TYPES OF PEGMATITES IN THE ARCHEAN AT GRAND CANYON, ARIZONA

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ABSTRACT

Granite pegmatites are abundantly developed in the Archean terrane in the Grand Canyon district. They are associated with the youngest Archean granites and appear to be later than the regional deformation. Simple composition is the rule, and complex varieties except for traces of boron facies, are almost unknown. Three types are recognized: the most abundant is similar to the common quartz-microcline pegmatites and is definitely intrusive into a series of meta-sediments and metabasites. A second type has developed by replacement, "pegmatization," processes. A third and very unusual type owes its origin to a late stage development of microcline within a quartz vein or quartz dike. The second and third types are only recognizable as such when the processes to which they owe their origin have stopped somewhat short of complete development. It is possible that many of what are regarded as Type I pegmatites may really be of Type II or Type III.

INTRODUCTION AND ACKNOWLEDGMENTS

For the past three field seasons the writer, with his colleague Dr. John H. Maxson, has been engaged in an investigation of the Archean rocks in Grand Canyon National Park. The investigation has been made possible by the generosity of the Carnegie Institution of Washington and has been greatly stimulated by the interest and counsel of Dr. John C. Merriam, President of the Carnegie Institution. As regards the particular phase of the investigation discussed herein, it is a pleasure to recall that it was Dr. Charles Palache who first introduced the writer to the fascinating problems of the pegmatites, and it is to Dr. Palache that he owes most of his knowledge of these most interesting structures.

RÉSUMÉ OF GEOLOGY

The principal contribution to our knowledge of the Archean rocks of this district is due to Noble (1916), who although recognizing and describing many types, both igneous and metamorphic, was uncertain as to the relationships between several of the major units. This was occasioned by the inaccessibility of the critical areas, making detailed examination impossible.

In the present investigation, the work has been very largely confined to the section exposed along the south side of the Colorado river and in its southern tributaries, from Boucher Creek on the west to Lone Tree Canyon on the east, and including an area on the north side of the Colorado in the vicinity of Bright Angel Creek.

Even within this small range, many portions of the section remain inaccessible from the Tonto platform, to which travel must be largely confined. For this reason, conclusions as to the major field and structural relationships of the units described are necessarily tentative. It is hoped that both the range and the completeness of observations may be greatly extended during the coming season. The present paper therefore does not purport to be a complete and final statement as regards any of the rock types. It is given at this time simply to set forth certain interesting relationships that can be demonstrated with the data at hand.

Within the area studied, the Archean history resolves itself into the following sequence:

First: deposition, upon a terrane still virtually unknown, of some thousands of feet of sediments, chiefly argillites and fine-grained sandstones. Near the end of this period of sedimentation, volcanism became active and toward the top of the section basaltic lavas were intercalated. Some of these flows very probably took place as submarine extrusions.

Second: a period of dominant volcanism, in which certainly many hundreds and quite possibly some thousands of feet of basaltic lava accumulated. Sedimentation was greatly interrupted but sandstones, argillites and possibly some cherts were deposited in at least small amount at intervals throughout this period.

Third: intense orogenic disturbance, "Arizonan" of Hinds (1936), whereby the sediments and lavas were strongly folded and very considerably metamorphosed.

Fourth: perhaps concomitant with the declining phases of the orogeny, and very likely continuing after it, came intrusions of granitic magma, which in its upper portions consolidated to form moderately concordant or stock-like masses, and which may have given rise to emanations responsible for "granitization"—the word is used as defined by G. H. Anderson (1937, p. 28)—in the meta-sediments, production of migmatites, etc. The last event of this intrusive period comprises formation of abundant pegmatites and scarcer aplites, many of which develop lit-par-lit structures in the paraschists and metabasites (largely amphibolites).

It is recognized that while some of the granites show marked foliation, others show little or none. This was first noted by Noble (1916, pp. 111–113) who suggested that the first might represent pre-deformation intrusives; the latter, post-deformation intrusives. Within recent years there has been increasing recognition of the fact that many granitic bodies owe their origin to replacement processes, perhaps largely hydrothermal, rather than to direct magmatic invasion. Quirke and Collins (1930) in Ontario, A. L. Anderson (1934) in Southern Idaho, Stark (1935) in the Sawatch Mountains, Kessler (1936) in South Carolina and G. H.

Anderson (1937) in the White Mountains of California-Nevada, have recently given convincing demonstrations of this relationship. In a granite formed in such manner, it is to be expected that foliation may be a matter of inheritance rather than of imposition, and the intrusion will actually be later than the development of the schistosity. While it is outside the scope of the present paper to discuss the detailed relationships of the Archean granites, it may be said that the foliated bodies offer strong evidence of replacement origin in such features as gradational boundaries with the enclosing schists, porphyroblastic structure, abundance of albite and myrmekites, etc. It is believed therefore that only one major period of plutonic activity is represented in this district, with the foliated granites due to replacement, the non-foliated bodies due to direct magmatic invasion, and both developing more or less contemporaneously.

