THE LITERATURE OF GEOLOGIC OCCURRENCES OF BERYLLIUM

by

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During the past few years certain industrial developments have led to a demand for a metal or an alloy which combines lightness, durability, strength, and workability. Chief among those industries requiring such a substance is the manufacture of aircraft, both lighter- and heavier-than-air types. In fact, so great is the need in this field that it has been said that the progress made along such lines during the past twenty-five years will be as nothing compared to the rapid strides which will follow such a discovery.

With this in mind, numerous investigators have begun a search for a metal which will conform to all the above requirements, and the result has been a greatly stimulated interest in the element beryllium, which seems to most satisfactorily fulfill the needs mentioned. The metallurgical problems governing the recovery of the metal from its ores have been studied with great care, and it may be stated that in a reasonable period of time such difficulties will no longer exist. The present trend is toward fusion methods and an electrolysis similar to that employed in removing aluminum from its ores, and the most notable advances are being made in France and Germany.

The greatest problem then, at present, is to locate commercial deposits of beryllium ores, and such prospecting is being constantly carried on, spurred by encouraging statements from individuals prominent in mining fields, predicting important discoveries in the near future. It is with a view to either substantiating these predictions or to declaring them baseless that the present paper is written. It would seem that a careful examination of all reports on geological occurrences and possible values of the metal would furnish suitable grounds for a rather definite statement in regard to the possibilities for commercial deposits of this much-sought element, and that something of the sort is much needed at this juncture.

A. C. Vivian makes the following observations:

The use of knowledge derived from the metallurgical process of the recovery of aluminum from its ores should be urged in regard to the extraction of beryllium. It is much lighter than aluminum, as light as magnesium, and harder and more resistant to corrosion than either. Phenacite sands occur in Liberia, and new and large deposits have been reported in South Africa. Mineral supplies of beryllium will be located in the British Empire which will give one million times the present supply. Such discoveries should be made in bauxite and in the acid rocks in India, Africa, Australia, and Canada. The search should be prosecuted vigorously and immediately. (1)

On the other hand, we may refer to an editorial in the Engineering and Mining Journal:

Beryllium is not a recent discovery. During the last ten years production of beryllium in Germany and the United States has been placed on a semi-commercial basis, although plant facilities at the present time are sufficient for an output of only a few pounds per month. Plant provision is not the only limiting feature of beryllium production, however, for deposits of beryl and other beryllium minerals are scarce. It is inconceivable that beryllium will ever be a cheap metal, although the present production costs of two hundred dollars per pound will undoubtedly be lowered. The number of industries that will be revolutionized or even materially affected during the next decade by this metal is very likely to be small. (2)

From these two attitudes alone, it is evident that it will be profitable to attempt to reach some conclusion regarding the possibilities of the metal, and a detailed resume of all the known occurrences would be of considerable value. In the following pages are contained accounts of all the occurrences of beryllium minerals of possible commercial value which have been mentioned in mineralogical and geological literature since such have been published.

The known minerals containing beryllium are here listed, together with the percentage of the element which they possess:

Beryl (beryllium aluminum silicate) 11-15%
Chrysoberyl (beryllium aluminate) 20%
Phenacite (beryllium orthosilicate) 44-46%
Leucophanite (beryllium sodium calcium fluosilicate) 10-12%
Euclase (hydrous beryllium aluminum silicate) 17%
Helvite (beryllium iron manganese thiosilicate) 10-14%
Gadolinite (beryllium yttrium, etc., basic orthosilicate) 5-11%
Beryllonite (beryllium sodium phosphate) 20%
Herderite (beryllium calcium fluophosphate) 15%
Hambergite (beryllium borate) 53%
Bertrandite (hydrous beryllium silicate) 39-43%
Meliphanite (beryllium calcium sodium fluosilicate) 10-14%
Trimerite (manganese calcium beryllium silicate) 16%
Eudidymite (sodium beryllium hydrous silicate) 11%
Danalite (beryllium iron zinc manganese thiosilicate) 14%

Of this list, the most important minerals are beryl, chrysoberyl, phenacite, danalite, herderite, and beryllonite. No mention is made of gem varieties such as the emerald, since they can never possibly constitute an important source of the metal.

