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MYRMEKITE-BEARING GNEISS FROM THE SZEGHALOM DOME (PANNONIAN BASIN, SE HUNGARY). PART I.: MYRMEKITE FORMATION THEORIES

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ABSTRACT

Myrmekite is a common textural feature in many magmatic and metamorphic rock types. Nevertheless, there are several theories concerning its genesis; myrmekite may form by igneous crystallization, solid state exsolution, progressive or retrograde metamorphism, metasomatism or even as a result of complicated deformation mechanisms. In this paper a brief compilation of these models is given and classified by myrmekite forming processes instead of rock types or minerals involved.

Key words: myrmekite, orthogneiss, Pannonian Basin

INTRODUCTION

Similarly to most metamorphic complexes, the crystalline basement of the Pannonian Basin consists essentially of different varieties of gneiss and amphibolite. Most of these gneisses are of medium metamorphic grade and contain rather consistent mineralogy; quartz, two feldspars and mica with some additional phases. This reason makes obvious characterization of certain gneiss types difficult, and spatial correlation among neighbouring gneiss terrains almost impossible. In order to be able to recognize gneiss types of different kinds of protolith and/or metamorphic evolution, one has to concentrate on accessory minerals and particular textural information.

In this paper we focus on occurrences of myrmekite in different metamorphic rocks. Myrmekite has been reported from several places of different rock types all around the world. Presence of myrmekite was published from granites (Shelley 1964; Collins 1997a, 1998; Phillips and Carr, 1973) basic igneous rocks (Shelley, 1967; Dymek, Schiffries, 1987; Pavlov, Karskiy, 1949) and from different metamorphic rocks (gneisses, mica schists, mylonites) (Phillips, Ransom, 1970; Phillips and Carr, 1973; Shelley, 1967, 1973; Siddhanta, Akella, 1966; Phillips et al., 1972; Nold, 1984; Simpson, Wintsch, 1989; Hippertt, Valarelli, 1998). It can develop through diverse processes; subsolidus exsolution, metasomatism, deformation, silica infiltration or even due to progressive and retrograde metamorphism.

Several authors reported presence of myrmekite from the metamorphic basement of the Pannonian Basin (e.g. Szalay, 1977; Balázs et al., 1986) too. In order to be able to better understand the origin of these myrmekitic feldspars, in the first part of our two end-to-end papers we briefly compile the diverse explanations one can find in the literature concerning myrmekite definition and genesis.

DEFINITION OF MYRMEKITE

A generally accepted, proper definition for myrmekite is still missing; almost every author has his own definition depending on the type of occurrence and related minerals..

Phillips (1974) among others assigned myrmekite as an intergrowth of quartz and plagioclase. He said the presence of K-feldspar is implicit adjacent to the intergrowth, while its absence is explained as the result of cut of thin section. According to Shelley (1973), myrmekite is a poikiloblastic intergrowth of quartz and plagioclase, Simpson, Wintsch (1989) defined symplectitic intergrowth of oligoclase and quartz as myrmekite. Augusthitis (1973) doesn't put a premium on the presence of K-feldspar and says myrmekitic quartz may occur in micas and epidote too as they represent intracrystalline solutions (Augusthitis, 1973, 1990). Dymek, Schiffries (1987) define labradorite – bytownite intergrowth as myrmekite too, while Koller, Kloetzli (1995), in concert with Augusthitis (1973), determinate symplectitic intergrowth of quartz and biotite as myrmekite as well.

Shelley (1993) gives a common definition of myrmekite: "*...myrmekite is an intergrowth of branching rods of quartz set in a single crystal of plagioclase, neighbouring quartz rods have the same lattice orientation and extinguish together. It is almost ubiquitous in granites and granitic gneisses and most commonly occurs at grain boundaries of K-rich feldspar. Myrmekites appear to have grown inwards from grain boundaries, invading and replacing K-feldspar. The quartz rods branch in that direction and the plagioclase may be euhedral or bulbous representing a minimum surface area to volume configuration for the plagioclase.*" As Shelley wrote this is the most common occurrence of myrmekite and this is a widely accepted definition but it cannot be generalized. In the highest sense of the word myrmekite always is associated with feldspars and quartz, so intergrowths of other minerals are better to call symplectites. Several models have been matured on myrmekite genesis over more than a hundred years, but a generally accepted model have not yet been published since the first description of Michel-Lévy (1875). According to its wide spread in different rock types beyond granites, Shelley (1964), Phillips (1972), Phillips, Ransom, Vernon (1972) agree that myrmekite may be polygenetic.

