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GEOLOGY AND MINERALISATION OF THE IOCG-TYPE OLYMPIC DAM DEPOSIT (SOUTH AUSTRALIA)

Рассмотрено геологическое строение и минеральный состав руд крупнейшего месторождения золота и меди Олимпик Дам (Австралия). Руды месторождения преимущественно прожилковые и состоят из флюорита, гематита, серицита, хлорита, барита, сидерита, доломита, кварца и сульфидов меди. Обсуждаются модели формирования и источники рудных компонентов, включая мантийные и седиментогенные.

The supergiant polymetallic Olympic Dam (OD) deposit is the world's largest uranium deposit, and fourth largest gold and copper deposit with significant Ag quantities and a total resource of about 9 Mt [BHP Billiton Annual Report, 2012].

The OD is located in South Australia and represents the type locality for Iron-Oxide-Copper-Gold (IOCG) deposits [Hitzman et al., 1992]. It is hosted by the Olympic Dam Breccia Complex (ODBC) that is situated within a Mesoproterozoic Roxby Downs Granite. This granite was intruded by numerous ultramafic and mafic dykes [Johnson & McCulloch, 1995; Ehrig et al. 2013]. The ODBC is covered by undeformed Late Proterozoic and Cambrian sedimentary rocks of the Stuart Shelf [Johnson & McCulloch, 1995].

According to Reeve et al. [1990], there are many types of different veins and veinlets in the deposit. They can contain fluorite, hematite, sericite, chlorite, barite, siderite, dolomite, quartz that may incorporate pitchblende and diverse copper sulphides. Some veins were precipitated within the fault zones and show multiple phases of brecciation. The paragenetic sequence though is very complex and multistage.

Geologists have been studying the genesis of the supergiant IOCG Olympic Dam deposit for more than 30 years, including numerous analyses such as radiogenic isotopes (U-Pb, Pb-Pb, Sm-Nd, Re-Os and Rb-Sr isotopes in various gangue and ore minerals), stable isotopes (C-O isotopes in siderite, O isotopes in magnetite, hematite, quartz and whole rock samples), fluid inclusion studies (siderite, quartz, fluorite), chemical composition (including REE) of some minerals and whole rock samples etc. However, there still exist many issues regarding its formation and especially sources of elements like U, Fe, Cu, REE, S and C. In addition, the ages of the multiple mineralisation events at the OD are still enigma. The proposed models for formation of the ODBC range from the maar-diatreme setting with a fluid mixing and mantle contribution to the mineralisation [e.g. Oreskes & Enaudi, 1992] to sedimentary-dominated [e.g. McPhie et al., 2011].

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DEVONIAN Fe-Mn NODULES OF THE URALS PALEOOCEAN

На марганцевых месторождениях Урала изучены Fe-Mn конкреции разной формы и величины, характеризующиеся присутствием структур роста и облекания, наличием реликтовой слоистости в законсервированной внутренней части и повышенными содержаниями Cu (46–325 г/т), Ni (47–144 г/т), Co (36–184 г/т), Ba (37–6467 г/т), U (0.2–2.78 г/т), сопоставимые с железомарганцевыми конкрециями современных океанов. Реликты вулканокластики и биоморфных структур в конкрециях свидетельствуют о важной роли литогенного и биогенного фактора в их формировании. Низкие содержания РЗЭ, небольшие вариации в аномалиях Ce (от –2.7 to +0.28) и появление небольшой положительной Eu аномалии в спектре РЗЭ конкреций отражают трансформации, происходившие в диагенетических процессах.

Introduction

Several metallogenic zones, including Sakmara, Magnitogorsk, and East Uralian zones, are distinguished in the Urals foldbelt. They are considered to be the paleogeodynamic sectors, corresponding to the marginal sea, island arc system, and uplift, respectively [Prokin, Buslaev, 1999]. Manganiferous rocks in the Southern Urals are hosted in the basalt-rich volcano-sedimentary complex of the Magnitogorsk paleoisland arc system, which consists of the West and East Magnitogorsk island arcs and Sibai inter-arc basin [Gavrilov, 1972]. The manganiferous mineralization occurs in association with the Middle Devonian stratabound hematite-quartz rocks and bedded red jaspers localized on the foot or hanging walls of massive sulfide deposits [Maslennikov et al., 2012]. Fe-Mn nodules are widespread in the jasper horizons, which occur at the flanks of manganese deposits. We have studied Fe-Mn nodules from the Faizulino and Yanzigitovo Mn-deposits, which were formed in the Sibai inter-arc basin, and compared them with well known Fe-Mn nodules from the modern oceans.