Beryl is generally found as an accessory mineral in granitic pegmatite veins in all parts of the earth, and is especially associated in these veins with quartz, micas, feldspars, garnet, corundum, and zircon. It occurs in the United States in New Hampshire, Massachusetts, Maine, Connecticut, Pennsylvania, Virginia, North Carolina, Alabama, Colorado, South Dakota, and in other parts of the country in sparing amounts. It is found in hexagonal prisms, or in large masses, either coarsely columnar or granular. It is green, blue, yellow, white, or rose-red in color, and has a hardness of 7.5-8, and a specific gravity of 2.6-2.8. Its luster is vitreous, its fracture conchoidal to uneven, and it possesses a white streak.

Chrysoberyl is found in green or yellowish tabular crystals, or as thicker emerald-green crystals, which are raspberry-red by transmitted light, and also in rolled pebbles. Discoveries have been noted at Haddam, Connecticut; New Hampshire; Greenfield, New York; and Norway, Stoneham, Stowe, Peru, and Stanton, Maine. Its hardness is 8.5, its specific gravity 3.5-3.84, and its luster is vitreous to greasy. It has a white streak, is brittle, and its fracture is uneven to conchoidal. Alexandrite and cymophane are other varieties.

Phenacite occurs as colorless, wine-yellow, rose-red, or brown rhombohedral crystals, often lens-shaped. Its common associates are amazon stone, beryl, quartz, emerald, and mica. In this country it is found in Colorado, New Hampshire, and Virginia. It is brittle, with a conchoidal fracture; its hardness is 7.5-8, its specific gravity 3. It has a vitreous luster and a white streak.

Danalite is confined to Massachusetts and El Paso County, Colorado, where it occurs as octahedrons of flesh-red to gray color. Its hardness is 5.5-6, its specific gravity 3.4, and its luster resinous. Its streak is similar to its color, but somewhat lighter.

Herderite is found at Stoneham, Auburn, and Hebron, Maine. Its crystals are low hexagonal pyramids in shades of yellow and green. Its hardness is 5, its specific gravity 3, its luster vitreous, and it has a subconchoidal fracture.

Beryllonite is found loose in disintegrated material of a granitic dike at Stoneham, Maine, in short prismatic to tabular crystals, colorless to pale yellow. The luster is vitreous, the hardness 5.5-6, the specific gravity 2.845, and the fracture conchoidal. (3)

Other occurrences of these minerals and others have been listed as follows:

Phenacite has been discovered in the emerald mines of Tokowaja, in the Ural Mountains; at Framont in the Vosges

Mountains; near Miask, inthe Ilmen Mountains; at Reckingen, Switzerland; at Durango, Mexico; and at Topaz Butte, Colorado.

Eudidymite occurs on the island of Oevre-aro, Norway.

Epididymite comes from Narsasik, Greenland.

Barylite is found at Langban, Sweden.

Euclase occurs with topaz in a chloritic schist of Villa Rica, Brazil; with topaz in auriferous sands of Orenburg, in the Ural Mountains; with pericline in a mica schist of Gransgrube in the Austrian Alps; with pericline at Mollthal, Germany. It is generally in pegmatites, with fluorite, which association indicates fluoriferous vapors present during the pegmatite formation.

Worobyewite is the caesia beryl of Vernadsky.

Davidsonite is a greenish-yellow beryl from Aberdeen, and was named by Thomson.

Rosterite is a rose-red, slightly altered beryl from Elba, and was named by Grattanola.

Heliodor is a yellow beryl investigated by Eppler, and contains 0.58% Fe_2O_3. It becomes luminous in cathode rays.

