GEOLOGICAL PRECONDITIONS, MANIFESTATIONS AND SIGNS OF PARTICIPATION OF NATURAL SALTS IN ALKALINE MAGMATISM

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The issue of the source of alkaline metals and volatiles is of great importance in the problem of genesis of alkaline magmatic rocks. Most often, various types of deep and super-deep inputs are discussed: through-magmatic solutions (D.S. Korzhinsky), alkaline melt fluids (L.N. Kogarko, et al.), fluid-salt systems (L.S. Borodin, et al.), derivatives of mantle recycling of the material of oceanic crust, which is drawn into the mantle in subduction zone (A.W. Hofmann), fluid plumes generated on the boundary with the liquid core (N.L. Dobretsov, F.A. Letnikov, et al.). The solution to the issue so far remains largely controversial. Meanwhile, in the earth's crust, a large source of both alkaline metals and volatiles is quite widespread along paths of the ascending movement of magmas. These are salt-bearing (often salt-carbonate) complexes and accompanying brines, which form large concentrated accumulations of sodium, potassium, chlorine, and a wide range of macro- and microcomponents, including volatile ones, in the earth's crust.

Preconditions. There are a number of preconditions to attract salts as a participant in alkaline magmatism. The main of them are: 1) similarity of sets of specific and typomorphic components and microcomponents of the composition of salt (halophilic – salt-loving) and alkaline (foidophilic, according to (Lazarenkov, 1988)) complexes; 2) their fairly frequent space proximity including affinity of potassium salts and potassium varieties of alkaline rocks; 3) similarity of a number of important patterns in the location of both of them (geotectonic position, stratigraphic distribution, inherited-cyclical character of location, etc.).

Salt-alkaline associations, distribution, examples. A purposeful comparative analysis of the regional and global material, characterizing the location of saline and alkaline complexes, showed their frequent spatial proximity and allowed to consider such complexes as salt-alkaline association, and their distribution areas as salt-alkaline provinces. The associations composition is as follows: alkaline magmatic complexes and older salts buried in their substrate (main dominant pair); sub-synchronous to magmatism "younger" salt strata, often associated with the destruction of older salts and their recycling (tectonic, salt-tectonic or injection-sedimentation) (Belenitskaya, 2016, 2017); frequently also older alkaline and salt layers.

Issues of old buried salts spread in zones of magmatism shows have been specially discussed in (Belenitskaya, 2017). Main difficulty of their detection in the substrate of alkaline complexes consists in poor preservation, while sharply decrease with time, and their poor accessibility for observation. In such environments deformation, displacement and partial removal of salts took place both during the time preceding alkaline magmatism and synchronously with its manifestations during tectonic-magmatic activation, and then in postmagmatic time under the influence of deep or near-surface factors. As a result, salt distribution in the substrate has often been relatively reduced already at the time of the development of magmatism, and at present, in most cases, it is not clearly expressed and can be reconstructed only by their relict fragments, injections, tectonic wedges, but more by a set of various indirect indicators, as well as by the presence of brines and young salts regenerative nature. The reconstruction of pre-magmatic salts almost always requires special research.

Depending on thesituation, three main tectonic types of salt-alkaline provinces are distinguished: 1) cover-folded, 2) riftogenic, and 3) activated passive margins. In the cover-folded type, the most widespread, conditionally involved folded areas (together with zones of tectonic overlaps by napped-

thrust packages of platform margins and median massifs), of various age, including those developed in the basements of young and ancient platforms.

Co-occurrences with older salt-bearing complexes are reconstructed most confidently and often for Neogene-Quaternary alkaline complexes, less often for older Phanerozoic and especially for Precambrian complexes (Belenitskaya, 2015). Typical representatives of neogeodynamic salt-alkaline provinces of each type – Italian, Upper Rhine, and Northwest African – are accepted as standard ones. The nature of their salinity of these regions is discussed in detail in (Belenitskaya, 2016, 2017), where a survey of studies on this problem was also presented. For each of the provinces traced the pattern of lateral and vertical relationships between alkaline and salt objects have been restored. In all the provinces, there are two main members of the association: Triassic salts (older ones) buried in the substrate (Busson, 1982; Yunov, 1980; Ziegler et al., 1996; et al.), and alkaline Neogene-Quaternary complexes (Alkaline..., 1974; Borodin, 1974; Peccerillo, Martinotti, 2006; Kogarko, Asavin, 2009; Mazarovich A.O. et al., 1990; et al.). Triassic salt (potassium-bearing) bodies in all the provinces are distributed at depths from 2-4 to 5-8 km and more. In the Italian province of cover-folded type, sub- and intrathrust salt bodies of residual and injective-tectonic nature is dominated. The Upper Rhine riftogenic province is characterized by buried in deep parts of rift structures residual and saline-tectonic deposits. In the Northwest African passive margin province injective salt masses (salt-tectonic and partially orthotectonic), deeply buried and laterally displaced up to the adjacent parts of abyssal areas (zones of frequent distribution of alkaline magmatism), prevail. Magmatism in all situations is due to tectonic-magmatic activation. In addition to the two dominant members, in the Italian and Upper Rhine provinces there are young salt bodies sub-synchronous to magmatism, whose formation, according to the author, is largely due to the high-intensity processes of tectonic (in the Italian province) or salt-tectonic (in the Upper Rhine) transportation of Triassic salts and their participation in the accumulation of salt masses of new levels. Potassium specialization is typical for salts of both levels and for alkaline magmatic complexes. Lateral and vertical relationships between alkaline and salt objects in each province form characteristic types of regional spatial zonality. In all the provinces, on the paths of ascending deep magmas the tomography data record the presence of intermediate magmatic chambers at about salinity levels.

