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PROGRADE MUSCOVITE PSEUDOMORPHS AFTER STAUROLITE IN THE RANGELEY-OQUOSSOC AREAS, MAINE

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ABSTRACT

Pseudomorphous aggregates of muscovite after staurolite are characteristic of the lower sillimanite- to upper sillimanite-grade metapelites in parts of N.W. Maine. Traditional interpretations for these pseudomorphs would include retrograde metamorphism or K-metasomatism. However, mineralogic, petrographic, and field evidence clearly shows that the pseudomorphs have formed as a byproduct of a simple prograde metamorphic event.

The exact mechanism by which the pseudomorphs develop remains unclear but seems to involve the dissolution of staurolite and concommittent replacement by muscovite.

INTRODUCTION

The transition from the staurolite to upper sillimanite zone in the Rangeley-Oquossoc area, Maine, provides an interesting example of aggregates of muscovite growing as pseudomorphs after staurolite. The onset of this phenomenon coincides with the appearance of sillimanite and is completed upon the final disappearance of staurolite. Subsequently the aggregates of muscovite coalesce into large flakes which commonly lie at high angles to the enclosing foliation. These pseudomorphs have been mentioned previously (Guidotti, 1965).

Traditional interpretations of this texture would include later retrograde effects and K-metasomatism. It will be shown that neither of these interpretations is valid in this case, but that the pseudomorphes result from reorganization of the original minerals. To develop this argument it will be necessary to (1) demonstrate a prograde transition, (2) show that the rocks approach being in equilibrium, and (3) consider the possibility of K-metasomatism. Suggestions for the mechanism effecting the pseudomorphs will then be given.

A very similar pseudomorphous effect has been described by Pankiwskyj (1964) in the Dixfield quadrangle, Maine. Pankiwskyj ascribed these pseudomorphs to a prograde reaction, primarily on the basis of textural, modal, and field evidence. Hietanen (1961, p. 87) has also reported pseudomorphs after staurolite, consisting of aggregates of small crystals of kyanite, muscovite, staurolite, and garnet. A prograde origin was suggested for these pseudomorphs but it was also stated that addition of potassium occurred. However, in Hietanen (1963, p. C46) it was emphasized that any addition of potassium involved only short distance migration between portions of essentially the same rock. Other pseudomorphic textures involving staurolite and muscovite along with other minerals (especially aluminum-silicates) have been described by Billings (1937A, p. 551) and Chinner (1961). Both cases are interpreted in terms of retrograde effects, and the data given seems consistent with such interpretations.

Pseudomorphs of white micas after aluminum silicates have commonly been described. For example, Green (1963, p. 1004) described coarse muscovite rims forming around andalusite, and Neathery (1965) described paragonite pseudomorphs after kyanite. In both cases, such pseudomorphs are ascribed to retrograde effects or an influx of potassium.

Description of the Pseudomorphs

The area under consideration includes the mutual corner of the Old Speck Mtn., Rumford, Rangeley, and Oquossoc quadrangles in N. W. Maine. Figure 1 indicates the distribution of metamorphic grades. Three grades are shown and have been designated by Guidotti (1966) as the lower sillimanite zone, where staurolite and stillimanite coexist; the upper sillimanite zone, where staurolite is no longer stable; and the upper staurolite zone, just downgrade from the first appearance of sillimanite. The most important and common assemblage in each grade is:

(1) upper staurolite zone: qtz+plag+musc+bio+staur+Mg-chlor +garn+ilm±pyr±graph

(2) lower sillimanite zone: qtz+plag+musc+bio+staur+sill+garn +ilm±pyr±graph

(3) upper sillimanite zone: qtz+plag+musc+bio+sill+garn+ilm ±pyr±graph

In the upper staurolite zone, moderately poikilitic, 1 cm subhedral to euhedral staurolite occurs in a medium-grained, well-foliated matrix of muscovite, biotite, quartz, and plagioclase. Coinciding approximately with the first appearance of sillimanite, staurolite in many specimens becomes anhedral with coarse laths of muscovite occurring around the outer rim (Fig. 2A). At progressively higher grades in the lower sillimanite zone the muscovite rimming becomes more pronounced and the enclosed staurolite shrinks (Fig. 2B) until it disappears at the isograd marking the upper sillimanite zone (Fig. 3A). The degree of pseudomorphing is readily observable even in the field. In some cases the pseudomorphs exhibit shapes typical of staurolite twins and occasionally include several 2 mm garnets. Above the isograd marking the upper sillimanite zone the aggregates of muscovite in the pseudomorphs tend to recrystallize into single large plates, up to 2 cm across, and commonly lie at high angles to the enclosing foliation (Fig. 3B). In some cases these muscovite plates contain swarms of fibrolitic sillimanite.