Beryl has also been reported in monazite sands by Boudouard. (4)

Some Rocks contain an excess of Al_2O_3 over and above that needed by the feldspars and nephelite. Such rocks are principally the nepheline syenites. The beryllium content of such rocks is probably more abundant than has been hitherto considered, and in the future interesting results would doubtless be obtained if this element were more often looked for and determined. It has also been shown recently to be in a titanolivine of the Val D'Ala, in the Piedmont, and also in that of Christiansand, Norway, where it had not been considered as existing before. From this it may be seen that the element may possibly be more abundant than previous estimates have indicated, and all facts point to its being included in aluminum determinations to a large extent in the past. (5)

A closer investigation of these occurrences will, I think, bring out some noteworthy points.

The pegmatites of Maine are perhaps the most famous in this country, and have provided considerable beryl to gem collectors. A somewhat detailed consideration of them would be appropriate here. An area of granite pegmatites extends in a northwesterly direction from the Kennebec River in Maine to New Hampshire. It composes a broad band of country twenty-five to thirty miles wide, and the veins occur as parallel dikes and sills between the bedding of the older schists, gneisses, and limestone. The section in which the gem-bearing pegmatites occur extends from Auburn to Newry, Maine, and is an area about seventy miles long by fifteen miles wide, near the center of the larger zone. The general strike is northwest, and the average dip ten to twenty degrees northeast. The southwestern side of the belt is flat or slightly rolling country, and the valleys are filled with glacial sands. The pegmatites do not weather away as fast as the mica schists above them, and so form long low bluffs, outcropping on the hillsides rather than on the tops. The most pronounced feature of the pegmatites is a coarse structure, one beryl crystal at Poland, Maine, being six feet in diameter. The dikes all show banded structure--next to the hanging wall is a medium-grained graphic granite, and below this is a zone of huge crystallization, with great mica plates, quartz masses and crystals, and soda feldspar. In the lower part of this zone are gem pockets, and this portion is called the "mineral sheet". Below this is a band of nearly pure potash feldspar. Underneath this is a narrow band of garnets, and from one to two inches thick. Next below this is another biotite graphic granite, and under this the footwall.

The beryls here are either white or blue or yellow, are generally opaque, and are embedded in the "mineral sheet".

The pegmatites have been intruded between the older metamorphic rocks. The larger fissures were filled with the original granite magma, while in the smaller fissures the magma has become more acid, due to the greater ease with which the vapors and superheated steam traversed these narrow openings. The vapors consisted of fluorides and borides of silicon, volatile compounds of iron, manganese, and the alkalies, with superheated steam. The volatiles have been concentratednear the middle portion of the dikes, where extensive mineralization has occurred. Beryls having black tourmaline crystals next to them, or growing into them, are always clearer and of deep blue, and cut better gems.

The succession when approaching a gem pocket is as follows:

Albite changes to cleavelandite; next a rock of quartz and black tourmaline having the structure of graphic granite is encouhtered; then lepidolite; then muscovite. Where an extensive amount of lepidolite occurs around the pocket, it will be found to contain apatite with little or no gems. (6)

A beryl occurrence is mentioned near Hissop Post Office, Alabama, seven miles south of Goodwater, on the Columbus and Western Railroad. Fine gem beryls are found loose on the surface and embedded in quartz boulders resulting from the disintegration of a granite gneiss. They are distributed principally on two distinct belts of gneiss, parallelling each other about eight miles apart. Schists which are coarsely banded and contain a heavy graphite and pyrite content, are present between these extensive granite ledges. (7)

New Hampshire beryls are found near the towns of Grafton and Acworth, thirty miles above the Massachusetts line on Cold River, at Williams Hill or Beryl Mountain, one mile south of South Acworth. Debris covers a steep slope between an old feldspar quarry and a woods; this debris consists of milky quargz with blue, green, and yellow beryl. At the entrance to the excavation into the hillside is rose quartz. Twenty-four beryl crystals, from six inches to one foot in diameter are set in the quartz forming the sides of a cavity. One crystal fifty-two inchds long byone foot in diameter is mentioned. Granitic rock is found about the beryl. Another beryl four feet long and two and one-half feet in diameter has been located in this quarry. Other localities are found principally on the highlands between the Connecticut and Merrimac valleys, where beryls are to obtained in veins of coarse granite.

