Delineating biotic and abiotic carbonaceous material in the Apex chert

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The Apex chert in Western Australia has been the center of many debates about whether these rocks contain unambiguous evidence of the early biosphere. Originally, these rocks were described to contain cyanobacterial microfossils [1] although later studies have described these features as having a morphology [2] and mineralogy [3] inconsistent with life. Additionally, these rocks contain carbonaceous material (CM) of unknown origin. This CM as been described by some as being of abiotic catalytic origin [2], and by others as biogenic [4]. Although Raman spectroscopy is not sufficient in and of itself to determine the source of CM, including whether it is biogenic [5], we recently used Raman spectroscopy in a paragenetic framework to demonstrate that the CM is from at least two separate populations [6]. Here we show using high-resolution transmission electron microscopy (HRTEM) that the CM found in the Apex chert exhibits at least four different microtextures. As different types of CM have different carbon crystallinities, the sources of these microtextures can be determined, revealing CM produced by processes such as abiotic catalytic synthesis, meteoritic input, and biological synthesis. These four populations of CM, combined with the geological history of the area, reveals over a billion years of fluid mixing and CM redeposition. Our study reveals that while care should be taken when interpreting bulk chemical data in samples from the Apex chert, HRTEM can offer the ability to delineate biogenic CM from abiotic CM in Archean sedimentary sequences.

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Mg-isotopic evidence for CBb chondrule formation by condensation from an impact plume

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Chondrules are millimeter-sized spherules formed as molten droplets and are a major constituent of chondrite meteorites. Using U-corrected Pb-Pb dating, it has been showen that chondrule formation started contemporaneously with calcium-aluminium-rich inclusions (CAIs) and lasted several Myr [1]. Of interest are chondrules from the CB group, which in contrast to typical chondrules have exclusively non-porphyritic textures and magnesium-rich compositions. Their formation is believed to have occurred >5 Myr after CAIs, that is, much later than most chondrules. Based on these observation, it has been suggested that CB chondrules formed from a plume produced by an impact between planetary embryos after dust in the protoplanetary disk had largely dissipated [2]. However, late formation of these objects in a disk environment cannot be excluded [3]. Here, we use high-resolution Al-Mg isotope measurements to explore the formation mechanism(s) of CBb chondrules.

We selected ten skeletal chondrules from the CBb chondrite Hammadah al Hamra 237 and determined their Mg isotope compositions and $^{27}Al/^{24}Mg$ values using methods described in [4]. The chondrules show variability in the mass-dependent $\mu^{25}Mg$ component (from -86±15 ppm to 292±7.1 ppm relative to Earth's mantle) that is correlated to their $^{27}Al/^{24}Mg$ ratios in a manner consistent with a condensation origin. Using a kinetic fractionation law (β=0.511) to determine the mass-independent $\mu^{26}Mg^*$ values results in a negative correlation in $\mu^{26}Mg^*$ and $^{27}Al/^{24}Mg$ space, establishing that the $\mu^{25}Mg$ variability was not imparted by kinetic processes. Instead, using the experimentally determined fractionation factor of β=0.514 [5] returns a single $\mu^{26}Mg^*$ population with an uncertainty that is comparable with the external reproducibility of our method (~2.5 ppm). These data indicate that CBb chondrules formed by condensation from a isotopically homogeneous reservoir >4.7 Myr after formation of canonical CAIs. The Mg-isotope composition of CBb chondrules are thus supportive of the giant impact scenario for the the formation of CB chondrites.

[1] Connelly *et al.* (2012) Science 338, 651 [2] Krot *et al.* (2005) Nature 436, 989 [3] Gounelle *et al.* (2007) EPSL 256, 521 [4] Bizzarro *et al.* (2011) JAAS 26, 565 [5] Davis *et al.* (2005) LPSC#36, 2334

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