In conjunction with the changes described above, textural changes

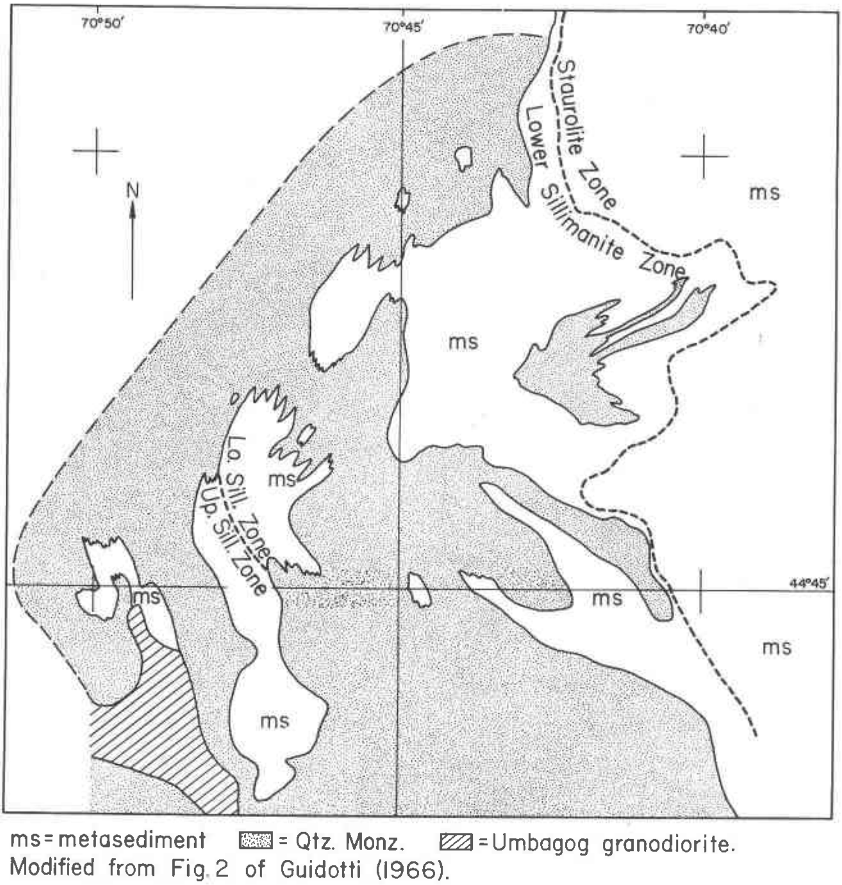

FIG. 1. Geologic map of portions of the Oquossoc, Old Speck Mtn., Rumbford and Rangeley Quadrangles, Maine. Modified from Figure 2 of Guidotti (1966).

occur with respect to the enclosing rock and its constituent minerals. These are best described in general as a progressive coarsening, enhanced schistosity, and darkening of color.

EVIDENCE INDICATING A PROGRADE TRANSITION

Considerable data on the petrography, textures, modes, and mineral compositions in the three grades has been given earlier (Guidotti, 1965, 1966, 1967). These data are consistent with a prograde transition from the staurolite to upper sillimanite zone and need not be repeated here. Additional data which corroberate the suggestion of a prograde transition are:

(1) Basal spacings of muscovite have been determined in many specimens ranging down to the garnet zone (garnet zone, ∼9.973 Å; upper staurolite zone, ∼9.936 Å; lower sillimanite zone, ∼9.955 Å; upper sillimanite zone ∼9.966 Å). By means of Figure 4 in Evans and Guidotti

