THE STUBBORNLY PERSISTENT REDOX GAP BETWEEN E AND H CHONDRITES

T.J. McCoy[1], C.M. Corrigan[1], T.L. Dickison[2], G.K. Benedix[3], D.L. Schrader[4] and J. Davidson[4],
[1]Dept. of Mineral Sciences, NMNH, Smithsonian Institution, Washington, DC USA (mccoyt@si.edu), [2]Science Matters Consulting LLC, Washington, DC USA, [3]School of Earth and Planetary Sciences, Curtin University, Bentley, WA, Australia, [4]Center for Meteorite Studies, SESE, Arizona State University, Tempe, AZ USA

Introduction: Since Klaus Keil's earliest work on the modes and mineral compositions in ordinary [1,2] and enstatite [3] chondrites, the gap in compositions between equilibrated members of these two groups has been perhaps the largest among chondritic meteorites. Enstatite chondrites, dominated by Fs_{0-1} enstatite, are highly-reduced (~IW-5), whereas ordinary chondrites, olivine-rich to -dominant of Fa_{17-32} [4], are moderately reduced (~IW-1) [5,6]. In the half century since this pioneering work, the compositional gap has proven surprisingly robust and its reflection of oxygen fugacity has strengthened. In the classic Urey-Craig diagram of oxidized Fe vs. reduced Fe, a nearly continuous progression of redox exists between H chondrites and CI chondrites, whereas the gap between H and E chondrites has barely infilled.

Despite the persistence of this redox gap in chondrites, primitive achondrites, including acapulcoites, lodranites, ureilites, winonaites, and silicate inclusions in IAB irons, span the range of olivine/pyroxene and mineral compositions between E and H chondrites, as revealed for IAB silicates in an early paper by Bunch, Keil and Olsen [7]. In the last paper Klaus published [8], acapulocites and lodranites alone were shown to span the range $Fa_{\sim3-15}$. Numerous authors have argued that these meteorites experienced either oxidation or reduction at or near the peak temperature during partial melting, suggesting that these compositions do not reflect that of the precursor material. At the same time, some chondrites that close this gap were only known from unequilibrated members, lending uncertainty to whether an equilibrated member of these groups would fill the redox gap. If correct, these suggestions reinforce the redox gap observed in chondrites.

With the first recognition of a member of the acapulcoite-lodranite clan that samples the chondritic precursor, we revisit the redox gap between E and H chondrites to examine intermediate chondrites and why this gap persists.

Closing the Gap: Grove Mountains (GRV) 020043 [9,10] is a type 4 chondrite, with abundant, well-delineated, pyroxene-rich chondrules, microcrystalline mesostasis, polysynthetically striated low-Ca pyroxene, and similarities in mineralogy, mineral compositions ($Fa_{10.3}$, $Fs_{10.4}$), oxygen isotopic composition, and fO_2 (IW-2.2 to IW-3.5) to the acapulcoite-lodranite clan. GRV 020043, despite modest thermal metamorphism, suggests that features of acapulcoites previously attributed to reduction were inherited from the precursor chondrite.

Chondritic meteorites with mineral compositions ($Fa_{\sim11}$) lower than typical H chondrites, but similar bulk compositions, are known [11-13]. Although [11] argued for reduction, peak temperatures during type 4 metamorphism were insufficient, instead suggesting a chondritic redox state intermediate between E and H chondrites.

At the more reduced end of this gap, CB chondrites [14] and K chondrites [15] contain magnesian silicates (Fa_{2-3}) and plot between E and H chondrites in the Urey-Craig plot. While some members of these groups are not fully equilibrated, others exhibit little variation in olivine compositions.

Finally, the Pontlyfni winonaite (Fa_1) contains relict chondrules [16], suggesting that it may be the least metamorphosed winonaite, although its peak temperature (975°C) is high enough that reduction could have occurred.

Why the gap?: More than 50 years after the redox gap between E and H chondrites was revealed, it remains stubbornly persistent. While we now have chondritic meteorites that fill part of that gap, much of it remains. Sampling bias is possible, but with tens of thousands of meteorites collected over five decades, this seems like an unsatisfying explanation. The most obvious explanation is that chondritic materials within this redox gap accreted sufficient ^{26}Al to produce widespread partial melting, producing the primitive achondrites. If true, why did, for example, E and K chondrites survive unmelted? Further, where did this occur? Interestingly, the meteorites that fill this redox gap include both samples within the isotopically-defined NC and, in the case of CB chondrites, CC groups [17]. If these are indicative of nebular reservoirs, relatively reducing conditions must have occurred in both. This might suggest that accretion time, heliocentric distance, and redox were, at least in some cases, decoupled and that locally reducing nebular reservoirs could have existed at a range of heliocentric distances.

References: [1] Keil (1962) *JGR* **67**, 4055-4061. [2] Keil and Fredriksson (1964) *JGR* **69**, 3487-3515. [3] Keil (1968) *JGR* **73**, 6945-6976. [4] Rubin (1990) *GCA* **54**, 1217-1232. [5] Righter and Neff (2007) *Polar Science* **1**, 25-44. [6] Righter et al. (2016) *Am. Min.* **101**, 1928-1942. [7] Bunch et al. (1970) *CMP* **25**, 297-340. [8] Keil and McCoy (2018) *Chemie der Erde* **78**, 153-203. [9] Li et al. (2018) *GCA* **242**, 82-101. [10] McCoy et al. (2019) *Geochemistry* **79**, 125536. [11] Wasson et al. (1993) *GCA* **57**, 1867-1878. [12] Russell et al. (1998) *MAPS* **33**, 853-856. [13] Troiano et al. (2011) *GCA* **75**, 6511-6519. [14] Weisberg et al. (2010) *MAPS* **36**, 401-418. [15] Weisberg et al. (1996) *GCA* **60**, 4253-4263. [16] Benedix et al. (1998) *GCA* **62**, 2535-2553. [17] Warren (2011) *EPSL* **311**, 91-100.