There are preconditions for the detection of older (pre-Neogen) Phanerozoic alkaline-salt associations, for example, in the following regions: Yuzhnoytamyrsko-Khatangsko-Pranabarskiy, Baikal-Nepsky, Varanger-Timan-Mezensky, Cordillera, Tien Shan, Ural-Predural, North Appalachian, Yeniseisko-Chadobetsky, Fitzroy-Kimberly, etc. The issue with Precambrian is more complicated, primarily because of the insignificant preservation of Precambrian salts. But nevertheless, special studies of their relics and indirect features allow the reconstruction of Precambrian alkaline-salt associations.

Geological model, role of salt components in magmatism. The results of analysis of many salt-alkaline provinces show that the occurrence of salt-bearing rocks on the paths of ascending movement of deep magmas related to tectomagmatic activation is a rather widespread and geologically regular phenomenon. Physico-chemical parameters of such rocks distribution levels are favorable for the formation of intermediate crust foci, centers of interactions of hot aluminosilicate magmas with the assimilated components of saline (or salt-carbonate) complexes, and of formation of various nonequilibrium melt mixtures, which are highly enriched (oversaturated) with alkali and volatile components.

Localized reserves of halophilic components in saline complexes can serve as their concentrated sources in processes of interaction with the aluminosilicate melts. On the character of the influence of saline complexes components on petrogenesis processes, two main groups can be conventionally distinguished: 1) material ones ("donors") – Na, K, partially Cl (main salt components), a number of smaller and microcomponents; 2) volatile components – CO_2, SO_3, H_2O, Cl, F, etc., enriching salts and paragenous anhydrite (gypsum) and carbonate. The role of those and others in alkaline magmatism (outside the connection with natural salts) was discussed in many works (Aiuppa et al., 2009; Kogarko, 1977; Kogarko, Ryabchikov, 1978; Purtov et al., 2002; et al.).

The contents of Na, K and Cl in salts (in 1 m^3 of sodium salts about 0.8 t Na and about 1.0 t Cl, and in 1 m3 potassium salts about 0.1-0.2 t K) can easily provide them necessary "additives" to the alkaline rocks. Inclusion of salt-bearing masses in the hot magmatic process explains quite simply the nature of the source of sodium and potassium, replenishing their reserve necessary for processes of alkaline magmatism. The source is powerful, concentrated and located in the areal of intermediate magmatic chambers. The excess of alkaline metals and their high activity, creating the preconditions for the formation of "oversaturated" minerals, including nepheline and leucite, can also promote their early crystallization, preceded by the formation of dark minerals, disrupting the usual sequence of mineral formation that determines the "agpaitic" features of emerging rocks. Participation in the interaction of salts of sodium (halite) or potassium types can determine the mainly sodium or potassium specialization of the forming alkaline complexes. In addition, the inclusion in the processes of potassium salts characterized by their "own" set of accompanying microcomponents (Rb, Cs, Br, etc.) can influence the spectrum of microimpurities that enrich alkaline rocks. Chlorine, not being an important rock-forming agent in magmatic aluminosilicate systems, in alkaline petrogenesis affects many specific features of chemical and mineral composition and, to a large extent, the character of conjugate mineralization (Ryabchikov, Hamilton, 1971; Marakushev et al., 1997; et al.). On the one hand, it contributes to wide distribution of many Cl-enriched petrogenic and accessory minerals, which in alkaline complexes often reach rock-forming values, on the other hand, to the differentiation of fluid-magmatic systems with the separation of chloride fluids, which dissolve and accumulate the complex of ore ("chlorophilic", according to A.A. Marakushev) components. Volatile components, enclosed in the composition of salt-bearing complexes, to a greater extent initiate and regulate the course of interactions, manifested in the specificity of the material, structural, morphological and spatial parameters of the rocks.

Thus, high contents of alkaline and volatile components in salt-bearing complexes together influence both the composition (rock, mineral, chemical, isotopic) of the alkaline magmatic bodies and the accompanying metasomatic formations, and on their structural and textural features, morphology and spatial relationships. The ability of these components to contribute to the emergence of all these specific features of alkaline rocks can serve as an important argument in favour of the reality of their participation.

