PARAGENESIS OF THE PEGMATITE MINERALS OF STRIEGAU, SILESIA

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Abstract

Pegmatite bodies within a granite mass at Striegau, Silesia, contain a great number of open druses, in which were deposited most of the minerals forming the basis of this study.

Five stages of mineralization are established for the Striegau pegmatites. The first, or magmatic, stage included the formation of the main quartz-feldspar pegmatite bodies, and the graphic intergrowth of quartz and orthoclase surrounding the druses. The cavities were probably formed during the second, or albitization, stage, during which albite and cleavelandite were deposited in the druses and replaced some of the orthoclase of the druse walls.

Chlorite (strigovite, prochlorite, and penninite), tourmaline, fluorite, epidote, clinozoisite, and axinite belong to the succeeding period of druse filling. Pneumatolytic and hydrothermal action are indicated.

Zeolites, chiefly stilbite, are characteristic of the fourth stage of mineralization, which was evidently a period of cooling thermal solutions. Calcite crystals in the cavities represent the final period of mineral formation.

A table of mineral paragenesis is presented.

General Geological Relationships

The Striegau intrusive granite mass is located about 60 kilometers southwest of Breslau in Prussian Silesia, at the eastern end of the Riesengebirge. The minerals forming the subject of this study were obtained from pegmatitic druse-bearing lenses in the Striegau granite mass.

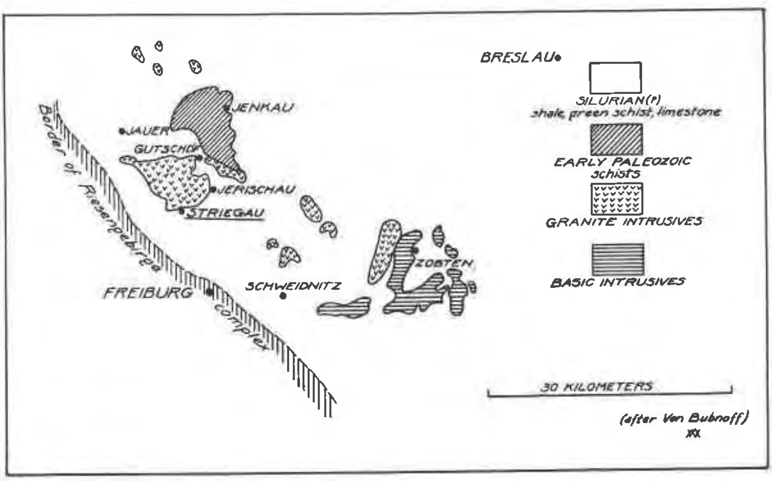

Fig. 1. Sketch map of the Striegau region, Silesia.

The intrusive is in the shape of a wedge pointing northwest, and has its greatest dimension, about 15 kilometers, in that direction (Fig. 1). The granite is in contact with gabbro and gneiss to the south; in the northeast it lies beneath the northwest-striking Jenkau schists of early Paleozoic age. The other surrounding rocks are shales, green schists, and limestones of Silurian(?) age. Where the granite touches schists and slates a distinct contact zone, high in tourmaline, has been developed. According to Cloos (quoted by Von Bubnoff, 1930), the Striegau granite was intruded along the gneiss-schist contact (Fig. 2).

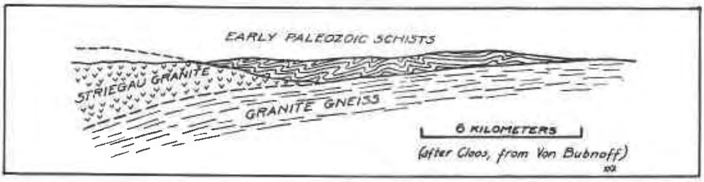

FIG. 2. Diagram to illustrate the possible mode of intrusion of the Striegau granite.

A lineation, trending northeast-southwest, has been observed in the granite. This lineation is nearly perpendicular to the elongation of the intrusive mass, but it is parallel to the regional structure.

The age of the Striegau granite has not been definitely determined, although it is perhaps late Carboniferous (Von Bubnoff, 1930, p. 538).

