Deep fluid flow – melt interaction and problems of granite-pegmatite system petrogenesis

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ABSTRACT

The petrogenetic model of granite-pegmatite systems, taking into account processes of deep fluid flow – melt interaction and formation of chemically heterogeneous melts, is suggested.

Keywords: *fluid-melt interaction, chemically heterogeneous melts, granite-pegmatite systems, Petrogenesis.*

INTRODUCTION

At present the magmatic nature of most granitic pegmatites is not contested. The models of equilibrium or disequilibrium fractional crystallization of pegmatites are mostly recognized. But the modes to transform granitic magma into pegmatite melts are not clear enough, specifically due to the ambiguity of relationships between pegmatites and granites. The problem of source granites is getting more complex in the cases with pegmatite fields being larger and their age older. In some regions, e.g. Kola Peninsula and East Siberia, the time gap between granites and rare-metal pegmatites in the Precambrian is so great, that the latter are classified as independent magmatic complexes (Makagon & Zagorsky, 2005).

Formation of pegmatite melts is commonly linked with the processes of crystallization and emanative differentiation of granitic magma. In case of large and unique pegmatite rare-metal deposits, the most complicated issue in terms of this concept is to identify the mode of strong concentrating and transport of huge amounts of rare elements into local chambers, even if there are enormous allegedly pegmatite-bearing granitic massifs as Pamir-Shugnansky at the Pamirs or massifs of the Lagman complex in Afghanistan. Being tabular, such massifs have limited possibilities to transport any components on the lateral when crystallized; and emanative differentiation must enrich the apical parts of massifs with rare elements more or less equally through their entire extent. Besides, calculations made with the coefficients of rare elements distribution indicate that the fluid/melt volume ratio should be many times in favour of the fluid, so that the fluid could transfer large quantities of rare alkalies and accumulate them in the melt to reach the contents peculiar to ongonites (Kovalenko & Kovalenko, 1982). Such ratio is unrealistic for a closed system. In the case of rare-metal pegmatites, with their much higher contents of Li, Rb and Cs, this inconsistency is even greater.

In many pegmatite fields the neighbouring vein bodies within at once intruded swarms, and even different parts of extensive veins often differ in composition so drastically, particularly in regard to K, Na Li, Rb, Cs, Ta, Nb, Sn, B and F, that they should be attributed to different types of pegmatites (Zagorsky, 2001). Due to small thickness and considerable extent of veins, and reliable evidence on crystallization proceeding from the contacts inward, the transfer of components over the strike of veins is not feasible when they crystallized. The distribution pattern of pegmatites of different types within vein swarms as well as strong differences in chemical composition of different parts of veins indicate that, when intruding, the pegmatite melts were chemically heterogeneous, especially after alkali contents. Possible modes of magma to become chemically heterogeneous are different and controversial. The most probable of them appear to be (a) deep fluid - melt interaction in magma chambers; (b) liquid immiscibility; (c) formation of clusters and their segregation in above-liquidus conditions.

DEEP FLUID FLOW – MELT INTERACTION

The global degassing of Earth contributed to formation of its external shells, the granite-gneiss layer included. The deep fluids with predominance of H, C and other reduced components, oxidized while ascending, and gradually enriched in H_2O, CO_2 and incoherent elements. The experimental data support the possibility for H_2O-CO_2-fluid, enriched in Si, Li, Be and other rare elements to be formed in the upper mantle (Zharikov, 1987). Fluids could also come from the crust blocks, which were sunk into the upper mantle and dehydrated. Being unique heat-carriers, the deep fluid induced melting processes and affected the evolution of melts, changing their composition in regard to silica, alkalis, incoherent rare elements and volatiles. After Korzhinsky (1972) such fluids are referred to as *transmagmatic*, and the processes of their interaction with melts as *metamagmatic* processes. In development of Korzhinsky's ideas about the involvement of transmagmatic fluids into the granitic magma evolution, the metamagmatic model of pegmatite formation is proposed (Zagorsky, 2001). According to this model pegmatite melts are interpreted as more evolved, more "mature", rather than residual, as compared to granitic magma, hypereutectic metamagmatic products, which appear in zones of the most intense drainage of fluids within magma chambers. The experimental results show that the fluid-melt exchange reactions are similar to the mineral–fluid ones (Perchuk, 1982; Korzhinsky et al., 1983), but the energy barrier of first of them is lower. The mass-exchange reactions are especially intense in the case of origination and floating of drops of fluid phase (Sharapov & Cherepanov, 1986). Intense acid fluid filtration can lead to formation of chemically zonal melt column similar to zonal columns of metasomatic rocks. In this process, evolution of the acidity-alkalinity of filtering fluids is the major factor responsible for the differentiation of alkalies, especially K, Na and Li.