Signs of salt participation. The presented views is confirmed by many material and structural-morphological signs typical of alkaline magmatic rocks (Aiuppa et al., 2009; Alkaline..., 1974; Borodin, 1974; Kogarko, 1977; Lazarenkov, 1988; Pokrovsky, 2000; et al.), which can be the result of processes of magma contamination with salts and at the same time their important evidence. They are as follows: (1) frequent significant enrichment of many varieties of magmatic rocks with chlorine (up to 1.2-1.3%), sulfate ion (up to 3.0%), and carbonate ion (up to 5.4%); widespread occurrence of minerals containing these ions (sodalite, hauyn, cancrinite, etc.), up to sodalite, hauyn and cancrinite rocks; (2) diversity and contrast character of changes in chemical and mineral composition; (3) coincidence of potassium orientation of alkaline magmas with that of spatially conjugated salts, often enrichment of both with Br, Rb, Cs; the presence of Cl, sometimes Br in solid and liquid inclusions in alkaline rocks, as well as in volcanic gases ("halogen degassing", according to (Aiuppa et al., 2009); the presence of salts in ejecta of active volcanoes; crystallization in craters and incrustation of their walls with salts and with native sulfur (due to the presence in the section of its main source - anhydrite); variations in the C, O, Sr isotope indexes (Alkaline..., 1974; Faure, 1986; Pokrovsky, 2000; et al.), which often correspond to those typical of salt-carbonate complexes and, on the whole, do not contradict the possibility of the participation of salt-bearing sequences in alkaline magmatism.

Many papers are devoted to experimental studies on the interaction of high-temperature alumosilicate melts with NaCl and KCl salt systems (for example, Aiuppa et al., 2009; Alkaline..., 1974; Carbonatites, 1969; Kogarko, Ryabchikov, 1978; Marakushev et al., 1997; Purtov et al., 2002; Safonov et al., 2007; and many others) and their results are very indicative. Unfortunately, as long as mainly low-concentration salt solutions are being studied, the information on the interactions of aluminosilicate melts with natural salts is limited. But the available experimental data do not contradict the given geological model, and in many respects confirm it.

All of the above allows author to give a positive assessment to the geological probability of salt participation in alkaline magmatism and to accept the presented ideas as a working version of the geological model of alkaline magma formation.

Comparative analysis of geological-genetic models. The large reserve of alkaline and volatile components contained in saline complexes makes up the advantage of salts as their source in aluminosilicate magmas before any mantle supplies, for which their quantity is constrained not only by possible concentrations in the incoming fluids, but also by possible total mass of the fluids themselves. The proposed model is most close to widely known concepts of assimilation of carbonate rocks by magma developed by R.A. Daly and S.J. Shand and supported to various extent by many researchers (Alkaline..., 1974; Borodin, 1974; Rittmann , 1962; et al.). These views, which have been corrected in accordance with data on litho-tectonic features of sedimentary sections crossed by the magma (first of all about their salt content) indicate a high probability of salt assimilation together with its almost constant satellites – carbonates, particularly dolomite. There are good reasons to believe that participation in the assimilation of both members of the persistent natural salt-carbonate paragenesis determines to a great extent the character of interaction processes, so their joint analysis is one of promising directions for further studies. In the course of such studies, theoretical and experimental developments in studying processes of carbonate assimilation by magma can be used.

As compared to the A.W. Hofmann's model (Hofmann, 1997), which allows the enrichment of super-deep reservoirs in alkaline and volatile components as a result of mantle recycling of oceanic crust material, the proposed model is focused on specialized crustal (cover-crustal) recycling – involvement in magmatism of salt-bearing (often salt-carbonate) components located at less significant depths, mainly within the continental crust, and possibly tectonically "dragged" in even deeper parts of the lithosphere.

The model discussed is not offered as an alternative to existing concepts; it does not deny the probability of emergence of high-alkalinity magmas in the mantle as well as the participation of other mechanisms of its growth in the process of their evolution. Manifestation of different processes and existence (and even combination) of alkaline rocks of different genesis due to different geological factors is quite possible. However, the author would like the proposed model with crustal alkaline metals and volatile sources could occupy a place as an appropriate link in the system of the discussed views on alkaline magma formation.

The model explains many specific, including some "unclear", features of the composition and structure of alkaline rocks repeatedly emphasized by many researchers. It can be used for forecasting in the studies of both alkaline and salt-bearing complexes, as well as attracting more serious attention to salts in studying alkaline-metasomatic and other endogenous processes, including ore-generating ones. Some of the geological concepts of the discussed model are presented by the author for the first time and undoubtedly require further studies with the participation of specialists dealing with the problems of alkaline petrogenesis.

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