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Review

Redox variations in the inner solar system with new constraints from vanadium XANES in spinels

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Abstract

Many igneous rocks contain mineral assemblages that are not appropriate for application of common mineral equilibria or oxybarometers to estimate oxygen fugacity. Spinel-structured oxides, common minerals in many igneous rocks, typically contain sufficient V for XANES measurements, allowing use of the correlation between oxygen fugacity and V *K* pre-edge peak intensity. Here we report V pre-edge peak intensities for a wide range of spinels from source rocks ranging from terrestrial basalt to achondrites to oxidized chondrites. The XANES measurements are used to calculate oxygen fugacity from experimentally produced spinels of known f_{O_2}. We obtain values, in order of increasing f_{O_2}, from IW-3 for lodranites and acapulcoites, to diogenites, brachinites (near IW), ALH 84001, terrestrial basalt, hornblende-bearing R chondrite LAP 04840 (IW+1.6), and finally ranging up to IW+3.1 for CK chondrites (where the ΔIW notation = $\log f_{O_2}$ of a sample relative to the $\log f_{O_2}$ of the IW buffer at specific *T*). To place the significance of these new measurements into context we then review the range of oxygen fugacities recorded in major achondrite groups, chondritic and primitive materials, and planetary materials. This range extends from IW-8 to IW+2. Several chondrite groups associated with aqueous alteration exhibit values that are slightly higher than this range, suggesting that water and oxidation may be linked. The range in planetary materials is even wider than that defined by meteorite groups. Earth and Mars exhibit values higher than IW+2, due to a critical role played by pressure. Pressure allows dissolution of volatiles into magmas, which can later cause oxidation or reduction during fractionation, cooling, and degassing. Fluid mobility, either in the sub-arc mantle and crust, or in regions of metasomatism, can generate values >IW+2, again suggesting an important link between water and oxidation. At the very least, Earth exhibits a higher range of oxidation than other planets and astromaterials due to the presence of an O-rich atmosphere, liquid water, and hydrated interior. New analytical techniques and sample suites will revolutionize our understanding of oxygen fugacity variation in the inner solar system, and the origin of our solar system in general.

Keywords: Oxygen fugacity, meteorites, solar nebula, spinel, chromite, vanadium, Invited Centennial article