Depending on the regime of fluid bubbling of melt, both gradual or sharp boundaries regarding the components involved in the exchange reactions are formed in melt (Sharapov & Cherepanov, 1986). The laminar inflow of the chemically heterogeneous melt into the vein-hosting cavities created conditions for formation of the banded structures which are typical of many fields of spodumene pegmatites. Along with the change of magma composition, the deep fluids increase the energetic potential of magmatic chambers. When its critical value is reached, the magmatic system is discharged with formation of new external chambers. The greater the depth of formation of pegmatite magma chambers and higher their critical energetic potential, the larger is the probability of a spatial "break-off" of the most evolved portions of pegmatite melts from the granitic proto-magma. This explains how pegmatite fields without source granites can be localized.

LIQUID IMMISCIBILITY

As it is known, acid fluids stimulate liquid immiscibility in melts. In felsic magmas it is generally manifested in regard to silica and alkali metals. K–Na immiscibility, if the silica content in liquid products is stable, reveals itself more rarely (e.g., in dacites, rhyodacites, rhyolites, ignimbrites and obsidian-perlites). Processes of liquid immiscibility are recognized by some researchers to be the major mode of acid magma differentiation leading to the formation of schlieren pegmatites, and they are considered to be responsible for the layering of Li–F granites as well (Marakushev et al., 1994; Letnikov, 1992). Very likely these processes might also occur in the deep chambers of pegmatite magma.

FORMATION AND SEGREGATION OF CLUSTERS IN ABOVE-LIGUIDUS CONDITIONS

The degree of the chemical inhomogeneity of pegmatitic melts achieved in the chambers can even increase more in time of their intrusion. Silicate melts occurring above the liquidus represent the liquids characterized by constant origination and destruction of molecular groups with chemical bonds typical for crystalline compounds. Prior to the crystallization, they make up clusters (proto-matrices of the future crystalline phases with vague boundaries) consisting of a quasi-crystalline nucleus and liquid-type shell that constantly exchanges substance and energy with the nucleus and parent melt. The clusters are surrounded by the low-viscosity zones enriched in non-stoichiometric components (primarily volatiles). The cluster microheterogeneity of melts creates favourable pre-conditions for its subsequent heterogenization on the ways of emplacement, because when ascending, melts become more disequilibrium relative to the ambient medium, and the tendency to self-organization and structuring of magmatic system increases (Letnikov, 1992). When magma is moving under barogradient conditions, between-cluster zones of lower viscosity conduce to uniting cluster polymeric structures of the same composition, i.e. the transition of the heterogeneous state of melts proceeds from the microlevel to the macrolevel. During magma injection the pressure drop provokes liquid immiscibility of melts as well. After being intruded each portion of pegmatite magma evolves independently under regime of a closed system crystallization.

CONCLUSION

To create petrogenetic models, it should be taken into consideration that, while intruding, pegmatite melts are often compositionally heterogeneous. This is an important issue not only for pegmatites, but also for dike swarms of ongonites, elvanites, topazites, etc. Regarding to the metamagmatic model proposed, the granitic magma transformed into pegmatite melts through fluid-magma interaction in the crustal magmatic chambers. In essence, the granite-pegmatite systems represent the evidence of the substance-energy anomalies in the development of granitic magmatism related to the most intense influence of deep fluid flows on magmas (Zagorsky, 2001). Therefore not every massif, not every dome of granites is accompanied with pegmatites. From this viewpoint it is clear usual localization of pegmatite fields close to the deep faults, which seem to be the main channels of fluids and ore components transport from mantle and the lower part of crust. The metamagmatic model provides explanation of the causes of different ore specialization of pegmatites, including those associated with the same granitic complex. Varying ore load of fluids draining magma may be defined by the chemical heterogeneity of the upper mantle, different depth of fluid source and their interaction with different rocks on ways of migration. The zones of ultrametamorphism in the lower crust which are depleted in F, Li, Be and other elements, being characteristic of pegmatites, could also be the source of transmagmatic fluids. The metamagmatic model is not the explicit alternative excluding the possibility of pegmatite formation due to crystallization and emanative differentiation of granitic magma in a closed system. However, the result of such a *spontaneous* differentiation is most likely relatively small occurrences of pegmatites, while unique and large pegmatite fields and deposits are originated in magma differentiation processes *induced* by fluid flows.

ACKNOWLEDGEMENTS

The study was supported by RFBR, projects 07-05-00987, 07-05-00819.

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