The granite of the Striegau intrusive is light colored and medium-grained to fine-grained. The chief constituents are white feldspar (principally potash feldspar, with subordinate plagioclase), gray quartz, and biotite. Muscovite is almost completely absent (Schwantke, 1896, pp. 2–3). Von Bubnoff (1930, p. 538) cites three sub-types of the granite: (1) coarse-grained biotite granite; (2) fine-grained acid granite; (3) some binary granite (this in contradiction to the statement of Schwantke).

The granite has a marked tendency to break readily along three mutually perpendicular planes, one nearly horizontal, the others approximately vertical and trending north-south or northwest-southeast (*Kopfabgänge*), and east-west (Schwantke, 1896, p. 3; Von Bubnoff, 1930, p. 538; Gürich, 1920, p. 310). This characteristic makes for easy quarrying and working of the rock, and the result is that a great number of quarries have been opened in the granite, permitting a rather thorough examination of its character.

The pegmatites contained in the granite are most abundant between Striegau and nearby Gräben. At Striegau the pegmatites are of two principal types: (1) vein-like bodies about 6 inches wide with parallel walls, discontinuous along strike and dip, and in many instances associated with aplites; (2) nearly horizontal, sheet-like, irregular bodies (Gürich, 1920, p. 309). The pegmatites consist of feldspar and quartz predominantly; in some there are fairly large mica sheets. Feldspar is by far the most abundant mineral. These pegmatites contain the open druses in which were deposited most of the minerals discussed here. Some pegmatite lenses, however, contain no druses.

The druses attain a diameter of as much as 1 meter (Gürich, 1920, p. 310), and they may contain large, detached, smoky quartz crystals associated with loose fragments of feldspar and epidote. The walls are made up of spiky quartz crystals with interstitial potash feldspar, all overgrown by albite.

In addition to the pegmatites, the Striegau granite contains numerous other inclusions (Gürich, 1920, p. 310; Schwantke, 1896, pp. 3–4). Aplites are associated with the pegmatites. Quartz veins are found near or along the contact of the granite with the schist. Fracture fillings (generally in the nearly vertical *Kopfabgänge*) consist of quartz, fluorite, pyrite, chabazite, and calcite. Basic inclusions, of minor importance, are believed to represent altered schist fragments. There are also small lenses of muscovite, molybdenite, and hematite.

Striegau Pegmatite Minerals

A brief discussion of the individual pegmatite minerals follows. The minerals are arranged as nearly as possible in their order of deposition. General paragenesis and the various stages of deposition are considered later.

Biotite

Laths of biotite are intergrown with the graphic quartz and feldspar which constitute the base upon which the druse minerals are deposited. It appears, therefore, that the graphic quartz-feldspar and the biotite are part of the earliest, or magmatic, stage of pegmatite formation and make up the bulk of the pegmatite bodies.

Biotite deposition seems to have been essentially contemporaneous with the formation of the graphic quartz and feldspar. The biotite is in shreds and long laths and is generally oriented with the flamboyant structure of the enclosing graphic intergrowth. Some biotite, however, follows cracks which cut across the graphic structure. Biotite of this early stage of deposition is of the green variety, and is relatively fresh, showing alteration to chlorite only rarely.

Biotite which appears to be of a later stage of deposition is found associated with albite and quartz. This biotite is strongly pleochroic, green to brown, and is considerably altered to chlorite and epidote.

The biotite of both stages of deposition, and especially of the later stage, is found only in small amounts in the specimens.

Orthoclase

Orthoclase, in graphic intergrowth with quartz, is the principal constituent of the pegmatite material which surrounds the druses.

The orthoclase is almost universally micro-perthitic. The perthitic intergrowth, however, is rarely distinct, and serves only to make the orthoclase in thin section appear cloudy or dirty. In a few cases distinct string perthite and patch perthite are recognizable, but none of the perthitic intergrowths shows regularity of form or orientation. A few grains of orthoclase in the graphic intergrowth are clear and are free from albite lamellae.

