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MINERAL REPLACEMENTS IN PEGMATITES*

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In discussing the subject of the origin of pegmatites you remember the controversy that raged sometime ago as to whether they were dikes or veins, the essential difference being that dikes are igneous in origin whereas veins were formed by the aid of circulating waters. A compromise was offered suggesting that the material from which they were formed was in an aqueo-igneous condition. But all these ideas postulated a single period of formation. I would like to offer for your consideration another explanation for the formation of pegmatites.

The general processes of nature producing igneous plutonic rocks may perhaps be classified into two general groups; the magma process and the hydrothermal process. Each of these processes possesses at least three distinctive features. The magma process is characterized by the fact that the finished product, the solid rock, is nearly one hundred per cent the same composition as the magma; that it is essentially a closed system; and that it owes its liquidity primarily to heat. The hydrothermal process, on the other hand, yields a solid end product which is only a very small part of the total quantity of material present and reacting during the hydrothermal stage; it is an open system, much material moving, coming in, and going out; and it owes its liquidity essentially to the presence of a solvent and not to heat. Now the effect of later hydrothermal material entering and reacting on the solid rock formed during the magma process is a reaction which I call replacement. So by the mineral replacements in pegmatites I mean that you first have a solid rock formed by the magma process which was then, later, more or less acted upon and replaced by minerals formed as the result of the hydrothermal process.

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Bowen has shown how solid minerals may react with the remaining liquid magma, on cooling, to form a new set of minerals, when the equilibrium and stability relations are changed. How much more readily such reaction series changes and replacements can take place in the hydrothermal stage! It should be emphasized at this point that although the two processes have their distinctive features and yield a different set of mineral combinations, they are both the effects of one single general magmatic process, are very closely related, and it may be difficult accurately to delegate certain stages of the general process to one or the other of the two processes mentioned.

So this is the theory I have to offer[1] for your consideration, namely, that a good many of the pegmatites as now seen are the result of two processes; the original formation by the cooling of the magma and the later reaction and more or less complete replacement by hydrothermal agencies. If this is true, then it seems, judging from field evidence, that the first magma process yielded a solid rock consisting essentially only of potassium feldspar with perhaps a very small quantity of sodium feldspar and only a very small quantity of quartz, *but no other minerals.* The later hydrothermal replacement process yielded a long series of minerals or mixtures of minerals. If but a single mineral is the end product of such replacement action, it may be quartz, magnetite, pyrrhotite, calcite, or others.

The view that pegmatites had such a history was developed[2] some two years ago in conjunction with Dr. Larsen as a result of study of pegmatites in San Diego County, California. Here it could readily be seen both in the field and later in laboratory studies, that all the minerals now present in the pegmatites, with the exception of the potassium feldspar and some quartz, were later introductions, for the rock here replaced is a beautifully developed graphic-granite with its very characteristic structure, the quartz as seen on the cleavage planes of the feldspar being elongated, and in sections normal to the feldspar cleavages, showing the well known six-sided or cuneiform shape. This structure could still be observed in many phases of the replaced

[1] This address represents a brief summary of the important points of a paper on the same subject to be published later, fully illustrated, probably by the U. S. Geological Survey.

[2] Preliminary paper published: Schaller, W. T., The genesis of lithium pegmatites: *Amer. J. Sc.*, Vol. **10**, pp. 269–279, September, 1925.

pegmatite and the gradual change from a microcline quartz graphic-granite to the finer-grained rock, now composed of sodium feldspar, mica, garnets, and other minerals, could readily be traced. The sodium feldspar first replaces the potassium feldspar, and then the quartz; later the micas and the garnets replace the sodium feldspar, new quartz comes in, and the lithium minerals, the phosphates, the beryls, etc., follow.

