline crystal contained, irregularly scattered through it, many grains of quartz. All parts composing a tourmaline individual were similarly oriented (although many of these were completely

[18] Ziegler, V. Lithia Deposits of the Black Hills. *Eng. & Min. Jour.*, **96**, 1053-1056, 1913. Condensed and republished by Darton and Paige, *U. S. Geol. Survey, Folio* **219**.

[19] Schwartz, G. M. The Black Hills Mineral Region. *Am. Mineralogist*, **13**, No. 2, p. 61, 1928.

isolated in the section) while no such realtionship existed between the quartz grains. The latter were originally present in the schist and were incorporated by the tourmaline at the time of the pegmatite intrusion, showing the enormous crystallizing power of that mineral. Some bleaching of the biotite accompanied the recrystallization of the other minerals. The contact metamorphosed schist oxidizes to a red colored rock.

A zonal structure may also be observed within the Hugo pegmatite. Going westward from the east contact a zone of granitic textured pegmatite from three to eighteen inches thick is first encountered. Minerals present are black tourmaline, quartz, feldspar, and muscovite. Next comes a very coarse crystalline rock consisting dominantly of black tourmaline with minor amounts of microcline and quartz. This zone varies in width from six to thirty-six inches. It is followed at the east side of the deposit by the main pegmatite, but on the west side a zone containing coarse books of muscovite lies between the black tourmaline and the giant pegmatite. Ziegler[20] has noted the occurrence of an irregular zone of coarse granite between the mica and the main pegmatite.

In his many years of observation while superintending mining operations Mr. Hesnard has noted a crude stratification in the deposit which is conformable to the steeply dipping foot wall.[21] Three layers occur between the lower contact and the top of the pegmatite. The first (lowest) consists mainly of muscovite and beryl. This is followed by a much thicker zone containing quartz, amblygonite, apatite, columbite, etc. The top layer consists mainly of microcline with a little quartz. At the outcrop the intermediate zone expands up into the overlying layer and contains large amounts of albite and cassiterite.

As in the usual granite pegmatite the minerals present in most abundance are quartz and microcline. The latter mineral occurs in exceptionally large masses in the top layer. In the middle zone some large nodules and shoots of amblygonite have been found, one of the latter measuring 15 by 22 by 40 feet. Spodumene is also present, in crystals which are large but not gigantic. Lepidolite, so dense as to be unrecognizable in the hand specimen, is scattered throughout the middle zone. Mining operations

[20] *Op. cit.*

[21] Hessnard, E. E. Informal communication.

have uncovered a big "horse" of schist near the west side of the pegmatite.

Peerless

The Peerless deposit has been briefly described by Hess[22] and Schwartz.[23] It is located at a considerable elevation on the spur between Battle and Grizzly Creeks, overlooking the town of Keystone. According to Hess the pegmatite is tear shaped in plan with a tail extending northwestward and a hump on the west shoulder. The areal dimensions are about 150 by 250 feet. The tail is 30 feet wide, pinching out in about 100 feet. The plunge of the deposit is to the northwest.

The country rock is a biotite schist with a small amount of tourmaline visible in the thin section. Adjacent to the contact on the southeast side of the deposit the schist is doubled over as though the intrusion had exerted pressure on the country rock and was part at least displacive. The pegmatite has at its border a zone of coarse black toumaline. A crude stratification upward from the base has also been observed in this deposit.[24] The foot wall zone contains coarse books of muscovite with subordinate quartz and microcline. Then comes the intermediate layer with a motley mixture of common and rare minerals. The top zone consists of feldspar and quartz.

Ingersoll

The Ingersoll mine is located on a group of three pegmatites situated at a high elevation two miles northwest of Keystone (see map). The country rock is a fine gray schist of varying composition. One specimen collected and sectioned was similar to the country rock at the Peerless, a biotite-tourmaline schist, except that the biotite was a little paler. In another specimen the biotite and tourmaline were very subordinate and muscovite and garnet were the important metamorphic minerals.

The pegmatites crop out on the side of a hill near the head of a small tributary of Battle Creek. The lowermost deposit is a plug which plunges about 70 degrees east, conformable to the dip of the

[22] Hess, Frank L. The Natural History of the Pegmatites. *Eng. & Min. Jour.-Press*, **120**, No. 8, p. 293, 1925.

[23] Schwartz, G. M. The Black Hills Mineral Region. *Am. Mineralogist*, **13**, No. 2, 61-62, 1928.

[24] Schwartz, G. M. *Op. cit.*

schist. Its most interesting feature is a white beryl crystal nearly four feet in diameter which crops out in the face of the quarry. Other minerals present in abundance are silvery and green mica, albite (cleavelandite), quartz, black tourmaline, and thin logs of spodumene.

The middle deposit lies up the hill and about 125 feet northeast of the first. It is the smallest of the three and contains quartz, white beryl, amblygonite, microcline, albite, and both clear and yellow mica.

Pegmatite number 3 lies about 300 feet southeast of number 2 and at a slightly higher elevation. This is the largest deposit and the one containing the greatest variety of minerals. The body is nearly square in plan with the sides about 85 feet across. The dip is to the east and nearly vertical. The contact between pegmatite and hanging wall is conformable to the plane of schistosity. The foot wall is concealed by the mine dump. The outermost three to five feet of pegmatite constitutes the contact zone with large books of muscovite the most conspicuous feature. Between the mica and the actual contact there is usually (but not invariably) several inches of granitic textured rock containing quartz, microcline, muscovite, and tourmaline. At one place the first foot inward from the contact consisted of quartz crystals about four inches long and one inch in diameter growing normal to the contact plane. Within the main pegmatite a distribution of some of the more abundant minerals could be discerned, but the arrangement is extremely irregular. Near the center is a large plug of lilac lepidolite and cleavelandite. Lying between this and the hanging wall is a thick mass of milky quartz which surrounds on three sides a pipe of amblygonite. Very large crystals of microcline occupy the northeast portion of the deposit, while the remaining parts of the outcrop consist of cleavelandite, quartz, lepidolite, indicolite, columbite, etc.

(To be continued)