

Earth's surface environments inferred from chemical sedimentary rocks deposited in a shallow ocean 3.2 billion years ago

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Geochemical data of ferruginous chemical sedimentary rocks (e.g., Banded Iron Formation: BIF) has been used for understanding the surface environments on early Earth. For example, Konhauser et al. (2011) recently argued that river waters became acidic to chemically mobilize Cr 2.48 billion years ago without involving any redox reactions, using the Cr/Ti ratios of various BIF samples throughout Precambrian era. However, comparing BIFs formed in different depositional environments is problematic since BIF that they found anomalous Cr/Ti ratios is the only one deposited from a shallow water environment in Archean BIFs. If Cr was mobilized in river waters, soluble Cr would have been precipitated in a shallow water environment. Therefore, we investigated geological, petrographic and geochemical characteristics of a newly found outcrop of ferruginous rocks in the Moodies group in the Barberton Greenstone Belt, South Africa, which has been interpreted to be deposited in a shallow ocean 3.2 billion years ago (e.g., Javaux et al., 2010). We also obtained unweathered ferruginous rocks in the Moodies group from an underground mine, and compared the characteristics of these samples. The objectives of this study are (1) to find chemical precipitates from a shallow water in the Moodies group; (2) to distinguish clastic and chemical components of the sedimentary rocks; and (3) to infer the depositional processes/environments of the chemical precipitate.

We collected 70 sedimentary rock samples of the Moodies Group. Samples were divided into Hematite-rich chert (HM group), Magnetite-rich chert/shale/sandstone (MT group) and Siderite-rich sandstone (SD group), based on the dominant Fe minerals. Samples in the HM group predominantly composed of fine-grained quartz (< 20 micro meter) and hematite (< 5 micro meter), which are interpreted to be chemical precipitates in origin. Samples in the MT group contain quartz, magnetite, siderite, ankerite, chlorite, biotite and chromite. The grain size of magnetite is much larger (20-150 micro meter) than that of hematite in the HM group. Magnetite is interpreted as a secondary mineral transformed from hematite during early diagenesis (Otake et al., 2007). Results of in situ oxygen isotope analysis by SIMS showed that magnetite in the Moodies group has similar $\delta^{18}\text{O}$ values to those in least metamorphosed BIFs. All chromite observed in the MT group is overgrown by magnetite. Samples in the SD group contain quartz, siderite, chlorite, biotite, and chromite. Chromite in the SD group is included in Mg-rich siderite or silicate minerals (e.g., chlorite and biotite). Oxygen isotope compositions of chromite indicate that chromite in both MT group and SD groups was hydrothermally altered.

Results of geochemical analyses of the bulk outcrop samples showed that $\text{Fe}_{\text{Total}}/\text{Ti}$ and Cr/Ti ratios of outcrop samples increase concordantly in the ferruginous zone, particularly in the MT group. The Cr/Ti ratios of the underground samples also increase with increasing the $\text{Fe}_{\text{Total}}/\text{Ti}$ ratios. On the other hand, Th/U ratios of the underground samples decrease with increasing with the $\text{Fe}_{\text{Total}}/\text{Ti}$ ratios. The changes in the Th/U and Cr/Ti require the oxidation of U and Cr to decouple geochemical behaviors of U and Cr relative to Th and Ti, respectively. The correlations of $\text{Fe}_{\text{Total}}/\text{Ti}$ ratios with U/Th and Cr/Ti ratios indicate that dissolved Cr and U species in ocean were coprecipitated with ferric (hydr)oxides during the formation of ferruginous rocks. These results suggest that a part of shallow ocean was oxygenated -3.2 Ga, containing oxidized Cr and U species, and that ferric (hydr)oxides were precipitated due to the oxidation of dissolved ferrous iron by molecular oxygen.

References

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