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AN ESSAY ON THE GRANITE GENESIS

For those who, as me, work in the Variscan orogenic belt, granite is the most common igneous rock, and the impression on the significance of granitic plutonism – strong. Indeed, granites are one of the most important components of the continental crust (Rogers 1984), and are the most common continental igneous rock. However, granitic magmas can occur also in the oceanic environment, and recent studies indicate e. g. rhyolites to occur in the convergent intra-oceanic margins in much greater amounts than it was assumed to be (Tamura and Tatsumi 2002).

At the beginning of this essay, I want to mention that 50 years ago the main discussion related to granites was that between transformists and magmatists and that it focused on the problem if the granites are magmatic or non-magmatic rocks! This shows at what stage was the petrology quite a short time ago, and how much has the generation of our professors done. If we turn to recent times, we realize that the present view on the granite genesis is based on the assumption that granitic magmas are in most cases generated by partial melting of various crustal protoliths. The melts are generated under fluid-absent conditions, and the decomposition of hydrous phases occurring in the protolith produces water present in granitic magmas, the view widely accepted after the classical paper of Thompson (1982). Under comparable pressure and temperature the amount of melt depends on protolith composition (especially the content of hydrous phases) which defines its "fertility" (i. e. the potential to produce the melt; Clemens and Vielzeuf 1987). The melts produced this way are, aside from the first drops, water undersaturated. This, together with high temperature, enables granitic melts to intrude to crustal levels located much higher than the places of their origin (e. g. Holtz and Johannes 1994). The composition of melts generated through partial melting of various protoliths is granitic, granodioritic or tonalitic (there exist many studies on this problem, including the pioneering study of Holloway and Burnham, 1972, and those of e. g. Beard and Lofgren 1991, Conrad et al. 1988, Montel and Vielzuf 1997, Rapp and Watson 1995 and Vielzeuf and Holloway 1988 among many others). This means that silica and alkalis are concentrated in the melt independently of the chemical and mineralogical character of the protolith. Moreover, little Fe and Mg is dissolved in granitic melts in temperatures typical of low- to medium melting degree (e. g. Naney 1983, Puziewicz and Johannes 1988). This leads to granites containing mainly quartz and feldspars, with small amounts of biotite and/or hornblende, which are so numerous in the Sudetic area, e.g. the granites of the Strzegom-

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Sobótka massif (Majerowicz 1972) or those of the Karkonosze massif (Borkowska 1966). The peraluminous granites rich in ferromagnesian phases, especially cordierite, do not fit this model. This kind of granites is common in some orogenic belts, the classical example being the Lachlan Fold Belt in Australia (Chappell et al. 1987). The ferromagnesian phases - rich granites originate supposedly from parental magmas rich in restite. The degree of restite unmixing during melting can thus be various, and basing on this criterion the granitic magmas can be divided into two groups: (1) those representing lower degree of protolith melting and good separation of the melt from restite and (2) those representing higher degree of melting and incomplete or poor restite separation. They correspond to the two mechanical regimes of melting: that of the continuous solid rock framework containing the melt and that of the melt containing the grains of restite, which is the framework disintegrated at the higher degree of melting (Vigneresse et al. 1996).

The recognition of partial melting as a basic granite-forming process was the foundation of the I/S granite classification of Chappell and White (1972). The A-type (Collins et al. 1982), M-type (Pitcher 1979) and C- type (Kilpatrick and Ellis 1992) were added later to the classification to cover the whole spectrum of granitic rocks. The original I/S classification divides, as a matter of fact, the granites of orogenic zones into groups derived from pelitic sedimentary or mantle-derived igneous protoliths. The “S” and “I” type definitions were never precisely formulated (see e. g. Miller 1985), which sometimes led to misunderstanding. The classification of Chappell and White (1972) suggests that granites can give hints on their protoliths, occurring at depths inaccessible for geological observations. The local example of granites showing “what is beneath” are the plutons of the Variscan Strzegom – Sobótka massif in the Fore-Sudetic Block. The term “massif” is traditionally used in Central Europe for continuous granitic outcrops, essentially with no genetic connotations. The Strzegom – Sobótka massif was considered to be a single pluton with various facies (Cloos 1922, Majerowicz 1972). Later detailed studies showed it to originate from three similar, but independent metaluminous magma batches of 280 Ma age plus one older (330 Ma?) peraluminous intrusive (Pin et al. 1989). The combined petrographic and geochemical data indicate that the massif developed on two different crustal blocks (Puziewicz 1990).