GENESIS OF MYRMEKITE

Here we give a short description of the most common models on myrmekite formation. Although, most approaches take into account effects of several processes, we classify the models in order to facilitate reader to look over them. In addition to the three classical ideas on myrmekite genesis (igneous crystallization; solid state exsolution; metasomatic replacement) also more up-to-date models, which appeared in the last decades are presented.

1. Igneous crystallization models

The theory of myrmekite genesis by igneous crystallization suggests that myrmekite forms as a result of a late stage simultaneous crystallization of plagioclase and quartz from a melt or solution. The textures, however, are more indicative of simultaneous crystallization are graphic or granophyric, which have no necessary relationship with myrmekitic textures. According to Shul'Diner (1972) myrmekitic plagioclase grain nucleates on the surface of another plagioclase grain and advances toward the adjacent K-feldspar. Myrmekitic plagioclase grows in optical continuity with the original plagioclase grain. But the available literature does not mention any suture in contact of the old grain, which is common on overgrowth structures (Hippertt, Valarelli, 1998). Hibbard (1987) regards myrmekite in orthogneiss as recrystallization at a late stage of deformation of an incompletely crystallized magma in the presence of water saturated melt.

2. Solid state exsolulion models

In Schwantke's (1909) solid-state exsolution model, the presence of a "high silica" $CaAl_2Si_6O_{16}$ molecule in high temperature K-feldspar is assumed. Through unmixing *An* produces releasing four molecules of silica. The existence of this "Schwantke molecule" has, however, not been proven yet.

3. Progressive metamorphic reaction models

"Progressive myrmekite" develops at the transition between greenschist and amphibolite facies in pelitic schist in quartz rich segregation layers, when albite changes to Ca-oligoclase (Shelley, 1973) in the following reaction (Ashworth, 1986):

$$(1+x)NaAlSi_3O_8 + xCa^{2+} = Na_{1-x}\,Ca_xAl_{1+x}Si_{3-x}O8 + 4xSiO_2 + 2xNa^+$$

He suggests that it will be preserved only if it formed at the thermal climax of metamorphism.

For biotite oligoclase gneisses of the Adirondack Massif, Collins (1997b) showed that the rock gained K and Si and lost Ca, Fe, Mg and Al during progressive thermal metamorphism. Following Engel, Engel (1958) in such a rock plagioclase is progressively replaced by microcline. Carl (1988) suggests that K was originated from breakdown of nearby biotite and muscovite. They all suppose myrmekite formation in connection with formation of microcline.

4. Retrograde metamorphic reaction models

Siddhanta, Akella (1966) examined three types of myrmekite in Pre-Cambrian sphene and epidote bearing hornblende plagioclase gneisses. Type I. is a myrmekite in association with microcline or orthoclase without any contact with non-myrmekitized plagioclase; type II. is a myrmekite in association with plagioclase; and type III. is a myrmekite, which forms between plagioclase and K-feldspar grains. During the retrograde evolution, K-metasomatism took place as it is inferred by presence of postkinematic biotite with no pre-existing potassium phase in the rock. They found a tight correlation between the amounts of sphene + epidote and myrmekite, respectively. It was explained by a series of consecutive reactions between hornblende, K-feldspar, anorthite, sphene and ilmenite, which may result in myrmekite formation of different occurrences. The main myrmekite producing reactions are the followings:

