Formation conditions and fluid component sources for volcanogenic massive sulphide deposits of the South Urals

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Volcanogenic massive sulphide (VMS) deposits of the Urals are located inside ensimatic Tagil-Magnitogorsk trough (Prokin, Buslaev, 1999). Their formation relates to arc-related calc-alkaline rhyolite-dacite series S_1l_2 of Tagil Megazone and D_2e-gv_1 and Na-basalts D_2e_1 of Magnitogorsk Megazone (Table 1). World-class deposits with 3-10 MT of (Cu+Zn) reserves are located within the Magnitogorsk Megazone (Fig. 1). VMS deposits consist of semimassive to massive sulphide lenses underlain by discordant stockworks of quartz-sulphide veins and related quartz-phyllosilicate alternation. Localities of the VMS deposits of the Urals are controlled by paleovolcanic structures (calderas, troughs, local depressions) and are usually connected with rhyodacitic to calc-alkaline rhyolitic domes.

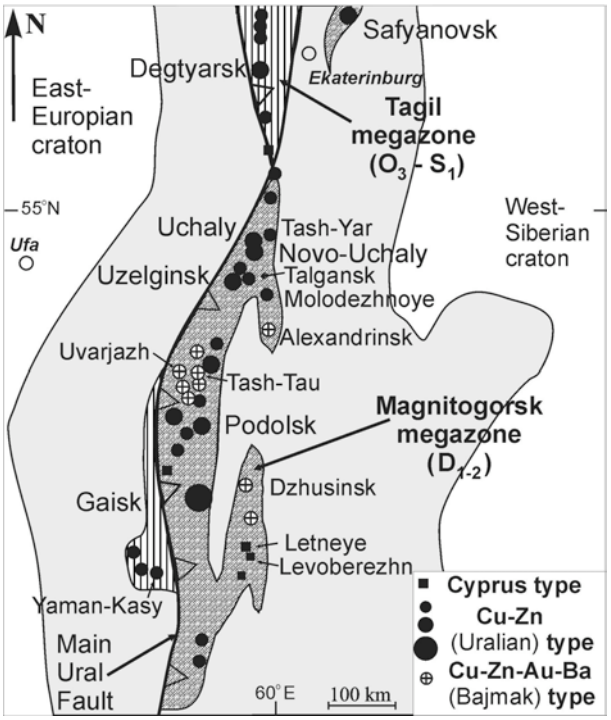

Fig. 1. Schematic map of Middle-South Urals and position of VMS deposits (Vikentyev, 2006).

Fluid inclusions (FI) in minerals from ore bodies and altered country rocks and melt inclusions (MI) and FI in quartz phenocrysts as well as stable (S, O, C, H) and radiogenic (Sr, Pb) isotopes for rocks and ores have been studied. Usually primary FI in minerals of ores (quartz, barite, sphalerite, carbonates) or secondary FI in quartz phenocrysts not exceed 10 μm. T_h range from 375 to 97 °C (routinely 300 – 200 °C). The pressure values range from 30 to 160 MPa that corresponds to buried, subbottom conditions of ore genesis for major deposits. Sulphur contents in fluid of vacuoles ranged from 160 to 250 mg/l, and copper from 0.3 to 1.2 g/kg in the solution. The CO_2 content may amount 40 mass%. Salinities range from 0.3 to 17 eq mass% Na^+ (Table 1). Minor phase separation occurred at deeper levels of some deposits. Na^+ and Mg^{2+} dominate among the cations in the fluid. For metamorphic-regenerated VMS deposits (Tarnjer, Degtyarsk, Tash-Yar, Dzhusinsk) T_h of FI were routinely higher (up to 440 – 465 °C), P = 100 - 180 MPa, w_{salt} = 1 - 18 eq mass% Na^+

Primary magmatic FI in quartz phenocrysts are round to negative crystal shaped and have a size between 25 to 100 μm. The gas bubbles have sizes between 8 to 40 μm. T_h of FI ranges from 124 - 245 °C with a salinity of w_{salt} from 1.2 to 6.2 eq mass% NaCl. Occurrences of sulphide globules (chalcopyrite, bornite, pentlandite and pyrrhotite) in some MI indicate an increased copper content in parent magmatic melt and are evidence of the important role of magma-derived metal components in ore formation. The concentrations of metals in glass of melt inclusion are 1100 ppm for Cu and 1400 ppm for Zn (LA-ICP-QMS).