Although in this field the graphic-granite is referred to as the rock replaced by the later hydrothermal solutions, I am not at all sure that the graphic-granite itself was the original rock for there is a decided sequence of formation of the different minerals of the graphic-granite. This is particularly true of the quartz rods for they clearly cut across the perthite lamellae. They have a definite oriented relation to the cleavage directions of the potassium feldspar and the cross-sections of the quartz rods, normal to their elongation, while six-sided, do not have angles of exactly sixty degrees but have angles several degrees different, apparently the resultant compromise of the crystal forces of both the feldspar and the quartz. In other words, the quartz of graphic-granite, has its position defined by the properties of the potassium feldspar and is clearly later than it. At present I am inclined to believe that the original rock formed by the magma process was a relatively fine-grained high-temperature potassium feldspar (possibly orthoclase) rock, which on cooling reverted to microcline, the low-temperature modification, which by its many planes of weakness, such as cleavage and twinning, afforded a maximum opportunity for the entrance of the replacing hydrothermal solutions. If such solutions contained almost no additional mineral matter but consisted essentially only of water, in some form, this may have had some sort of an annealing or recrystallization effect on the fine-grained inverted orthoclase, yielding the very large crystal units of microcline now found.

I have no belief in the validity of the idea of ascribing the structure of graphic-granite to eutectics, in fact I am rather inclined to believe that in general, for rocks, a eutectic-like structure can almost be considered as evidence not of simultaneous crystallization but of replacement effects.

So that for pegmatites the general sequence of mineral formation seems to be somewhat as follows: High-temperature potassium feldspar, inversion to microcline, a little perthite, quartz, albite, muscovite, and the general group of such minerals as black tourmaline, garnets, common beryl, followed by the lithium minerals, the phosphates, sulphides, carbonates, and oxides. Quartz seems to come in pretty generally all along the line of replacement. Any one of these minerals may have more than one generation and reversals of order of formation also occur. The euhedral crystals of microcline commonly found in pegmatites are of a later generation than the massive compact microcline.

If this sequence of replacement is correct, then the rare minerals should not be found in any pegmatite which has not been subjected to the replacement process. Or, in other words, there should be associated with such rare minerals those of replacement origin, such as albite, quartz, muscovite, etc. Now the examination of a good many specimens of pegmatite containing rare minerals, has shown that albite is always present and has replaced more or less completely the original potassium feldspar. This fact has not been generally recognized; for example, in a recent published description of a rare mineral, the host mineral was described three times in the text as microcline and the legend under the illustration described it as microcline, whereas a microscopic study of the feldspar showed that it had all been changed to the sodium feldspar albite and that there was no microcline remaining. In the magnetite pegmatites of northern Minnesota, described by Grout, the albite present increases correspondingly with the magnetite.

In a recent paper on the feldspars by Alling, he is surprised that petrographers have often failed to recognize in perthites two distinct generations of the sodium feldspar and I would add that I am surprised that petrographers have failed to recognize that the second type which constitutes the great bulk of perthites is a secondary replacement for it is not difficult to find in many pegmatites examples where the microcline contains a varying quantity of the perthite lamellae which reach a percentage of almost one hundred. In other words, the microcline has been practically completely perthitized.

In order to convincingly prove that such replacement processes have been at work, one must carefully consider what are the criteria of replacement. Rounded masses of minerals, optically uniformly oriented, can not be universally considered as residua of replacement, but each set of mineral associations must be considered by themselves. For example, in myrmekite, an intergrowth of plagioclase feldspar and quartz, derived as a secondary reaction from potassium feldspar, the quartz is in elongated or rounded detached masses, optically uniformly oriented, yet no one would suggest for a moment that these quartz masses are replacement residua. On the other hand, such rounded masses of microcline may well be indicative of residua. But one of the best and most satisfactory evidences of replacement are cross-cutting veins, especially with smaller apophyses, and if accompanied by isolated impregnations diminishing in quantity when further away from the main cross-cutting vein and especially if the cross-cutting vein follows a cleavage or fracture line of the host. Examples of such replacements where the sodium feldspar has entered the microcline and where quartz, mica, and garnets have followed the cleavage planes of the microcline, can be found in most pegmatites, and show that the history of pegmatites is not the result of a single event but on the other hand is the result of a long continued process of the reaction series type.

If the theory of the formation of pegmatites, as outlined above holds, namely, that if they consist of minerals other than potassium feldspar they are largely replacement effects, then one is justified at least in asking whether or not a similar condition holds for many igneous rocks. If it does, and if the accessory minerals and other hydrous minerals such as the hornblendes and the micas for example, in a granite, are not original pyrogenic minerals formed directly from the magma but are later reaction products in an already formed rock, then not only must our ideas of the genesis of igneous rocks in general be modified but a new scheme of genetic classification of rocks will be needed.