$$3\ Ca_2(Mg,Fe)\ 4\ Al(Si_7AlO_{22})(OH)_2 + 4\ KAlSi_3O_8 + H_2O =$$

(common hornblende) *(potassium feldspar)*

$$= 4\ K(Mg,Fe)_3(Si_3AlO_{10})(OH)_2 + 3\ CaAl_2Si_2O_8 + 3\ CaO + 15\ SiO_2$$

(biotite) *(anorthite)* + *(quartz)*

$$3Ca_2(Mg,Fe)\ 4Al(Si_7AlO_{22})(OH)_2 + 4KAlSi_3O_8 + 3TiO_2 + H_2O =$$

(common hornblende) *(potassiun feldspar)* *(rutile)*

$$= 4\ K(Mg,Fe)_3(Si_3AlO_{10})(OH)_2 + 3\ CaAl_2Si_2O_8 + 3\ CaTiSiO_5 + 12\ SiO_2$$

(biotite) *(anorthite)* *(sphene)* *(quartz)*

A model for myrmekite formation during a retrogressive metamorphic evolution was given by Phillips (1972) as well. He proposed the following reaction:

$$3KAlSi_3O_8 + H_2O = KAl_2(AlSi_3)O_{10}(OH)_2 + 6SiO_2 + K_2O$$

(potassium feldspar) (muscovite)

Phillips, Ransom, Vernon (1972) point out that retrogressive metamorphism appears to be connected with myrmekite formation and in these cases muscovite is an important accompanying mineral. The reaction may take place as follows:

$$3\ KAlSi_3O_8\ .\ NaAlSi_3O_8 + CaAl_2Si_2O_8\ .\ NaAlSi_3O_8 =$$

(alkali feldspar) *(calcic plagioclase)*

$$= CaAl_2Si_2O_8\ .\ 2\ NaAlSi_3O_8 + 6\ SiO_2 + KAl_2AlSi_3O_{10}(OH)_2 + K_2O$$

(more sodic plagioclase) *(quartz)* *(muscovite)*

$$3\ KAlSi_3O_8 + H_2O = KAl_2AlSi_3O_{10}(OH)_2 + 6\ SiO_2 + K_2O$$

(orthoclase) *(muscovite)* *(quartz)*

5. Metasomatic replacement models

The idea of myrmekite as a result of metasomatic replacement was first published by Becke (1908) whereof myrmekite replaces K-feldspar by the following reaction with Na and Ca bearing fluids:

$$1.25\ KAlSi_3O_8 + 0.75\ Na^+ + 0.25\ Ca^{2+} = Na_{0.75}Ca_{0.25}Al_{1.25}Si_{2.75}O_8 + 1.25\ K^+ + SiO_2$$

(137 cc/mol) *(100 cc/mol)* (23 cc/mol)

Drescher-Kaden (1948) suggests that myrmekite forms during a reaction in which K-feldspar metasomatically replaces plagioclase. He showed that at some cases myrmekite is older than K-feldspar. The origin of excess silica, which is needed for this replacement reaction, was explained by Bhattacharyya (1972) and Phillips (1972). In their opinion silica can be introduced from solutions or by dry ionic diffusion, and they stated there is no direct relationship between the amount of myrmekitic quartz and the basicity of plagioclase. Pavlov, Karskiy (1949) made investigations on the origin of myrmekite in basic rocks where K-feldspar was absent. They recommend a reaction between quartz and plagioclase as follows:

$$3(CaAl_2Si_2O_8 . NaAlSi_3O_8) + CaO = 4\,CaAl_2Si_2O_8 . 1\,NaAlSi_3O_8 + 3SiO_2 + Na_2SiO_3$$

(plagioclase) *(more basic plagioclase)* *(quartz)*

Dymek, Schiffries (1987) examined myrmekite in andesine anorthosites. They stated that non-myrmekitized plagioclase is $An_{40\pm3}$, while myrmekitic grains are An_{80} in composition. In their model sodic plagioclase was replaced by calcic plagioclase accompanied by precipitation of quartz. They calculated the amount of quartz that would have precipitated during the alteration of An_{40} to An_{80} and the result accords well with the observed amount of quartz in thin section. In their opinion these calcic myrmekites are products of interaction between plagioclase crystals and a magmatically derived aqueous fluid.