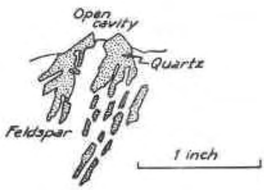

FIG. 3. Graphic texture in druse wall.

The fine-grained graphic intergrowth of this perthitic orthoclase with quartz is the universal enclosing material of the druses. The intergrowth near the druses in some cases shows a flamboyant structure perpendicular to the walls of the cavities (Fig. 3). Near the druse walls albite may take the place of orthoclase in the graphic intergrowth.

In addition to the micro-perthitic orthoclase of the graphic intergrowth, there are in several specimens large orthoclase crystals projecting from the walls into the open cavities. This euhedral orthoclase appears to be continuous with that of the graphic intergrowth. The orthoclase crystals (in one instance a complete Carlsbad twin) are pink or yellowish in color, are coated with later minerals, especially the chlorites, and are associated with crystalline albite and smoky or white quartz crystals. These minerals are evidently later than the orthoclase, and in some instances the albite has clearly attacked orthoclase by replacement. Some of the euhedral orthoclase shows "mutual" relations with albite, indicating a probable contemporaneous formation of the latest orthoclase and the earliest albite. Some of this euhedral orthoclase is perthitic, but it is not certain that the larger latest orthoclase crystals contain micro-perthite lamellae because there are no thin sections which cut them. In any case, neither thin sections nor hand specimens indicate any break in deposition between the orthoclase of the graphic intergrowth and the crystalline orthoclase of the druses.

Oligoclase and andesine

A few grains of oligoclase were observed completely enclosed in microperthitic orthoclase. Determination of the mineral in thin section indicated oligoclase containing 18% An. These grains were probably derived from the surrounding rock and incorporated in the pegmatite material: they do not appear to form part of the pegmatite texture.

A little andesine was also seen in thin section. It was found in graphic intergrowth with quartz in the same manner as the microperthitic orthoclase. The origin of the andesine, found only in a single thin section, is doubtful. It may be a replacement of orthoclase in the intergrowth, or it may be of the same age as orthoclase and quartz.

Quartz

There are three modes of occurrence of quartz in the Striegau specimens: (1) quartz in graphic intergrowth with feldspar, forming the pegmatite material surrounding the druses; (2) white, crystalline quartz on the druse walls and projecting into the open cavities; (3) crystalline smoky quartz in the druses projecting into open space. The first two types grade directly into each other; the smoky quartz appears to belong to a distinct and later period of mineralization, but it is contemporaneous with some of the white quartz (Fig. 4).

Most of the quartz of the graphic intergrowth is contemporaneous with the associated orthoclase, although some of the quartz is earlier, as shown by perthitic potash feldspar filling cracks in quartz.

Quartz deposition continued without a break into the period of albitization to form the crystalline white quartz. This white quartz is either intergrown with contemporaneous albite, or has, in some cases, attacked and covered albite in the druses.

The smoky quartz is associated with albite (cleavelandite), grows on albite in some instances, and covers or encloses large orthoclase crystals. The smoky quartz forms the largest of the quartz crystals.

All of the quartz is coated in the druses by younger minerals, especially chlorite, epidote, and zeolites.

Albite

Albite is found in these specimens as (1) perthite lamellae in potash feldspar; (2) in graphic intergrowth with quartz near the druse walls; (3) as coarse white crystals (cleavelandite) lining the druses. It is apparent that albitization is a distinct stage of mineral deposition.

There is evidence in hand specimen and in thin section that albite is replacing orthoclase. In one section albite with perthitic potash feldspar cores was observed. The albite which is in graphic intergrowth with quartz apparently gives way to orthoclase at a distance from the druses, and is probably, therefore, a replacement of the graphic orthoclase in the main part of the pegmatite. The cleavelandite deposition continued after cessation of potash feldspar formation, and cleavelandite covers orthoclase in the druses. It is reasonable, on the basis of this extensive albitization, to consider the irregular, microscopic, string perthite and patch perthite lamellae of albite in potash feldspar as being also the result of replacement, although Schwantke (1896, pp. 70, 77–79) believes that the perthitic albite is contemporaneous with the graphic potash feldspar.

