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10. K- AND Si-METASOMATISM IN THE DONEGAL GRANITES OF NORTHWEST IRELAND

Lorence G. Collins

email: lorencec@sysmatrix.net

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Introduction

There is no doubt that the Donegal intrusions (Fig. 1) were originally magmatic in origin. The magmatic style, petrologic history, age, and structure of the Donegal granites have been thoroughly studied (e.g., Pitcher and Berger, 1972; Holder, 1979; Berger, 1980; Hutton, 1981, 1982; Pitcher and Hutton, 1982). Magmatism is not questioned, but puzzling mineral textures in the plutons suggest that chemical and mineralogical modifications by metasomatic processes during subsequent deformation (after solidification of the magmas) have been greater than has been previously recognized.

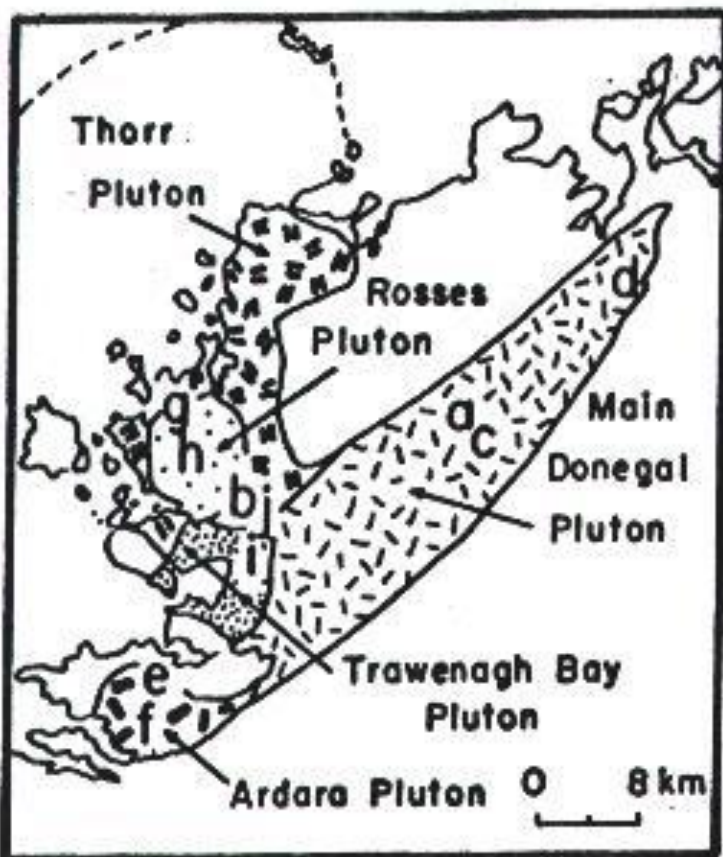


Fig. 1. The granitic plutons of Donegal (modified after Pitcher et al., 1987), showing locations of myrmekite-bearing rocks some of which are illustrated in Figs. 5, 6, and 7. (a) Locality 4 on map of the Main Donegal Granite. (b) Locality 2 on map of the Geology of the Thorrr District, Co. Donegal. (c) Locality 3 and (d) between localities 10 and 11 on map of the Main Donegal Granite. (e) Locality 2 and (f) locality 9 on map of the Ardara pluton. (g) Locality 7 and (h) locality 4 on map of the Rosses Granite Complex. (i) and (j) Locality 1 on map of the Geology of the Thorrr District, Co. Donegal. Map locations taken from Pitcher et al. (1987).

Although large-scale, Na- and Si-metasomatism (fennitization) of mafic magmatic rocks to form felsic rocks which contain arfvedsonite, acmite, and sodic plagioclase is not debated (Kresten, 1988), recognizing large-scale metasomatism where K and Si are introduced has been problematic. Evidence is accumulating, however, that large-scale K-metasomatism of metasedimentary and former magmatic rocks to form granites is possible (Cela and Yague, 1982; Wenk, 1982; Collins 1988a, 1988b, 1989; Kresten, 1988; Collins and Davis, 1992; Hunt et al., 1992). A study of the Donegal plutons gives further evidence for metasomatic alteration after magma solidification.