The range of $(^{87}Sr/^{88}Sr)_o$=0.70597 - 0.70625 for carbonates, indicating a lower involvement of marine and higher input of

magmatic water, are characteristic for ores and host rocks. Deepseated mantle sources were the main ones for lead of galena (Chernyshev et al., 2008).

Isotope compositions of O and C of carbonates ($\delta^{18}O$= +13 to +26.5 ‰, $\delta^{13}C$= -28 to +1 ‰ for massive ores and $\delta^{18}O$= +9 to +27 ‰, $\delta^{13}C$= -20 to -1‰ for altered igneous rocks) testify to important addition of magma-derived components. Values of $\delta^{34}S$ in sulphides of ores ranging from -1 to +6 ‰ CDT for majority of VMS deposits confirm the dominant input of magmatic sulphur to hydrothermal fluid, with subordinated role of sea water sulphate and biogenic sulphur. Data for the δD and $\delta^{18}O$ of fluid deposited silicates and quartz of Aleksandrinsky, Uzelginsky and Uchalinsky deposits lie between marine and magmatic values.

Summary. The formation of the VMS deposits of the Urals related to shallow chambers of acidic magma. Ore bodies have been formed over discharge channels approaching sea floor or at subbottom position from moderately high temperature (up to 390 ^{o}C) hydrothermal solutions at pressure values ranged 30 – 160 MPa. Sr, Pb and stable isotope (S, O, C, H) studies revealed dual (oceanic and juvenile) nature of the ore-forming fluid source. The deposits are related to magmatic fluids as well as alteration of underlying felsic and basic volcanic rocks by circulating fluid system of evolved oceanic water. High amounts of CO_2 in fluid inclusions may also be indicative for a magmatic source of the hydrothermal fluids. This is also supported by high metal contents in primary fluid inclusions in quartz phenocrysts.

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Age	Deposit type	Magmatic complexes	Main ore elements	Deposits	T_h, $^{\circ}$C	w_{salt}, eq.% NaCl	Cations
S_1l_2	Cu-Zn-pyritic (Uralian type)	Sodium rhyolite-basalt	Cu ≥ Zn (Au, Ag)	Shemur	178-119	9.3-1.2	Mg, Na Na (+Mg)
			Zn > Cu (Au, Ag)	Yaman-Kasy [1], Valentor	290-110	16.9-0.6	Na, Mg Na (+Mg) Na
	Zn-Ag-pyritic	Potassium-sodium andesite-dacite	Zn, Au, Ag (Cu, Pb)	Galkinsk	170-114	4,0-1,4	Na, Mg Na (+Mg)
D_2e_1	Cu-Co-pyritic (Cyprus type)	Tholeite-basalt	Cu (Zn, Co)	Letnee, Levoberezhn	305-182		
D_2e-gv_1	Cu-Zn-pyritic (Uralian type)	Sodium rhyolite-basalt	Cu ≥ Zn (Au, Ag)	Safjanovsk, Podolsk	337-104	15.3-0.3	Na Na (+Mg)
			Zn > Cu (Au, Ag)	Uzelginsk, Uchaly, Novo-Uchaly, Chebach'e, West-Ozerny	375-97	7.8-0.3	Na K Na (+K) Na (+Ca) Na (+Mg)
	Cu-Zn-barite-pyritic	Sodium rhyolite-basalt	Cu, Zn, Ba (Pb, Au,Ag)	Alexandrinsk	340-160		
	Cu-Zn-Au-barite (Baymak type)	Potassium-sodium andesite-dacite	Cu, Zn, Au, Ba (Pb, Ag)	Tash-Tau [2], Uvarjazh	239-103	8-0.5	Mg (+Na) Na (+Mg) Na

Table. 1. Types of nonmetamorphosed VMS deposits of the South Urals and parameters of hydrothermal fluid (with use of data of Simonov et al., 2006 [1], and Zaykov, Ankusheva, 2008 [2]