ISSN 1526-5757

39. Scientific errors that can result when myrmekite and geologic evidence are ignored

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April 18, 2001

Introduction

The present studies of granitoid rocks from the 1980s into the year 2001 are dominantly directed toward chemical analyses and experimental and theoretical petrology rather than the determination of textures and petrography as seen in thin sections. Values for chemical studies of the granitoids are that they (a) support classifications into source types (S-I-A-M), (b) demonstrate liquid line of descent toward the temperature minimum of the Ab-Or-Qtz system, (c) enable the plotting of Harker diagrams of major oxides and spider diagrams of major and trace elements to show differentiation trends, (d) serve to discriminate among possible tectonic settings, and (e) provide data to enable the determination of ages by using various isotopes (Winter, 2001). For most granitoids this method of investigation is without reproach. However, when ***only*** chemical studies are used to study a granitoid, many changes in the solidified magmatic rocks may be hidden or unsuspected. Therefore, ***scientific errors in interpretation can result***.

Recent work suggests that where the granitoids contain rim and/or wartlike myrmekite, improper assumptions can be made concerning the complete history of these rocks (Collins website articles in http://www.csun.edu/~vcgeo005/index.html). Following solidification, deformation and modification by fluids containing K and Si can cause differentiation progressively toward the temperature minimum of the Ab-Or-Qtz system. This occurs because recrystallized minerals in granitic rocks formed by replacement processes below melting temperatures are stable there just as those formed from a melt. Moreover, the elemental characteristics of their primary magmatic sources and much of their physical features (e.g., enclaves, dikes, zoning, hypidiomorphic textures) are inherited by the metasomatized rocks so that internally and outwardly they retain much of their magmatic ancestry. The **chemical analyses can look the same** (or nearly so) in either magmatic or metasomatically altered granitoids, not only because of inheritance, but also because the changes in chemical compositions during metasomatism parallel what is observed in a liquid line of descent. It is only by analyzing textures, as seen in thin sections, that extensive changes in chemistry and mineralogy can be detected that are unrelated to magmatic processes. ***Understanding the significance of myrmekite is important*** because its presence in a thin section is an indication that additional study is needed in order to fully comprehend what the chemical data mean (Collins, 1988a). The historical background for the shift to modern styles of granitoid investigation and its consequences are presented below as well as problems caused by sampling bias. Because of these problems, guidelines for sampling granitoids are suggested.

Historical background

An examination of articles published since Michel-Lévy (1874) first discovered myrmekite shows trends which illustrate progressive changes in attitudes towards this unusual plagioclase-vermicular quartz intergrowth (see references listed by decades). Becke (1908) was the first to propose that myrmekite was formed by Na- and Ca- metasomatism of K-feldspar. Then, Schwantke (1910) countered with the idea that myrmekite resulted from exsolution of Na, Ca, Al, and Si from high temperature K-feldspar. Because of the conflict between these two models, myrmekite became a subject of great research interest, and investigators presented many arguments as to which one was correct. In the 1940s, 1950s, and later years, new kinds of myrmekite were described, having different kinds of textural patterns and mineral relationships. Because some textural patterns did not seem to be best explained by either of the above two models for myrmekite origin, other models for myrmekite formation were formulated. All of these early models were discussed and evaluated by Philips (1974), but none had sufficient support to say that the origin of myrmekite had been resolved.