Granitic melts generated in the crust can interact with the mantle-derived basaltic magmas. The role of mantle-derived basaltic magmas in triggering crustal magmatism is widely accepted (Hildreth 1981) and the exposed sections of lower crust, such as the Ivrea-Verbano Zone, show convincingly that the lower crust is injected with mafic/ultramafic material coming from the mantle (for recent review see Harlov and Förster 2002). The mixing of mafic and felsic magmas leading to homogenous granitic magma is possible if their viscosities are similar, which typically requires their thermal equilibration (Sparks and Marshall 1986, Frost and Mahood 1987). The geochemical characteristics of granitic magmas affected by mixing and those produced by partial melting of mafic rocks characterized by low strontium isotopes initial ratios or their weathering products is similar. To define which process is responsible for the magma evolution, we must look for more information in the rock which crystallized from that magma. Possibly this can be solved by detailed studies of mineral populations present in the granite (are some of the grains restitic or coming from mafic magma?) and plagioclase zonation styles. However, this group of problems is still one of the open questions of igneous petrology.

The structure of granites is usually the magmatic one. The analysis of relationships between the nucleation densities and growth rates of main rock forming minerals enables to describe the structure development. An instructive example is the development of porphyritic structure in some granodiorites. At comparable undercoolings, the K-feldspar nuclei are not numerous relative to those of quartz and plagioclase, but grow significantly faster. This leads to large, but not numerous crystals of K-feldspar embedded in the finer-grained matrix of quartz and plagioclase (Swanson 1977). More sophisticated methods of crystal size distribution analysis (for review see Marsh 1988) are the potential tool to get better insight into the kinetics of crystallization of granitic magmas. The recent experimental data on the interfacial energies in non-granitic systems (Ikeda i in. 2002) explain the crystal clustering at the late stages of crystallization of granitic rocks as well.

An important factor in preserving the igneous structures in granites is the quantitative mode of their crystallization. The isopleths in the diagram or-ab-an (Tuttle and Bowen 1958) are steep outside the “thermal valley”. This means that if the magma composition is close to that defined by the thermal valley (as is typically the case), small amount of crystals will crystallize over large temperature interval, and the prevailing part of the magma will crystallize over few degrees Celsius interval when melt composition enters the region of thermal valley. The massive crystallization of most of grains over small temperature interval enables freezing of flow structures formed at high melt percentages.

Many of students of granitic rocks are surprised by the fact that the granites are not so magmatic as they appear to be, and that much of the primary igneous record is obliterated at the post magmatic stage. This refers to the magmatic composition of the minerals which can easily exchange cations in their lattice at the post magmatic stage. The process is triggered by water, which is usually present in amounts enabling at least local cation exchange after the magma solidification. The post-magmatic readjustment of composition affects mostly alkali feldspar, which eventually exsolve, and biotite. The latter easily exchanges Fe and Mg in octahedral layer and the ratio of these two elements supposedly is fixed at the post-magmatic stage (Puziewicz 1995). However, the Ti substitution in biotite is complex and due to this, titanium content may be representative of magmatic stage (Puziewicz 1995). Plagioclase typically preserves the complex zonal structure which reflects the changes of conditions during its crystallization and thus belongs to those minerals which exhibit the record of magmatic conditions. Granitic hornblende is generally assumed to preserve the magmatic composition (the Al-in-the-hornblende geobarometer is based on that assumption!), but to my knowledge there exists no detailed assessment of the effect of post-magmatic changes in igneous hornblendes, especially if the cooling host is water-rich. The magmatic or non-magmatic provenance of muscovite in two-mica granites is also a problem. Since the classical study of Miller et al. (1981) the basic criterion for defining the “magmatic” muscovite is its titanium content (should be above 0.2 atoms pfu) as well as the magmatic appearance of the plates of the mineral. It is very important that each of these features alone *does not* indicate the magmatic origin of muscovite. My years-long friendship with granitic muscovite shows that it may cunningly pretend to be a magmatic phase and yet be a post-magmatic one. An illustrative example is very magmatic-looking muscovite (nice, large plates) being in reality the pseudomorphs after the magmatic andalusite, occurring in the Gęsiniec granite in the Strzelin Hills (NE part of the Fore-Sudetic Block; Puziewicz and Pietranik, submitted). Another example is clearly secondary muscovite containing 1.0 –2.4 wt % of TiO_2, coexisting with secondary chlorite and ilmenite in the Kamienna Góra granite in the northern part of the Žulová pluton (SE part of the Fore-Sudetic Block; Puziewicz 1999).

Since the main rocks forming granite minerals – quartz, alkali feldspar and plagioclase – are anhydrous, at final stages of its crystallization the granitic magma is usually enriched in water, and the separation of vapour phase (called sometimes "resurgent boiling") may take place (the basic reviews of the problem are those of Burnham, 1967 and 1979). This leads to crystallization of pegmatites and much neglected, but common aplites (Puziewicz 1985). The appearance of vapour phase commences transition from the purely magmatic processes to the post-magmatic granite self-metamorphism and alteration. I think that in that late-magmatic stage I can finish this essay, which intention was to review the magmatic processes of granitic magma origin and evolution.

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