ON THE GENESIS OF GRANITIC PEGMATITES

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Abstract

A pegmatite vein is described in this article as representing a typical example of a large number of similar veins of the Transbaikal region. The structural peculiarities of this vein contribute information concerning the pneumatolytic-hydrothermal genesis of the pegmatite and indicate certain conditions pertaining to the genesis of pegmatites in general. Based upon this conception an attempt has been made to explain certain petrological phenomena. Especial attention has been given to the origin of graphic granite.

The pegmatites under consideration occur in Gold Mountain, Borshov range, 120 kilometers to the South of Nerchinsk Transbaikal, U.S.S.R. In 1934 the writer served as superintendent in the prospecting for piezo-quartz and monazite in this region. More than fifteen veins were discovered and these furnish the material for this article. The striking similarity in mineralogical composition, texture, and structure of all these veins makes it possible to select one of them as an example. The vein chosen shows a visible deficiency of mineralization and this feature permits the investigation of pegmatites in their embryonic stage.

Description

The mineral composition of these pegmatites is very simple. The essential components are a potash feldspar with a small amount of albite. There are also minor amounts of brown mica, monazite, magnetite, beryl, and topaz.

The structure of the vein shows bilateral symmetry (see Fig. 1), a feature common to all the veins. The bilateral plane is indicated by a row of cavities. Greatly elongated and flattened openings alternate with smaller ones of a lenticular character. The cavities are lined with druses of morion and orthoclase with a small amount of cleavelandite. There occur also the above mentioned accessory minerals. Druse-forming crystals have their roots in the adjoining zone which is a coarse-grained aggregate of quartz and feldspar. Because this aggregate has a quasi-graphic texture it is termed "pegmatoid" in this paper. The pegmatoid zone is composed of grains of quartz and feldspar which in cavities have developed into well-faceted crystals. This phenomenon is widely found in pegmatites and was also noted by the writer in other pegmatites of the Ural and Transbaikal regions. The width of pegmatoid zone is from 30–40 cm. The average grain size of the feldspar is 15–20 cm. across, and that of quartz 3–5 cm.

Adjoining the pegmatoid zone is a zone representing an aggregate having the same mineral composition, but showing a true graphic texture. There is no sharp division line between these zones that would denote an interval in the time of their formation. Moreover, individual grains of feldspar and quartz, located on the border of these zones, belong to both. It may be clearly seen that the more or less equi-dimensional quartz grains of the pegmatoid zone grow at the periphery into the elongated rods and form graphic intergrowths with the feldspar. This phenomenon is much better observed on the feldspar crystals, due to their perfect cleavage. It is clearly seen that while one half of a feldspar grain is in a quasi-graphic intergrowth with quartz, the other half is in true graphic relationship. The average thickness of the graphic intergrowth zone is from 20–25 cm., and the thickness of the feldspar grains varies from 15 to 20 cm. The length of the rods is about 15–20 cm., and their thickness varies from nearly invisible filaments to 2–3 mm.

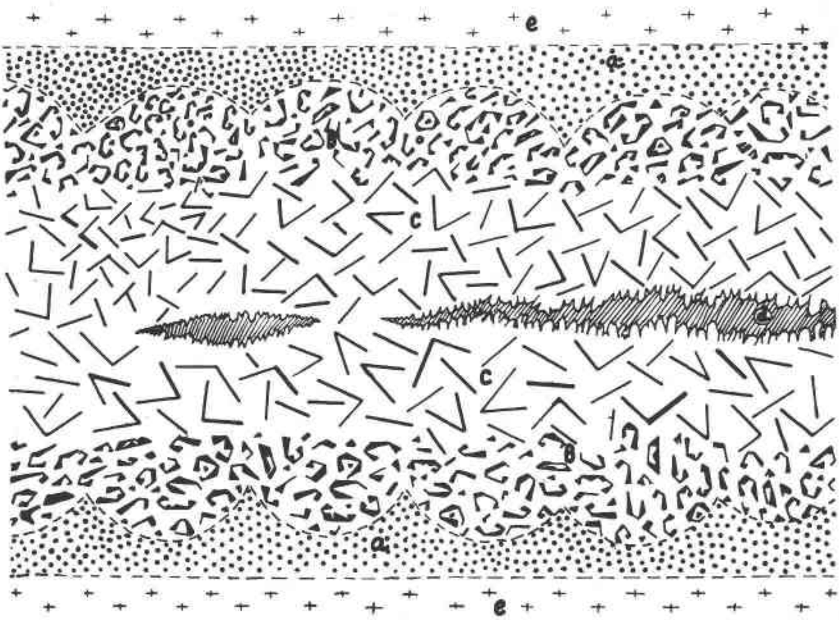

FIG. 1. a—aplite; B—graphic granite; c—pegmatoid; d—cavities; e—granite. Scale 1:14.