A mica quarry in pegmatite in Fletcher Mountain, two miles south of Rumny Station, at Groton, New Hampshire, has yielded many large beryls. (8)

Beryl crystals eighteen feet long and four feet across occur within a few feet of the surface at the Bumpus feldspar quarry near Bethel, in Albany township, Maine. The probabilities are that this is a pegmatite dike. (9)

Palache and Shannon indicate the discovery of beryllonite crystals embedded in albite of the platy cleavelandite type, and some herderite with embedded tourmaline, in a talus slope at Newry, Maine. The original pegmatite ledge has never been located. (10)

At Middletown, Connecticut, pegmatites are found which consist mostly of quartz and perthitic feldspar with muscovite and biotite. The minerals project from the walls of cavities and are covered by platy cleavelandite. The pegmatites occur in schists, metamorphosed sediments, and paragneisses. The beryls are mostly of the precious variety. The magma was evidently folded while viscous into the pliant schist which was already present at the time of the Appalachian Revolution, and has not been rendered schistose during later movements. (11)

At Strickland's Quarry, Portland, Connecticut, a coarse pegmatite in a purplish muscovite-biotite schist is found. Its extreme width is twenty meters, and it consists of buff microcline and smoky quartz. The beryl occurs as dull but well-bounded crystals, of a pale green color. (12)

In San Diego County, California, beryls are located in a pegmatite in the northern part of the county, but no commercial shipments had been made up to 1925. The price at that time was 4-5¢ per pound in carload lots. Phenacite is recommended as the ore instead of beryl, as the separation from the aluminum of the beryl is too difficult. The commercial ore should carry 10-12% beryllium. (13)

In the peninsula of Lower California, beryl occurs in pegmatites with tourmaline, rubellite, sapphire, turquois, and essonite. (14)

The Black Hills are another famous locality for all kinds of pegmatite minerals, but from 1914-1917 only $2,463 worth of beryl had been supplied from this region, and hence it cannot be regarded as a possible commercial source of the metal. (15)

Near Simpson Springs, Utah, red beryl, a new mineral anomaly, has been found. The crystals are small but distinct, and are colored by some manganese compound. They are located in the Dugway range, in a rhyolite matrix, with topaz, bixbyite, and altered garnets. (16)

At Franklin Furnace, New Jersey, beryllium has recently been found in vesuvianite, cyprine, and barylite. This is of uncommon interest because of the present intensive search for such occurrences of beryllium. The authors of this article believe that beryllium is a normal constituent of vesuvianite, and that it will also be found in willemite. In the latter, it will be present probably as a post-ore element introduced in the deposits by the contact action of granite pegmatites. (17)

In Ontario, Quebec, and Nova Scotia, beryl has been found in pegmatites, in gneiss, in mica schist, and in limestone. The most extensive deposits occur in Lyndoch township, in Modoc township, in Hastings county, in Calvin township of the Nipissing district, and in the Rainy Lake district of Ontario. Important deposits of the mineral are anticipated in eastern Canada, where there are a large number of pegmatites. (18)

Additional mention is made of beryl with microcline, albite, tourmaline, garnet, quartz, and magnetite in pegmatites in Ontario, Canada. (19)

In Manitoba beryl is found with purpurite, heterosite, tantalite, etc., in the Oiseau River district, in lithium pegmatites. (20)

Beryl occurs in the pegmatites of the San Luis Potosi of Mexico, with quartz, topaz, and the rare earths. (21)

Another Mexican occurrence is with topaz at Realejo in a pegmatite dike. There is alsomentioned a new occurrence of dumortierite in a granite at Guadalcazar, in northern Mexico. (22)

Leaving now the North American localities for this element, we take up those of the important mineral fields of Africa.

