

Models of formation of ore deposits genetically related to magmatism*Marakushev A.A., Shapovalov Yu.B.*

Institute of Experimental Mineralogy
 Russian Academy of Sciences
 Chernogolovka Moscow dist.142432 Russia

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This paper presents an extension of the experimental study on the ore-bearing ability of magmatic systems as applied to the analysis of the genesis of both magmatic and magmatic-hydrothermal ore deposits (Marakushev, Shapovalov, 1998 etc.).

Magmatic systems in their physical-chemical nature are eutectic ones. They are characterized by the minimal temperatures specific of each depth facies of igneous rocks. Orogenic minerals are present in small proportion in their eutectic composition. This provides an ordinary scattering of orogenic metals while magmatic systems reach limiting states in the processes of either accessory mineralization or as an impurity in the rock-forming minerals and geochemical aureoles arising around the intrusives at the separation of fluids. So the overwhelming majority of rock intrusives are not associated with formation of ore deposits. Metallogenic specialization of intrusives takes place under specific conditions of transformation of conventional eutectic systems into the systems of magmatic immiscibility. The latter are characterized by the isolation of liquid phases, which selectively concentrate orogenic metals. The transformation may be isothermal. But as it is connected with the growing fluid effect on the systems or changing the compositions of the latter (presence of salts in residual melts, etc.), for the most part it occurs under the conditions of decreasing temperature (fig.).

The content of orogenic metals in eutectic compositions in the course of transformation remains unchanged or increases essentially as a result of the expansion of crystallization fields of petrogenic minerals. Accordingly, the transformation of eutectic systems results in the formation of either small deposits of low-grade ores or large and giant deposits. It is seen on an example of Kempirsaisk deposit of chromite ores where transformation of hartzburgite-chromspinel eutectic system is followed by the formation of small deposits of low-grade chromite ores of the main intrusive body. Contrastingly, deep-seated desilication of melts with the expansion of the crystallization field of olivine relative to chromspinel displaced by chromite led to the appearance of the eutectic system of liquid immiscibility. Its transformation into the system of liquid immiscibility was accompanied by the separation of the giant, on a global scale, deposits of chromite ores localized in the south part of Kempirsaisk intrusive.

Transformation of magmatic systems resulting in the formation of ore deposits is affected by different factors including desilication and alkalization of melts (1), transmagmatic sulfurization of iron-rich differentiates (2), and accumulation of salt components in residual magmas (3). Consider the effect of these factors.

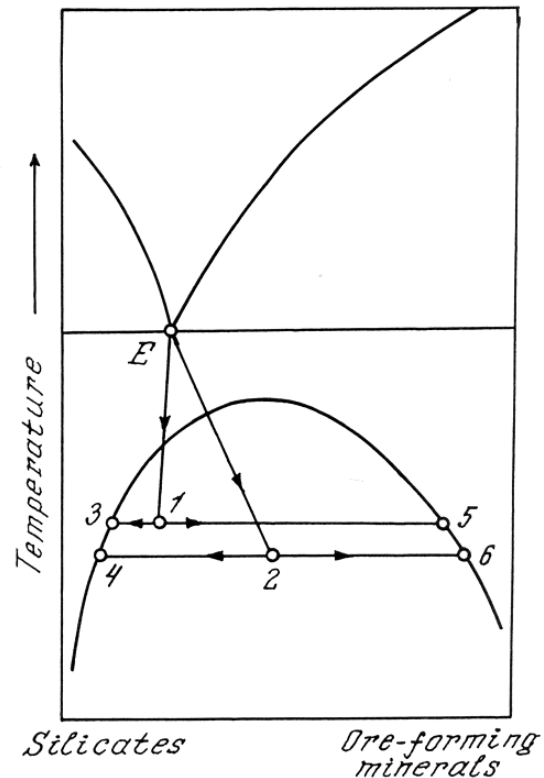


Fig. The diagram of the transformation of magmatic systems into the systems of liquid immiscibility resulting in formation of ore deposits. E- eutectics which reflects the scattering of orogenic metals in magmatic systems approaching limiting (eutectic) states. 1,2- transformed states of the systems retaining eutectic composition (1) and with expanded region of silicate crystallization (2); 3,4- silicate liquid phases; 5,6- liquid phases of the concentration of orogenic metals whose separation leads to the formation of ore deposits – small (5), large and giant (6). Arrows show the directions of the transformation of systems and ore-silicate splitting of melts.

1). Alkalization of ultrabasite melts is accompanied by growing the importance of strong bases (CaO, SrO etc.) replacing weak bases (FeO, MnO etc.) in silicate groups. This leads to replacing hartzburgites by lherzolites and verlites: $MgFeSi_2O_6 + CaO = CaMgSi_2O_6 + FeO$. Liberated thus iron is involved in the reactions of disproportionation $4FeO = Fe_3O_4 + Fe$ and stimulates separation from dunites of magnetite-chromspinel melts containing native iron and having, therefore, high chemical affinity to platinum. This makes the basis for the formation of the unique ferroplatinum deposits of the platinum-bearing belts of Urals and Alaska as well as ring intrusives of the Siberian platform (Konder et al.). Iron-rich differentiates of Bushveld hortonolite dunites type are also effective concentrators of platinum due to its pronounced siderophile properties.

