

# FORMATION CONDITIONS OF TYPE B CALCIUM-ALUMINIUM-RICH INCLUSIONS IN CV CHONDRITES: A COMPARISON OF NATURAL CAIS AND EXPERIMENTAL ANALOGUES

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**Introduction:** Calcium-aluminum-rich inclusions (CAIs) are the oldest solids (~4.567 Ga) in our Solar System, and therefore provide evidence of early protoplanetary disk processes and conditions [e.g. 1]. It is commonly agreed that CAIs formed by evaporation, condensation and aggregation within a hot gas of solar composition, likely near the protosun [1]. Some CAIs were also partially melted [1], however, their formation histories and thermal constraints on melting conditions are not well understood. This has hindered agreement on a CAI formation model and how CAI melting relates to the formation conditions of chondrules [2].

The most commonly studied melted CAIs are Type B, found almost exclusively in CV (Vigarano-like) chondrites [2]. Type Bs mainly comprise of spinel (Sp), melilite (Mel), Ti-Al-rich pyroxene (Pyx) and anorthite (An) (Fig. 1a), and have experienced multiple melting episodes [e.g. 2]. The equilibrium crystallization sequence of Type Bs has been established [3], as well as general constraints on peak temperature and cooling rates during melting [4-6]. However, these constraints remain broad and non-linear cooling rates or multiple stages of heating have not been widely explored. We aim to further constrain the formation conditions of Type B CAIs by reproducing the texture, mineralogy and mineral chemistry of natural Type Bs using experimental analogues formed under a range of conditions.

**Methods:** We examined CAIs in 3 oxidised (Allende, Northwest Africa 6603 and Northwest Africa 7678) and 2 reduced (Vigarano and Leoville) CV3 chondrites. Dynamic crystallization experiments are performed in a Deltech one-atmosphere furnace. Starting materials were prepared from a mix of dry powder oxides (SiO<sub>2</sub>, MgO, Al<sub>2</sub>O<sub>3</sub>, CaO and TiO<sub>2</sub>) and trace element solutions (V, Cr, Mn, Li, Be, REEs) as outlined by [7]. The bulk composition of the starting material is an average of natural Type B bulk compositions obtained from [8,9]. Scanning electron microscopy (SEM) imaging and elemental X-ray mapping was conducted on a FEI Quanta 650 FEG SEM. Quantitative mineral analyses were performed on a Cameca SX 100 electron microprobe. We plan to measure trace elements using a Teledyne Excite+ 193 nm ArF excimer laser ablation system coupled to an Agilent 8900 triple quadrupole ICP-MS.

**Results:** Experiments with a peak temperature (T) of 1400°C and linear cooling rates between 1.5-50°C/hr exhibit a similar texture, mineralogy and major element mineral chemistry to natural Type Bs (Fig. 1). A multi-stage experiment, consisting of two heating cycles at peak Ts of 1400°C and 1350°C and linear cooling in both cycles at a rate of 11°C/hr, was also representative. Experiments with i) linear cooling rates at peak T > 1400°C, ii) linear cooling rates between 60-150°C/hr at a peak T of 1400°C and iii) a non-linear cooling rate which varied from 1000°C/hr at 1400°C to ~350°C/hr below 800°C, did not show texture, mineralogy and mineral chemistries comparable to the natural Type Bs. These linear experiments produced dendritic melilite and anorthite, as observed by [4], whilst the non-linear experiment formed spinel and glass only.

**Discussion:** Our results support slow cooling of Type B CAIs from an initial peak T of 1400°C, consistent with [4-6], and suggest that subsequent melting episodes had similar slow cooling rates. We also conclude that cooling at >50°C/hr, and peak Ts > 1400°C, are not possible. These formation conditions are more restricted than those proposed for chondrules [e.g. 10], implying that CAI melting requires a different formation mechanism to that of chondrules.

**References:** [1] Krot A. (2019) *Meteoritics & Planetary Science* 54:1647-1691. [2] MacPherson G. et al. (2022) *Geochimica et Cosmochimica Acta* 321:343-374. [3] Stolper E. (1982) *Geochimica et Cosmochimica Acta* 46:2159-2180. [4] Stolper E. and Paque J. (1986) *Geochimica et Cosmochimica Acta* 50:1785-1806. [5] MacPherson G. et al. (1984) *Journal of Geology* 92:289-305. [6] Davis A. and MacPherson G. (1996) *Chondrules and the Protoplanetary Disk* 71-76. [7] Beckett J. et al. (1990) *Geochimica et Cosmochimica Acta* 54:1755-1774. [8] Beckett J. (1986) *PhD Dissertation University of Chicago*. [9] Srinivasan G. et al. (2000) *Meteoritics & Planetary Science* 35:1333-1354. [10] Jones R. et al. (2018) *Chondrules: Records of Protoplanetary Disk Processes* 57-90.

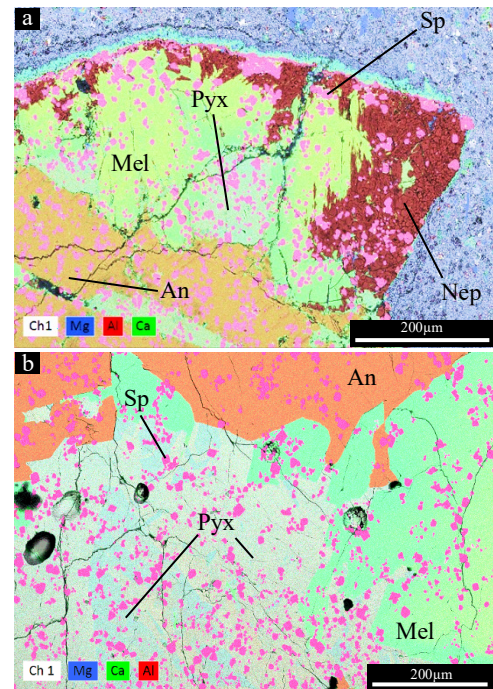


Fig.1. Elemental maps of a (a) natural Type B CAI in NWA 6603 and (b) Type B experimental analogue, formed at a peak T 1400°C and cooling rate of 1.5°C/hr. Nepheline (Nep) in (a) is a secondary alteration phase.