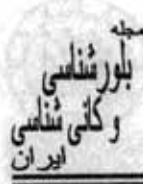




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چکیده: ذخیره روی و سرب مهدی‌آباد واقع در ایران مرکزی، یکی از بزرگترین ذخایر روی در این ناحیه است. توده معدنی از دو بخش سولفیدی اولیه و سوپرژن غیرسولفیدی تشکیل شده است. ذخیره معدنی از یک توده کانه‌دار اصلی سولفیدی- غیرسولفیدی تشکیل شده است، که در زیر کف دره قرار دارد. بخشی که معدن کالامین نامیده می‌شود، کاملاً غیرسولفیدی است، که در دامنه کوه توسط گسله‌ها از بخش اصلی جدا شده است. سنگ میزبان کانه غیرسولفیدی معدن کالامین به طور محلی در لایه‌های کرتاسه (آلبین) سازند آبکوه هستند که از ماتریکس برش‌های کارستی یا گسلی منشاء گرفته‌اند. کانی‌های ماده معدنی، شامل همی‌مورفیت، اسمیت‌زونیت، گوتیت و به مقدار کمتر می‌میت، هتائولیت و سوکونیت هستند. از نظر بافتی، برای کانی همی‌مورفیت می‌توان دو تیپ بافت متفاوت در نظر گرفت. تیپ اول- به صورت اشکال ساب و انهدرال است که اغلب با گوتیت و یا هیدروزینکیت همراه می‌باشند. این نوع همی‌مورفیت دگرسان شده، معمولاً بخش‌هایی از آن حل شده و باقیمانده، در مقیاس میکروسکوپی، بافت جعبه‌ای نشان می‌دهند. تیپ دوم- همی‌مورفیت انهدرال است که در شکستگی‌ها و فضای باز سنگ میزبان و برش‌ها رشد کرده است. حداقل سه مرحله متفاوت برای ژنز کانی‌زایی همی‌مورفیت در نظر گرفته شده است: (۱) شکل‌گیری همی‌مورفیت تیپ اول از کانه‌های سیال سوپرژن، (۲) حل شدن نسی و دگرسانی همی‌مورفیت تیپ اول به هیدروزینکیت که احتمالاً با ته‌نشینی گوتیت بر اثر تغییرات شرایط Eh-pH همراه بوده است، (۳) و بالاخره ته‌نشینی همی‌مورفیت تیپ دوم درون شکستگی‌ها و فضاهای باز شده سنگها بوده است.

واژه‌های کلیدی: کالامین، غیرسولفیدی، روی، اکسیداسیون، سوپرژن، همی‌مورفیت، دگرسانی.



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Mineralogy of Non-sulphid ore from the Mehdi Abad zinc-lead deposit, Central Iran

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Abstract: The Mehdi Abad zinc-lead deposit, which is located in central Iran, is one of the largest zinc deposits of the region. The orebody consists of primary sulphide as well as supergene non-sulphide ore. The deposit comprises a main sulphide/non-sulphide orebody below a valley floor and of the so-called Calamine Mine (exclusively non-sulphides), on the flank of a mountain, separated by faults from the former. The non-sulphide ore of the Calamine Mine is hosted within Cretaceous (Albian) strata of the regional Abkou Formation, and occurs as a matrix of fault- and karst breccias. Ore minerals are composed of hemimorphite, hydrozincite, smithsonite, goethite, as well as small amounts of mimetite, hetaerolite, and sauconite. Texturally, hemimorphite occurs as two different types. Type-1 displays sub- to anhedral shapes and is commonly associated with goethite and/or hydrozincite. This type-1 hemimorphite is commonly altered and partly dissolved to relict box work textures on a microscopic scale. Type-2 hemimorphite is euhedral and has grown in fractures and open spaces of the host rock and in breccias. At least three different stages are proposed for the genesis of the hemimorphite mineralisation: (i) formation of type-1 hemimorphite from supergene ore fluids, (ii) the partial dissolution and alteration of type-1 hemimorphite to hydrozincite, probably accompanied by the precipitation of goethite due to a change in Eh-pH conditions, and finally (iii) the precipitation of type-2 hemimorphite within fractures and open spaces.