The graphic zone is then succeeded by common aplite. The contact between these zones is quite sharp, appearing almost as if "fused" together. There are neither cavities nor abnormal features in the boundary contacts. The aplite consists of quartz, microcline, and albite with some white and brown mica. The grains are about 1 mm. in diameter. The texture is aplitic. The contact of the aplite with the enclosing granite is sharp but there are no fractures discernible.

The granite is composed of quartz, microcline, and albite with some accessory apatite and ore minerals.

Close to the pegmatite veins considerable brown mica is disseminated in the granite. The type of contact surface between the graphic aggregate and the aplite is of a special interest (see Fig. 1). It is formed by a combination of perfectly outlined spherical segments intersecting each other. In cross-section they appear as festoons with a 10–15 cm. radius. The convex surfaces of the arcs penetrate the aplite.

However, the graphic texture itself is of much more interest (see Fig. 2). The zone of the graphic texture aggregate is made up of a series

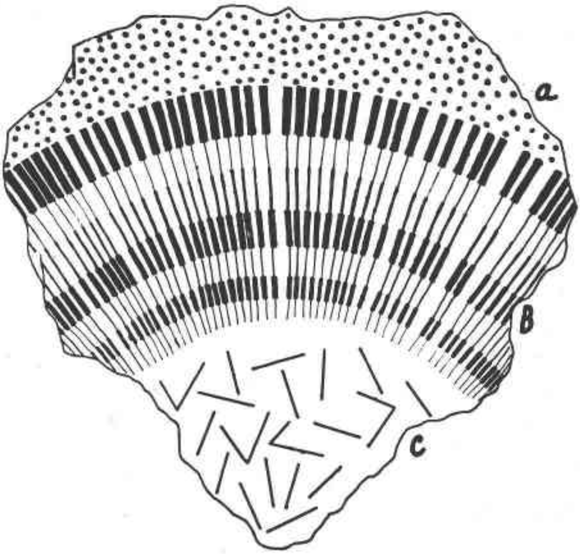

FIG. 2. Structure of the graphic granite: a—aplite; B—graphic granite; c—pegmatoid.

of more or less thick spherical zones. The radial character of the sections of these zones shows clearly that they in turn have a concentric zonal structure and are made up of a series of sub-zones. The sub-zone boundaries are well defined in a unique manner. The quartz rods radiate from the center of the zone. The thickness of the rods changes suddenly and simultaneously in the whole series of rods forming this intergrowth zone.

The rows of rods of the same thickness, which vary in different sections, seem to form sub-zones, and the ends of the sections give the impression of being the boundary lines of these sub-zones. As a whole this resembles the botryoidal structure of malachite or hematite. However this impression is not correct for the sub-zone boundaries are defined neither by fractures nor by abnormal features and are in fact only a function of the shape of these rods. The feldspar surrounding this series of rods may be a single crystal, a twin, or an irregular intergrowth of two or three crystals. The feldspar has no constant orientation in relation to the zone itself, in contrast to the quartz rods that are all oriented along the radii of the limiting segment. All these features can be observed on the feldspar cleavage planes.

These graphic intergrowths of quartz and feldspar appear in tangential cross-section like common graphic granite. In the graphic zone one may observe as many as 15 sub-zones, their thickness varying from 5–15 mm.

Interpretation

I. Campbell (1) has indicated that the shape of cavities in rocks which is characterized by an alternation of pinchings and swellings with resulting wedging-out and subsequent reappearance, is the result of the activity of circulating solutions. These solutions may dissolve minerals and then deposit the dissolved material in the same cavities in the form of grain-aggregates and druses.

Evidently, a similar process took place in veins at the time of druse formation. Hydrothermal origin of druses in cavities of pegmatite veins is universally accepted at present.

Keeping in mind the above relations of the components in druses and in the pegmatoid zone, the latter being adjacent to the druse zone, it is hardly to be doubted but that the origin of the pegmatoid aggregate is likewise the result of the same process of formation. Analogies may be found in innumerable ores, quartz, and other veins, and in the deposition of chalcedony grading into crystals of quartz, etc. It might be inferred that druses and pegmatoid aggregates in pegmatite veins have resulted from the same hydrothermal process.

