

CHEMICAL EVIDENCE FROM GUJBA FOR DIFFERENTIATION AND EVAPORATION/RE-CONDENSATION PROCESSES DURING THE CB-IMPACT EVENT: J. Oulton¹, M. Humayun¹, A. Fedkin², L. Grossman², ¹National High Magnetic Field Laboratory, Florida State University, Tallahassee, FL 32310, USA (jjol1d@my.fsu.edu); ²Dept. of the Geophysical Sciences, The University of Chicago, Chicago, IL 60637, USA.

Introduction: Chondrule formation during impacts has been proposed as an important source of chondrules [1-2]. Chemical evidence indicates that bencubbinites formed by condensation in impact plumes [3-6]. Gujba is a CB_a chondrite characterized by abundant Fe-Ni metal clasts, barred-olivine (BO) and cryptocrystalline (CC) silicate clasts within a dark silicate matrix [7-8]. Oxygen and nitrogen isotopic studies have linked the CBs to CR and CH chondrites [7]. Siderophile element variations in bencubbinite metal indicate that condensation of the metallic clasts occurred from a dense vapor plume generated by impact of a metallic body [4-6] on a differentiated or chondritic target [9-10]. New condensation models that reproduce the compositional range of the BO and CC clasts of bencubbinites indicate that the target body had to be differentiated into crust and mantle [10]. To better understand the origin of chemical variability in the bencubbinites we performed a detailed Laser Ablation Inductively Coupled Plasma Mass Spectrometer (LA-ICP-MS) analysis of silicate clasts from Gujba.

Samples and Analytical Methods: Five polished slices of Gujba were analyzed for the abundances of 74 elements in both silicate and metal clasts by LA-ICP-MS. A New Wave UP193FX excimer (193 nm) laser ablation system coupled to a Thermo Element XR was used following procedures described elsewhere [11-12]. Thirteen silicate clasts were analyzed using a 150 µm beam spot, with a 20-second dwell time, at 50 Hz. To minimize surface contamination each analyzed spot was pre-ablated using a 150 µm spot, 5-s dwell time at 50 Hz. A 10-s washout cycle was allowed prior to the main ablation. Individual spot analyses taken within a given clast were averaged and these averages were used below. The precision with which Ce anomalies can be resolved by our LA-ICP-MS technique was assessed by taking an average of all the spot analyses within an individual clast and using the 1-sigma relative standard deviation as the error.

Results: Silicate Major Element Chemistry. Major element compositions of silicate clasts are shown on a CMAS plot (Fig. 1) together with data from [8]. Clasts span a broad range of CaO+Al₂O₃ wt% (6.71%-28.51%). CIPW norm calculations show that all clasts, except SkOl 622, are 70-90% olivine+hypersthene normative. Compared to clasts reported in [8], the CC clasts from Gujba are close to chondritic. The BO clast

SkOl 622 is more enriched in CaO+Al₂O₃ (5xCI) and depleted in volatiles (0.01xCI) than BO clasts from CB_b [8]. CC clasts are observed to have a less extreme depletion of volatiles than BO clasts. Two of the clasts that appear to be BO-like in reflected light microscopy are chemically ambiguous and are marked “BO/CC?”.

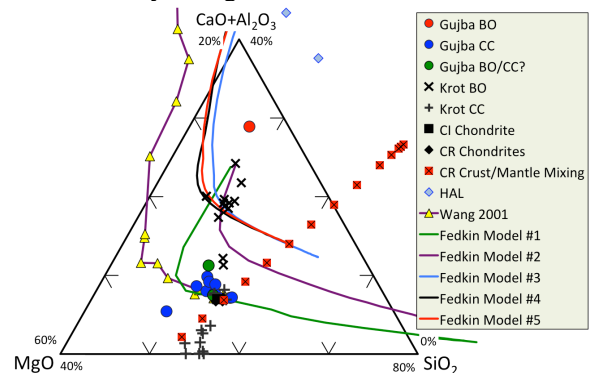


Fig. 1: Ternary plot showing Gujba and QUE 94411/ HaH 237 [8] compositions, with condensation curves from [10] and vacuum evaporation of CI [13]. A mixing line between model CR crust and mantle [10] is shown as red x's.