Methods

Identification of Fe-Mn nodules was based on their superficial color, external morphology and size. Selected samples were cut vertically in two parts with respect to their position on the seafloor. Individual nodules of special interest for mineralogical and geochemical determinations were first thoroughly examined in reflected light and by SEM microscopy. The internal structure was described, outlined and photographed. The chemical composition was analyzed with atomic absorption (AAS) using a Perkin Elmer 3110. The trace elements and REE concentrations were determined using induced coupled plasma mass spectrometry on a Agilent Technologies 7500 cx in the Center for Geo-Environmental Science, Faculty of Engineering and Resource Science, Akita University.

Faizulino deposit

Manganese nodules 1.5 ? 2 cm in size and less occur in the top of the jasper horizon and are hosted in the fine hyaloclastic siliceous rocks. Most of them have oval, lenticular, lens, and mushroom-shaped morphology with columnar structure of prominent sinters and thin-laminate external layers. The well visible outer layering is caused by stratification of separate Mn and Fe layers with thickness up to 1 mm. The layers differ by reflection resulted from enrichment in Mn or Fe. The nodular cores have complicate structure with relict lamination in the internal part. The non-opaque fine volcanic glass is scattered inside the manganese minerals. All varieties of the nodules contain abundant microfossil molds and silica filaments (Fig. a).

The Mn layers are composed of fine-grained K-psilomelane, which replaces jacobsite. The composition of K-psilomelane is as follows (wt %): MnO* 71.70–89.44, FeO* 1.20–13.27, SiO_2 0.83–2.00, Al_2O_3 0.44–3.52, TiO_2, 0.42–0.59, K_2O 0.96–1.22, CaO 0.89–1.17.

Jacobsite has gray color with a specific olive shade in the matrix of ferruginous layers. Its composition varies relative to stoichiometric species (wt %): MnO* 48.51–58.88, FeO* 25.49–37.99, SiO_2 0.75–2.08, Al_2O_3 1.81–2.87, TiO_2 0.40–0.42, K_2O 0.64–0.77, CaO 0.62–1.07.

Numerous magnetite crystals with a good facet occur in the core and Fe-rich layers of the nodules. Magnetite is enriched in MnO* (up to 3.73 wt %) and TiO_2 (up to 3.69 wt %) and, locally, it has extraordinary high Mn and Ti contents (wt %): MnO* 12.35–17.25, FeO* 57.80–70.12, SiO_2 0.58–1.87, Al_2O_3 1.08–2.09, TiO_2 15.20–21.09 (pyrophanite?). The elevated Mn and Ti contents in magnetite could possibly be related to the replacement of Ti-hematite. The replacement textures are observed in the nuclear part of the nodules, where ferruginous minerals predominate above the manganese ones. The cores of the nodules are enriched in volcanic glass identified by the higher Al, Mn, Fe, and K contents and sporadic pyrite inclusions.

Yanzigitovo deposit

Manganese nodules are localized at the contact of the hematite-quartz lens and hanging wall jaspers. Several horizons with manganese nodules indicate the discontinuous and periodical formation of nodules. Nodules have slightly asymmetric structure, rough surface, and sharp contacts with overlying rocks and are composed of Mn-oxides, clasts of felsic glass and microconcretions of Mn-biotite filaments overgrown by Mn-oxides. Ba-psilomelane is the major manganese mineral of the nodules (wt %: MnO* 76.73–78.33, BaO 12.57–14.69, K_2O 0.54–0.72, CaO 0.70–0.97). Numerous inclusions of radiolarian are widespread in the external layers of the nodules (Fig. b). Supergene processes formed veins and nests with late Mn-oxide.

Chemical composition of nodules

Manganese (5–40 wt %), iron (1–15 wt %), and silica (14–40 wt %) are the principal components of the nodules admixed with varying contents of (wt %) Al_2O_3 (2–5), MgO (0.4–1.3), Na_2O+K_2O (0.7–2.2), CaO (2–3), and P_2O_5 (0–0.07). The high concentrations of Zr, Ti, V and Al are probably related to the relict volcanic glass. The variations of concentration (ppm) of Cu (46–325), Ni (47–144), Co (36–184), Ba (37–6467), Sr (35–527), V (0.51–214), Zr (1–135) and U (0.2–2.78) are the specific features of nodules.