If we admit that the pegmatite under discussion has resulted from the crystallization of a magma according to the principle of a closed physical-chemical system, we are faced with the contradiction of the development of large grains during the crystallization of a limited amount of magma with a small reserve of heat. A general explanation of this phenomenon on the basis of an abundance of volatile components in the magma in this case cannot hold as all evidence leads us to the conclusion that there was no large excess of mineralizers but rather a deficiency during the formation period of this vein.

A similar conclusion may be reached by studying the relations between the components of the pegmatoid and graphic zones. The formation process of these zones was entirely a hydrothermal one.

The structure of graphic intergrowths is in conformity with this view. F. L. Hess (3) demonstrated that the radial orientation of crystals in pegmatites is due to their metasomatic origin. The orientation of the quartz rods in the pegmatites is in strict agreement with Hess' statement. Concentric sub-zones, described above, are none other than zones of the simultaneous growth of feldspar grains and quartz rods.

Synchronous variations in the thickness of the quartz rods, independent of the direction they intersect feldspar crystals, point to the simultaneous growth of both minerals. No evidence was found of the subsequent intrusion of quartz rods into the feldspar, either in field observation or under the microscope.

In general, the formation of the vein in question took place in the following manner. In the first stage, the aplite dike was formed, perhaps by crystallization of a magmatic intrusion into granite fractures. The crystallization of this material was rapid and having begun at the walls of the fracture it extended into the dike toward the bilateral plane. As the solidification of the aplitic material was taking place the concentration of the volatile constituents originally present in the magma was increasing in the residue of the latter. Finally, there was left a solution differing greatly in its composition from the original magma. The mineral constituents of the vein suggest that the composition of the solution was not a complex one. Probably it was an aqueous alkaline solution with a small amount of fluorine. We have no definite indication of the phase status of this solution, but it is quite probable that it represented a liquid amply saturated with gases. Toward the end of the aplite crystallization the gas pressure had been so increased that the solution began circulating and it resulted in the formation of pegmatite. The bulk of the solution moved along the bilateral plane of the vein, but some of it penetrated into the consolidated aplite, dissolving some of the aplite which was deposited later. Druses were formed in open cavities, but the bulk of the consolidated aplite underwent recrystallization. Thus, the process of pegmatite formation cannot be called metasomatic as no interchange of material took place in the process. The process may be defined as a recrystallization of aplite to form pegmatite. With increased distance from the bilateral plane, the lower became the temperature and the impregnation of the solution into the aplite decreased.

The concentration of the solution depends on the amount of the solvent, the latter being dependent on the rate of diffusion which in turn depends on the pressure and the temperature. As would be expected the formation process of the vein in question was controlled by the three factors of the physical-chemical system, namely, temperature, pressure and mineral concentration. It is evident that the modification of the pegmatite texture also depends on these same three factors. The zonal structure of the vein indicates a change of the physical-chemical factors, the texture of each zone being in accordance with a definite relationship existing between them.

Attempts to determine the quantitative value of these factors favorable to pegmatite formation encounter great difficulties and the results obtained are not exact. There are no criteria for determining the pressure that existed in the process of pegmatite formation. However, keeping in mind that the depth of the pegmatite vein formation was 2–3 kilometers, the pressure must have been considerable.

In regard to the temperature distribution in the vein during the process of formation, the following considerations may be stated. The greater portion of the solutions was following the direction of least resistance, that being the bilateral plane of the vein. Thus, there was a continuous source of heat and the temperature in the zone of druse formation was kept at a fixed level. Solutions diffused into the next zone —the zone of pegmatoid formation—in rather small amounts. Because of that fact the temperature here depended largely on the temperature of the aplite and was accordingly lower. The same may be said about the graphic intergrowth zone, but its temperature was still lower as it was farther from the main channel. This was the lowest temperature zone of the pegmatite vein.

The following observations may help in explaining this fact. Besides the pegmatite veins there are many aplite dikes in Gold Mountain. These rocks consist of quartz, potash feldspar, and albite with some brown and white micas. They have an aplite texture. In these aplite dikes are numerous epigenetic features. These are of three types. In cracks there was observed a yellowish-green aggregate—cookeite with a small amount of hematite scales. Also observed in the dikes were inclusions of pegmatoid aggregates which are clearly apparent, due to their coarse-grained texture. The pegmatoid inclusions consist of quartz, and potash feldspar with a small amount of albite, and show a zonal character free from cavities. The contact between the pegmatoid inclusions and aplite is sharp, and both rocks appear as if fused together. The pegmatoid bodies are lens- and vein-shaped but often are of irregular form. Sometimes cracks can be seen in the aplite that served as main channels for solutions that have formed the above described pegmatoid bodies.