The coarse crystalline albite on the druse walls, resting on fine-grained graphic orthoclase, illustrates the most prominent mode of occurrence of the mineral. The albite is in some instances in comb-like forms, the result of the combination of $\{001\}$ and $\{\bar{1}01\}$, as Schwantke (1896, p. 32) has previously observed. The albite of the druse walls is closely associated with contemporaneous white, crystalline quartz and with large smoky quartz crystals. Some of the smoky quartz crystals grow on albite. Albite also forms a base for chlorite, epidote, zeolites, and calcite.

Magnetite

A few fairly large irregular grains of magnetite bordered by biotite and chlorite were seen in thin section associated with albite and quartz. The exact paragenetic position of the magnetite is doubtful. It was not seen in hand specimen.

Sphalerite

One individual of sphalerite was observed. The sphalerite, associated with biotite, was perched on quartz and albite.

Chlorite (strigovite, prochlorite, penninite)

The principal mode of occurrence of the chlorite minerals, of which the three named above were identified, is as a thin coating on earlier quartz and feldspars. Where the chlorite coating has formed on quartz, the chlorite coats selectively the prism faces rather than the pyramid. The chlorite coating may also form a layer separating albite from zeolites and calcite, and chlorite commonly forms a base for bunches of epidote prisms.

The chlorite minerals are also found in cracks in the quartz and feldspar of the druse walls.

Of the three chlorite minerals identified, strigovite and prochlorite are the most abundant. The strigovite is found in formless, fine-grained, dark green masses and coatings. The prochlorite is in very small green flakes, intimately associated with strigovite. Penninite, identified in only one specimen, is in fairly large mica-like flakes of pale green color, associated with the other chlorites. Tourmaline needles grow on the penninite.

Tourmaline

Tourmaline is rare in the specimens. It was observed in very thin, hair-like, colorless needles and fibres growing on chlorite. Many of the tourmaline needles are enclosed in later stilbite, and the tourmaline can be seen extending through the transparent stilbite and protruding from opposite sides of the stilbite crystal.

The indices of the tourmaline show that the mineral contains a considerable proportion of lithium and manganese.

Fluorite

Fluorite is found in scattered small crystals, isolated and growing on quartz, feldspar, or chlorite, or in open cracks in quartz or feldspar. The mineral is pale violet in color. Epidote prisms of younger age grow against and around many of the fluorite crystals.

Muscovite

Muscovite, chiefly as sericite, is of very rare occurrence. It was observed in thin section associated with epidote and replacing potash feldspar.

Molybdenite

In a single specimen a fairly large bunch of radially arranged sheets and flakes of molybdenite can be seen on chlorite which is coating feldspar and quartz. Stilbite has formed on some of the molybdenite.

Epidote and clinozoisite

Epidote and clinozoisite together are, with chlorite, the most abundant minerals of the later druse-filling stage. Epidote is found as beautiful bunches and reticulating networks of slender apple-green prisms on the walls of the cavities. Clinozoisite grows in the same manner, but it is pale gray-green in color. There are evidently all gradations from normal epidote to clinozoisite containing up to 7% of the iron-epidote molecule.

These minerals are commonly found on chlorite and are associated with later interstitial stilbite. Epidote and clinozoisite have also grown on other earlier minerals, chiefly albite, quartz, and fluorite. In thin section epidote was observed extending along cleavage planes of biotite and chlorite, and in cracks in quartz and feldspar.

Axinite

Axinite is the last mineral deposited in the later druse-filling stage. It is found in well-formed, clear, tan-colored crystals on chlorite, albite, or euhedral orthoclase. Stilbite may be seen perched on axinite.

Heulandite

Although the succession of the zeolites is not clearly defined, heulandite appears to be the earliest. It was identified with certainty only in one specimen, where it can be seen in fairly large (up to 3 mm.), pale, yellow-brown crystals exhibiting perfect {010} cleavage and the characteristic opalescent luster.

Heulandite has grown on epidote and feldspar, and it is evidently earlier than stilbite, which rests upon the heulandite.

