Origin of Late Cretaceous ironstones Deposits, Northern Oman Mountains, Oman: REE geochemistry approach

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- Ironstone deposits developed on the top parts of the lateritic soil of the Late Cretaceous, Northern Oman Mountains during the early Cretaceous time
- Seven ironstone beds were sampled and examined for petrographic and geochemical analyses, but here we report only the REE geochemistry, with the following objectives:
  - ✓ Investigate the REE's mobility within the ironstone deposit.
  - ✓ examine the origin of ironstone deposition based on REEs study
- The present study is part of large investigation of Phanerozoic ironstones deposits in Northern Oman Mountains, which include petrology, major and minor element geochemical analyses and SEM analyses. This study represents the first investigation of ironstone deposits associated with the laterite soil in the Late Cretaceous Northern Oman Mountains

1. Geological seating:

The 600 km long by 150 km wide and 5 to 10 km thick Late Cretaceous (ca. 78 Ma BP, Coleman, 1981) obducted Semail Ophiolite of Oman represents one of the world's best and most complete examples of well-exposed Alpine–Himalayan fold belt (Searle and Malpas, 1980; Glennie et al. 1974; Coleman, 1981; Lippard et al., 1986; Peters et al., 2005). Shortly after the obduction of this Semail Ophiolite, it undergone intensive weathering to develop laterite profiles in some areas of the northern Oman Mountains (Fig. 1). See Al-Khirbash (2015, 2016) for detailed work on the laterite soil.

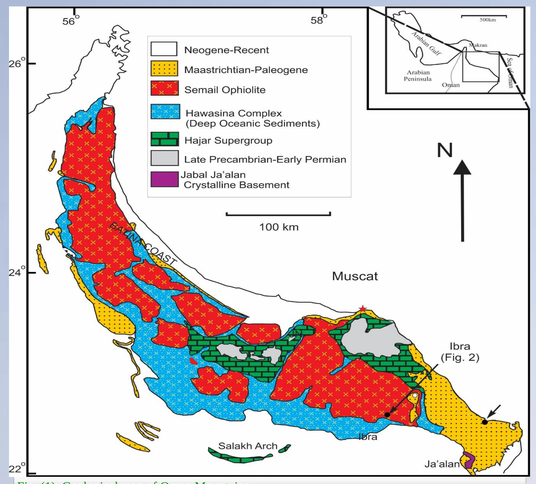


Fig. (1): Geological map of Oman Mountains

2. Geology of the ironstone bed:

Ironstones, particularly\ the oolitic ironstones are important source of iron. The term iron-rich is restricted to sedimentary rocks that contain at least 15% of total iron (Kimberley, 1994). Ironstone term is used for non-banded, non-cherty, commonly oolitic, iron-rich sedimentary rocks (Boggs, 2006).

The present study is based on the investigation of seven iron localities (Fe-1, Fe-2, Fe-3, Fe-4, Fe-5, Fe-6, and Fe-7) within the Northern Oman Mountains (Fig. 1). It varies in thickness from few meters to about 16 meters. The ironstone bed is underlain by the peridotie or layered gabbro that had undergone extensive weathering forming the saprolite zone and directly capped by the Palaeogene carbonates rocks in some areas (Figs. 3a,b).

The ironstones occur generally as massive lenticular beds as in the southern parts (Fe-7, Fig. 3c) or as laminated or pisolitic/oolitic beds as in the northwestern parts of the study area (Fe-1, Fe2, Fe-5) (Figs.3d,e). It covers but the overlaying carbonate scree (Fig. 3f)

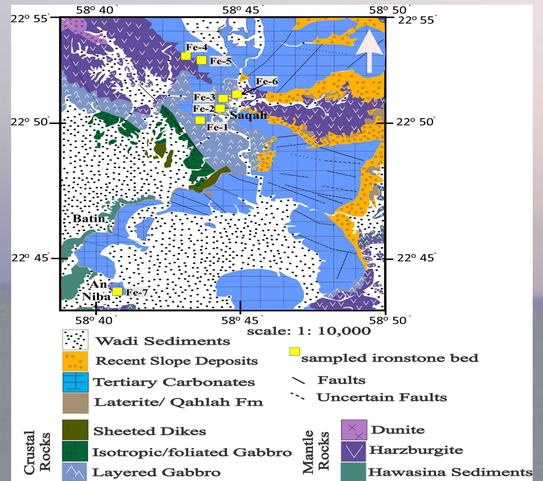


Fig. (2): Geological map showing the location of the sampled ironstone beds (modified after Peters et al., 2005).