In the 1940s through the 1960s, authors of articles on granitic rocks and gneisses commonly reported myrmekite in their petrographic descriptions, listing it as an accessory or alteration mineral along with chlorite, sericite, epidote, calcite, clay, iron oxides, apatite, allanite, titanite, and zircon. In this same period, many authors also included discussions, indicating their favored model for the origin of myrmekite. In the 1940s and 1950s, however, a great debate raged about the origin of ***all*** granite bodies, as to whether they were entirely formed (a) by subsolidus replacement processes of sedimentary rocks ("granitization") or (b) by magmatic processes. See papers by Read, Buddington, Grout, Goodspeed, and Bowen presented at a meeting of the Geological Society of America held in Ottawa, Canada, December 30, 1947 (Gilluly, 1948). The debate was subsequently won by the experimentalists, and their conclusion that ***all*** granites of large size are magmatic in origin modified opinions about myrmekite. If granite bodies were entirely magmatic in origin, then myrmekite could only be a deuteric alteration mineral that was produced during the final stages of crystallization of magma. Moreover, because in the 1950s and 1960s, no definitive criteria had been developed to decide whether (a) Ca- and Na-replacement of K-feldspar or (b) exsolution was the correct origin of myrmekite, and because the presence of myrmekite did not seem to indicate any important relationship affecting the petrology of the granite in a major way, many authors of articles about granite in subsequent years no longer even mentioned myrmekite nor promoted their preference for its origin. Myrmekite’s tiny modal volume (generally less than 0.5 volume percent), its uncertain origin, and its relegation to a mineral formed by alteration during the last stages of crystallization of a magma seemed to suggest that myrmekite could be ignored without any serious consequences.

On that basis, interest in myrmekite waned after the 1960s, and the arguments for magmatism as the primary origin of ***all*** granite were seemingly so powerful that support for large-scale "granitization" also disappeared in most educational institutions and geological surveys and in undergraduate geology textbooks. Anyone supporting "granitization" was automatically regarded as being "behind the times." Thereafter, experimental work on granitic melts and chemical studies became the dominant accepted ways to investigate granites. Petrography and textural analysis of the rocks, as obtained through studies of microscopic thin sections, were relegated to the "trash heap," and editors of journals were not interested in publishing such information. In place of thin section studies, chemical analyses of major oxides and trace elements, and theoretical and experimental petrology based on thermodynamics became the dominant emphasis. Cathodoluminescent techniques, fluorescent x-ray, and scanning- and electron-microprobe methods of analysis soon replaced wet-chemical methods to determine chemical compositions, and the addition of isotopic age-dating methods, using various isotopes, became the accepted ways to study granitic rocks (Winter, 2001).

On the basis of these modern methods of studying granitic rocks, published articles in the decades since the 1970s contain little mention of petrography. Once it had been decided that all granites were magmatic in origin, the study of petrography was no longer needed, and any hypothesis suggesting that not all granites were totally magmatic in origin was not even considered. With this mind set, many articles, describing the chemistry or isotopic compositions of granitic rocks, mention only the main component minerals. No detailed descriptions of textures occur, and the barest information about accessories or alteration minerals is given, if at all. Even in other articles not emphasizing chemistry, progressively through the decades since the 1960s, myrmekite commonly is omitted from the petrography sections, even when it is relatively abundant. This is in spite of the fact that other alteration minerals are reported. When other alteration minerals are mentioned but not myrmekite, ***the lack of noting myrmekite is an example of scientific negligence***. All mineral data, including myrmekite, should be reported when describing rocks even if the authors do not regard myrmekite as being important.

In the 1960s and 1970s, research on myrmekite was in limbo. Because it was felt by editors of journals that myrmekite had been thoroughly studied, articles on this topic were generally rejected. Even abstracts submitted for presentation at professional conventions were rejected because the reviewers felt that attendees would not be interested in them. However, many geologists were still not satisfied with the then-available models for the origin of myrmekite, and, surprisingly, a few articles proposing new models continued to appear in the literature in the 1980s and 1990s as new kinds of myrmekitic textures were found in different rock types. See the reference list by decades.