Fifth: Ep-Archean Erosion.

The Pegmatites

Like the granites with which they are associated, the pegmatites are believed to belong to essentially one period of intrusion, and since some are found definitely cutting all other rock types, they can be assigned with confidence to the last stages of igneous activity within the Archean. On the basis of Landes' (1933) classification, all of the pegmatites would fall within the "acid" group. The great majority would also be classed as "simple." However, certain types found do not readily fit into any existing system of classification. Simply for convenience in discussion, and not with any desire to add to or to emend present classifications, three types are recognized.

Type I, Intrusive Pegmatites. The commonest type, designated as "intrusive pegmatite," appears superficially to parallel the schistosity of the enclosing rocks, but on closer inspection the dikes frequently can be seen to be transgressive at a low angle, and occasionally they may cut directly across the schistosity. On the basis of their mineralogy, the great majority would correspond with Landes' "simple, acid" type. They consist almost entirely of quartz and microcline*, the latter in crystals ocasionally up to six inches in length. Muscovite is a minor constituent in many dikes, and abundant in a few. It may form plates and books up to 4 or 5 inches in diameter. Magnetite is a not uncommon constituent, sometimes occurring in well formed octahedra up to an inch in diameter. Garnets are infrequently found.

* First recognition of microcline as the predominant feldspar of these pegmatites is due to Waesche (1933).

Except for a few pegmatites in which black tourmaline is a scant constituent there is nothing to indicate the development of "complex" types. They are in fact notable for their absence.

Aplites occur, and not infrequently, but they are vastly fewer in number, and bulk much less in the individual bodies, than do the pegmatites. Spurr (1923, 309–331), Olaf Anderson (1930) and others have discussed the relationship between pegmatites and aplites. There is much here that is still a puzzle; but the prevailing idea clearly favors a difference in viscosity, dependent in turn on a difference in the amount of volatiles as the essential difference between aplites and pegmatites.

FIG. 1. Type I pegmatites in hornblende-schist, Phantom Creek. The great majority are approximately conformable with the schistosity of the country rock. A few are distinctly cross-cutting, and it is in these that ptygmatic folding is often conspicuously developed.

The fact that pegmatites are relatively abundant, aplites relatively scarce, within this terrane, would argue in favor of a rather "wet" magma. Why, with large supplies of volatiles, there is not more evidence of hydrothermal effects within the pegmatites; why there are no concentrations of the minerals characteristic of the complex pegmatites cannot be answered. A suggestion might be that the portions now exposed represent a section close to the roots of the pegmatites while effects due to more mobile solutions would expectably be found in the higher parts of the structures removed in the Ep-Archean erosion. Donnelly (1936) has recently indicated such a relationship for the more gem-worthy portions of the Pala pegmatites, and the principle is of course frequently applied in the case of the larger plutonic structures (Butler, 1915; Shand, 1922).

An alternative explanation of the barren character of these pegmatites may be found in the suggestion of Eskola (1930) that palingenic magmas are notably "sterile," and it is not improbable that the Archean granites are in large part palingenic.

Type II, Replacement Pegmatites. A second type of pegmatite which in theory may seem distinct from the first, but which in actual practice is often impossible to differentiate, is designated "replacement pegmatite." This type has formed in a manner entirely similar to the granitic bodies originating by "granitization" and by analogy these pegmatites might be described as formed by "*pegmatization*" of favorable horizons in the schists. The evidence for such origin is similar to that indicating granitization in the granites. Here, too, one frequently finds gradational boundaries with the country rock. Biotite is much commoner in pegmatites believed to belong to Type II than it is in Type I. Much of this mineral may represent recrystallization of the finer grained biotite of the original mica schist. In the coarse foils in which it occurs, it shows no tendency to alignment. On the other hand, a helizitic structure is sometimes found in which tiny inclusions of muscovite in linear and parallel arrangement indicate the former schistosity of the rock, despite the formation of heterogeneously oriented metacrysts of albite and quartz in which these inclusions occur.

Albite, either alone or with microcline is the chief feldspar of these pegmatites. Some of its appears as perthitic patches in the microcline, but the larger part is in distinct units. It is not the cleavelandite variety so sommon in complex pegmatites, but develops in metacrysts of simple form and stubby or equant shape. In hand specimen it often shows a reddish color similar to that commonly developed by microcline, and indeed it is indistinguishable from the potash feldspars except under the microscope. The red color appears to be due to minute flakes of an iron oxide disseminated, without any obvious crystallographic control, through the mineral. This recalls the hydrothermal albite of certain aplite dikes, recently described by Bastin (1935). He ascribed the formation of hematite to destruction of ferromagnesian minerals in the original diabase which the albite aplites had replaced. In the present instance, the origin of the included hematite is not clear.