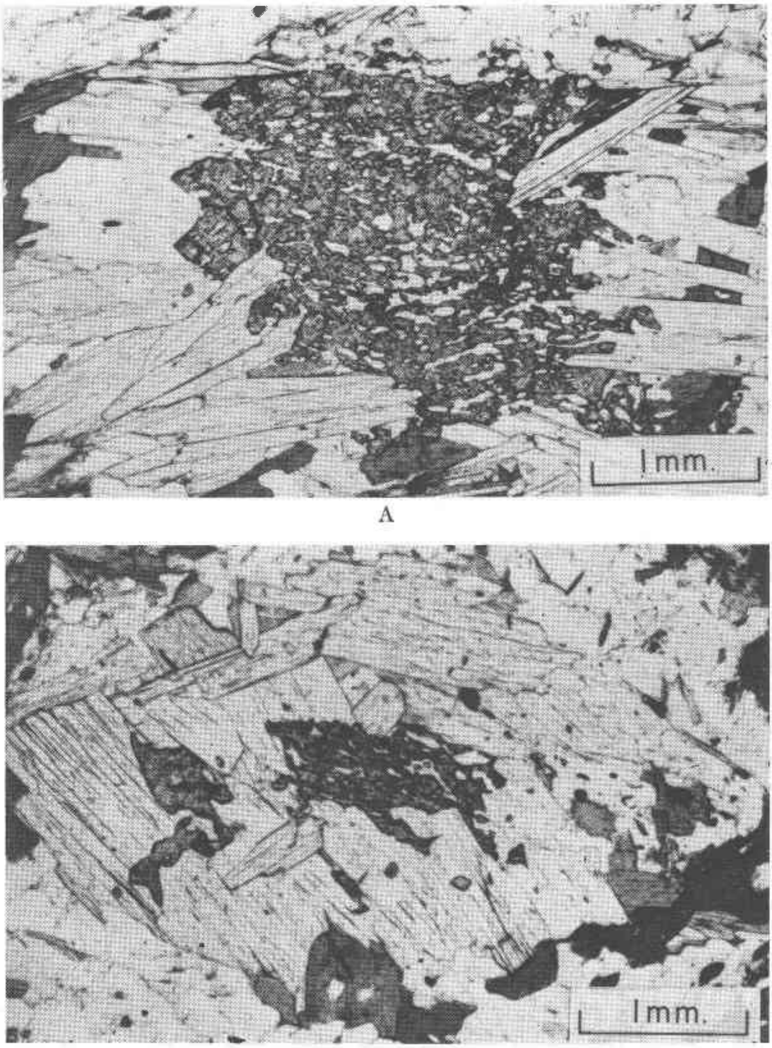

FIG. 2. Early stages of muscovite pseudomorphism: (A) Incipient muscovite plates forming around staurolite, (B) Coarse muscovite plates completely rimming remnant staurolite grains. Note sharp grain boundaries.