Beginning in 1972, my own work supported the general feeling that **all large masses of granitic rocks have been emplaced by magmatic processes and that no large granite mass has formed by subsolidus "granitization" of sedimentary rocks**. However, in the late 1970s, 1980s, and 1990s evidence became available to me that *some* large plutonic igneous masses, ***after emplacement and solidification,*** have been modified by K- and Si-metasomatism to change them into rocks of a more-granitic composition, having increasing percentages of K-feldspar and quartz (Collins, 1988a; Hunt et al., 1992; Collins website articles at http://www.csun.edu/~vcgeo005/index.html). In a few places, even adjacent metasedimentary wall rocks had undergone similar and simultaneous K- and Si-metasomatism as the magmatically emplaced pluton was metasomatized. This metasomatism ***required deformation of solid rocks*** below melting temperatures in order to create tiny fractures in which fluids could enter and interact with the primary minerals in the rocks. These fluids utilized local or outside sources of K and Si and removed some Ca, Al, Fe, and Mg among other elements from the rocks. **No migration of these elements was by solid-state diffusion through undeformed rocks across vast distances (meters and kilometers)** as was assumed to occur by some geologists during the old style "*granitization*" process. The only amount of solid-state diffusion was on a scale much less than a millimeter and only through half the diameter between closely-spaced, microscopic fractures within a mineral grain. Significantly, the tiny fractures created by deformation generally have gone unnoticed by petrologists because such brittle breakage of plagioclase crystals **cannot be seen in thin section under plane or cross-polarized light.** Only strong deformation that bends albite twin lamellae or cataclasis that rotates broken fragments is observed under cross-polarized light. Seeing these tiny fractures requires cathodoluminescence imaging, which is a technique that petrologists have not commonly applied to the study of granitic textures (Hopson and Ramseyer, 1990a; Collins, 1997b; http://www.csun.edu/~vcgeo005/Nr2Myrm.pdf). Consequently, these clues to the K-metasomatism have been missed. At any rate, the main means of elemental migration must be in fluids moving through fractures and by ionic diffusion through these fluids rather than by solid-state diffusion. The residual effects of ion exchanges along the fractures during these movements are readily seen in **cathodoluminescent images**. Subsequently, the element identification along such fractures can be verified with **scanning- and electron-microprobe analyses (**Collins, 1997b; http://www.csun.edu/~vcgeo005/Nr2Myrm.pdf).

Resistance to this new K- and Si-metasomatic model was enormous and increasingly so after the 1970s to the year 2001 because the general feeling among most granite petrologists is that "*granitization*" had been disproved. K- and Si-metasomatism must have sounded like "*granitization*" all over again, even though it was entirely different. Assumptions were made by most petrologists that when a magmatically-emplaced granitic body became crystallized, it was static, and, henceforth, it did not change (except by weathering), even for billions of years. Therefore, any hypothesis suggesting large-scale changes by metasomatic fluids was wrong. While agreeing with the conclusion that all granitoids are emplaced and crystallized from magmas, I suggested that the thin section evidence, field studies, and chemical analyses (including electron-microprobe analyses) showed that large-scale K- and Si-metasomatism is valid in some deformed plutonic masses, and myrmekite is the clue to this metasomatism (Collins, 1988a). Nevertheless, the increasing resistance to a model that sounded like "granitization" has continued in the 1970s, 1980s, and 1990s, regardless of the evidence that was provided.

Objection to large-scale K- and Si-metasomatism is surprising for the following reasons.

1) **Granite petrologists have already accepted large-scale Na-metasomatism during fenitization** (Winter, 2001), and the chemistry of Na is not

much different from that of K so that both should behave in the same way. Examples of large-scale Na-metasomatism in granitic rocks are demonstrated in northern New York (Collins, 1997r; http://www.csun.edu/~vcgeo005/Nr18LyonMtn.pdf).

(2) **Large-scale K-replacement of plagioclase crystals (from the exterior inward) is known to occur throughout some granitic plutons during late-stages of the crystallization of the magma** (Collins, 1997s; http://www.csun.edu/~vcgeo005/Nr19Myth.pdf). Therefore, lowering the temperature just a few degrees below melting conditions should not change the capability of K to replace plagioclase. However, the style of replacement changes to that of replacing the plagioclase crystals from the interior outward rather than from the exterior inward. The difference in style occurs because in magma, *not* totally solidified, the ability of fluids to flow between early-formed crystals creates space for the expanded, lower-density lattice of K-feldspar to grow as it replaces the denser lattice of plagioclase. In contrast, in completely crystallized granitoids, no expansion between sealed and interlocking solid crystals can occur. First fracturing must occur, and then the extra needed space for the K-feldspar lattice to form must be produced by removal of elements from the interiors of the deformed plagioclase crystals. As replacement occurs, it is not mass-for-mass, as in balanced chemical equations, but volume-for-volume (Collins, 1988a, 1997a, http://www.csun.edu/~vcgeo005/Nr1Myrm.pdf; 1997b, http://www.csun.edu/~vcgeo005/Nr2Myrm.pdf).