Prospecting for beryl has been active in the Leydsdorp district of South Africa, and in the Ural Mountains also. The Soviet government, with its extensive Siberian deposits, will probably control the prices on future raw material. (23)

A beryl-emerald occurrence has been noted in the Murchison

Range in the northern Transvaal, and is about thirty miles long. The occurrence is that of a lenticular mass five hundred feet long and two hundred feet wide, in a mica schist of biotite and fuchsite. The cleavage of the schist is diagonally across that of the deposit. Another deposit fifteen miles north of Steinkoff in Namaqualand has been noted. Here it is in a pegmatite, and seems to continue with depth. The mineral has been found in tons over a large area. (24)

Additional information is given concerning the Namaqualand field. The beryl is located in pegmatite veins, as scattered crystals of large size, and in crystalline aggregates forming pockets of several tons, up to sixteen tons. Tantalite, lepidolite, and tourmaline are associates. Twenty tons of beryl have been produced, and the totaltonnage of the rock mined amounts to four hundred tons. Kovaloff predicts hundreds of thousands of tons of beryl on the property. (25)

Near Walfish Bay, in Southwest Africa, beryl is found near Rossing Station, in a wide pegmatite sheet, with tourmaline, muscovite, white and rose quartz. Beryl and apatite are also mentioned as being obtained from a pegmatite in Tonkerhoek, German Southwest Africa. (26)

Madagascar has been an important source of a number of excellent gem specimens, and beryl occurs here in several localities.

Pink beryl is found at Maharita, in Madagascar, in the Valley of the Sahatony River, a tributary of the Mandaor, passing along the west slope of Mount Bity. Here there are numerous veins of pegmatites, penetrating layers of limestone, mica schist, and quartzite. The veins are sometimes one hundred feet thick, and consist of quartz, amazonite, albite, lithia, tourmaline, lepidolite, beryl, etc. This variety has been named Morganite, and also occurs with kunzite at Pala, San Diego County, California. It contains lithia and caesia. (27)

Heavier types of beryl, with a specific gravity of 2.910, are found in pegmatites with lithium minerals in Madagascar, while the lighter ones, with a specific gravity of 2.707, are are associated with muscovite pegmatites. Beryl in general occurs in potassium pegmatites. (28)

At Ambatofisaorana, Madagascar, beryl is located in a pegmatite with almandine-spessartite, developed at the contact with a granite.(29)

Beryl is very abundant in Madagascar pegmatites, sometimes associated with microcline, muscovite, quartz, bismuthinite, struverite, etc., especially near Ampangabe. (30)

At Tsarasaotra, Madagascar, on the Tsibohaina River, beryl is found with scapolite, euxenite, and monazite, in a potash pegmatite. (31)

On the western portion of the island of Madagascar, precious stones have been discovered in pegmatites intersecting Archean gneisses. Among these are beryl, tourmaline, corundum, garnet, spodumene, amethyst, etc. (32)

In India, beryl has been obtained from pegmatite quarries at Nellore, and from the Lakshminarayana and Kubera quarries. These are evidently located in pegmatite dikes. (33)

Beryl has also been located in India in pegmatite veins traversing biotite gneiss near Daso in Kashmir. Here it is associated with tourmaline and garnet. The material is abundant and the pegmatites cover a wide area. (34)

Beryl is found in India as an accessory in the coarse mica pegmatites of Bihar, Orissa, Nellore, and Kishengarh. It is used as a gem, from these localities. A possible Indian production of ten tons per year is estimated. (35)

In Ceylon, beryl occurs in white crystalline limestone with corundum, tourmaline, zircon, quartz, apatite, scapolite, etc. Here it is evidently contact-metamorphic in origin. (36)

Many famous European localities exist, and these are now tabulated in the following pages.