Stilbite (and epidesmine)

Stilbite is the most abundant of the zeolites, and is found in nearly every specimen. It grows in characteristic tufts and bunches of straw-yellow prisms in open spaces in the druses, perched upon various earlier minerals, especially smoky quartz, feldspar, and chlorite. Stilbite may be seen in abundance in the openings between reticulating epidote prisms.

Microscopic study of some very pale-colored crystals having the appearance of stilbite indicated that they are probably the orthorhombic mineral epidesmine. Different investigators, however, do not agree exactly as to the properties of epidesmine.

Laumontite (caporcianite)

Laumontite was observed in bunches of tiny white needles associated with earlier epidote crystals and growing on chlorite. The indices of the mineral indicate the variety caporcianite, an alteration product which has lost about 18% of its original water content.

Chabazite

Red chabazite is found in several of the specimens in small characteristic psuedo-cubes (i.e., rhombohedrons). The mineral grows on quartz, clinozoisite, or chlorite. In one specimen the red chabazite is embedded in younger crystalline calcite.

Calcite

Calcite apparently represents a final stage of mineral deposition in the druses. It is found as colorless or flesh-colored crystals in open spaces and coating earlier minerals. It is definitely younger than stilbite and chabazite. It may be found growing also on smoky quartz, feldspar, and chlorite. In one specimen there is a layer of calcite crystals (maximum diameter 1 cm.) having the hexagonal form resulting from the combination of the prism and the basal pinacoid. This layer of calcite is separated from albite by a band of chlorite.

Limonite

A little limonite was seen forming a botryoidal black coating on quartz, feldspar, and zeolites. This is evidently of very late origin, probably resulting from the action of meteoric waters percolating into the cavities.

Manganese oxide

A dull black coating on albite and epidote is apparently manganese oxide. The origin is probably similar to that of the limonite.

Discussion of Mineral Paragenesis

The paragenetic sequence of the Striegau minerals, as presented here, is the result of the study of a relatively small number of specimens and thin sections. All of the specimens consist of parts of the lining of open druses in the pegmatites. The age relations determined are presented diagrammatically in Fig. 4. The diagram is not intended to imply the inflexibility which it seems to express, but it is believed that the general sequence, the depositional ranges, and the mineralization stages are in a general way correct.

I. Magmatic stage of mineral formation

This stage represents the earliest period of pegmatite formation. During this stage the main pegmatite bodies were produced, and, in the specimens studied, the minerals of this period are found as the fine-grained graphic quartz and feldspar intergrowth surrounding the druses. Potash feldspar and quartz are dominant and are evidently of simultaneous deposition. They are associated with some interstitial biotite, a little andesine, some other plagioclase derived from the surrounding rock, and perhaps a little albite of contemporaneous age. Toward the end of this period and in the beginning of the following period of albitization, the magmatic solutions were of such a character as to dissolve out part of the previously formed pegmatite material, leaving the druses in which the later pegmatite minerals were deposited. The character of the solutions which produced the druses cannot be determined. In some instances, however, the formation of potash feldspar was able to continue and to develop the relatively large orthoclase crystals found on some of