(3) **Experimental work of Orville (1962, 1963) has already shown that K-metasomatism can be demonstrated** and that it occurs at rates that permit the conversion of plutonic rocks containing plagioclase as the only feldspar into granite containing K-feldspar during the geologic time frames that are available (Collins, 1999b; http://www.csun.edu/~vcgeo005/Nr36Experimental.pdf).

And finally, (4) economic geologists have observed the broad extent of metasomatism by large quantities of introduced fluids to form many different kinds of metallic ore deposits. Having seen the evidence for such great volumes of "metal" replacements in deformed but solid rocks, **our colleagues find it surprising that granite petrologists do not accept large-scale K-metasomatism** (Tim H. Bell, email communication, 1997).

The problem for accepting large-scale K- and Si-metasomatism to form *some* granitoids is partly because granite petrologists have not seen the evidence in thin section via cathodoluminescent imaging and because they have been looking in the wrong places, as is suggested in the next section.

Sample bias

There is an anecdote about a person in the middle of the night coming upon an old man on his knees under a street lamp looking for his glasses. After learning of the man’s loss, this person decides to help in the hunt. After several minutes of looking, however, and finding nothing, this person asks: "Where did you lose your glasses?" The old man points to the dark shadows and says: "Over there." "Then, why are you looking here?" To which the man replied: "Because the light is here."

This anecdote illustrates an analogous problem in studying myrmekite. Myrmekite-bearing granitic rocks generally form resistant outcrops because of the abundance of quartz and feldspars. The outcrops of granite ("where the light is") stand above the valleys ("the shadows where the origin of myrmekite can be found"). In this analogy the investigators of myrmekite have looked only in the granite where the final product has been produced and not where the progressive stages that led to the formation of the myrmekite have taken place. One must look beyond the granite in the transition rocks where biotite is commonly abundant to find the answer to the origin of myrmekite. Unfortunately, biotite-rich rocks are easily weathered and eroded, and in many places glaciers and streams have removed these weaker rocks, and vegetation, soil, and other deposits cover them. Thus, natural processes force a sample bias on the person wanting to collect rocks in a given terrain. Only the resistant rocks in outcrop can be collected unless diamond drilling of covered rocks is used to obtain core samples. Because of this limitation, in many places only the final product of K- and Si-metasomatism can be collected, forcing an unfortunate sample bias. Moreover, in many places the replacements and recrystallization of the original rock found in the resistant outcrop have removed *nearly* all evidence for its original composition and for its former deformation that permitted the K- and Si-metasomatism.

Another bias in sampling occurs because modern studies of granites deal with their chemistry and isotopic compositions. Rocks needed for these investigations must be fresh, and only a few samples are required. When the investigator already believes ("knows") that the granite is entirely magmatic in origin, there is no purpose in collecting lots of samples to prove its magmatic origin, and samples that might be weathered or messy are avoided. Two thin sections may be sufficient to determine the main minerals. Yet, it is the abundance of samples in the wall rocks and transitions to the granite and their thin sections (***the geologic evidence***) that may reveal the true history of the rock.

Guidelines for sampling granitoids

On that basis, to avoid sampling bias certain rules should be followed when collecting samples of granitic rocks.

1. The sampling must be systematic, making sure that a grid distribution of samples is obtained wherever the outcrops make it possible.

2. Even though the granitoid may appear to be uniform (magmatic in appearance), two samples need to be taken at each collection site in a grid in order to see the local and broad variations that occur. Where a granitoid is not uniform, all rock types should be collected at a given grid site.

3. Where foliation is present, strike and dip must be measured, and the sample that is collected must be taken from the same place that the rock attitude is determined. The structural attitude of the sample relative to attitudes of rocks in surrounding or adjacent areas may determine the sample’s mineral and chemical composition because the composition may result from metasomatic fluids moving into low pressure sites that are controlled by the structure.