In Bohemia, beryl is found in feldspar quarries, in pegmatites near Pisek. The opaque common beryl and the yellow or bluish noble beryl have been discovered. Bertrandite and phenacite also occur here, produced from the decomposition of the beryl. (37)

The pegmatites of the Velka skala (Great Rock) in Bohemia yield gigantolite, beryl, albite, and apatite. (38)

In the Tabor granite, near Vejrec, Bohemia, beryl has been discovered in aplitic veins accompanying the granite. (39)

At Marienbad, in Bohemia, beryl has been found with perthite, mica, tourmaline, quartz, fluorite, zircon, etc., in a phosphate pegmatite. (40)

Beryl has been found at Budislava, in Bohemia, in biotite pegmatites penetrating gabbro-diorite, and associated with quartz, tourmaline, orthite, zircon, etc. (41)

On Lundy Island, off the English coast, granite of the muscovite-biotite type, with dark quartz, has been found, in which gem minerals have been located. Orthoclase and plagioclase, much twinned, occur; as does quartz with many gaseous and liquid inclusions. Traversing this granite are numerous aplite veins, and these pass on the margins into coarse-grained pegmatites. Topaz and beryl occur in drusy cavities and fissures in the pegmatites and the normal granite, with smoky quartz, albite, mica, orthoclase, tourmaline, fluorite, and apatite. The beryl is pale yellow or blue or colorless, in prisms 0.7 centimeters long by 0.3 centimeters wide. (42)

In France beryl is found in pegmatites in several localities in the Loire-Inferieure. Here it is associated with ilmenite and quartz in micaceous schists. (43)

Near Olliergues, in the Puy de Dome area, beryl has been located in a granite pegmatite with much quartz, microcline, muscovite, and black tourmaline. The beryl is slightly kaolinized. (44)

At Miseri, near Nantes, beryl has been noted in pegmatites withorthoclase and plagioclases, with smoky quartz, biotite, muscovite, molybdenite, chalcopyrite, tourmaline, arsenopyrite, etc. The crystals were ten to fifteen centimeters long, and were greenish or yellowish. This occurrence is unusual because of the association of the metallic sulphides. (45)

One locality has been mentioned in Spain, and that at La Alcubilla in the municipality of Villaviciosa, in large crystals. Here at the Las Esmeraldas mine some are fifteen centimeters wide by thirty-five meters long. Chromite occurs with it, and the occurrence is in pegmatites. (46)

In Italy, beryls are found in loose blocks of gneiss with tourmaline and manganese garnets near Craveggia, in the Val Vigezzo. (47)

Another mention of Italian beryls is given as large beryl crystals from a pegmatite on the small peninsula of Piona. (48)

In Austria, beryl occurs in a pegmatite at Kreuzberg. (49)

In the Tyrol, a pure white massive beryl has been discovered in a mica schist near Meran. This contains 13.47% beryllium oxide. (50)

Russian beryls have been found in the government of Perm, at Alabaska and Musuka. The Rossing Station locality is also mentioned here,and it is interesting to note the presence of uranium oxide in the heliodore of these pegmaties, which is held to indicate the radioactive nature of the solutions forming the pegmatite. (51)

Bertrandite comes from an aquamarine pegmatite at Mount Irkutka. (52)

In Russia, a widespread occurrence is that of beryl, galena, pyrite, tourmaline, and the other pegmatite minerals, in quartz veins traversing amphibolite. Mention is also made of the association of huebnerite and scheelite. (53)

Near Ekaterinburg, pegmatite veins traverse crystalline schists bounded on the west by a granite and on the east by a dunite-pyroxenite massif. A transfer of calcium, magnesium, iron, chromium, vanadium, manganese, and titanium from the surrounding rocks is indicated. Beryl is present. (54)

