Depositional age and geochemistry of the 2.44-2.32 Ga Granular Iron Formation, Songshan Group, North China Craton: Tracing the effects of atmospheric oxygenation on continental weathering and seawater environment

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We firstly found that Granular Iron Formation (GIF) occurring in the Songshan Group of the North China Craton was deposited at the period of 2.44-2.32 Ga via detrital and magmatic zircon U-Pb dating. Positive $\delta^{13}C$ excursion in carbonates located in the upper and lower levels of the GIF in the Songshan Group further indicates elevation of atmospheric oxygen at 2.44-2.32 Ga. No significant correlations between redox-sensitive trace elements (Cr, V, Mo and U) and Al_2O_3 suggest that they are authigenic enrichments in the Songshan GIF. The enrichment of Cr contents and Cr/Ti ratios of the Songshan GIF and its authigenic hematite indicate that Cr was solubilized via strong continental oxidized weathering and subsequently Cr-rich drainage contributes to seawater. In addition, very high V, B and P contents in the Songshan GIF and its hematite also suggest continental oxidative weathering input. The Songshan GIF and its hematite exhibit significantly positive Ce anomalies and negative Y anomalies, which is different from most early Paleoproterozoic to Archean and after GOE IFs. These features probably resulted from Fe(II) slowly oxidation and deposition and further indicated shallow waters at 2.44-2.32 Ga were oxygenated but not enough for Fe(II) rapidly oxidation. Given that soluble Cr (VI) and V (V) transform into Cr (III) and V (III) in suboxic-anoxic bottom waters and then are removed via authigenic burial, high Cr and V contents of the Songshan GIF and its authigenic hematite favor a scenario for deposition of the GIF in which precipitation occurred due to upwelling of deep, anoxic, reduced Cr-V-rich ferruginous waters into an oxygenated, high productivity shallow-water setting. Oxidation of shallow water at ca. 2.45-2.10 Ga is a gradual process.