Keywords: *Calamine, Non-sulphide, Zinc, Oxidation, Supergene, Hemimorphite, Alteration.*

1 Introduction

The Mehdi Abad deposit is located approximately 100 km southeast of the city of Yazd and about 500 km southeast of Tehran on the margin of the Central Iranian Desert (Fig. 1). The UTM coordinates are 40R 0310158, 3484911. The altitude of this area is about 1850 m above sea level (a.s.l.) with an arid to hyper-arid climate. Mehdi Abad is a combined sulphide/non-sulphide zinc (-lead) deposit and exploration in this area has started during the 1950ies. This exploration activity had resulted in the opening of the so-called Calamine Mine, which produced zinc metal until 1959. The mine produced high-grade ore consisting mainly of hemimorphite, hydrozincite, and smithsonite.

According to exploration data, the entire Mehdi Abad deposit has a reserve of 97 Mt at 8,6 % Zn (1,7 % Pb) or 208,5 Mt at 7,7 % Zn (2,0 % Pb) of both oxide and sulphide ore (Union Capital, 2000). The proportion of sulphides to non-sulphides is still uncertain and available figures vary (depending on cut-off grades) between 52,5 % to 61 % sulphide ore, 13. % to 16 % mixed sulphide/oxide ore, and 25,5 % to 31,5 % oxide ore [6].



Fig. 1 Location of the Mehdi Abad sulphide/non-sulphide zinc-lead deposit, Central Iran.

2 Geological Overview

The main portion of the sulphide/non-sulphide ore is located in a depression surrounded by hills and mountains with an altitude of up to 2500 m a.s.l.. Except for the mountains and ridges, the area is covered by alluvial overburden which partly covers a Lower Cretaceous succession. This succession comprises from bottom to top the Sangestan, Taft, and Abkou Formations, which generally consist of detrital siliciclastic and carbonate rocks with an increase in carbonates towards the top.

The altitude of the Calamine Mine, which is separated by faults from the main sulphide/non-sulphide ore body, ranges from 2000 up to 2300 metres and represents the highest parts of the exposed mineralization. In contrast to the mixed main sulphide/non-sulphide orebody, the Calamine Mine contains no sulphides.

The structural geology is controlled by N-S-, NE-SW-, and NW-SE-trending faults systems, which make up the boundaries of orebodies of the Calamine. No ore occurs outside this fault-bounded area.

The zinc-lead mineralization occurs east of the Black Hill Fault, a normal dip slip fault, striking NNW-SSE, dipping 65°-70° to the NE. The Forouzandeh Fault is a dextral strike-slip fault with a strike of approximately 60°, dipping 50°- 80° to the NW. The strata within this fault-bounded area are intensively folded. The folding of this block is due to the movement of the faults mentioned above and is relatively unique within the area of the Mehdi-Abad zinc-lead deposit. Folding appears less pronounced away from these two major faults but several major thrusts and distinct duplex structures give evidence of the strong compressional deformation of the area.

3 The Calamine Mine

The Calamine Mine consists of numerous adits which follow the folded and duplicated ore horizon at different levels (Fig. 2). Three adits, on the 2006 m-, 2080 m-, and 2230 m-level have been sampled from W to E and a total of 36 specimens have been analyzed by light microscope, XRF, ICP, XRD, SEM, and SEM-EDX.

3.1 Geology of the Calamine Mine

The Calamine Mine is wedged-in between two important faults (Fig.2), bounded to the west by the Black Hill Fault and to the east by the Forouzandeh Fault. The non-sulphide zinc-lead ore occurs on mainly three different levels, which is the result of fold repetition [2].