In Finland, beryl, biotite, oligoclase, and fluorite are found in the first stage of a pegmatite, and a potassium feldspar, pyrite, epidote,and calcite at a later stage. Sericite and chlorite occur as alteration products. There is no quartz, which is not usual. (55)

Beryl is found with amblygonite, lepidolite, feldspar, etc., in a lithium pegmatite from the island of Uto near Stockholm. (56)

In Bavaria, phosphate pegmatites from Marchaney, Plossberg, Pleystein, Hagendorf in the Oberpfalz, and Rabenstein inthe Bavarian Forest, yield anhydrous and hydrated phosphates, beryl, and columbite. (57)

Mongolian beryl is found in granite pegmatite veins forty kilometers west of Urga on the Gorikho river. The beryl is associated with topaz, fluorite, martite, malacon, etc. (58)

Near Jihlava, Moravia, beryl occurs with orthoclase, albite, tourmaline, quartz, muscovite, apatite, etc., in a pegmatite vein. (59)

Beryl has been discovered with wolframite in decomposed pegmatites near Torrington, in New South Wales. (60)

In South Australia, beryl is present in weights up to one hundred pound crystals of a greenish color in quartz veins and in pegmatites intersecting the granite of the Boolcoomatta Hills, north of Olary. (61)

In the cryolite mine at Ivigtut, Greenland, beryl occurs where the cryolite forms a pegmatitic intergrowth with feldspar. (62)

Beryl is found in the pegmatites at Tanokami, Japan, with orthoclase, quartz, corundum, muscovite, tourmaline, monazite, manganite, cinnabar, etc. (63)

Beryl has beem discovered in the statesof Minas, Ceara, Rio Grande do Norte, Bahia, Sao Paulo, Espirito Santo, and Rio de Janeiro in pegmatites, and in the Botafogo granite, surrounded by quartz. (64)

In Colombia, emeralds with carbonates, sulphides, quartz, fluorite, etc., are found in veins of calcite traversing black carbonaceous shales and shaly limestone of Cretaceous age. These beds have been greatly folded. The gem deposition is the result of pneumatolytic contact metamorphism. (65)

It is evident from what has gone before in dealing with those beryllium minerals which are not the products of secondary alteration that we are concerned with an extremely specialized occurrence, for the most part. It is notable that in the vast majority of cases, the minerals occur solely in pegmatites. It is my purpose now to consider pegmatites from a standpoint which to my knowledge has not been stressed in the past, in order to better arrive at some conclusions regarding the occurrences of beryllium.

Although there are many widely divergent opinions concerning the exact method of formation of pegmatites, the fact that they are ultimately derived from the mother liquors which take their being directly from the molten magma appears to be incontrovertible. It is also generally admitted that magmas follow the laws of true solutions in practically all instances, and this assertion is especially emphasized in accounting for the order of crystallization of the minerals from a molten mass containing their constituent elements in varying proportions. It should then be practicable to apply the laws of solution and precipitation somewhat more broadly and attempt to explain by means of those laws the occurrence and minerals of pegmatites.

In so doing, I consider it difficult to over-emphasize the importance of the law of mass action as affecting precipitation, since it can hardly be disputed that this principle has been highly important in the production of a vast number of geological phenomena, and it is possible that it may be extended still further to cover the particular case in which we are interested.