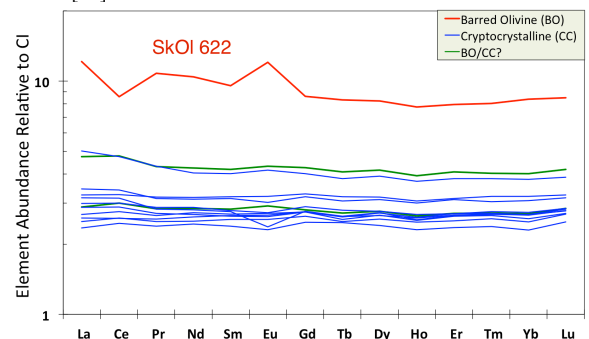


Fig. 2: REE abundances normalized to CI in Gujba clasts. Note Ce anomalies, particularly in the BO clast.

REE Chemistry. REE patterns in silicate clasts from Gujba are enriched by 2-10xCI (Fig. 2), with the BO clast SkOl 622 having the highest enrichment (10xCI). Some of the REE patterns show LREE-enrichment, while others are flat; the (La/Sm)_{CI} ratio is 0.98-1.27. Eu anomalies are observed in several of the clasts, with a prominent positive anomaly in SkOl 622, which contains no obvious plagioclase. Interestingly, Ce anomalies are observed, with small positive Ce anomalies seen in CC clasts (1.00-1.10) whereas a large negative Ce anomaly (0.75) is seen in the BO clast, SkOl 622. Fig. 3 shows the Ce anomaly plotted against the CaO/MgO ratio in Gujba silicate clasts,

together with data on the CB_b chondrites [8], where the positive Ce anomalies are large (1.5) in the latter.

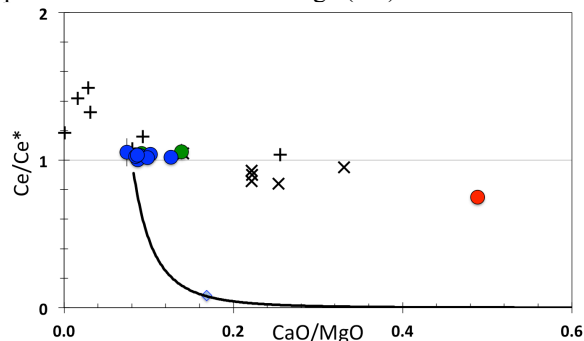


Fig. 3: Cerium anomalies in CB clasts anti-correlate with increasing CaO/MgO. The CI evaporation experiments [13] (dark line) and HAL [14] are shown for comparison. Legend as in Figure 1.

Discussion: Evidence for differentiation is best observed in the major element chemistry. Included on Fig. 1 is a mixing line between the crust and mantle end members of a differentiated CR-body [10]. These end members were calculated using MELTS as a 20% partial melt of a CR starting composition and its residue [10]. Variable mixing of these two components (shown in 10% increments) results in a line that trends towards too low a $(\text{CaO}+\text{Al}_2\text{O}_3)/\text{SiO}_2$ ratio compared to the CB clasts. Fig. 4 plots the SiO_2/MgO ratio of Gujba and the CB_b chondrites [8] against the CaO/MgO ratio of these samples. The silicate clasts (Gujba/HaH 237/QUE 94411) form a linear trend with SiO_2/MgO increasing with increasing CaO/MgO.