Much work remains to be done, and many occurrences must be sampled before any criteria can be established that will serve to distinguish unequivocally between Type I and Type II pegmatites. It is obvious that evidence of pegmatization can never hope to be as satisfactory as evidence of granitization may sometimes be. The coarser the crystallization or recrystallization, the less the chance that any palimpsest structures will survive to indicate the origin of the rock. Field boundaries in themselves mean little, for many definitely intrusive pegmatites show gradational walls; while it is to be expected that many replacement pegmatites will show sharp boundaries against enclosing schist. The mere occurrence of albite signifies little, for although many will agree with Bowen (1928) in considering this mineral to be almost invariably of

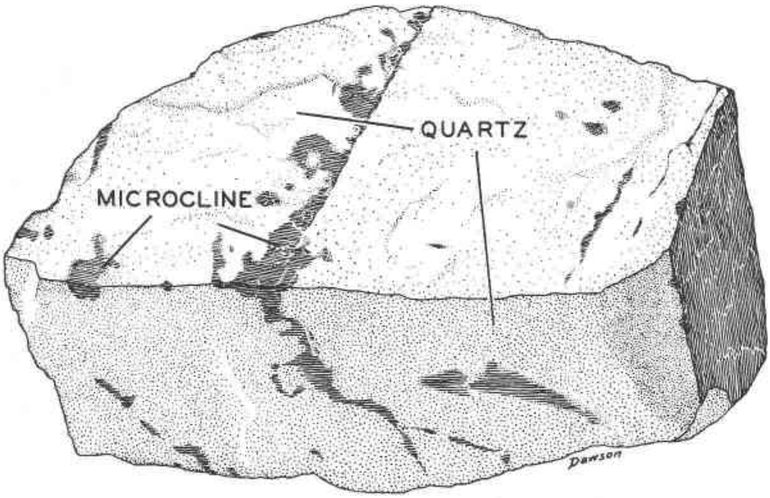

FIG. 2. Sketch of hand-specimen of silexite from Clear Creek. This shows the incipient stage in the development of a Type III pegmatite.

secondary development, its presence in a pegmatite indicates only the operation of a replacement process to limited degree, and does not prove that the entire structure is due to pegmatization. Indeed, unless definitive relict structures can be found there is little opportunity for certain recognition of a Type II pegmatite.

Type III, Feldspathized Quartz Veins. Occasionally pegmatites seem to give way to rocks best described as silexites. They are composed almost entirely of quartz, but an occasional crystal of pink feldspar occurs. Such facies occur notably in Lone Tree Canyon and near the mouth of Boucher Creek where as shown by Campbell and Maxson (1935) the section consists largely of paraschists showing less intense metamorphism than elsewhere in the district. There is nothing unusual in finding quartz dikes apparently gradational with pegmatites. Spurr (1923) has described numerous instances, and the literature has been more recently summarized by Tolman (1931). In practically all such cases, the assumption is that the pegmatite grades, by diminution of feldspar, into silexite and eventually into a quartz "dike" or vein. The discovery of the silexite dikes in Lone Tree Canyon and in Boucher Creek seems entirely compatible with a location farther from the "hot centers" of metamorphism as is indicated by the character of the surrounding rocks and the absence of granite intrusives.

In some instances tiny pink veinlets may be seen threading through the silexite. These were dismissed at first with little attention and attributed to a supergene oxidation along fractures. Further observations however compelled recognition of the veinlets as feldspathic material, definitely later than and replacing quartz, which when developed to sufficient extent, yielded a rock to all appearances the equivalent of any of the simple pegmatites. It was confidently expected that this vein feldspar would turn out to be albite; but microscopic examination clearly indicates microcline. The indices of refraction correspond exactly and while portions are untwinned, the characteristic quadrille twinning is frequently developed.

