**Highlights and Breakthroughs**

**Spinel in planetary systems**

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**Abstract:** Spinel is ubiquitous as a rock-forming mineral in terrestrial, lunar, and planetary basalts and closely associated meteoritic equivalents. A major unknown is whether these rocks formed under similar conditions of partial melting of primary or modified mantle, whether redox environments played a role in evolutionary trends, and did mineral crystal chemistry have any influence on elemental partition between solids and liquids? In a novel approach by Papike et al. (2015), spinel is used as an informative, albeit complex indicator of oxygen fugacity, site occupancy of multiple valence elements, and spinel structural types. Planetary basalts may be reduced (IW-3), oxidized (Earth at FMQ), or of intermediate redox state (Mars). Taking an expansive view, the spinel approach holds enormous promise in understanding the magmatic differentiation of asteroids. **Keywords:** Spinel, inverse spinel, planetary systems, asteroids

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**Spinel:** Latin *spina*, spine [or thorn in allusion to the sharp-edged skeletal form of quenched crystals in basalts and slags (Haggerty 1976)]. **Spinel:** Among the first minerals to be examined by X-ray analytical techniques (Bragg 1915a, 1915b), preceded by another cubic mineral, diamond in 1913. **Spinel:** Solid solution members (chromite to ulvöspinel-magnetite) and ilmenite form the unheralded oxide third arm to Bowen’s magmatic silicate crystallization series of olivine to quartz, and anorthite to albite. **Spinel:** In association with ilmenite solid solutions was the first experimentally determined temperature and oxygen geobarometer ($f_{O_2}$) (Lindsley 1976) to show, on application to igneous rocks across the silica spectra, that basalts and gabbro indeed formed at higher $T$ and lower $f_{O_2}$ than corresponding rhyolite and granite that crystallized at lower $T$ and higher $f_{O_2}$ (Buddington and Lindsley 1964). **Spinel:** In structurally transformed olivine (ringwoodite), demarcates the boundary between the upper and lower mantles in Earth.

With classic papers by Irvine “**Chromian spinel as a petrogenetic indicator**” (Irvine 1965; Irvine 1967) and the experimental study by Hill and Roeder (1974) on “**The crystallization of basalt as a function of oxygen fugacity**,” let’s fast forward to the latest study of the spinel mineral group in martian basalts. Forward, not

“**Classic**” spinel crystallizes early and at relatively low $f_{O_2}$. With increasing crystallization, there is a continuum in compositions from high Cr and Mg to increasing concentrations of Fe$^{2+}$, Fe$^{3+}$, and Ti$^{4+}$; this is accompanied by a progressive change to the inverse spinel structure and as Papike et al. (2015) convincingly show, V$^{2+}$ changes to V$^{3+}$ as $f_{O_2}$ becomes more oxidizing on cooling. There are compositional miscibility gaps between “classic” and inverse spinel groups (summarized in Haggerty 1976); the discontinuity in structural types may not be sharp but “domains” of inverse structure may persist (must as Papike et al. 2015 note) to accommodate Ti and limited quantities of ferric iron. Chrome

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1 There is nothing “**Normal**” about this distribution. And that applies equally to Earth’s geomagnetic polarity so “**Classic**” is suggested, and indeed is preferred.