History of the Donegal granites

The early magmatic history of rocks in the Donegal area begins with intrusions of mafic appinitic bodies in the Dalradian metasedimentary rocks (French, 1966, 1976; Pitcher and Berger, 1972; Pitcher et al., 1987). This is followed by the intrusion of the Thorr granodiorite pluton and successively younger and relatively more-granitic plutons that rose forcefully into a surrounding envelop of sedimentary rocks. In that magmatic process an aureole of high-temperature metamorphism was created that formed sillimanite or kyanite and locally garnet and/or cordierite in the adjacent pelitic wall rocks (Pitcher and Berger, 1972; Atherton et al., 1975; Pitcher et al., 1987). Many of these pelitic rocks have also been enclosed in the magmatic bodies as disoriented, angular blocks that also exhibit a contact metamorphic aureole.

Origin of the Donegal granites

In interpreting the petrology of the Donegal granites, previous investigators have assumed that the gradational compositional changes from mafic to more granitic facies resulted entirely from magmatic differentiation by fractional crystallization. During fractional crystallization biotite, hornblende, zoned plagioclase, sphene, allanite, and iron oxides form in early stages, and K-feldspar and quartz are added in late stages. Early-formed, heavy, mafic minerals are assumed to settle in a deep magma chamber so that successive younger intrusions are progressively more felsic. In any case, the K-feldspar is considered *not to be formed at temperatures below the melting interval for granite*.

Pitcher and Berger (1972) and Pitcher et al. (1987) suggested, however, that K-feldspar in the Donegal granites forms by metamorphic differentiation under subsolidus conditions because the K-feldspar megacrysts cut the foliation and older dikes. I agree with their interpretation, but suggest that replacement has been more extensive with both K- and Si-metasomatism occurring.

Evidence to support the later K- and Si-metasomatism

Six different textural features provide evidence to support K- and Si-metasomatism: (1) the association of K-feldspar with deformed xenoliths in the Ardara pluton, (2) the association of K-feldspar with strong banding and foliation in the Main Donegal granite, (3) a room problem, (4) the late occurrence of K-feldspar, (5) the formation of myrmekite and relationships of quartz vermicule size in the myrmekite, and (6) development of quartz sieve textures in biotite and hornblende.

1. *K-feldspar megacrysts and deformed xenoliths.*

Evidence for post-magmatic formation of K-feldspar by replacement is provided by the mafic xenoliths that are enclosed in the Ardara pluton (Fig. 1). Xenoliths near the center of the pluton are almost equidimensional. Closer to the rim, however, they become increasingly elongated until at the rim their long dimensions are ten times their widths (Holder, 1979; Pitcher et al., 1987); see Fig. 2.

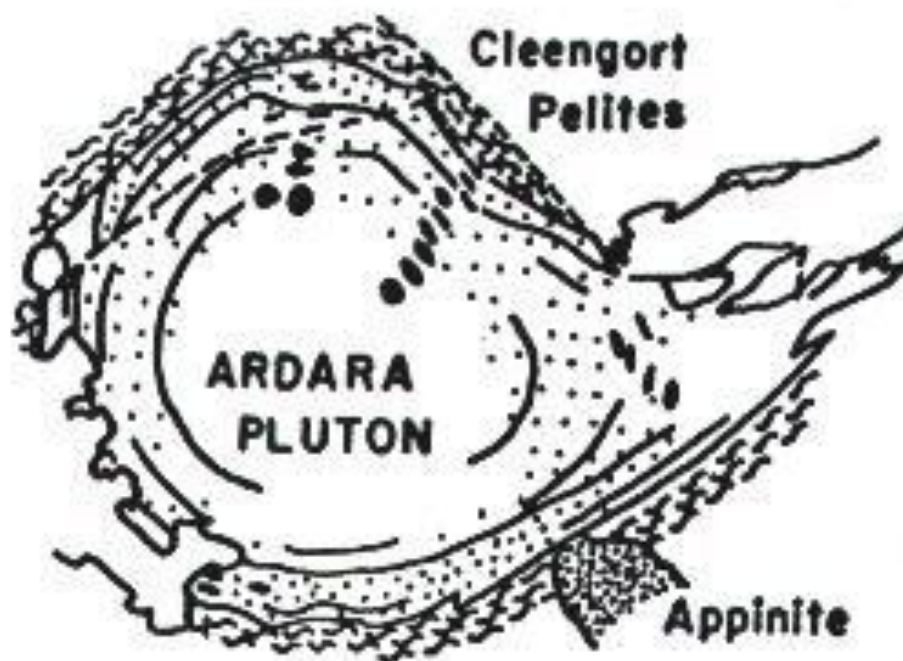


Fig. 2. Diagrammatic sketch of xenolith shapes in the Ardara pluton (modified after Pitcher et al., 1987).

