Abstract

The general metallogenetic model presented here is based on observations from the Iranian combined non-sulphide/sulphide zinc deposit Mehdi-Abad and the non-sulphide Koladahrvazeh mine in the Irankuh mining district (Iran). The resulting geochemical model has been tested and refined by the simulation of complex hydrochemical models using the PHREEQC software developed by PARKHURST & APPELO (1999).

The non-sulphide zinc ore spectrum has two end members: red zinc ore, rich in Zn (>20%), Fe (>7%), Pb - (As) and white zinc ore with typically high zinc grades (up to 40%) but low concentrations of iron (<7%) and lead. These typically high concentrations of iron and lead in red zinc ore can be observed in many non-sulphide zinc deposits in Iran and elsewhere (e.g. Sierra Mohada, Mexico) and have been described by other authors as well (e.g. CABALA, 2001). Common minerals of the red zinc ore are Fe-oxyhydroxides, goethite, hematite, hemimorphite, smithsonite and/or hydrozincite, and cerrusite. These minerals are also common within the ‘white zinc ore’ although in different proportions. Metal separation is caused by a gradual change from an acidic oxidation zone to alkaline conditions in the adjacent carbonate wall rock. The establishment of an acidic oxidation zone within carbonate host rock is facilitated by the “armouring” of calcite by gypsum and hydrous ferric oxides (HFO) (HUMICKI, 2004; HUMINICKI & RIMSTIDT, 2004) and by several pH-buffering reactions (BLOWES & PTACEK, 1994). Iron precipitates within the oxide zone mostly as immobile HFO, which additionally adsorbs various amounts of Pb and Zn, depending on pH (MARTINEZ & MCBRIDE, 2001; DZOMBAK & MOREL, 1990). The high activity of SO$_4^{2-}$ ions during the oxidation stage immobilises lead and to the precipitation of (under these conditions) highly insoluble anglesite. A major portion of the zinc (up to 80% at pH 6 or 97% at pH 5) leaves the oxidation zone and precipitates as zinc carbonates in adjacent parts of the carbonate host rock. The neutralisation of the sulphuric acid by reaction with the carbonates of the host rock during the ‘oxidation stage’ liberates CO$_2$. Consequently, the CO$_2$ partial pressure ($P_{\text{CO}_2}$) increases drastically and forms a CO$_2$-halo around the active oxidation zone. Thus, most of the zinc precipitates as smithsonite, which occurs exclusively in a high $P_{\text{CO}_2}$ environment. Subsequent to the oxidation process, i.e. during the ‘post-oxidation stage’, the $P_{\text{CO}_2}$ decreases and reaches the level of atmospheric $P_{\text{CO}_2}$. Now, hydrozincite becomes stable and starts to replace smithsonite. Most of the stage-I smithsonite becomes corroded and altered to stage-II hydrozincite. The ‘post-oxidation stage’ is also associated with the successive local formation of zinc silicates, according to the availability of SiO$_2$ within the solution and the partial mobilisation of lead and the replacement of anglesite by cerussite.

In general, an arid climate provides the best conditions for the preservation of non-sulphide deposits. The limited availability of meteoric water and deep to very deep water tables protect the sulphide ore from subsequent dissolution.

The Mehdi Abad zinc-lead deposit is located in central Iran and is one of the largest zinc deposits of the region. The orebody consists of both primary sulphide and supergene non-sulphide ore. The deposit comprises a main sulphide/non-sulphide combined orebody (Valley Orebody, VOB), and an exclusively non-sulphide orebody (Mountain Orebody, MOB). The VOB is located in a valley and is covered by alluvial overburden. The exclusively non-sulphide MOB is located on the flanks of a mountain, separated by faults from the VOB. The non-sulphide ore of the MOB occurs as a matrix of fault- and karst breccias. Ore minerals comprise hemimorphite, hydrozincite, smithsonite, goe-
thite, as well as small amounts of mimetite, hetaerolite, and sauconite. Two separate types of the non-sulphide ore of the MOB can be distinguished: red zinc ore and white zinc ore. The red zinc ore is characterised by high Fe, Mn, Pb, and Zn concentrations. The white zinc ore, in contrast, is very high in Zn but low in Fe and Pb. Both types of zinc ore occur spatially (i.e. laterally and/or vertically) separated from each other. The formation of the two distinct non-sulphide ore types of the MOB is due to a rapid oxidation process. One of the main controlling factors was a high pyrite concentration of the sulphide protore, which generated a high acidity during the oxidation process. The above-mentioned geochemical processes led to a metal separation resulting in the formation of white and red zinc ore. The VOB, in contrast is covered by alluvial overburden. Its deep location prevents oxygen to reach the orebody in large quantities. The oxidation process is slow, produces only minor acidity, and thus has limited ability for metal separation processes. The still active oxidation of the VOB has produced Fe-rich non-sulphide ore without a differentiation into white and red zinc ore type.

The Kolahdarvazeh pit in the Irankuh mining district is dominated by white non-sulphide zinc ore and minor amounts of sulphide ore. The main portion of the non-sulphide mineralisation occurs as cement of a dolomite (karst-) breccia, but it also occurs as filling of faults and fractures. Smithsonite, hydrozincite, hemimorphite, cerussite, leadhillite, malachite, calcite, goethite, hematite, limonite, coronadite, and barite have been detected within the non-sulphide ore. The ore is hosted in Cretaceous dolomites. The sulphide ore is still observable in several bore holes and consists predominantly of sphalerite and galena. Pyrite and other Fe-(Cu-) bearing minerals are rare. In the Kolahdarvazeh mine the red zinc ore is absent. There is no evidence, that the white zinc ore of the Kolahdarvazeh mine has been formed due to metal mobilisation and differentiation. The main portion of the white zinc ore is proposed to be a result of in situ replacement of sulphide protore by non-sulphide minerals. Only a small portion has been successively mobilised by meteoric water and has locally formed a high quantity of white zinc ore as cement of karst breccias. The formation of the non-sulphide ore has been supported by the proximity of a footwall aquitard (shales) where the metal bearing fluids became ponded. The location of the Kolahdarvazeh pit between two important faults and impermeable shales below likely played an important role in the genesis of this deposit. The shales acted as an impermeable and insoluble barrier for both the ore-delivering fluids and the ground water system. This hydraulic barrier stopped the fluid-flow, which caused a long lasting and effective enrichment process that affected the dolomite and the limestone adjacent to the Kolahdarvazeh fault and the shales.