4. Exotic structures and textures (enclaves, schlieren, etc.) are commonly attractive, and the investigator must be careful in the field not to bias the sampling by making a collection consisting of 80-90 percent of the exotic rocks and 10-20 percent from the common rock type. The sampling should be proportional to the relative volumes of the different rock types.

5. Efforts must be made to find and collect from transition rocks. For example, (a) if the granitic rock contains K-feldspar megacrysts, then transitions to portions of the granitic body must be looked for in which the megacrysts are absent. (b) If the K-feldspar megacrysts are zoned, then transitions to places where they lack zoning must be sought. (c) If pegmatite dikes are found, then the dikes need to be walked out along strike to see if they grade into zones of deformation and then to where the dikes and deformation disappear. And (d), similarly, if migmatites occur, the granitic portions need to be sampled progressively along strike until the granitic rocks disappear. Samples of these different kinds of transition rocks are likely to provide clues to the evolutionary history of the granitoid.

Because myrmekite cannot be seen in the field, when it is discovered later in thin section, one should go back in the field, perhaps several times, to collect additional samples and narrow down the transitions to where myrmekite first appears. Because perthitic intergrowths also cannot be seen in the field, if the albite lamellae in the K-feldspar are not uniformly distributed and are irregular in size, then additional sampling is needed. If the perthite lamellae have uniform distribution and are nearly constant in size, then they are likely formed by exsolution from orthoclase. If the lamellae are not uniform, this perthite could be formed from replacement of plagioclase by K-feldspar. Return trips may also show progressive Si-replacements, producing interior quartz blebs in hornblende and biotite across the transitions. At any rate, without such a guideline to seek transition areas, these many different things to look for might be missed if the investigator has preconceived notions that the granitoid is entirely magmatic and unchanged since emplacement. As Goethe said: "We see what we know."

Some of these sampling rules may go against one’s natural tendencies in the field. In some places great numbers of samples do not seem to be necessary. I have had to remind myself many times to follow these rules when my instincts said: "What is the use of sampling here?" However, the unaided eye cannot see mineralogical and textural changes that are important. Moreover, I discovered that it was only when I collected hundreds of samples systematically and made thin sections of these samples that structural attitudes at outcrops could be tied to metasomatism. It was only when I collected 900 samples of amphibolite and interlayered biotite-orthopyroxene-plagioclase (An_{80}) gneiss in eight different layers from noses to limbs in isoclinal folds did the thin sections and other methods of analysis reveal convincing evidence for progressive losses of iron from the ferromagnesian silicates in deformed amphibolite in the limbs (Collins, 1969). These losses explained how magnetite concentrations were formed in sufficient quantities to be mined as iron ore. This same extensive sampling also showed the progressive changes in the limbs in the deformed biotite-orthopyroxene-plagioclase gneisses to convert them into myrmekite-bearing granitic gneisses. Likewise, in other terranes it has been only when great numbers of samples were collected from areas outside a granite body through transitions into the granite that I could observe the progressive stages of myrmekite formation. See index of articles at http://www.csun.edu/~vcgeo005/index.html

Conclusion

On the basis of the above, new attention needs to be applied to thin section studies of more than a few samples and to the occurrence and absence of myrmekite in granitic rocks. Although granitic plutons are emplaced by magmatic processes, such replacements do not mean that these rocks will necessarily remain unchanged through eons following their solidification. The constant stirring in the mantle, causing crustal plate motions, must deform at least some of the crystallized plutons, enabling metasomatic fluids to move through them. It is agreed that using only petrographic studies of thin sections is inadequate to explain what happens in the plutons during their entire evolutionary history. But so also is a study limited to chemical analyses inadequate***. Investigators need to combine experimental, chemical, and theoretical studies with geologic evidence obtained in the field and from detailed thin section analysis, concomitant with cathodoluminescence studies, if scientific errors in interpretation are to be avoided.***

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Acknowledgments

I thank my wife, Barbara, whose many excellent suggestions greatly improved this article. I also express my appreciation to David Liggett, who has helped me with the technical computer problems for getting this article and all the other articles on line for this electronic publication.