IGNEOUS INCLUSIONS IN THE BARWELL L6 CHONDRITE

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Introduction: Igneous-textured inclusions in ordinary chondrites have previously been investigated to provide evidence for early planetary differentiation, the timing of thermal metamorphism, and implications for impact history and mixing in the early Solar System [e.g. 1-8]. Characterising such inclusions helps to determine their origin and relationship to the bulk meteorite, i.e. whether they formed on the chondrite parent body, resulted from impact melting, or are fragments of an achondritic projectile. Previous studies of Barwell (L6) inclusions showed fractionated REEs patterns [1] and old I-Xe ages (≤1 - 3 Ma after CAI) [1, 9, 10]. Here we present the results of a new study that explores the frequency, diversity, nature and origin of inclusions in Barwell.

Methods: Multiple inclusions, representing ~ 0.7% of a total 285 cm^3 of host meteorite analysed, were identified using the Nikon HMXST 225 micro-CT scanner at the Natural History Museum [11]. Four inclusions were subsampled from the host and characterised using the Zeiss EVO 15LS SEM. Geochemistry was carried out using the Cameca SX100 electron microprobe and an ESI New Wave UP193FX laser ablation system coupled to an Agilent 7500cs ICP-MS. Oxygen isotope compositions of subsamples of the four inclusions were measured at the Open University by laser fluorination using a Thermo Fisher MAT 253 isotope ratio MS. System precision (2σ) for $\delta^{17}O$, $\delta^{18}O$ and $\Delta^{17}O$ is ±0.05‰, ±0.09‰, and ±0.02‰, respectively. The short-lived ^{182}Hf-^{182}W chronometer ($t_{1/2}$ = 8.9 Myr) was applied to two inclusions identified in this study and three inclusions previously identified [5]. Tungsten isotope compositions were measured on the Neptune *Plus* MC-ICP-MS at the University of Münster. This system is well suited to date these inclusions due to its sensitivity to metal-silicate fractionation and can provide insights into the age and origin of these inclusions [12].

Results: The inclusions are mostly dominated by olivine (inclusions *A*, *C*, *D*) and/or pyroxene (*B*) with interstitial feldspar. These silicates are equilibrated with the host material. Bulk lithophile element compositions are broadly similar to ordinary chondrites but all inclusions are depleted in siderophile elements, suggesting chondrite melting with loss of metal and sulphide. Analysis of trace elements will be carried out by ICP-MS for evidence of fractionation in the REE pattern of the inclusions. Oxygen isotope results indicate preservation of primitive signatures, maintaining isotopic heterogeneity despite considerable metamorphism (Barwell is a type 6 OC). Inclusions span a range in $\delta^{18}O$ from 4.40 ‰ to 5.44 ‰ and in $\Delta^{17}O$ from 0.37 ‰ to 0.90 ‰. These inclusions are depleted in ^{17}O compared with bulk Barwell measurements ($\delta^{18}O \approx 4.83$ ‰ and $\Delta^{17}O \approx 1.15$ ‰), possibly indicating fractionation from a H chondrite-like source, but also exhibiting oxygen compositions similar to those reported for individual chondrules in low petrological type L and LL chondrites [13]. Further exploration of the implications of the O isotope compositions will be considered in conjunction with other results. Three inclusions (*B* from this study; *3* and *6* from [5]) show superchondritic Hf/W ratios and display radiogenic ^{182}W excesses. Assuming formation from a chondritic source with Hf/W similar to the L chondrite reservoir, they provide model ages of ~ 2 - 3 Ma after CAI formation. This may indicate a contemporaneous formation with chondrules, and possibly a shared origin. Moreover, the three points also define an isochron suggesting that the timing of inclusion formation can be dated using a bulk inclusion Hf-W isochron, which will be further tested after separation of additional inclusions.

Conclusions: The data indicate that igneous inclusions share many characteristics with chondrules in OCs, despite their size and apparent exotic nature. Identification of such igneous inclusions in unequilibrated OCs, which would lack the overprinting of metamorphism, would further our understanding of the origin of this material. These inclusions may point to chondrules being more diverse in size and composition than previously recognized. The similarity in age and isotopic composition of the inclusions to OC chondrules points to them forming by a similar mechanism, but they must have formed from siderophile-depleted precursors.

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