The nodules show low REE contents (up to 155 ppm) and Ce/La ratio (0.42–1.73) compared to the average content of the hydrogenous deep-seabed nodules from the oceanic areas and also exhibit a negative Ce anomaly. Magnitude of the Ce anomaly, ranging from –2.7 to +0.28, was calculated using the equation of log [3Ce/(2La+Nd)], where Ce, La, and Nd are the NASC normalized values [Elderfield et al., 1981]. The positive Eu anomaly indicates the presence of hyloclastic detritus and mineral precipitation from the fluids with a hydrothermal component under reduced conditions. The nodules are enriched in LREE that is evident from the La/Lu* ratio ($[La_{sample}/La_{shale})/(Lu_{sample}/Lu_{shale})]$) of 0.54–1.85.

Discussion and conclusions

Fe-Mn nodules, which were formed in the Devonian Urals paleoocean, could be compared with those from the modern oceans. Good preservation of delicate textures of the nodules is related to their fast overlapping by the fine-grained sediments. The morphology and columnar structure of the nodules are also typical of modern Fe-Mn nodules [Halbach et al., 1981; Baturin and Dubinchuk, 1989; Banerjee et al., 1999]. The nodules are diverse in shape and Fe and Mn contents. The external zones of the nodules have layered structure. The growth structures are most typical for nodules in contrast to the corrosion, excluding dissolution of volcanic glass and its replacement by manganese minerals

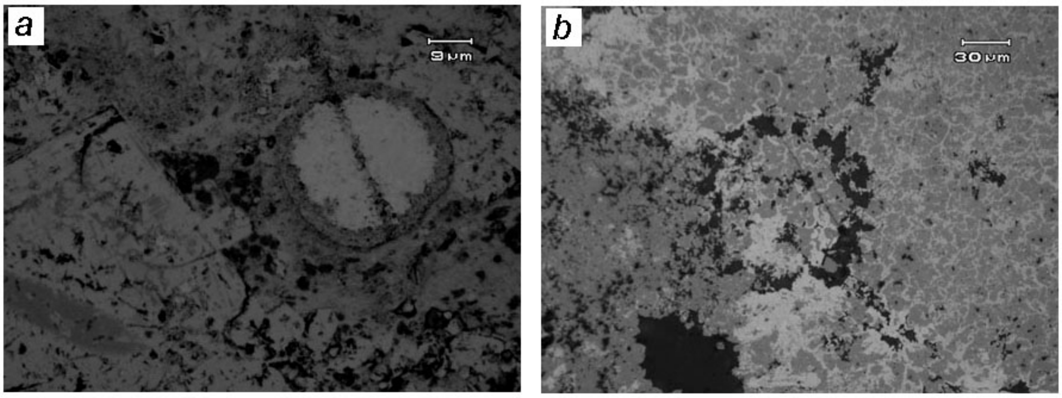

Fig. Microfossils in the Fe-Mn nodules: a – Faizulino, and b – Yanzigitovo deposits.

The common presence of radial cracks, cross-cutting the oxide layers, and the high porosity and permeability of the nodules are evidences of somewhat open formation conditions. The primary manganese minerals (probably, manganite and vernadite) of the nodules have not been found yet and the occurrence of jacobsite in the Faizulino deposit points to some degree of postsedimentary alteration.

It is suggested that the volcanic glass is one of the main source of Fe and Mn owing to their correlation with high Ti and Al content. The biogenic (mainly radiolarian, some individual filaments, and spheroidal microforms) relics in the nodules are thought to play a vital role in the variation of chemical composition (possibly including radionuclide) in the internal part of the nodules, since plankton is known to scavenge the trace metals during the life cycles similar to the modern Fe-Mn nodules [Ehrlich, 1980]. An accumulation of some amount of K^+ in the filaments may be also related to the organic matter [Harder and Dijkhuisen, 1983].

Thus, the studied nodules are comparable to the modern counterparts by high grades of Ni, Co, Ba, Cu, and elevated of Fe contents. The depletion in ΣREE in the nodules may reflect diagenetic processes. The formation of Fe-Mn nodules could represent a combination of hydrogenetic and diagenetic conditions under important role of biogenic factor.

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BIOMORPHIC SIGNATURES OF METALLIFEROUS FERRUGINOUS AND MANGANIFEROUS ROCKS FROM THE URALS VMS DEPOSITS

В оксидно-железистых и марганцевых продуктах придонных преобразований известковисто-сульфидно-гиалокластитовых осадков колчеданных месторождений Урала обнаружены