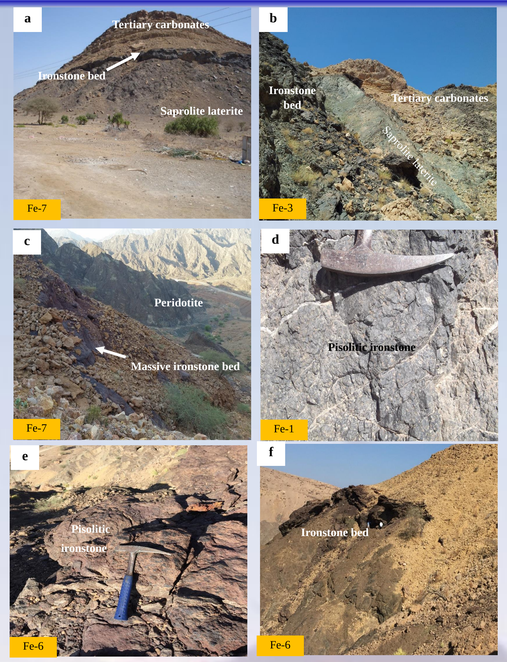


Fig. (3): Field photos showing the occurrence of the studied ironstone beds.

3. Petrology & Mineralogy

Mineralogical observation and back scattered electrons (BSE) images of the studied ironstones from Northern Oman Mountains indicated that they are composed mainly of hematite, magnetite, goethite, in addition to secondary chlorites, carbonates, gypsum, chromite, and sulfates (Fig. 4a).

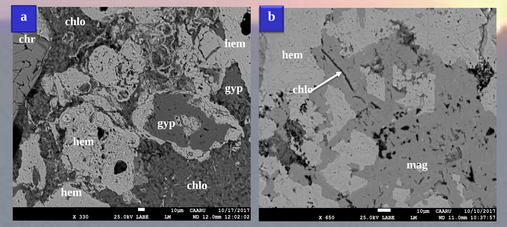
Magnetite occurs as rounded or anhedral grains with different sizes. It replaces by hematite or surrounding and replacing chromite grains (Figs. 4a,b,c). Hematite also occurred as large crystals that been replaced by secondary carbonate or chlorite (Figs. 4d,e,f)

Chromite grains including Cr spinels are of different sizes and shapes. They are inherited and normally intensively fractured and replaced by hematite. They appear in the BS images as gray cracked individual fresh grains. These fractures are filled with magnetite (Fig. 4g) and gypsum.

Chlorite (mostly chamosite) appears as individual grains or replacing and cross cutting other mineral phases such as iron-oxides or within the groundmass and surrounding the ooids (Figs. 4h,i). The pisolites are concentric with magnetite, quartz grains, clay fragments nuclei and kaolinite thin layer alternating hematite (Fig. 4i). Some of these pisolites contain several smaller pisolites/oolites which might reflect that they occurred in energetic environment.

Other carbonate, gypsum, and alunite are present as secondary products filling fractures, ooids, and replacing oxide minerals (Figs. 4h,j)

Small inclusions of Millerite? (NiS) are observed within the magnetite grains for the first time in this ironstone bed (Fig. 4h).



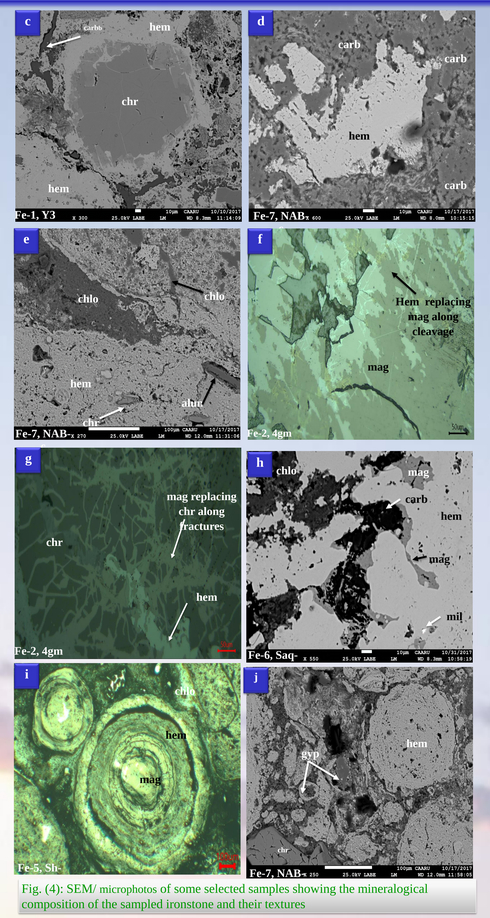


Fig. (4): SEM/ microphotos of some selected samples showing the mineralogical composition of the sampled ironstone and their textures