2) The above deposits can form under the specific conditions in relative isolation from the flows of transmagmatic

fluids, which prevent the transformation of liberated iron into the native form and it is subjected to sulfurization: $4\text{FeO} + \text{H}_2\text{S} = \text{Fe}_3\text{O}_4 + \text{FeS} + \text{H}_2\text{O}$. Sulfurization stimulates the separation of low-sulfide melts (magnetite-chromspinel, pyroxenite, norite etc.), which selectively concentrate palladium-platinum metals. This type of mineralization is characteristic of giant platinum deposits of Bushveld and Stillwater type.

Copper-nickel deposits are subdivided into ultrabasite and basite types. The deposits of ultrabasite type form on the basis of olivinite melts. The olivinite melts undergo sulfurization to yield silicate-sulfide copper-nickel ores containing platinum and palladium (giant deposit of Jinchuan in China). Transmagmatic sulfurization at their formation gave rise to the splitting of ore melts into olivine (ore-bearing dunites), which selectively concentrate platinum and olivine-pyroxenite ones (ore-bearing olivine pyroxenites) which preferentially concentrate palladium. Platinum and palladium behave in a different way because of the dissimilar acidic properties shown up in the values of metals electronegativity ($\text{Pt}^{2+} = 1100 \text{ kJ}$, $\text{Pd}^{2+} = 920 \text{ kJ}$). Due to this dissimilarity there are different tendencies in the accumulation of platinum and palladium in copper-nickel sulfide ores: platinum mostly concentrates in the ultrabasite (dunite) formation and palladium – in the basite (dolerite-picrite) one. This accounts for the key distinction of the copper-nickel deposits of Jinchuan related to the lherzolite-dunite association of ultrabasites and sulfide deposits of Norilsk region at the Siberian Platform which are connected with picrite-dolerite layered intrusives. The latter are genetically related to the sulfurization of the iron-rich differentiates of the lower horizons of these intrusives which stimulated silicate-sulfide immiscibility of melts: $\text{MgFeSiO}_4 + \text{H}_2\text{O} = (\text{FeS}) + \text{MgSiO}_3 + \text{H}_2\text{O}$. This immiscibility is responsible for the high ore content in them. In these deposits, by contrast to Jinchuan ones, palladium concentration is higher than that of platinum.

However, copper-nickel specialization of both deposits is related to basite-ultrabasite formations they belong to, which provides nickel accumulation in the course of differentiation. Formation of iron-rich differentiates in the basite formation proper is followed not by nickel but by zinc concentration. In the processes of their transmagmatic sulfurization (with the gain of copper and chalcophile metals) large pyrite (zinc-copper) deposits form which are distant from the mother intrusion bodies, the processes of wall rock metasomatism being involved in their formation.

3). In the ore-free magmatic process accumulation of salts in residual melts of acid and basic intrusives occurs under their relative isolation from the transmagmatic fluid flows washing out salts from the magmatic chambers. By contrast, in ore-bearing chambers there occurs the isolation of dense salt melted phases capable to selectively concentrate oreogenic metals involved thereafter in the hydrothermal process.

In this connection consider the model of formation of gold-rich quartz veins. What pooled quartz and native gold in the processes of ore veins formation? That long time has remained an obscure question. The salt extraction of gold from residual melts accompanied by silicon concentration in liquid salt phases was such a combining factor. Based on the extraction mechanism the process of formation of gold-quartz veins can be described by the reaction:

$(\text{SiF}_4 + 3\text{AuCl}) + \text{H}_2\text{O} = (\text{SiO}_2 + 2\text{Au}) + (\text{H}_2[\text{AuCl}_3\text{O}] + 4\text{HF})$. The reaction combines the accumulation of gold and silicon ($\text{SiF}_4 + 3\text{AuCl}$) in the salt melted phases of the residual cham-

ber of granite or granodiorite intrusion, subsequent migration of salt productive phases into the crack zones together with hydrothermal solution ($3\text{H}_2\text{O}$). The latter provokes separation of gold-quartz veins ($\text{SiO}_2 + 2\text{Au}$) and loss of the residual easily soluble components ($\text{H}_2[\text{AuCl}_3\text{O}] + 4\text{HF}$) providing partial geochemical scattering of gold in metasomatic aureoles upon wall rock alteration.

The proposed petrological model accounts for all the main attributes of gold ore quartz veins genetically related to the residual chambers of granite and granodiorite intrusion bodies including wall rock ore aureoles with enhanced gold content. The model is based on the transformation of the migration forms of gold stimulated by the transformation of gold from monovalent into trivalent form. As the temperature decreases this leads to mass precipitation of gold as a native metal together with quartz forming ore veins and its partial scattering in metasomatic aureoles. The transformation of migration forms is of the most common importance and dictates the behavior and metallogenic properties of gold.

Reference:

1. A.A. Marakushev, Yu.B. Shapovalov. Immiscible salt-rich melts and the genesis of magmatic-hydrothermal ore deposits. // Proc. Of the Ninth Quadrennial IAGOD Symposium. Stuttgart, 1998, p. 165-176.