ISSN 1526-5757

37. Overlooked experimental evidence for K-replacements of plagioclase and origin of microcline in granite plutons

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June 5, 2000

Abstract

Experimental studies show that K replacement of Na in triclinic plagioclase under hydrothermal conditions results directly in triclinic microcline without forming intermediate monoclinic orthoclase. These experiments bring laboratory and field evidence into agreement for the K-metasomatic origin of granites which contain exclusively microcline as the potash feldspar. Such replacements of a more mafic rock can be on a plutonic scale and range from barely perceptible to being so extensive that almost no trace of an original relatively-mafic rock remains. Microcline, as the exclusive K-feldspar, and myrmekite may be the only clues to the metasomatism.

Introduction

Marmo (1955, 1958ab, 1961) and in discussions with Schermerhorn (1961) noted the fact that "*some granites contain predominantly orthoclase whereas others contain exclusively microcline as their potash feldspar*." Although both granite types have the same physical appearance of being intrusive, having dikes and sills with sharp contacts, the microcline granites commonly are syn- or late-kinematic, occurring in orogenic terranes, but the orthoclase granites are generally post-kinematic and appear to have crystallized from dryer magmas. The microcline granites are typical of Precambrian areas, but the orthoclase granites are sporadic and characterized by being in younger alpine regions or are rapakivi granites. The orthoclase crystals are generally inhomogeneous, exhibiting various stages of inverting to microcline. Such orthoclase and the patchy microcline in the orthoclase contain uniformly distributed albite lamella as hair perthite or cryptoperthite. In contrast, microcline in microcline granites either lacks visible perthite lamellae or commonly has an irregular distribution of albite lamellae of varying sizes.

Marmo (1958a) compared orthoclase with microcline and noted that orthoclase is the monoclinic modification of potash feldspar that is crystallized in laboratory melts. ***Triclinic microcline has never been produced experimentally from melts***. On the basis of these experiments and for crystallographic reasons, Laves (1950, 1955) and MacKenzie (1954) argued that all microcline with grid-twinning must have originally been monoclinic orthoclase before inverting to microcline. Nevertheless, Marmo (1955), on the basis of petrologic reasons, suggested that microcline in microcline granites had a triclinic ancestry rather than inverting from monoclinic orthoclase. He found it peculiar that microcline granites contain no traces of orthoclase and that where microcline aplite dikes cut older orthoclase granites, the orthoclase generally shows little to no inversion to microcline. If orthoclase ***always*** inverts to microcline through time, why should younger granite have potash feldspar that is totally inverted to microcline whereas adjacent orthoclase in older granite shows little to no evidence for inversion? On the basis of these petrologic observations, Marmo questioned whether the origin of some microcline granites was fully understood.

Marmo (1958a) also reported that microcline had been produced experimentally by indirect synthesis. Wyart and Sabatier (1956) showed that ***when Na in albite was replaced by K in the laboratory under hydrothermal conditions, microcline is formed***. These researchers had expected that microcline would be produced because the albite lattice was triclinic and because the simple substitution of K for Na would produce microcline by inheriting this triclinicity. However, Marmo (1958a) did not use the results of these experimental studies to explain the origin of microcline granites. Instead and in order not to be in conflict with the hypotheses of Laves (1950, 1955), Goldsmith and Laves (1954), and MacKenzie (1954), Marmo suggested that in the microcline granites, the early symmetry of the first nucleating cell of a K-feldspar lattice would have been monoclinic, but it quickly inverted to the triclinic array. He thought that "*if potash feldspar crystallized sufficiently slowly and at a temperature lower than that at which the triclinic form is replaced by the monoclinic form, microcline will grow instead of orthoclase*." And if "*either the temperature is somewhat elevated, or the duration of crystallization is short, orthoclase will grow instead of microcline*." He also suggested that sluggish intrusions favored microcline whereas rapid emplacements favored orthoclase.