The most interesting phenomenon, however, is the following: sometimes the aplite dikes are corroded and contain cavities that resemble worm-eaten wood. These cavities have capricious shapes and are lined on the inside with druses of albite on which at times are perched quartz crystals, and occasionally cookeite rosettes. The quartz crystals are perfectly transparent, golden colored and beautifully facetted with the common forms. Both ends of these crystals are similarly developed, the crystals being attached to albite by their prism faces.

There is no doubt but that all these phenomena are the result of the same process involving pneumatolytic-hydrothermal solutions in the solidified aplite dikes. Their close proximity to the pegmatite veins indicates an origin from the same source.

Cavities in the aplite originated from the activity of solutions. Material was undoubtedly taken from the same aplite dikes. But it is interesting to note that only albite was deposited while the entire potash feldspar and nearly all the quartz have been carried away. In technology this process is known as fractional-distillation. The separation of the components during such a process depends on the difference in volatility of the components and the selected temperature. The compounds of potash are known to be more volatile than those of sodium. Hence, the phenomenon may take place in aplites at a temperature that would separate these silicates of the alkalies during the fractional-distillation process, under a high pressure.

According to the experiments of N. I. Hitarof and L. A. Ivanof (4) 1 cu. meter of H_2O vapor at about the critical temperature can transport 2.5 kilograms of K_2SiO_3, or 18 kgs. of Na_2SiO_3. Therefore, alkalies will not separate either at this temperature or at one higher than the critical temperature. Consequently, the temperature of their differentiation must be lower than the critical point of the alkaline siliceous solution.

Returning to the pegmatite vein, it should be noted that there are no traces of the transfer of material, in any considerable amount, either in the pegmatoid or in the graphic zones. There are no signs of stratification of mineral constituents or of their preferable growth in any definite direction. The whole structure of the aggregates, on the contrary, brings us to the conclusion that the transformation of aplite into pegmatite took place in situ. Somewhat more extensive transfer took place in the druse formation zone, however, but this transfer was also quite negligible.

If this be true, then the temperature of druse formation in the pegmatites is lower than that of alkali silicate differentiation during the process of fractional distillation. The temperatures of the pegmatoid and graphic granite formations were consequently still lower.

The concentration may be considered as having taken place in the following manner. The concentric sub-zones in the graphic intergrowth are none other than the zones of simultaneous growth of feldspar and quartz crystals. No evidence has been found in the pegmatites in question to favor W. T. Schaller's contention that a subsequent metasomatic intrusion of quartz rods took place into the feldspar matrix. There is also no evidence that feldspar had originated in the form of fine-grained aggregates during the first stage of graphic intergrowth and that later on it recrystallized into coarse grains.

The existence of sub-zones in the graphic intergrowths indicates variation of the physical-chemical conditions during the process of their formation. However, these affected only the quartz. According to C. S. Hitchen's experiments (5) the solubility of SiO_2 in water under conditions analogous to those of N. I. Hitarof's experiments is 0.22 parts in 100 parts of water.

Apparently this was the reason for the zonal structure of the graphic intergrowths. Metasomatic solutions penetrated the aplite non-uniformly, in other words by impulses. A slight deficit of the latter has produced a high supersaturation of the solution with silica, the quartz crystallizing in the form of thin needles. The subsequent addition of solvent lowered the silica concentration and resulted in formation of thicker rods. It is evident that variations in the amount of the solvent were so insignificant that they had no effect on the concentration of the more soluble alkalies, for the feldspar grains grew to 20 cm. in diameter in the same period. The graphic intergrowth was formed in the peripheral zone of the vein where the variations mentioned above were quite likely, since there always was some excess of the solvent in the pegmatoid zone, which was next to the main channel. Accordingly, the pegmatoid texture is uniform and both its components grew to equally large grains.

A. E. Fersman (6) is of the opinion that the quartz and feldspar of the graphic intergrowths are the result of the simultaneous growth of both minerals. He looks for simple crystallographic relations between the components and offers a law of quartz and feldspar intergrowth in "graphic granites" known as the Fersman's law.

In 1925 N. N. Gornostaev (7) and in 1938 L. A. Kosoy (8) also offered their laws relating to these intergrowths.

The elongated form of the quartz rods is explained by Fersman as due to the inductive influence of the growing feldspar crystal facets on the growing crystals of quartz.