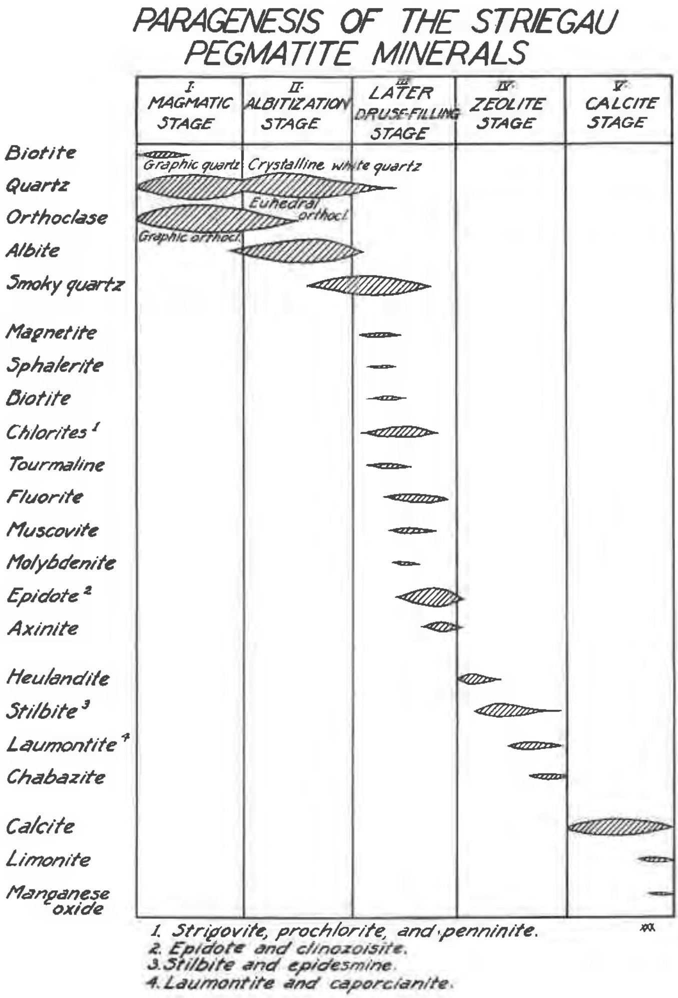

Fig. 4

the druse walls. The specimens do not show, except in coarseness of grain and better crystalline development, any marked difference or evidence of depositional break between the potash feldspar of the graphic intergrowth and the orthoclase crystals on the druse walls.

Silica mineralization continued through this and the next stage without interruption.

II. Albitization stage

The beginning of this stage of mineralization, although probably not separated by any cessation of deposition from the magmatic stage, is marked by the formation on the druse walls of coarse-grained albite and cleavelandite. Albite in continuation with this is found in graphic intergrowth with quartz next to many of the druses and, as far as it is possible to deduce from the small specimens available, albite gives way to potash feldspar (which is in graphic intergrowth with quartz) at greater distance from the druses. It can be seen in some hand specimens that albite apparently attacked and replaced potash feldspar crystals in the walls of the cavities.

It seems, therefore, that the formation of albite represents a later stage than the magmatic one, although not separated by a depositional break, and that a change in the character of solutions, perhaps the same change which caused the formation of the open spaces, resulted in crystallization of cleavelandite in the druses and even caused replacement by albite of some of the potash feldspar of the druse walls. The possibility is suggested that the micro-perthitic albite lamellae in the potash feldspar are also the result of replacement during the albitization stage.

Schwantke (1896, pp. 70, 75–76, 77–80), however, considers albite as part of the magmatic stage of deposition, at first contemporaneous with quartz and orthoclase, but continuing after cessation of potash feldspar deposition. He considers the perthite to be definitely the result of contemporaneous deposition of orthoclase and albite. It is obvious that, if Schwantke's idea of the continuation of albite deposition after the formation of potash feldspar be given prominence, his concept and that presented here are not greatly at variance, except that Schwantke does not recognize replacement by albite.

During the albitization stage silica deposition continued, and the white crystalline quartz associated with coarse albite in the druse walls was formed. White quartz deposition also continued into the succeeding mineralization stage. Toward the end of the period of albitization large crystals of smoky quartz were formed.

III. Later druse-filling stage

A distinct break between depositional stages apparently occurred at the close of the albitization stage. After cessation of the abundant albite deposition, the character and quantity of the minerals changed radically.

During this later druse-filling stage minerals were deposited in relatively small quantities, but they contain a great variety of elements. The minerals of this period are found in many cases in cracks in the druse walls and in the earlier-formed minerals. This indicates a possible period of contraction and consequent fracturing at the close of albite mineralization.

The paragenetic positions of magnetite, sphalerite, and biotite are doubtful because they are found only in very small amounts and are isolated. Chlorites (strigovite, prochlorite, and penninite) are important in this stage, and are early in the sequence. They coat earlier-formed quartz and feldspar. Tourmaline and fluorite are indications of some possible pneumatolytic action. Epidote and clinozoisite are important toward the close of this stage, and probably indicate hydrothermal action following pneumatolysis. Schwantke (1896, pp. 81–82) believes that the epidote was formed by the action of thermal waters on potash feldspar, on biotite (the source of the iron), and on plagioclase from the surrounding rocks (source of the CaO). Axinite is the only mineral of this stage which is later than epidote, and may also represent hydrothermal action, the waters bringing into the druses some of the material previously deposited by pneumatolytic solutions (Schwantke, 1896, p. 82).