In order for this degree of deformation of the xenoliths to occur, the pluton must have been subjected to extreme stress after it was solid or nearly so, at least in its rim. Otherwise, if the xenoliths were surrounded by magma, pressures would have been equal in all directions, and the mafic xenoliths would *NOT* have been deformed. On the other hand, if the pluton were solid, then all its primary minerals would have *to be deformed at the same time that the xenoliths were deformed and to the same degree*. That is, if K-feldspar megacrysts (2 to 3 cm long) are primary phenocrysts, formed by crystallization from the magma, then it logically follows that after solidification these megacrysts should have been plastically stretched or cataclastically broken in the pluton rims to dimensions of 10-to-1 like the

xenoliths. Instead, Pitcher et al. (1987) reported that the K-feldspar megacrysts have length-to-width ratios of 2 to 1, which are the approximate dimensions of the long and two shorter axes of a *normal K-feldspar crystal*: $a:b:c = 0.662:1:0.557$ (Deer et al., 1963). The well-developed foliation in the groundmass minerals and lack of deformation of the K-feldspar crystals firmly support the hypothesis that they are metacrysts formed after solidification.

2. K-feldspar, strong banding, and foliation in Main Donegal granite.

In the northwestern side of the Main Donegal granite, where remnants of the Thorr pluton are present, the formation of K-feldspar is associated with banding and strong foliation (Fig. 3). The absence of K-feldspar in those parts of the Main Donegal granite that are undeformed supports the hypothesis that growth of K-feldspar is related to deformation episodes.



Fig. 3. Strong banding and foliation in Thorr remnants and Main Donegal granite.

3. A room problem.

The secondary formation of K-feldspar in deformed rocks is also supported by K-enrichment zones in the center of the Main Donegal granite where a room problem exists if these K-enrichment zones are formed by injection of magma (Fig. 4). The K-enriched zone shown in Fig. 4 (light gray; left side), where K-feldspar-bearing granite appears in the middle of the magmatic, felsic tonalite (dark gray), *cannot be the result of physical intrusion of K-rich magma, otherwise the adjacent tonalite would have been deformed to make space for this magma*, and no such deformation or bulging is apparent in the tonalite. The dike-like K-enriched zone (right side) has megacrysts of K-feldspar in it as well as depleted amounts of ferromagnesian silicates and shows a faint foliation because of alignment of felsic minerals. Solutions of K and Si could easily enter along fractures and move through cataclastically broken crystals to replace the more mafic rock and produce the more felsic rock without having a room problem.



Fig. 4. K-enrichment zones (light gray) in magmatic tonalite (darker gray).

4. Textural features indicating late K-metasomatism.

Indications that the K-metasomatism is late in the Main Donegal granite include: (1) veins of K-feldspar into plagioclase and jagged tendrils along grain

contacts, (2) bent or broken albite-twin lamellae in plagioclase while quartz and microcline show no signs of strain, and (3) obliteration of twin lamellae in plagioclase and decalcification of cores of oscillatory zoned plagioclase as K-feldspar is introduced into the cores to form antiperthite (Pitcher and Berger, 1972).

Similar textural features, indicating late introduction of K, occur in the Thorr pluton. Microcline replaces weakly zoned plagioclase in interdigitations, and remnant plagioclase in larger microcline crystals are in optical continuity with external plagioclase crystals. Moreover, these same K-replacement features are found in mafic inclusions in the Thorr pluton and not just the granodiorite or diorite of the main pluton (Pitcher and Berger, 1972). Similarly, in the Ardara pluton deformation of plagioclase, decalcification of plagioclase cores, obliteration of twinning, and interior replacement of plagioclase by undeformed K-feldspar occur (Hall, 1966).

5. *Myrmekite.*

All Donegal granites containing K-feldspar also contain myrmekite. The interior replacement features of primary plagioclase by secondary K-feldspar accompany myrmekite formation and are observed in zones of gradation from undeformed primary rock to deformed and replaced rock. See also presentations 1, 2, and 3. Abundances of myrmekite increase in proportion to modal percentages of K-feldspar. Maximum vermicule size is related to Ca content of the primary plagioclase. Where primary plagioclase has a relatively high Ca-content ($>An_{40}$), the recrystallized plagioclase in myrmekite contains relatively coarse quartz vermicules. Coarsest vermicules occur in the mafic Thorr facies enclosed in the north-northwest end of the Main Donegal granites (Fig. 1-a; Fig. 5), but vermicules nearly as coarse also occur in myrmekite (Fig. 1-b; Fig. 6) in a mafic facies of the Thorr pluton.

