LARGE SILICA-RICH IGNEOUS-TEXTURED INCLUSIONS IN THE BUZZARD COULEE (H4) CHONDRITE.

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Introduction: The Buzzard Coulee (H4 S2 W0) chondrite [1,2] contains white and tan inclusions ranging in diameter up to ~1 cm. We used microanalytical techniques (OLM, SEM, EMPA, SIMS) to study three examples of the two inclusion types (white: Bz-1 and Bz-2; tan: Bz-3) for comparison to previously studied large inclusions in ordinary chondrites [e.g., 3-5]. The inclusions in ordinary chondrites have igneous textures and solidified from melt volumes one-to-six orders of magnitude larger than coexisting chondrules [3-5], but their origin and significance is not well known. Shock melting [e.g., 3-7], the melting of vapor-fractionated condensate mixtures [4-5], and differentiation in a parent body [e.g., 8-10] have all been proposed. For Buzzard Coulee, we suggest that the inclusion melts formed by igneous differentiation, but that they experienced transit through a space environment that resulted in rapid cooling and vapor phase phenomena.

Bz-3: Bz-3 (2.0x2.1 mm across) is a clast which contains phenocrysts of low-Ca pyroxene ($Wo_{1.2\pm0.5}En_{90.4\pm2.4}Fs_{8.4\pm2.1}$) and high-Ca pyroxene (augite, Wo_{20-40}; pigeonite, Wo_{5-14}) set in feldspathic glass (Na-rich, K-rich) (Fig. 1). High-Ca pyroxene often forms overgrowths on low-Ca pyroxene. Trace element abundances of the pyroxene grains mainly show patterns consistent with igneous fractionation, but one low-Ca pyroxene core grain and augite overgrowth show what appears to be a hybrid between a Group II condensation signature and an igneous signature. Both types of glass have negative Yb anomalies, and sometimes also negative Sm anomalies. The bulk composition of Bz-3 (~62 wt% SiO_2) is rich in normative feldspar and pyroxene, and is enriched in incompatible elements and depleted in ferromagnesian elements (Fig. 2).

Bz-1 and Bz-2: These inclusions (2.0x2.1 mm and 2.3x3.6 mm across, respectively) are fragments of the same, nearly holocrystalline lithology, composed of pyroxene (~63-66 area%) and cristobalite (~33-36%) (Fig. 1). Low-Ca pyroxene (mostly orthobronzite, some clinobronzite) ($Wo_{0.5-4}En_{81-85}Fs_{15-18}$) and aggregates of cristobalite have rims rich in high-Ca pyroxene (diopside, $Wo_{44-47}En_{48-51}Fs_{4-6}$). Trace element compositions of orthobronzite and diopside are generally consistent with igneous fractionation, but two analyses of clinobronzite both have a composition suggestive of either disequilibrium, or the presence of glass and chomite inclusions, or both. The bulk compositions of Bz-1 and Bz-2 (~67 wt% SiO_2) are rich in normative quartz and pyroxene and poor in feldspar, and are fractionated in refractory element abundances with a tenfold variation between Ca (~2xCI) and Al and LREE (~0.2xCI) (Fig. 2).

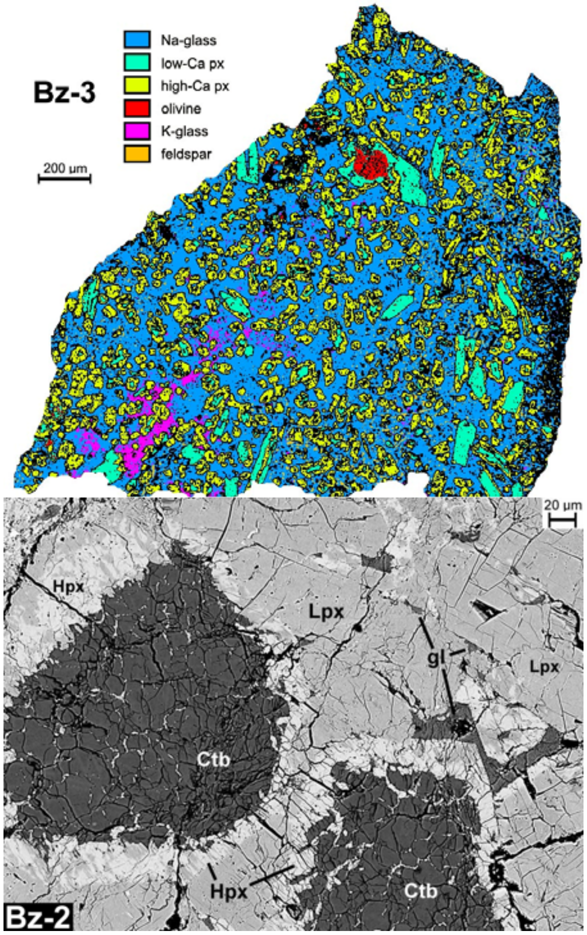

Fig. 1 (top): Colorized phase map for Bz-3 showing pyroxene (px) phenocrysts set in glass of two types (Na-rich, K-rich). One olivine grain is at top. (bottom): BSE image of Bz-2 showing aggregates of cristobalite (Ctb), grains of low-Ca pyroxene (Lpx, medium grey), high-Ca pyroxene (Hpx, light grey), and a small amount of glass (gl).