The minerals of this stage of deposition are found principally as crustifications, bunches of needles, or as isolated grains resting on the older minerals in the cavities and in open cracks in these minerals.

IV. Zeolite stage

The introduction of zeolites marks another distinct stage of mineralization, and there may well have been an appreciable time interval following the later druse-filling stage before zeolite deposition commenced. Schwantke (1896, p. 83) finds prehnite as the earliest mineral of the zeolite stage, and believes that this mineral forms a gradation between the two mineralizing periods. However, no prehnite was recognized in the specimens studied here.

It is difficult to establish a sequence of deposition for the various zeolites from the specimens at hand because a single specimen rarely contains more than one or two zeolites. The sequence shown in Fig. 4 is thought to be as accurate as possible for the material studied. Stilbite is decidedly more abundant than the other zeolites.

The late deposition of the zeolites as a whole is clearly shown: these minerals are found perched on the surfaces of minerals of the preceding stages in hollows and open spaces. They probably represent the final waning action of cooling thermal waters.

V. Calcite stage

Calcite alone is the representative of a final mineralization period, and is the result either of the action of meteoric waters or of carbonate-bearing hydrothermal solutions. Crystalline calcite is found in considerable abundance in certain of the druses, and it is definitely younger than the zeolites.

Schwantke (1896, pp. 83–85) quotes Websky as believing that the calcite represents the remains of blocks of limestone which were caught up in the pegmatite material. Websky explains many of the druses as having been formed by the dissolving out of these limestone fragments. Schwantke considers it possible that the druses were once completely filled with calcite, much of which has been removed in solution, but he finds in the plagioclase of the granite the probable source of the calcium carbonate, and he sees no evidence of the contact minerals which would be expected in the druse walls if limestone fragments had been engulfed in the magmatic material. Gürich (1920, p. 310) also is of the opinion that the druses were once entirely filled with calcite, but he thinks that the deposition of calcium carbonate was part of the magmatic process, and that the calcite material was derived neither from limestone fragments nor from the plagioclase of the granite.

Actually there is no positive evidence for a former complete filling of the druses by calcite, and there certainly is no support for the limestone fragment idea. The source of the calcium carbonate is a matter of question, and it is equally difficult to decide whether meteoric or hydrothermal waters are responsible for calcite deposition.

Summary

Within a granite mass at Striegau, Silesia, are vein-like and horizontal sheet-like pegmatite bodies. The pegmatites consist largely of feldspar and quartz, feldspar being by far the most abundant mineral. The pegmatites contain a great number of open druses in which were deposited most of the minerals discussed here.

During the first, or magmatic, stage of mineral formation the main pegmatite bodies were produced. The fine-grained graphic intergrowth of quartz and potash feldspar forming the druse walls belongs to this period. Deposition of quartz and orthoclase continued into the second, or albitization, stage. Coarse-grained albite and cleavelandite lining the druses are characteristic minerals of this stage. The albite evidently replaced some of the potash feldspar. The formation of the open cavities is to be assigned to the early part of the albitization period.

A distinct break marks the end of the albitization stage, which was succeeded by a second period of druse filling. The minerals of this stage include chlorite (strigovite, prochlorite, and penninite), tourmaline, fluorite, epidote, clinozoisite, and axinite. These minerals are found in relatively small amounts as crustifications and isolated crystals perched on the earlier minerals which line the cavities. Pneumatolytic and hydrothermal action are indicated.

Another distinct stage of mineralization is represented by zeolites, principally stilbite. These minerals were probably deposited in the druses during the waning action of cooling thermal solutions.

Calcite in the cavities is representative of a final mineralization period and is the result of deposition either from meteoric waters or from carbonate-bearing hydrothermal solutions.

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