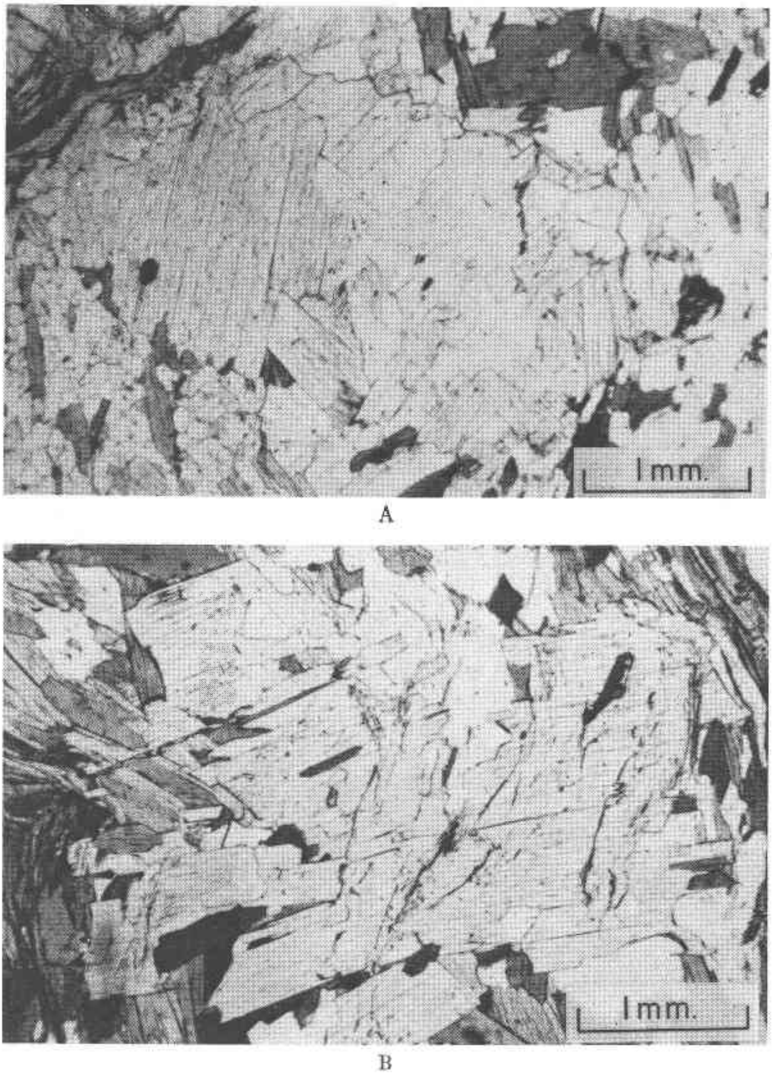

FIG. 3. Later stages of muscovite pseudomorphism. (A) Completed pseudomorph of muscovite flakes after staurolite. Fibrous material in upper left is sillimanite. (B) Muscovite re-crystallized into a single large flake. Fibrous trains through muscovite are sillimanite.

(1966) it is clear that the most sodic muscovite occurs in the upper staurolite zone with more K-rich muscovite at higher and lower grades. Inasmuch as such a distribution is consistent with the pseudobinary phase diagram for the muscovite-paragonite join as determined by

Eugster and Yoder (1955) it lends support to the suggested prograde transition.

(2) The prograde reactions defining the isograds shown on Figure 1 have been given by Guidotti (1967) as:

Upper Staurolite to Lower Sillimanite Zone

$$\text{staur} + \text{Mg-chlor} + \text{sodic-musc} \rightleftharpoons \text{sill} + \text{bio} + \text{K-richer musc} + \text{Ab} + \text{qtz} + H_2O \quad (1)$$

Lower Sillimanite to Upper Sillimanite Zone

$$\text{staur} + \text{musc} + \text{qtz} \rightleftharpoons \text{sill} + \text{bio} + \text{K-richer musc} + \text{Ab} + H_2O \pm \text{garn} \quad (2)$$

Such reactions imply prograde metamorphism. Consistent with this suggestion is the following compositional data on biotite (determined by atomic absorption):

[a] Upper staurolite zone

Fe (total)	(13.84 to 16.14), Ave. = 15.12 wt %	
Mg	(5.46 to 6.41), Ave. = 5.88 wt %	Av. of 9 specimens
Ti	(.82 to .99), Ave. = .90 wt %	

[a] Lower sillimanite zone

Fe (total)	(15.13 to 17.58), Ave. = 16.33 wt %	
Mg	(4.34 to 5.38), Ave. = 4.82 wt %	Av. of 43 specimens
Ti	(1.00 to 1.47), Ave. = 1.22 wt %	

[a] Upper sillimanite zone

Fe (total)	(15.21 to 17.78), Ave. = 16.32 wt %	
Mg	(4.03 to 5.39), Ave. = 4.77 wt %	Av. of 19 specimens
Ti	(1.21 to 1.65), Ave. = 1.49 wt %	

[a] All of these samples come from specimens with the common assemblages listed in the preceding section.

Inasmuch as the oxide assemblage remains constant through the three grades, the ferrous/ferric ration in the biotite remains almost constant. Hence the above changes in biotite composition are expected in prograde reactions such as equations 1 and 2.

In summary, the transition from the staurolite to upper sillimanite grade in the Rangeley-Oquossoc area seems to be a prograde transition.

Evidence Favoring a Close Approach to Equilibrium

Several lines of evidence suggest an approximation to chemical equilibrium in the transition from staurolite to upper sillimanite zone in the Rangeley-Oquossoc area:

(1) The composition of muscovite varies in a manner to be expected from the experimental work of Eugster and Yoder (1955) on the muscovite-paragonite join.

(2) The basal spacings of the groundmass muscovite are the same as those of the larger flakes which constitute the partial or completed pseudomorphs.