Discussion

If Marmo's above requirements for the formation of microcline or orthoclase are evaluated, it seems unlikely (1) that significant differences occur in the rates of magma intrusion, (2) that magmas could have been kept at low temperatures below the point at which orthoclase forms, and/or (3) that different rates of crystallization would cause one magma to form exclusively microcline and another orthoclase. For example, his suggestion that rapid emplacement or crystallization in a short time interval favors orthoclase is inconsistent with his observation of a microcline aplite dike, cutting orthoclase granite. Therefore, Marmo's contrived model (1958a) for the origin of microcline to conform with the restrictions demanded by Laves (1950, 1955) lacks reasonable support and goes against his own intuitive observation that microcline in microcline granites must have had a triclinic ancestry. To his credit, Marmo (1958a) noted that in microcline granites in a syn-tectonic environment, where K-feldspar was mostly introduced metasomatically (e.g., Eskola, 1956), it is exclusively microcline. This petrologic observation is the same as that found by Collins (1988, 1996 ab, 1997 abd; http://www.csun.edu/~vcgeo005/Nr2Myrm.pdf; http://www.csun.edu/~vcgeo005/Nr3Myrm.pdf; http://www.csun.edu/~vcgeo005/Nr9Twenty.pdf; http://www.csun.edu/~vcgeo005/Nr13Rubidoux.pdf; http://www.csun.edu/~vcgeo005/Nr22Ponaganset.pdf, who showed that during K-metasomatism of deformed and altered primary plagioclase grains, the first K-feldspar to form is ***microcline, not orthoclase***. Collins (1997c, 1998a; http://www.csun.edu/~vcgeo005/Nr19Myth.pdf; http://www.csun.edu/~vcgeo005/Nr26Controversy.pdf;) further suggested that where K replaces Na and Ca in triclinic plagioclase, the triclinic microcline would result by inheriting the triclinic lattice from the plagioclase and leave irregular islands of perthite lamellae of various sizes and in seemingly random distributions because of differential incomplete replacements. At that time, Collins was not aware of the experimental work of Wyart and Sabatier (1956), which confirms that this inheritance is not only possible but actual. Nevertheless, using the experimental studies of Orville (1962), 1963), Collins (1999; http://www.csun.edu/~vcgeo005/Nr36Experimental.pdf) demonstrated reasons why the secondary origin for K-feldspar by replacement of plagioclase is possible and expected.

Applications of experiments to geologic terranes

The application of the overlooked experiments by Wyart and Sabatier (1956), which show that triclinic microcline is formed directly by K-metasomatism of plagioclase, is far reaching. There is no doubt that igneous plutons, which are now microcline-bearing granitic rocks (lacking orthoclase), formerly had a primary magmatic origin. However, the experiments show that the microcline need not have crystallized from the original magma as former orthoclase. Because the microcline granite, created by replacement processes, inherits the features of the original mafic rock, e.g., primary hypidiomorphic textures, enclaves, sharp contacts, and cross-cutting dikes, as well as any metamorphic aureole in the wall rocks, these features can still be preserved just as the microcline inherits its triclinicity from the plagioclase which it replaces. Moreover, relatively uniform mineralogical and chemical compositions throughout a large mass of microcline granite can be expected and is observed because the original mafic pluton that was replaced was also relatively uniform in composition.

The formation of more and more granitic rocks on a plutonic scale through time is logical because the compositions of mafic rocks can continue to ***evolve*** following their solidification from magma. For example, continued changes are observed where former mafic rocks have been weathered and/or subjected to low grade metamorphism. In such rocks the relatively-calcic cores of zoned plagioclase crystals become sericitized because nano-sized fractures have permitted the metasomatic introduction of K and water. If K can be introduced into a plagioclase under low temperature conditions, K is even more likely to be introduced at medium- to high-grade metamorphic conditions, where microcline is the stable K-bearing mineral instead of sericite or muscovite. Because experimental studies by Wyart and Sabatier (1956) apply directly to what is observed in the field, granite petrologists now need to realize that K-metasomatism on a large scale is normal and expected.

Summary of the conditions for the formation of microcline granite

In order for microcline granite to form, a solidified, primary relatively mafic, igneous rock must be deformed so that hydrous fluids can enter and alter the rocks composition. The old idea suggested by early "granitizers" for solid state diffusion to cause large-scale metasomatic granites to form is untenable. Deformation, affecting the whole rock and opening closely-spaced avenues for hydrous fluids to move, is necessary for large-scale K-metasomatism to occur. The deformation preceding metasomatism could range from (1) slight cracking of the crystal boundary seals and micro-fracturing of grains with little to no displacement of broken fragments to (2) intermediate stages of general crushing and bending of twin lamellae, to (3) extensive cataclastic shearing that causes displacements of fragments and results in a gneissic or schistose fabric. After deformation, the degree of K-metasomatism to produce microcline-bearing granites will range from (1) barely detectable, where the replacements are nearly isochemical, where the microcline is interstitial and of low modal abundance (traces to perhaps as high as

10 percent), and where rim myrmekite is the common type of myrmekite, to (2) intermediate stages where the amounts of microcline have changed the rock's composition into granodiorite or quartz monzonite even though much of the original mafic rock still remains and where rim myrmekite may (or may not) coexist with wartlike myrmekite and, finally, (3) to the extreme stage, where the K-metasomatism is so extensive that microcline exceeds modal plagioclase and converts the rock to true granite, where almost all evidence of a former relatively mafic rock is destroyed during the replacement and recrystallization processes, and where wartlike myrmekite is the only coexisting myrmekite type.