In conception of Collins (1997b) myrmekite in deformed granodiorites may form during progressive replacement of fresh normal zoned plagioclase by inversely zoned plagioclase. During the replacement process, deformed plagioclase crystals have ample openings for fluids and elements to move inside or outside. Primarily Ca and Al subtract and Na is left over, while K infiltrates and begins to grow inside the plagioclase grain. While K replaces Ca and Al, the volume of the plagioclase grain increases inducing pressure at the adjacent grains. Displaced Na atoms infiltrate to less altered plagioclase grains to cause them recrystallize as a more sodic plagioclase. According to the zoning of the original plagioclase in the diorite the core is $An_{37\text{-}39}$ while the rim is $An_{17\text{-}20}$ in composition. The recrystallized plagioclase is an $An_{12\text{-}15}$ oligoclase with albite twinning. Myrmekite forms at places where Ca, Al, Na and Si remain in a wrong proportion to recrystallize only as plagioclase. Replacement of Na and Ca with K however is never perfect, relic islands may remain that later separate to form albitic perthite lamellae. The shape and thickness of quartz vermicules depend on the composition of the original plagioclase.

Another hypothesis by Collins (1997a) is based on processes he observed in clinopyroxene granites. Here Na^+ and Ca^{2+} bearing fluids as follows metasomatize perthitic K-feldspar:

$$KAlSi_3O_8 + Na^+ = NaAlSi_3O_8 + K^+$$

$$2\,KAlSi_3O_8 + Ca^{2+} = CaAl_2Si_2O_8 + 4\,SiO_2 + 2K^+$$

(myrmekite)

Collins (1997a) observed that the K-feldspar part of perthite is replaced by An_{20} plagioclase, while relic plagioclase lamellae remain untouched and no myrmekite forms. If alteration took place by mass-to-mass mode, quartz vermicules would appear in the plagioclase so the alteration must happen by volume-to-volume way. Because of the larger density of the secondary plagioclase, silica is consumed in the process and no excess quartz appears.

Following Koller (1995 in Collins 1997c) myrmekite formed by exsolution shows perthitic appearance with Ba-zoning, while myrmekite formed by K-metasomatism appears at the edges of perthitic microcline lacking Ba-zonation. Ghost myrmekite is the characteristic of the later too, which may appear strongly depending on thin section orientation Passchier, Trouw (1996).

6. Deformation models

The significant modification of the stability field of minerals under high strain conditions was first suggested by Harker (1932); Wintsch, Knipe (1983) showed that deformation also might result in replacement reactions. In the last decades the relationship between deformation and myrmekite formation at grain boundaries came into prominence. (e.g. Hanmer 1982, Tullis 1983, Simpson 1983, Hibbard 1987, Simpson, Wintsch, 1989).

Shelley (1964, 1993) interprets myrmekite as a special kind of poikiloblastic texture without any proportional relationship between the amount of quartz in myrmekite and basicity of plagioclase. In his model albite in solid-state exsolves from high-T feldspar, which also encloses quartz inclusions. Following a cataclastic event these quartz grains recrystallize and form vermicules in myrmekite. However in many granites with well developed myrmekite there is no evidence for presence of strained quartz. Further this hypothesis does not explain myrmekite around plagioclase inclusions in alkali feldspar megacrysts (Hippertt, Valarelli, 1998).

Hanmer (1982) studied deformed granites from Newfoundland and showed that myrmekite must be of post-deformational origin, since the soft vermicular texture would have been destroyed during deformation. Simpson (1985) has observed progressive intergrowth of myrmekite in millimetre scale shear zones in mylonitic granodiorites from East-California that provides evidence for syn-deformation myrmekite emplacement.

Simpson, Wintsch (1989) made examinations on deformation-induced myrmekites in amphibolite facies mylonites derived from granitoid protolith. The samples were muscovite poor S-C mylonites and foliated mylonitic gneisses. In that instance Simpson and Wintsch (1989) defined symplectitic intergrowth of oligoclase and quartz as myrmekite that developed on both edges facing the incremental shortening direction of strained K-feldspar grains. Myrmekite does not occur on the edges of the incremental stretching direction. Replacement of K-feldspar by plagioclase and quartz results in decreasing volume that favours high strain surrounding the grain. Although P, T and the chemical conditions govern the replacement reaction, because of additive shear it concentrates along the edges facing incremental shortening direction of the K-feldspar. The role of stress and shear energy in replacement reactions has not yet been clarified.

