FLUID INCLUSION STUDY AT THE BU-AZZER COBALT DEPOSIT (MOROCCO)

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The Bu-Azzer cobalt deposit is one of the largest deposits of nickel-cobalt-arsenic (five-element) assemblage on the world. Fluid inclusion study (microthermometry, cryometry, Raman spectroscopy, water leaching analyses, microprobe analyses of the salt residua and LA-ICP-MS) was carried out mainly on quartzs from three stages of ore formation: pre-arsenic stage (quartz veins with chalcopyrite, hematite, molybdenite and gold), arsenic stage (quartz - carbonate veins with Ni- and Co- arsenides) and post-ore stage (quartz - carbonate veins with sulfides and sulfosalts).

Table 1. Gas phase composition of fluid inclusions (Raman spectroscopy data)

№	Sample	Depth (м)	Mol. %	
			N_2	CH_4
Pre-ore quartz 1				
1	3014	215	91,5	8,5
2	145-13	145	84,1	15,9
3	3053-1	0	90,8	9,2
4	3051-9	0	95,9	4,1
Ore quartz 1				
5	Baz-300-7	300	90	10
6	Baz-255-1/4a	255	96,8	3,2
7	3012	215	71,1	29,1
8	3019	215	93,2	6,8
9	St-2	145	51,4	48,6
10	3036	95	78,5	21.5
11	3046	50	78,6	21,4
12	3046	50	-	100
Post-ore quartz 5				
13	Baz-340-2/1	340	100	-
14	Baz-300-8	300	95.3	4.7
15	Baz-255-1	255	100	-
16	3012	215	89,2	10,8
17	3013-3	215	41.4	58.6
18	3030-2	50	88.2	11.8

1. Fluids of pre-arsenic stage are characterized by high salinity (up to 36.5 wt.% NaCl eq.) and chloride-sodium-calcium composition; the ratio of main components (NaCl and $FeCl_2$) varies from 0.5 up to 0.65. In addition, Mg, K, S (up to several wt.%) is present in the composition. Temperature of ore-formation (240°C - 180°C), salinity and composition of fluids are similar to different parts of ore body (Fig. 1, 2). Nitrogen prevails in a gas phase. Carbon dioxide and methane occur at in insignificant amounts.

2. Ore-forming fluids of arsenic stage are characterized by high salinity (from 28 up to 40 wt.% NaCl eq.) and chloride composition. The main salt components are $FeCl_2$ and NaCl, $NaCl/FeCl_2$ ratio varies from 0.25 at deep depths (300 м) up to 1 on the surface. Fluids contain (in wt.%) Br up to 0.28-0.45, (Br/Cl ratio is 0.011-0.014), Ba 0.1-3.6, Sr up to 4.5. At deep depths of the ore veins (h> 215 м) hydrothermal ore-forming fluids contain ore elements in significant quantities, in contrast to samples from higher horizons: Sb up to 200 ppm, As up to 450 ppm, Zn up to 1400 ppm, Ag 14-200 ppm, Ni 850-800 ppm, Cu up to 1200, and Co (determined qualitatively). The analysis of water extracts from ore quartz shows the presence of NH_4^+ ions in inclusions. The temperature of ore-forming fluids of the deep horizons varies during consecutive crystallization of minerals from 275° up to 170°C, and decrease from deep parts of ore veins up to the surface from 275°C up to 130-90°C, an average vertical temperature gradient is 8.5-9°C /100 m.

According to Raman spectroscopy, the composition of gas phase of fluid inclusions varies in the ore veins from essentially nitrogen (N_2 - 90 mol. %; CH_4 - 10 mol. %) to nitrogen-methane (N_2 - 66 mol. %; CH_4 - 34 mol. %) at higher horizons of the deposit.

3. Fluids of the post-ore stage are characterized by the same composition and high salinity (up to 30-31 wt. % NaCl eq.). $NaCl/FeCl_2$ ratio on deep horizons is 1.4-1.7, up to 5.3-6.8 at higher horizons. Mg, K, S (up to several wt. %) also occur in the composition, and Br 0.04-0.08 wt. %. The temperature of formation of minerals varies from 178°C-100°C down to 50°C at the final stages of mineral deposition.

The results of this study allow us to make the following conclusions:

- Important feature of genesis of the Bu-Azzer cobalt deposit is low temperatures of ore formation and high salinity of ore-forming fluids, which almost did not vary at different stages of hydrothermal process, even on post-ore stages. The fluids are characterized by pH 4-5 and low Eh values (as indicated by presence of CH_4 and $FeCl_2$ in fluid inclusions).
- Decrease of temperature occurred during migration of ore-forming fluids to the surface, with increasing of $NaCl/CaCl_2$ ratio and decreasing contents of Br, Fe, Ba and other ore elements. The gas phase composition varies from nitrogen to methane – nitrogen.
- Presence of significant amounts of NH_4^+ in inclusion fluids (in water leaching) suggests that Ni and Co could transfer as ammonium, as well as chloride species.

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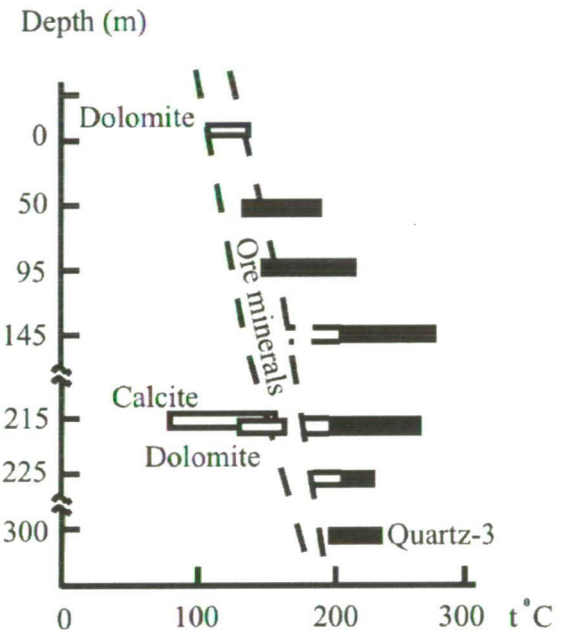

Fig.1. Homogenization temperature of fluid inclusion solutions in the minerals from different horizons of Bu-Azzer deposit

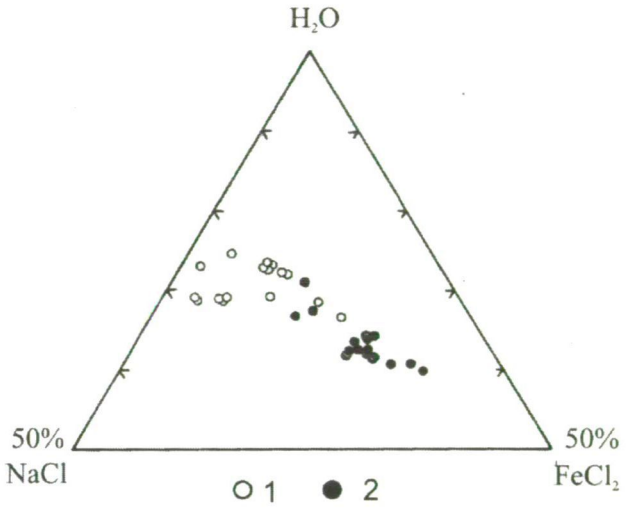

Fig. 2. NaCl and $FeCl_2$ contents in fluid inclusions in post-ore (1) and syn-ore (2) quartz of Bu-Azzer deposit.