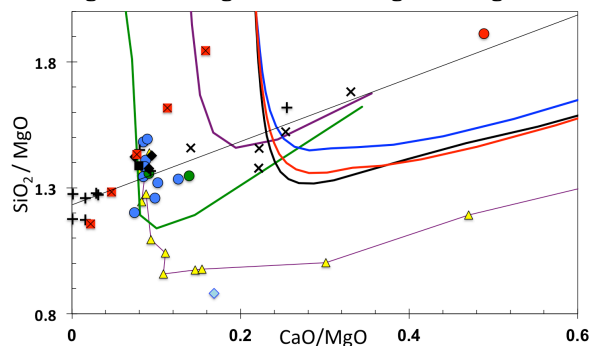


Fig. 4: SiO_2/MgO vs. CaO/MgO in CB clast compositions compared with condensation curves [10] and vacuum evaporation experiments [13]. Legend as in Figure 1.

Results from vacuum evaporation of a CI chondrite composition [13] and condensation curves for $\text{Si}/\text{H}=300\text{--}500$ [10] indicate that evaporation/condensation processes should result in a decrease in the SiO_2/MgO in the initial 50% of vaporization or last stages of condensation so that evaporation/condensation curves do not plot near the data. The CR basaltic crust is enriched in CaO and SiO_2 compared with MgO, so the observed correlation is an indication of crust-mantle

mixing inherited from the target. The compositions of Gujba CC clasts intersect perpendicular to the mixing trend (Fig. 4) indicating volatility control [10, 13].

Evidence for evaporation and recondensation: It is well known that Ce^{3+} becomes volatile as Ce^{4+} under oxidizing conditions such as those intrinsic to evaporation of silicate rocks [13–14]. Although the data of Krot et al. [8] also indicate the presence of Ce anomalies in silicate clasts from CBs similar to those reported here in Gujba, they [6, 8] do not mention this. Thus, this is the first report of the presence of ubiquitous Ce anomalies in the silicate clasts of CB_{a/b} chondrites. During an impact such as proposed for CB origin [10], vapor formed by evaporation of silicate droplets would be oxidizing enough to explain the initial creation of negative Ce anomalies. This vapor must mix with reducing nebular gas [10] returning Ce to a trivalent state that then recondensed into CC clasts. Thus, we interpret the BO clast SkOl 622 as a residue of partial evaporation, while the CC clasts recondensed Ce from the vapor phase.

Conclusions: The chemistry of silicate clasts in Gujba (and other CBs [6, 8]) reflects its enigmatic history of formation by impact between a differentiated body and a metallic body. The correlation between SiO_2/MgO and CaO/MgO, LREE enrichment and Eu anomalies in Gujba silicates indicate inheritance of these chemical features from the crust and mantle of the differentiated body. Ce anomalies in CB silicate clasts are anti-correlated with enrichment of refractory lithophiles and depletion of volatile lithophiles. These traits are indicative of an evaporation/recondensation process operating on droplets that represented mixtures between remelted crustal and mantle lithologies within the CB-impact plume. Such an impact plume is consistent with an impact of the type envisioned by [1, 6], but is not consistent with an internally molten planetesimal [2]. The Ce-anomaly correlation with an index of differentiation is unexpected.

References: [1] Asphaug E. et al. (2011) *EPSL* 308, 369–379. [2] Sanders I. S. and Scott E. R. D. (2012) *MaPS* 47, 2170–2192. [3] Wasson J. T. and Kallemeyn G. W. (1990) *EPSL* 101, 148–161. [4] Campbell A. J. et al. (2002) *GCA* 66, 647–660. [5] Rubin A. E. et al. (2002) *GCA* 67, 3283–3298. [6] Krot A. N. et al. (2001) *Science* 291, 1776–1779. [7] Weisberg M. et al. (2001) *M&PS* 36, 401–418. [8] Krot A. N. et al. (2001) *M&PS* 36, 1189–1216. [9] Fedkin A. et al. (2013) *LPSC* 44, abstract# 2309. [10] Fedkin A. et al. (2015) *LPSC* 46, abstract# 1038. [11] Humayun M. et al. (2007) *GCA* 71, 4609–4627. [12] Humayun M. et al. (2010) *JAAS* 25, 998–1005. [13] Wang J. et al. (2001) *GCA* 65, 479–494. [14] Davis A. M. et al. (1982), *GCA* 46, 1627–1651.