In the Collins (1997a) model existence of original high-T ternary feldspar is assumed; a K-feldspar (orthoclase) containing dissolved Ca and Na. On lower T under stress conditions orthoclase alters into microcline, Na and Ca in turn dissolute from the K-feldspar to form myrmekite at the edges of the grain. Plagioclase with more anorthite component requires less amount of silica than K-feldspar or Na-feldspar thus the amount of myrmekite is determined by the composition (An component) of the plagioclase:

$KAlSi_3O_8$		$KAlSi_3O_8 + NaAlSi_3O_8 + SiO_2$
$NAlSi_3O_8$	=	$CaAl_2Si_2O_8$
$Ca(AlSi_3O_8)_2$		
H-T K-feldspar		K-feldspar, myrmekite

Several myrmekite generating models among the numerous deformation-induced approaches assume silica infiltration following deformation, first of which was suggested by Michel-Lévy (1875).

Hippertt, Valarelli (1998) examined K-feldspar porphyroblast-bearing high grade (720-750 °C, 3-6 kbar) mylonitic augen gneisses. They observed two types of myrmekite occurences: 1. a lobe shaped myrmekite on the edge of K-feldspar megacryst, 2. bulbous myrmekite inclusion in K-feldspar megacryst. They found that K-feldspar replaces myrmekite in both cases. Silica needed to form myrmekite can be served by pressure solution of the matrix quartz. This process also is necessary to compensate the volume growth of the growing K-feldspar. The fact that myrmekite is not present in rocks lacking quartz suggests that silica necessary for myrmekite formation must originate from internal sources. The brittle deformation structure of the plagioclase grains may be the result of local stress, which is caused by the volume increase during plagioclase replacement by K-feldspar. Microcracks serve suitable pathways for silica infiltration. K-feldspar apophyses grow into the quartz vermicules indicate that K follows Si in infiltration. Myrmekitic plagioclase usually is richer in Ca than the recrystallized grains, but its *Ab/An* ratio is identical to the non-recrystallized plagioclase relics in the matrix. This observation suggests that myrmekitic plagioclase is the original phase that hosted subsequently developing quartz vermicules. Si infiltration is evidenced by occurrence of undeformed quartz vermicules or rods in deformed plagioclase grains. The source of Si and the factors of transportation are still not known.

CONCLUSIONS

Far the most frequent rock types in the metamorphic basement of the Pannonian Basin are different kinds of gneiss. As they are of close to identical chemical composition and metamorphic evolution, their mineralogy and textural features are rather similar as well. The aim of this paper was to introduce how informative myrmekitic feldspar grains of different origin may be in discriminating and correlating gneiss localities in a terrane of complex metamorphic evolution.

Abundant literature on myrmekite genesis shows that myrmekite can form due to diverse igneous, metamorphic and other processes. Despite, however, intensive investigations, important questions concerning the origin of this texture are still under debate. There regularly appear new rock types with myrmekitic grains, which do not fit to any of the models listed above. A cautious study of microscopic features and mineral chemical data is needed to be able to interpret myrmekitic texture correctly and so to utilize myrmekite for characterization of certain gneiss types.

We aimed to collect mineral systems, reactions as well as possible processes, which may develop myrmekite, just as to offer a brief survey of dozens of theories about myrmekite formation. There are several ways how to organize these ideas to serve a well-arranged system. In this paper an arbitrary classification scheme is presented, in which models are listed by myrmekite forming processes instead of rock types or minerals involved.

In the second part of our papers we attempt to interpret origin of myrmekitic feldspar grains found in a small area of the metamorphic basement of the Pannonian Basin (Szeghalom dome, Fig. 2. in M Tóth, Zachar, 2002). Here myrmekite occurs in intensely deformed polymetamorphic gneiss samples. Granite-related fluids also metasomatically altered the terrane.

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