(3) Virtually all of the specimens studied appear to be perfectly fresh with *no* obvious signs of retrogressive metamorphism, such as chlorite partially replacing biotite, serictized plagioclase, etc.

(4) The grain boundaries between staurolite and the enclosing muscovite are perfectly sharp; moreover the staurolite remaining in a partial pseudomorph appears to be fresh.

(5) The modes, assemblages, and compositions of coexisting minerals seem to be consistent with data recorded in numerous other parts of the world.

(6) The composition of muscovite in different assemblages *within a given metamorphic grade* varies in a manner to be expected from the phase relations of muscovite as portrayed on an A-K-Na projection: *i.e.*, more sodic in assemblages which indicate a higher Al_2O_3 content in the rocks.

The presence of two size fractions of muscovite in specimens with pseudomorphs would seem to suggest at least some textural disequilibrium. However, as noted by Zen (1963, p. 939), "lack of textural equilibrium does not mean lack of chemical equilibrium." Hence, in view of the evidence given above, favoring equilibrium, there is little reason to suggest a retrograde origin for the pseudomorphs of muscovite after staurolite.

Evidence Bearing on the Questions of K-Metasomatism

No direct evidence supports an influx of K^+ as an explanation for the pseudomorphs. On the contrary, the available data argues against a metasomatic origin for the muscovite in the pseudomorphs:

(1) The sodic muscovite in the upper staurolite and lower sillimanite zone is not the expected product of K-metasomatism.

(2) Only staurolite, the mineral which is slowly reacting out of the rocks in the lower sillimanite zone shows any significant rimming by muscovite. Sillimanite, a mineral commonly replaced by muscovite in other areas (*e.g.*, Billings, 1937B) shows no alteration whatsoever.

(3) Rimming of staurolite by muscovite begins only when sillimanite "comes in." It would seem overly fortuitous if the limit of a metasomatic front supplying K^+ were to just coincide with the trace of an isogradic surface.

Suggested Explanation

An explanation for the growth of muscovite pseudomorphs after staurolite probably involves nucleation phenomena. Such phenomena are difficult to explain. Alternatively one might ask why the site of the pseudomorphs is one of lower free energy for muscovite than is the groundmass.

Pankiwskyj (1964) has suggested that the dissolution of the staurolite could produce a pressure void into which muscovite might readily recrystallize. It is evident, according to reactions (1) and (2), that muscovite is involved in the reactions and thus in an activated state. Under such conditions we might expect it to readily go into solution and then reprecipitate by replacing staurolite which is dissolving. The result will be a decrease in free energy inasmuch as fewer but larger muscovite grains result. Moreover, the reaction is progressing with a rise in T, thus favoring a more K-rich moscovite. If the new muscovite forming in the pseudomorphs is even slightly more K-rich than the groundmass muscovite this will tend to make the groundmass muscovite somewhat metastable and so enhance its liklihood of dissolution and then reprecipitation as more K-rich muscovite in the pseudomorphs.

The observation that the pseudomorphous aggregates continue to recrystallize into single large flakes (after staurolite is gone) and the groundmass muscovite disappears is readily explained by the greater stability of a few large muscovite flakes rather than many smaller flakes which would result in a much higher surface area and higher surface energy.

Discussion

It is clear that the picture developed above suggests a simple prograde origin for a textural feature which traditional interpretations, based largely upon textural evidence, would attribute to later retrograde metamorphic events or K-metasomatism. Although the present note concerns pseudomorphs after staurolite, it is possible that similar ideas may in some cases be germane to the muscovite rims commonly seen around andalusite.

A further point on textures concerns the 1/2–1″ megacrysts of muscovite which are common in the sillimanite and potassium feldspar+sillimanite gneisses in much of southern Maine and New Hampshire. These megacrysts, which commonly lie at high angles to the foliation, have been interpreted as forming late (*i.e.*, post high temperature), or as a retrograde product after some aluminum silicate. While this is probably true in some cases, the work of Evans and Guidotti (1966) demonstrated that, at least in the Bryant Pond region, Maine, the megacrysts of muscovite are part of the high temperature assemblage. In view of the picture presented above, it seems likely that the megacrysts may be re-crystallized pseudomorphs after staurolite (or an aluminum silicate).

In summary, it has been shown that the pseudomorphous effect described in this paper may be the result of a prograde reaction which proceeded at near equilibrium conditions.

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