Discussion: The inclusions lack metal and are depleted in siderophile elements (Fig. 2), implying metal loss if they were derived from a chondritic precursor. An H chondrite origin seems likely for Bz-1 and Bz-2 given their H-like pyroxene ferrosilite content and is plausible for Bz-3. However, bulk FeO/MnO ratios are low compared to H chondrite silicate, suggesting FeO reduction followed by metal loss. For Bz-3, the amount of FeO reduction needed would be ~70%, and for Bz-1 and Bz-2, ~35-45%.

The bulk compositions of both types of inclusions are distinct from the compositions of melt pockets formed by shock melting in ordinary chondrites, and there is no evidence that either type formed by shock melting. Nor do the inclusions have bulk compositions suggestive of strong volatility control (Fig. 2), as one would otherwise predict if they formed by the melting of condensate mixtures. Instead, we suggest igneous differentiation was mainly responsible for forming the inclusion liquids.

The composition of Bz-3 lies close to the olivine-pyroxene reaction boundary, consistent with an origin as a partial melt of an ordinary chondrite. However, there are features of Bz-3 that cannot be easily explained by igneous processes alone, including negative Yb and Sm anomalies in glass, modified Group II-like patterns for some pyroxene grains, and a bulk negative Yb anomaly (Fig. 2). We interpret Bz-3 as having formed as a partial melt of an ordinary chondrite that experienced FeO reduction and complete metal loss, as well as some vapor phase partitioning. We suggest that Bz-3 oiginated when melt from a partially molten body was lofted into space, where it partly evaporated in a reducing environment and quickly cooled. Upon cooling, alkalis and other highly volatile elements re-entered melt or glass.

The compositions of Bz-2 and Bz-1 lie close to the pyroxene-silica cotectic, which is the composition one would expect for solids crystallizing from Si-oversaturated parental liquids with chondritic feldspar proportions. To explain this liquid, both FeO reduction and metastable crystallization of olivine from a high-degree partial melt of an ordinary chondrite would be needed prior to crystallizion of pyroxene and cristobalite. Before solidification, any interstitial feldspathic melt was largely removed, possibly by buoyancy or surface tension effects. The data for Bz-1 and Bz-2 suggest relatively slow cooling and an approach to equilibrium during crystallization, but the presence of some clinobronzite probably signifies rapid cooling at high temperatures. Such pyroxene can form by shearing forces during shock or by relatively rapid cooling at high temperatures, but there is no evidence for shock in the inclusions other than brecciation.

We suggest that the Bz-1/Bz-2 precursor melt formed after partial melt from a differentiated body was lofted into space, causing the melt to become FeO-reduced and to cool rapidly at first, as for Bz-3. Unlike Bz-3, metastable olivine crystallization drove the melt into a Si-oversaturated condition and the melts soon reaccumulated into an insulating secondary body, which allowed slower cooling and cumulate formation.

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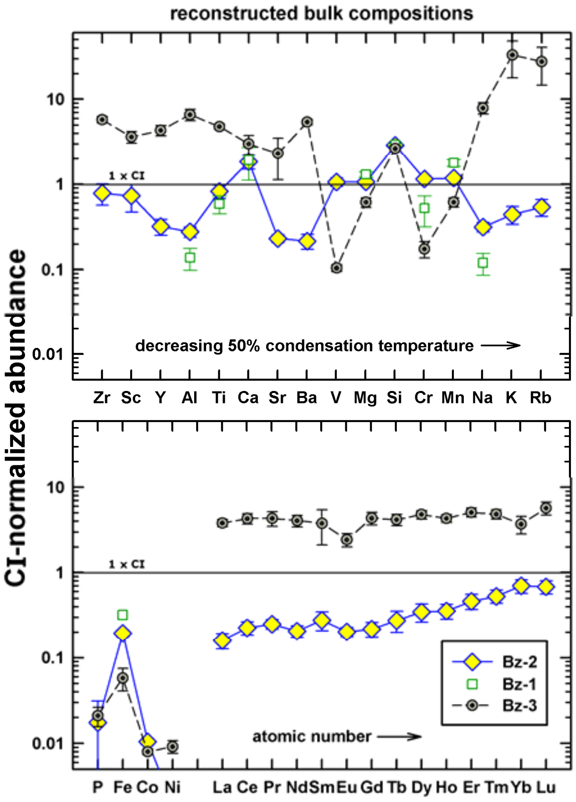

Fig. 2: Bulk compositions of inclusions determined by modal reconstruction (Bz-2 and Bz-3: SEM + SIMS data; Bz-1: SEM + EMPA data). The top panel shows elements ordered by volatility (50% condensation temperatures), the bottom panel by atomic number.