The normal composition of the magma is believed by most geologists to accord closely to that of a gabbro. Analyses of a number of gabbros reveal the following percentages

SiO_2	40-50%	CaO	8-15%
Al_2O_3	9-19%	Na_2O	.6- 3%
Fe_2O_3	1- 9%	K_2O	.1-.8%
FeO	5-12%	H_2O	.5- 1%
MgO	5-15%	XyO	.7- 5%

(XyO is small quantities of the various oxides, chiefly TiO_2)

An examination of these figures will show clearly the considerable preponderance of silica, alumina, ferrous and ferric oxides, magnesia, and calcium oxide in the rock, and the minor percentages of sodium and potassium oxides and water. A simple application of the principle of mass action to these compounds in solution under the temperatures and pressures under which a magma of this type exists would lead to the following conclusions:

With decreasing temperature and pressure:

(1) Those compounds which are present in the largest amounts would precipitate out first; more specifically, the femic minerals.
(2) Those compounds present in the greatest proportions in the residuum would be thrown down next; these would be the basic plagioclases high in calcium.
(3) The next minerals to form would be the acid plagioclases, and then the potassium aluminum silicate, orthoclase.
(4) Quartz being present in a considerable excess over and above that necessary to form the foregoing compounds, and after a manner of speaking the solvent material for the other materials, would crystallize out last.

This is the normal order of crystallization of a magma, neglecting the accessory minerals of high specific gravities, according to all conclusions arrived at from experimentation. The observed order substantiates the suggestion of mass action as the prime factor in first forming the minerals developing from the molten mass. This process would of course be subject to considerable modifications according to varying affinities, solubilities, etc. No suggestions are made as to the methods of migration of the minerals once formed through the melt, or as to any similar problems which have been dealt with by authors on the subject. The principle of mass action is here stressed in order to support an assumption to be made later concerning the possibilities of commercial production of beryllium.

The question of the application of all this to the occurrence of beryllium minerals in pegmatites should now be considered. If the principle of mass action is to be followed, it should reasonably be expected that beryllium compounds, since beryllium is a very rare element, would form as one of the last products of crystallization from the magma, leaving out of consideration various modifying factors such as affinities, etc. So likewise should any other mineral compounds of the rare elements. If the pegmatite is considered as practically the last step in the crystallization of the magma, then we should suppose that it would be composed of quartz, the acid feldspars, some slight amounts of ferro-magnesian material, and the rare element minerals, since their concentrations in the original molten mass would not under ordinary conditions be sufficient to produce their early precipitation.

Observations in practically all cases confirm this supposition. Those rare minerals which occur in pegmatites are for the most part largely confined to such a type of occurrence, and the list of pegmatite minerals is a definite and characteristic group. The beryllium minerals fall indisputably within this class.

Reasoning conversely, it may be stated that since beryllium is practically confined to the pegmatites in its larger mineral occurrences, it is present in the earth in very slight amounts. In other words, since it is found in pegmatites, it should not reasonably be expected to occur in any considerable quantities in any other rocks, and in addition should not be regarded as an abundant element in any sense of the word. The discovery of extremely large crystals of the pegmatite minerals merely indicates that there is a very nice state of equilibrium in the mother liquors ascending through the fissure openings, and that certain conditions of temperature, pressure, and concentration favor most strongly the crystallization of a certain mineral within a definite narrow vertical range. The first precipitation having been accomplished, the original conditions would be supported by selective precipitation, and the minute crystal nucleus would possibly reach considerable proportions.

Accepting these principles as correct, I am not in agreement with those writers who predict important commercial deposits of beryl on a scale somewhat to be compared with the more common metalliferous ores. It is my impression that either they are not familiar with the geological conditions governing such occurrences, or that they have allowed themselves to be carried away by baseless hopes. It is true that discoveries of such concentrations of beryl as they mention would be revolutionary in the airplane industry, for instance, and would doubtless lead tonew and important uses for the metal in a number of other fields. Such authors must have allowed their writings to be more greatly influenced by their desires than by the actual facts. They point to the phenomenal success of aluminum, a metal which had such inauspicious beginnings as regards extensive usage, forgetting that aluminum is far more abundant in the earth than is beryllium--the analogy ends with the low specific gravities of the two metals and certain similarities in their metallurgical processes. So, in closing, it might be said that one twenty-ton beryl crystal and an infinite amount of hoping will never suffice to make beryllium a commercial product.

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