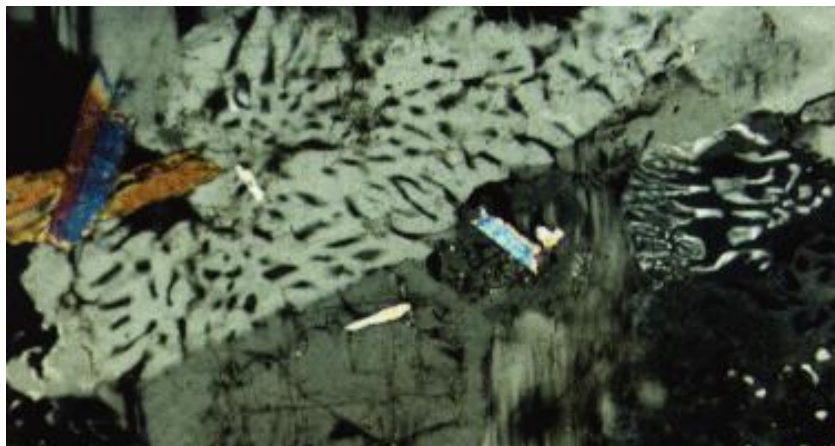


Fig. 5. Relatively coarse vermicules in myrmekite (top, center) in the Thorr granodiorite interlayered with the Main Donegal granite (north-northwest side). Biotite and muscovite are bright-colored grains. K-feldspar (gray and black) occurs at top.



Fig. 6. Relatively coarse vermicules in myrmekite in the Thorr granodiorite west of southwest end of the Main Donegal granite. Epidote (reddish brown, center) with tiny quartz inclusions and biotite (green and brown) are coexisting minerals. K-feldspar (black and gray, cross-hatched twinning) is in upper left. Plagioclase (white, upper right) is adjacent to myrmekite.

Myrmekite vermicules of medium size occur in the Main Donegal, Ardara, and Travenagh granite bodies (Fig. 1-cdefi, Fig. 7), where primary plagioclase ranges from An₂₂₋₃₃. Tiniest vermicules, too small to be reproduced in this web site, occur in the most felsic granites, such as the Rosses pluton and in some of the two-mica granites (Fig. 1-ghj), where primary plagioclase ranges from An₁₅₋₂₂. When the plagioclase is too sodic, as in other two-mica granites (plagioclase ranges from An₅₋₁₅, myrmekite does not form (Collins, 1988a).



Fig. 7. Quartz vermicules of intermediate size in myrmekite (center) enclosed in K-feldspar (light gray). Coexisting biotite occurs enclosed in plagioclase (black).

6. Quartz sieve textures.

In transition zones where modifications of plagioclase form K-feldspar, localized quartz replacements of biotite and hornblende also occur, forming quartz sieve textures (Fig. 8). Presence of tiny quartz blebs inside the hornblende and biotite suggests Si-metasomatism.



Fig. 8. Quartz sieve textures (white) in hornblende (grayish green). Coexisting biotite (tan) borders the hornblende.

For comparison, the following are examples in two other localities.