4. REE geochemistry

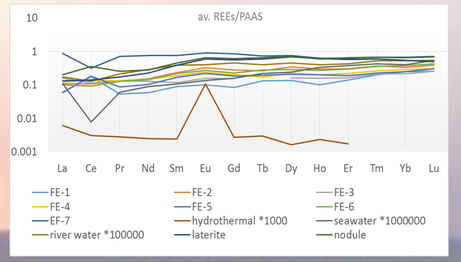


Fig. 4. PAAS-normalized REE patterns of ironstone samples showing HREE enrichment and a negative anomaly in Ce. Other sources (fresh and sea water, hydrothermal fluids, nodules) were included in the Fig. for comparison. Contribution of sea and fresh (meteoric) water, in addition to fraction of terrigenous source is evident. Compared to REEs in the underlain laterite soil, there is less enrichment in middle REEs (MREEs). Hydrothermal fluids have different patterns which exclude their contribution in the deposition of ironstone.

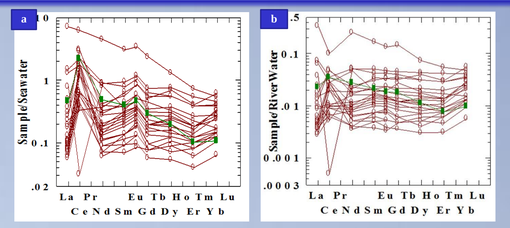


Fig. 5. Normalized REE patterns of ironstone samples to (a) seawater and (b) river water. Both patterns are flat without fractionation except for Ce which may reflect detrital inputs buffering the negative anomaly in Ce. Although the REE concentrations in the ironstone are more than 1000 times higher than sea and river (meteoric) water, but such patterns reflect the role of seawater and meteoric waters in the deposition of ironstone. Note: sample NAB6 is distinguished by its high concentrations of REEs and its enrichment in LREEs which may be related to an important detrital inputs compared to the other samples. In the opposite sample Saq-4 is distinguished by its low content of REEs and its very significant negative Ce anomaly in relative to the sea and to meteoric waters which may suggest a less detrital inputs and maybe remobilization of Ce.

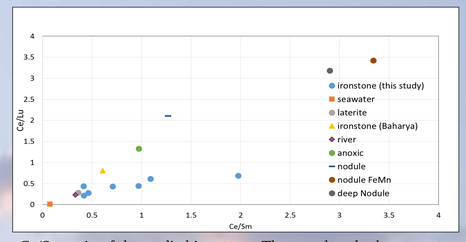


Fig. 6. Ce/Lu vs Ce/Sm ratio of the studied ironstone. The samples plot between two endmembers the seawater (Ce/Lu = 0.015 and Ce/Sm=0.074) (Freslona et al, 2014) and Fe-Mn Nodules (Ce/Lu =3.4 and Ce/Sm=3.3) (Dubinin and Sval'nov, 2000). Most of samples are more enriched in Ce than the underneath laterite soil. River water and ironstone samples from Afify et al., (2015) have higher Ce/Lu ratio than ironstone of the present study.

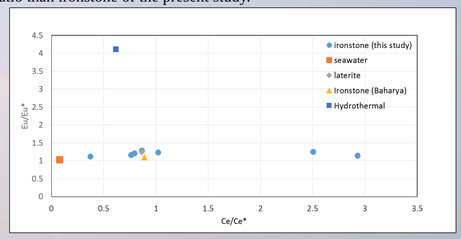


Fig. 7. Based on the relationship between Eu and Ce anomalies, there is more fluctuations of Ce/Ce* generating positive and negative anomalies which may reflect the oxydo-reduction conditions associated with fluctuation of water level. The Eu anomaly is less affected by these fluctuations which might indicate that there is an involvement of meteoric water into the depositional environment.

5. Conclusions

- The ironstone within the study area varies in thickness from few meters to up 16 m and it is composed of hematite, magnetite, and goethite as the main iron minerals, in addition to some silicates, carbonates, and inherited chromite and authigenic chlorite.
- The present study represents the first geochemical study on ironstone deposits in Northern Oman Mountains
- Ironstone deposits are characterized by a wide range of REE element geochemistry ranging from 1.55 ppm to 373 ppm
- PAAS normalized patterns show an enrichment in heavy rare earth elements (HREEs) relative to light REEs (LREEs).
- The positive and negative Ce anomalies might reflect a fluctuations in depth of basin water during transgressions and regression episodes which led to mixing of reducing sea water and oxidizing meteoric water during the deposition of iron
- No evidence for hydrothermal system contribution in ironstone deposition