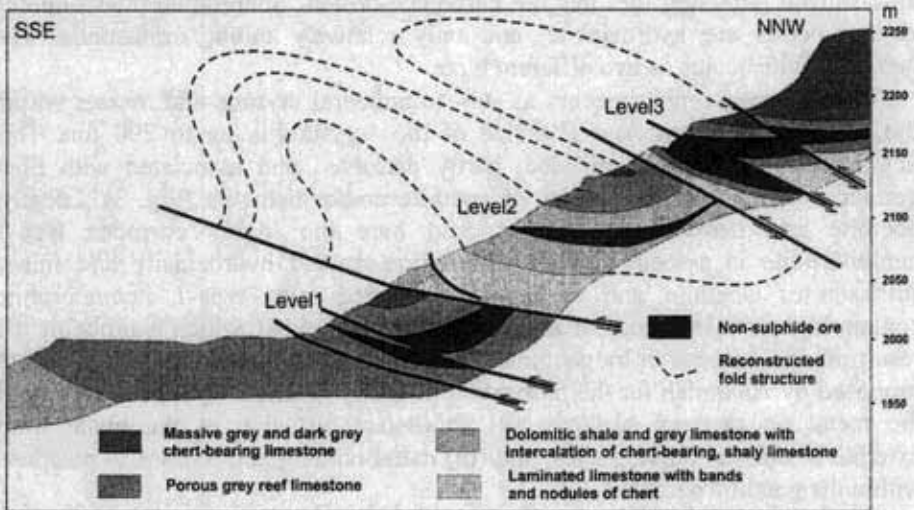


Fig. 2 Schematic x-section NNW-SSE of the folded and faulted strata at the Calamine Mine area. The ore-bearing strata are stacked in three main units due to folding, faulting, and thrusting. The dotted line indicates reconstructed fold shapes [4].

The calamine ore is predominantly hosted within the massive limestone of the K^{12}_a member of the Abkuh Fm. (Albian), and particularly at the contact between the K^{12}_a and the K^{sh2}_a -member. The K^{sh2}_a -member consists of yellow to greenish dolomitic and calcareous shales and laminated limestones. These host rocks to the Calamine Mine are intensive faulted, brecciated and locally mylonitised. In contrast, the main sulphide/non-sulphide zinc orebody is hosted in the stratigraphically-lower Taft Fm. (Barremian/Aptian) [2].

3.2 Mineralogy of the non-sulphide ore

The ore is carbonate-hosted by limestone and low magnesium dolomitic limestone. The distribution of the mineralization and the ore textures are highly dependent on the scale of observation. The occurrence of the ore is strata-bound on a regional scale, but underground the mineralization is spatially related to faults, fault-breccias, and possibly to localized (karst) solution collapse breccias. Most fault breccias show a high content of zinc and lead within the matrix (Table 1), whereas the wallrock shows relatively low concentration of base metals.

It is important to note, that the predominant ore mineral is hemimorphite, a

zinc-silicate, although the ores are carbonate-hosted. Subordinate non-sulphide zinc minerals are hydrozincite, and only relatively minor smithsonite. The hemimorphite occurs as two different types:

Type-1 hemimorphite occurs as sub- to anhedral crystals and masses within the matrix of the breccias. The size of the crystals is up to 200 μm . This hemimorphite is highly corroded, partly dissolved and associated with fine-grained coatings, which consists of goethite and/or hematite (Fig. 3). Locally, goethite and hematite are absent, and here the highly corroded type-1 hemimorphite is associated with white, fine-grained hydrozincite and minor smithsonite. Goethite and hematite, associated with type-1 hemimorphite contain high concentrations of zinc (approximately 15 %), which is probably the result of zinc adsorption by goethite (Ankomah, 1992). Several mechanisms are proposed by Ankomah for the adsorption of Zn by goethite: (i) the adsorption of the metal on external surfaces, (ii) solid-state diffusion of the metal from external to internal binding-sites, and (iii) metal binding and fixation at positions within the goethite particles.

Type-2 hemimorphite occurs commonly in veins and open spaces of fault zones and -breccias, and in the matrix of fault breccias as euhedral crystals, which have grown perpendicular to the underlying surface of fractures and spaces. The size of the type-2 hemimorphite is up to 300 μm .

Hydrozincite is a minor component within the goethite-rich breccia matrices, associated with type-1 hemimorphite. However, hydrozincite is the predominant zinc mineral within several fault zones, and fault breccias, and occurs also associated with type-1, and type-2 hemimorphite. Other zinc minerals, such as hetaerolite, or sauconite are rare. The main lead-bearing minerals of the Calamine Mine are mimetite, and small amounts of segnitite. Mimetite occurs commonly as yellow needles and aggregates, which are segmented into numerous small euhedral crystals (Fig. 4).

Table 1 Average concentrations of typical, goethite-rich non-sulphide ore samples. (n = 9, ICP-MS, all concentrations in ppm).

Cu	Pb	Zn	Co	Ni	Ag
44	17518	360003	25	72	7

Cd	Sb	Mo	Sr	As
365	339	4	694	7217



Fig. 3 SEM-photograph of a typical boxwork structure, which consists of 'onion-skins' of porous goethite (white arrows), containing some 15% Zn and relict core (black arrow) of partly dissolved hemimorphite (type-1).