The quartz of the silexites appears similar to that of the pegmatites, crystallizing in coarse anhedrons with an abundance of minute bubble-like inclusions. Strain shadows and small fractures are common; but there is no granulation. Adams (1921) has discussed the characters of vein quartz, and this shows no marked resemblance to any of the more distinctive vein textures. On the other hand, Tolman (1931) from his study of quartz bodies of igneous origin concluded that there were few positive criteria by which such quartz could be explicitly distinguished. Whatever may be the origin of the quartz in the silexites, the interesting and almost unique feature is the time relationship between the quartz and the microcline. In the better defined examples and in the incipient stages of the process (see fig. 2) there can be no question of the secondary (doubtless hydrothermal) nature of the microcline. The same relationship is observable also in thin section. Microcline, along with quartz has of course long been recognized as one of the last minerals to crystallize in the normal sequence in igneous rocks. Where found in pegmatites, however, it is very generally considered one of the first, if not indeed the very first mineral to crystallize. Schaller (1927) has indicated that in such rocks a high temperature potassium feldspar (probably orthoclase) was the first constituent to form; that this reverted on cooling to microcline; and that the quartz (even the quartz of the graphic intergrowths) is secondary to this.

In the present cases, this relation is reversed; for microcline belongs to a distinctly later generation than the quartz, which it clearly replaces. Instances of feldspathization of quartz are by no means unknown. Anyone who has studied veins characteristic of the epithermal zone can recall many instances of adularia developing at the expense of quartz and other constituents of the rock or vein in which it occurred. This to be sure is rather different from the case under consideration. An interesting example of feldspathization, although again not strictly analogous, is described by Reynolds (1936) from Colonsay. She has also summarized occurrences in which there has been feldspathization of quartz or quartzite. In the Colonsay example quartzite xenoliths have been feldspathized, largely with the development of perthites (the albite is secondary to the potash feldspar of the perthite) and what corresponds to syntectic pegmatite is developed on a small scale.

In the present case, the source of the feldspar, whether magmatic, syntectic, palingenic, etc., is as much or more uncertain than the source of the quartz. Nor is there, in view of the marked time difference between these two minerals, any assurance that they are in any way related to a common source. Microcline is regarded by many as a strictly pyrogenic mineral; but its structural relationships in these occurrences would place it as more likely to be hydrothermal.

In view of their apparent distance from any of the larger granite masses of the area, it was an obvious suggestion that these pegmatitic silexites might have originated by palingenesis. Daly (1914) has said: "During intense regional metamorphism . . . deep-seated rocks charged with much interstitial water may reach the relatively low temperature at which minerals corresponding to the quartz-feldspar eutectic go into solution with the water and other volatile fluxes. Such small, locally generated pockets, lenses or tongues of fluid may be driven through the solid country rock for an indefinite distance; subsequently to crystallize with the composition and habit of true batholithic derivatives." That the Type III pegmatites here described might have originated in some such manner is disproved by the proportions of the quartz and feldspar which are in no way comparable to those of the eutectic suggested by Vogt (1931, p. 423). On the other hand, that these are "batholithic derivatives" is by no means clear: the time relationships of the quartz and the microcline are not readily compatible with such an origin. That they are bedding plane quartz veins developed early in the history of the meta-sediments in which they are found, and have since been feldspathized, is not impossible. But it should be mentioned that these veins at times show the curious crenulations and irregularity of structure (found also in the Type I and Type II pegmatites) to which Sederholm (1913) has given the name of "ptygmatic folds." Such a structure is interpreted by some geologists (Grout, 1932, p. 360) as requiring injection during deformation. Bedding plane quartz veins would not, on this hypothesis, develop ptygmatic folds.

What the quantitative importance of the Type III pegmatites may be is uncertain. As was the case with the Type II structures, a complete development entirely obscures the origin, and it is quite possible that many Type I and Type II pegmatites may actually have developed in the manner indicated for Type III, viz., replacement by microcline of what was originally a quartz vein.

Summary and Conclusions

An increasing opinion and body of knowledge indicates that granite may have formed in several ways other than by direct invasion of primary magma. Eskola (1932) and Collins (1933) have contributed noteworthy discussions on this subject. With the close association known to exist between granite and pegmatite, it is only reasonable to expect that pegmatites may also have formed initially in ways other than by simple intrusion.

Emphasis in recent years has been placed on the long and complex cooling history frequently shown by pegmatites. It now seems probable that the initial formation of pegmatites may in some cases be as complex as is their later history. This has been anticipated to a certain extent by Schaller (1933) who said: "Notwithstanding the fact that all writers on pegmatites seem to accept their origin as being directly related to end products of differentiation of magmas, it will not be amiss to call attention to the possibility that they may represent the 'sweat,' or the most easily liquefied portions that have been squeezed out of various kinds of rocks by orogenic processes."

Because of their coarser crystallization and occasionally more complex history, pegmatites will not in general indicate their true origin as clearly as is sometimes the case with granites. Nevertheless in the Archean area in Grand Canyon evidence exists suggesting three possible modes of origin: by magmatic intrusion; by "pegmatization"; and by hydrothermal feldspathization of quartz veins. Only under very fortunate circumstances, or else in the incipient stages of development can the second and third types be unequivocally distinguished from the first.

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