The barely detectable amounts of K-metasomatism could begin during late stage deuteric alteration of an almost solidified magma and continue after total solidification at temperatures below melting conditions, provided that deformation of the crystallized rock allows hydrous fluids to continue to move through the system. The recrystallization of the deformed rock may range from − slight modifications that still preserve evidence for cataclasis, such as bent and broken albite-twining, − to textures that produce a massive, magmatic-appearing granite in which almost all evidence of former cataclasis is eliminated. Compositions that result from this recrystallization can be uniform and occur in equigranular granites or aplites or in porphyroblastic rocks having either microcline augen in gneissic granite or microcline megacrysts in massive granite. Thus, each kind of microcline-bearing granite (quartz monzonite, granodiorite, or true granite) which is formed by replacement of a non K-feldspar-bearing, more-mafic rock is a product of the degree of deformation, the availability of K, the openness of the system, and the extent to which the system is kept open by repeated deformation. In any case, the combination of the experimental work of Wyart and Sabatier (1956) and the field and laboratory studies by Collins (1988, 1996 ab, 1997 abc) makes it clear that ***microcline (in the absence of orthoclase) is formed by K-metasomatism of primary plagioclase***.

It is without question that some quartz monzonite, granodiorite, syenite, and hypersolvus granite exist in which the K-feldspar in these rocks has crystallized from melts. In these rocks, however, myrmekite is absent, and any microcline would have inverted from former orthoclase rather than having been formed by replacement of plagioclase. Perhaps, most granitic rocks by volume in the earth's crust have crystallized from magma. Nevertheless, many large granitic plutons have evolved from more-mafic intrusion that becomes more granitic in composition and exclusively microcline-bearing because of K-metasomatism.

Applications to earth history

The common occurrence of microcline granites in Precambrian areas, observed by Marmo (1958a), can be explained by the history of the development of the early crust. During older Precambrian times the great amounts of heat released from the decay of primary radioactive elements produced melts that migrated upward to be emplaced as crustal plutons. In those places in the mantle where potassium was abundant, the incompatibility of potassium allowed it to be brought up in fluids and melts that crystallized to form ***biotite-bearing*** tonalite, diorite, and gabbro. The wetness of these early magmas would have favored the crystallization of the potassium in biotite rather than in anhydrous K-feldspar (orthoclase). Biotite-rich mafic rocks would have been more easily deformed than tonalites, diorites, and gabbros, containing mostly pyroxenes and hornblende because biotite has a hardness of 3 and planar cleavage. Pyroxenes and hornblende have hardnesses of 6 and are less easily cleaved or fractured. On that basis, where crustal rocks were subjected to underlying mantle convection, any overlying biotite-rich plutons would have been the most likely places where the greatest deformation would occur during geologic time. The upward migration of hydrous fluids into these deformed rocks would enable quartz to replace the biotite and release its K. In this way the K would have become available to replace triclinic plagioclase and form triclinic microcline. As a result, large volumes of former biotite-rich tonalite, diorite, and gabbro would be converted over time to microcline granites ***without any room problem***. Such metasomatic granite could be mobilized as a hot plastic solid and injected into fractures; for example, as dikes cutting hot orthoclase granites. Or, if temperatures rose sufficiently, the newly formed granitic rocks could be re-melted to become magma again. Even so, after crystallization of this magma, if the solidified rock were deformed so that hydrous fluids could be introduced again, it could go through another cycle of K-metasomatism, producing microcline again. In this way the newly generated metasomatic rock would become even more granitic.

Microcline conversions to orthoclase

Although the emphasis in the early part of this article is on the fact that microcline results from K-replacement of plagioclase at temperatures below melting conditions, in some terranes after microcline has been formed, temperatures have risen high enough to convert the microcline to orthoclase while still being below temperatures at which orthoclase would melt. This is possible because at higher temperatures the ordered Al and Si atoms in the triclinic microcline lattice become disordered to produce the monoclinic orthoclase lattice (e.g., Collins. 1998b; http://www.csun.edu/~vcgeo005/Nr28Popple.pdf). In such terranes myrmekite is present, whereas in terranes where orthoclase has crystallized from a melt and the original granite is undeformed, myrmekite is absent.

Conclusions

It is logical for older relatively-mafic igneous plutons to evolve through time to become more granitic in composition as long as deformation of the solidified rocks allows hydrous fluids, carrying K, to move through tiny fractures. Evolution of granitic rocks should not be limited to magmatic differentiation processes but can also occur by metasomatic processes. Such metasomatic evolution of granites should be expected because the earth's crust has not been static over billions of years. This article does not argue against the magmatic origin of many granites and granitic rocks. Instead, this article calls attention to overlooked studies of Wyart and Sabatier (1956) whose experimental work is in harmony with laboratory and field studies, showing that *exclusively* microcline-bearing granitic rocks are formed by K-metasomatism. Therefore, not only is myrmekite a clue to K-metasomatism, but also microcline as the *sole K-feldspar in a rock*.

Acknowledgements

I wish to thank my wife, Barbara, for many helpful editorial suggestions.

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