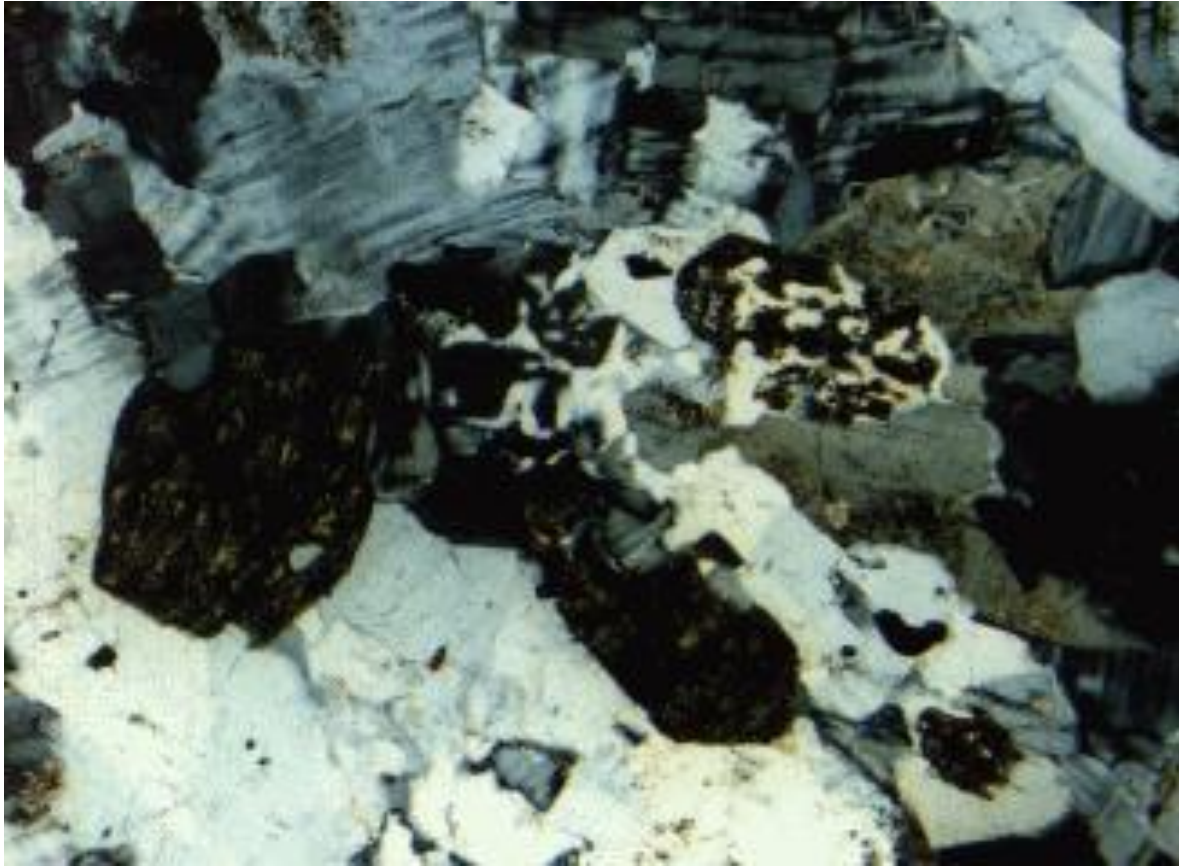


Fig. 5 from <http://www.csun.edu/~vcgeo005/Nr3Myrm.pdf>. This is a photomicrograph of the Salem diorite adjacent to myrmekite-bearing granite, showing some hornblende crystals (dark brown to black) being replaced by quartz (center, white) in a sieve texture while other hornblende crystals still remain unreplaced. Microcline (gray, grid twinning) has also been introduced here, but is absent farther into the diorite.