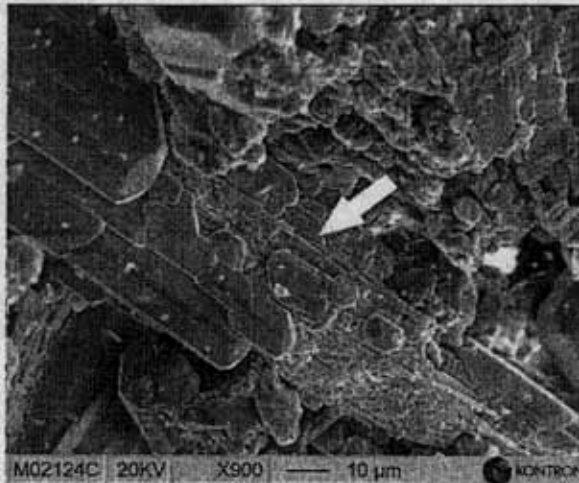


Fig. 4 SEM-photograph of a euhedral mimetite aggregate (white arrow) enclosed by and small grains of anhedral barite. Textural evidence suggests that the barite has undergone partial dissolution.

3.3 Geochemistry and ore-genesis

The supergene, non-sulphide ores are, not surprisingly, characterised by very high Zn-, high Pb-, and very low Ag-contents (Tab. 1). However, unexpectedly high concentrations of As, Sb and Sr, point to (a) complex and exotic metal source(s) than expected for typical carbonate-hosted Zn-Pb deposits. A hydrothermal input from a magmatic source appears to be likely and this phenomenon will be the focus of our forthcoming studies.

The present ore body has formed during several stages, during which formation, dissolution, and re-precipitation appear to have been competing processes with hemimorphite and hydrozincite being the ore minerals.

Type-1 and type-2 hemimorphite represent different stages of the ore-forming process of the Calamine Mine orebody. After Takahashi (1960) and Ingwersen (1990), the precipitation of hemimorphite can be described as an equilibrium reaction between hemimorphite and smithsonite/hydrozincite, which is mainly controlled by the partial pressure of CO₂ (PCO₂), pH, and the concentration of H₂SiO₄. Hemimorphite becomes more stable under relatively low PCO₂ (< 10⁻² bar) and low pH (< 6,9) conditions. After the formation of hemimorphite-dominated ore, the geochemical conditions have apparently changed. Hemimorphite became unstable under these new conditions and was probably altered to hydrozincite. According to textural observations, the alteration of hemimorphite to hydrozincite has been accompanied by the precipitation of goethite and/or hematite.

A reason for the pH-change might have been a rise in PCO₂, possibly due to microbial CO₂ production within the soil profile and ground water of the palaeo weathering surface under a more humid (palaeo-) climate. Under these conditions, hydrozincite is the more stable zinc mineral compared to hemimorphite. However, part of the liberated zinc ions formed a separate, iron-free non-sulphide ore phase, hydrozincite, within fault- and karst-breccias. During a third stage, the climate changed to the present arid to hyper-arid climate, and hemimorphite became more stable again and euhedral type-2 hemimorphite precipitated within fractures and open spaces, locally overgrowing the earlier mineral phases.

4 Conclusions

The non-sulphide ore of the Calamine Mine at Mehdi Abad occurs on three different levels due to tectonic repetition. At least three different stages of ore formation or alteration have been identified:

i) Precipitation of stage-1 hemimorphite (and possibly minor smithsonite, hydrozincite, goethite, and hematite) within the fault-zones and breccias.

- ii) Alteration of hemimorphite to hydrozincite, and precipitation of goethite/hematite.
- iii) Precipitation of type-2 hemimorphite as mineralisation within fractures and open spaces of the fault-breccia and the non-sulphide ore without significant precipitation of goethite/hematite.

No clear indications for sulphide protore have been identified yet, which might be due to the thorough oxidation, folding, and faulting of the strata and solution collapse. The non-sulphide mineralizing and ore-modifying processes at the Calamine Mine of Mehdi Abad appear to be relatively young or have continued until relatively recently. Mineralized breccias of tectonic and solution collapse origin document the earlier stages of the non-sulphide mineralization. Locally, the open, partly mineralized pore-, fracture-, and breccia-spaces contain extremely delicate dissolution textures and euhedral supergene non-sulphide zinc minerals without deformation by folding or gravitational compaction. The processes of ore formation, partial dissolution, and re-precipitation have only been terminated and 'mummified' by the current arid to hyper-arid climate.

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