

Gold behaviour in the process of acid magma crystallization

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Gold is very well-known as a precious metal. Many books and papers are concerned with its chemical properties and behaviour, especially in hydrothermal processes and gold distribution in vein minerals – mostly sulphides. But there are fewer investigations in the field of gold distribution in rock-forming minerals and particularly in minerals of granitoids.

Many gold deposits are related genetically to granitoids, but till now it is not clear how gold separates from magma and becomes concentrated. The most popular opinion is that gold, like other metals, concentrates in residual melts and then in hydrothermal solutions (Boyle, 1973). Gold forms complex compounds with Cl even if the concentration of this element is very low, but these compounds are unstable at high oxygen fugacity. Gold dissolves easily in quartz and Fe-minerals.

For comparison gold behaviour in the process of magma crystallization was investigated through its distribution in ore-forming and accessory minerals from gold-bearing (O, D) and non-gold-bearing (D) granitic massifs from Central Kazakhstan (Table 1). Genetically these massifs belong to I (O), I-S (D) and S (D) - types. Formation of granitoids of O complex was probably related to subduction; of D complex - to collision.

On the basis of petrographical studies, it was established that crystallization of all granitoids occurs in three stages (three textural groups of minerals): plagioclase + hornblende (30–35 vol.%), quartz + alkali feldspar (60–65 vol.%) and biotite + magnetite + sphene (< 5 vol.%). This sharp division on groups is, to a certain extent, conditional because some minerals of the different groups were crystallized more or less simultaneously for instance, border parts of plagioclases and central parts of alkali feldspars; magnetite and sphene were formed in two stages: little part of them on the early stage but the bigger part on the late stage. Nevertheless such division into three groups as a whole corresponds to succession of the main volume of minerals crystallization.

Gold content in minerals is represented in Table 1. In general the Au contents of the rock-

forming minerals of all complexes are similar for the minerals of the early stage of crystallization but are different for the minerals of the last stage. In the minerals of gold-bearing complexes (O and D) concentrations of gold are similar. The tendency of gold distribution in minerals of gold-bearing and non-gold-bearing granites is more or less the same. It is clear also that accumulation of gold in minerals of the late stage crystallization is much more intense in the magma of non-gold-bearing granitoids.

According to average gold concentrations, all minerals can be divided into two groups: 1) gold concentration < 0.70 (only rock-forming minerals – Hb, Pl, K-Na Fsp – mostly of the early stage of crystallization) and 2) gold concentration > 1.5 (rock-forming minerals – Bi and Q and, especially, accessory minerals – Sph and Mt – late stage of crystallization). Difference between gold concentration in the same minerals of gold-bearing and non-gold-bearing granitoids is rather sharp (fig. 2). In gold-bearing rocks average gold concentration in minerals with high gold content is lower than in non-gold-bearing, but in minerals with low gold concentration quite the reverse. During magma crystallization gold concentration increases in crystallizing minerals: more intense in non-gold-bearing-granitoids in comparison with gold-bearing. These data are in contradiction with the idea that in gold-bearing magmas accumulation of gold must be higher than in non-gold-bearing.

Study of ore-bearing granites provides evidence that there exists specific type of inclusions – silicate - salt melt-brines (salts concentration 70 mass.) with high concentration of H₂O, F, Cl, etc. and metals (W, Sn, Fe, etc.). These melt-brines separate from the initial acid melt at high temperature – before, or at the very beginning of its crystallization (Reyf *et al.*, 1982; Nautov *et al.*, 1981; Sobolev, 1992, 1993). Such melt-brines were also established by experimental investigations (Marakushev, *et al.*, 1993). When melt-brine separates from silicate melt it takes from the melt most of the metal (gold). Gold forms stable complex compounds with Cl even if in the melt-brine there is low Cl concentration (Marakushev,

TABLE 1. Average gold concentration in minerals of gold-bearing and non-gold-bearing granitoids, $n \times 10^{-6}$ mass %

Age of granitoids	Mt	Q	Sph	Bi	K-Na feldspar	Hb	Pl
Upper Ordovician (n = 308)	6.63 (60)	4.90 (41)	2.33 (34)	2.74 (39)	0.70 (43)	0.63 (28)	0.60 (63)
Middle Devonian (n = 222)	11.33 (40)	7.92 (63)	5.32 (17)	1.51 (31)	0.52 (18)	0.48 (28)	0.37 (24)
Upper Devonian (n = 278)	6.63 (60)	2.15 (44)	2.50 (27)	2.90 (47)	0.64 (51)	0.66 (19)	0.65 (30)

Method of atomic absorption

Mt - magnetite, Q - quartz, Sph - sphene (titanite), K-Na Fsp - alkali feldspar, Hb - hornblende, Pl - plagioclase.

1978). This process (separation of melt-brines) leads to a very sharp decrease of the metal concentration in acid silicate melt. Thus gold concentration in minerals of the first stage crystallization in gold-bearing granitoids is low (lower than in non-gold-bearing) – most of the gold was removed in melt-brine; during such magma evolution the increase of gold concentration in residual melt (and in minerals of late stage crystallization) is not very intense. During magma evolution of non-ore-bearing granitoids, melt-brine does not separate from initial silicate melt and the metal(s) remains in melt. Although the metal concentration in non-ore-bearing magmas is not very high, nevertheless the gold concentration in minerals increases more intensely during melt crystallization and minerals of the late stage crystallization are characterized by high gold concentration.

Thus, separation from initial silicate melt of a specific phase (melt-brine) with high metal (gold) concentration is typical for ore-bearing acid magmas and this process explains metal behaviour (and distribution in minerals) in the process of magma crystallization.

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