It can be easily shown that the simultaneous growth of quartz and feldspar cannot in itself be the cause of a graphic texture. In the pegmatoid zone, and in many other cases, these minerals grow simultaneously for the most part, but there is no evidence of a graphic texture. The failure of simple crystallographic laws in graphic intergrowth has been established by E. E. Wahlstrom (9) who proved that such laws do not exist at all. This conclusion is confirmed by the above described relations between quartz and feldspar in the pegmatites of Gold Mountain.

The inductive influence may be said to have really taken place, though the inducting element was not a feldspar facet, but the mobile plane of separation between the aplite and the growing graphic intergrowth. This plane during the process of penetration by metasomatic solutions into the aplite moved towards the latter so as to elongate the quartz rods along with the movement. In this case the plane was of spherical form and that is why the rods growing as it moved are normal to it and have formed a radial structure.

Summary and Conclusions

The pegmatite veins of Gold Mountain with accompanying graphic granite have originated by a pneumatolytic-hydrothermal transformation of aplite dikes. The active agents in this process were aqueous siliceous alkaline solutions containing a small amount of fluorine. These solutions originated from the volatile components originally contained in the aplite substratum and from the mother liquor of the granite magma.

The physical-chemical conditions of formation of the zones constituting the pegmatite vein involved high pressure but the temperature was below the critical point of the aqueous siliceous alkaline solution, and the concentration of silica and alkalies reached the point of supersaturation. The transfer of material during the pegmatite formation was insignificant. The various factors may be detailed for the separate zones as follows:

Zones	Temperature	Pressure	Degree of supersaturation		Transfer
			With SiO_2	With alkalies	
Druses	High	High	Low	Low	Intensive
Pegmatoid	Medium	Medium	Moderate	Moderate	Weak
Graphic granite	Low	Low	High	Moderate	Insignificant

The absence of any simple crystallographic law of orientation in the quartz and feldspar graphic intergrowths is confirmed.

The inductive influence was present during the growth of the quartz rods and it is established that the inducting agent was not a crystallographic element of the feldspar, but the mobile plane of separation between the aplite and growing graphic intergrowths.

If we free ourselves from the traditional concept that graphic intergrowths of quartz and feldspar are a specific magmatic phenomena, then several more or less mysterious phenomena may be satisfactorily explained.

One of such unsolved riddles is the presence of pegmatite lenses in the norite of the nickel-bearing eruptive rock at Sudbury. This riddle cannot be solved if the magmatic origin of graphic granite is a condition sine qua non. But following the view expressed in this article, this phenomenon may also be easily explained. A combination of physical-chemical conditions corresponding to the zone of graphic granite involving circulating solutions is easily imaginable. Such solutions can transfer and deposit the corresponding substances in a proper form and in the same way in which the formation of quartz, barite, and other vein minerals has taken place. The pegmatite-forming solutions may not be related to the rocks enclosing the pegmatite.

Certain petrographic phenomena are also clarified. A. N. Zavaritsky (10), who has investigated the nature of the Ural rapakivi, says: "In two samples of rapakivi granite micropegmatitic intergrowths are restricted to the contact between large grains of quartz and those of feldspar, and are similar to the phenomenon pointed out by Polkanof, Laitakari, and Beliankin as secondary micropegmatites found at the contact of the granite with diabase dikes."

This phenomenon may be explained as follows: the granite already solidified, may have been subjected to a strong pressure and begins to melt. When liquid drops of a quartz-feldspar composition appear in some places in the rock, the pressure may cease and these drops crystallize according to the eutectic principle into graphic intergrowths. This complicated explanation, however, is not likely to be true and lacks proof.

The writer thinks that a granophyr is also the product of metasomatic activity. Some points in favor of this view are the following: (a) The structure of the micropegmatite intergrowths in the rapakivi of Berdiaush. There they form at the boundary between the quartz and feldspar grains and as deep penetrations into the grains of quartz and feldspar. Micropegmatite intergrowths occur also between the nucleus of the orthoclase and the oligoclase shell. (b) The relationship of the diabase dike to the granophyrous portion of the granite, as was emphasized by Zavaritsky. (c) The conception of graphic intergrowth genesis as presented in this paper. (d) The interpretation of rapakivi texture by Zavaritsky who states that it originates as the result of the granite being acted upon by the metasomatic activity of solutions diffusing through it.

The writer suggests that the presence of granophyre in granite can be considered, in general, as evidence of metasomatic activity in the process of granite formation.

Acknowledgment

This paper is an attempt to expand the ideas of Frank L. Hess and Waldemar T. Schaller (11) on the genesis of pegmatites. The writer has

used his conception for the explanation of some petrographic phenomena, being quite convinced of the truth of the conclusions reached and expressed in Schaller's presidential address.

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