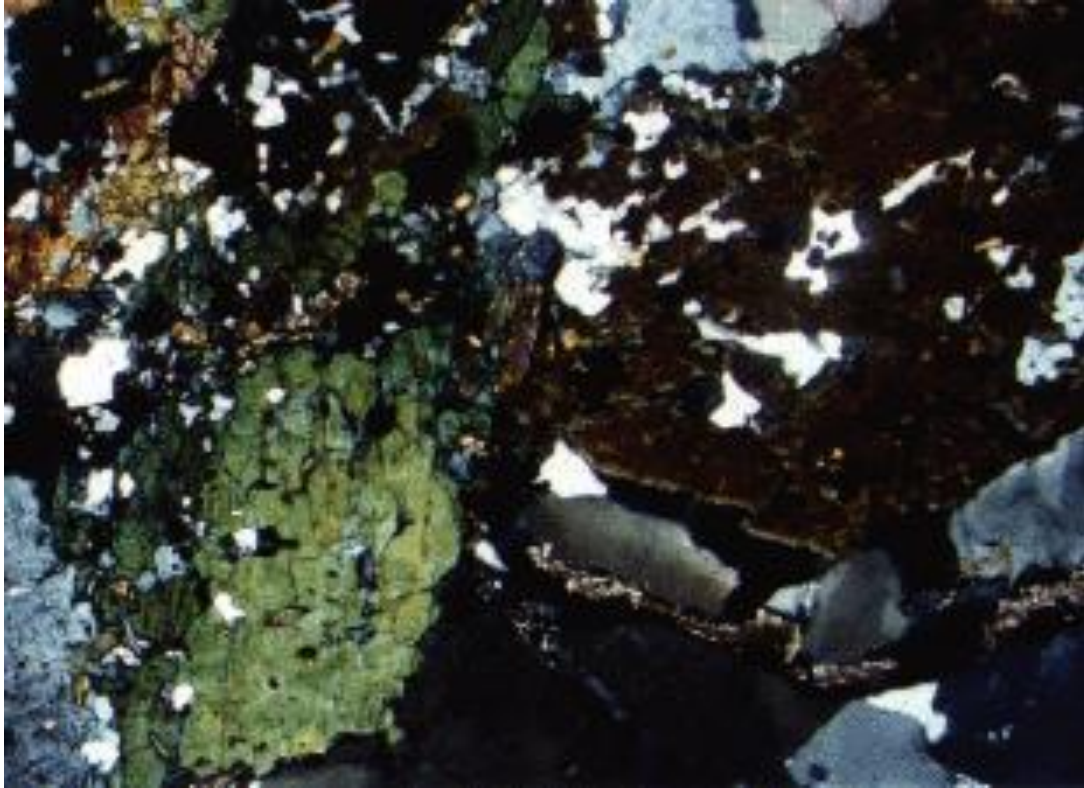


Fig. 6 from <http://www.csun.edu/~vcgeo005/Nr9Twenty.pdf>. Felsic diorite, showing slight cataclastic texture. Hornblende (brown and green) has a sieve texture of tiny islands of microcline (gray) and quartz (white, gray, and cream). Albite-twinned plagioclase (white and gray) is in upper left. Microcline is less than 1 vol. % of the rock. (Photo magnification is 52.5x)

Where total replacement of biotite and hornblende occurs, isolated quartz grains are formed that look as if they were primary in origin. Total replacements, however, destroy the evidence for replacement which can only be deduced from transitional deformed rocks in which quartz sieve textures first appear but are absent in the more-mafic, undeformed, primary igneous rock.

Conclusion

The early, primary, magmatic history of the various Donegal granites is well supported (Pitcher et al., 1987). When the initial magmas in each pluton were forcefully emplaced, a room problem did not exist, but subsequent modifications of these granitic bodies, after their solidification, impose a room problem if magmas are hypothesized to be injected to produce the modifications. This room problem can be resolved if deformation of the solidified rocks created openings in which hydrous fluids were introduced that caused the modifications. The strong banding

in the northwestern side of the Main Donegal granite mass testifies to the subsequent deformation of this body, and the strong foliation in the margins of the Ardara pluton and in various places in other plutons support the existence of this deformation. In thin sections this deformation is also demonstrated by the broken and bent primary crystals.

Where hydrous fluids were introduced, two replacement processes are suggested to occur simultaneously: (1) the replacement of biotite and hornblende by quartz and (2) the replacement of primary relatively-calcic plagioclase by K-feldspar, secondary sodic plagioclase, and myrmekite.

Several cycles of magmatism and metasomatism likely occurred during the evolution of these granite plutons, as are suggested by the four increasingly-more-granitic facies of the Rosses pluton from the rim to the core (Fig. 1) and the increasingly more felsic composition eastward in the Main Donegal granite mass. Although modal compositions of many of these granite bodies fall on the thermal valley of a Ab-Or-Q ternary diagram, these granites need not have formed entirely by earlier magmatic differentiation, because such compositions can also be arrived at by subsolidus replacement processes while inheriting much of the early structures of the magmatic plutons.

On that basis, it is obvious that the above metasomatic model does not rule out magmatic differentiation because magmatic differentiation occurs above melting temperatures, whereas replacement processes occur below melting temperatures and require deformation of solid rocks. Therefore, once a melt has been created at depth, magmatic differentiation could have aided in making subsequent intrusions more granitic in composition, as in the four concentric intrusions that occur in the Rosses pluton. Moreover, the metasomatic model does not rule out renewed melting following replacement of older mafic intrusions to make them more granitic in composition, if temperatures are raised sufficiently. But, on the other hand, the magmatic model does not rule out metasomatism as a contributor to making former mafic rocks more granitic, even on a plutonic scale.

Because deformation is necessary for metasomatism, it should be emphasized also that the K- and Si-metasomatism in the Donegal granites is not "solid-state replacement" as presented by the "old school" of geologists who promoted "granitization," but involves hydrous fluids moving along broken seals between grain boundaries and through crystals along microcracks.

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