

**ORIGIN AND THERMAL HISTORY OF LITHIC MATERIALS IN THE BEGAA LL3 CHONDRITE.** R. Okazaki and T. Nakamura. Department of Earth and Planetary Sciences, Faculty of Science, Kyushu University, Hakozaki, Higashiku-ku, Fukuoka 812-8581, Japan (okazaki@geo.kyushu-u.ac.jp).

**Introduction:** Chondrites are one of the most primitive meteorites and consist of CAIs, chondrules and matrix. Besides CAIs and chondrules, some other materials that appear to have been derived from high-temperature processes are found: isolated mineral grains (e.g., isolated olivine), metal sulfide lumps, igneous rock fragments (mostly derived from impact melt), and metamorphosed chondrules, and chondritic clasts. These materials have information about the thermal processes in the nebula and the chondrite parent bodies.

The Begaa LL3 chondrite was collected from southeast Morocco in 1999 [1]. In a specimen there are two lithic materials that are 3mm in apparent diameter, much larger than the mean chondrule size of LL chondrites (0.9mm [2]). Unlike usual chondrules, these large lithic materials show white internal reflections under a reflected light microscope. Here we report characteristics of the two Begaa lithic materials in terms of major/minor element abundances, oxygen isotope compositions, and rare earth element (REE) abundances. Based on these analyses we suggest that the large lithic materials are akin to type IIAB chondrules but depleted in Na and K due to long duration heating under low  $fO_2$  condition in the solar nebula.

**Experimental procedures:** We have prepared a polished section from the Begaa chondrite with 150  $\mu\text{m}$  thick. The polished section was investigated with a polarizing microscope under reflected light and with a scanning electron microscope (SEM) before and after the ion microprobe analysis. Chemical compositions of the two lithic materials and their constituent minerals were determined with an electron microprobe analyzer at Kyushu Univ.

Oxygen and REE measurements were performed with the Cameca 6f ion microprobe at Kyushu Univ. For the oxygen measurements, the 0.6nA  $\text{Cs}^+$  primary ion beam was focused in aperture-illumination mode to produce a  $\sim 30\mu\text{m}$  spot. The secondary mass spectrometer was operated at 9.5kV with a mass resolving power of 5500 and a 75eV energy window.  $^{16}\text{O}$  was measured with the faraday cup and  $^{17,18}\text{O}$  were measured with the electron multiplier. The normal-incident electron flood gun was used for charge compensation. A San Carlos olivine was used for standardization. REE abundances were determined following the method described in [3]. The 2nA  $\text{O}^-$  primary beam was focused in critical-illumination mode to  $\sim 30\mu\text{m}$ . The secondary-ion mass spectrometer was operated at 9.5kV accelerating voltage, with an 80eV offset, a

50eV energy window, and a mass resolving power of  $\sim 500$ .

**Results and discussion:** The optical microscope and SEM observation revealed that the Begaa chondrite preserves the chondritic textures, not brecciated. Chondrules in the specimen are well recognized, which is consistent with the announced classification of LL3 for this meteorite. Most of the chondrules are 0.5-1mm in apparent diameter, ranging within the typical chondrule size, while the two lithic materials (hereafter BLM-1 and BLM-2) are unusually large. The BLMs consist mainly of magnesian olivine, magnesian low-Ca pyroxene, and anorthitic plagioclase:  $\text{Fo}_{82-89}$  and  $\text{An}_{87-94}$  for BLM-1, and  $\text{Fo}_{77-81}$  and  $\text{An}_{75-87}$  for BLM-2, respectively. The Fo#s are relatively constant at the cores and rims of the BLMs. Plagioclases are stoichiometric: they are possibly crystalline. Chemical compositions of pyroxenes are shown in Fig. 1. The outer layers of the BLMs consist predominantly of low-Ca pyroxenes, suggesting the formation of pyroxene from interaction between olivine and Si-rich gas [4]. The mineralogy and chemical compositions of the two BLMs are similar to those of plagioclase-rich inclusions [5]. Primitive achondrites also have similar mineralogy but clearly different in respect of the occurrence of metal and sulfides that are very rare in the BLMs.

Oxygen isotopic ratios were determined for olivine grains in BLM-1 and BLM-2. Most of the data points plot close to the TFL (Fig. 2) and below the ordinary chondrite chondrules [6]. The oxygen data indicate that the lithic materials originated from a gas reservoir different from those for plagioclase-rich inclusions that are  $^{16}\text{O}$ -rich in variable degrees (e.g., [7]).

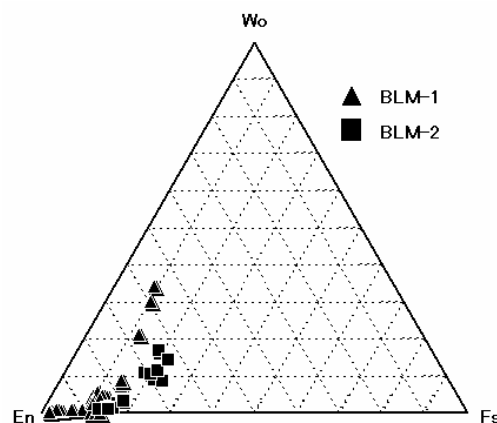
Considering the modal abundances and chemical compositions of constituent minerals along with oxygen isotope compositions, we suggest that both of the BLMs may have been derived from precursory materials similar to those for type IIAB chondrules. The major element abundances of the lithic materials are close to the typical compositions of type IIAB chondrules but there are distinct depletion in Na and K abundances ( $\text{Na}_2\text{O}=0.05$  and  $0.25$ ,  $\text{K}_2\text{O}=0.03$  and  $0.04$  for BLM-1 and BLM-2, respectively). Thus the important question to be addressed is how the Na and K were depleted.

REE abundances of anorthitic plagioclase in the BLM-2 exhibit a fractionated REE pattern:  $\text{LREE} > \text{HREE}$  fractionation with positive Eu anomaly (Fig. 3). This REE pattern is quite similar to those for

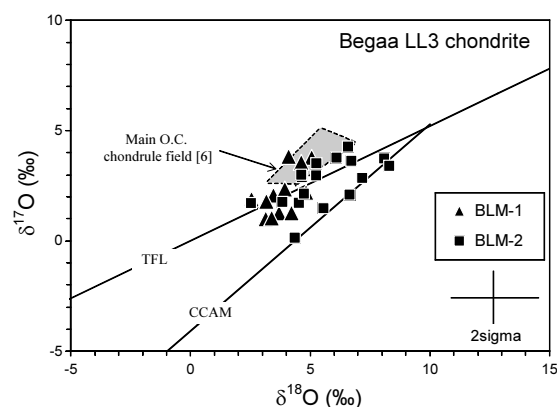
igneous materials such as acapulcoites [10], but different from those for mesostasis glass of porphyritic olivine chondrules [11]. Olivine and pyroxene grains in the BLM-2 show the complementary REE pattern, although the data have large errors due to the lower REE abundances (about 10 times lower than those in the plagioclase). Hence it is likely that the LREE/HREE fractionation and the positive Eu anomaly are resulted from fractional crystallization, suggesting that the Begaa lithic materials have been heated for significantly long duration and/or at slow cooling rate. The compositional variation in pyroxene (Fig. 1) is consistent with the crystallization at slow cooling rate.

Based on the bulk compositions, the liquidus temperature of the BLMs is around 1650-1600 °C [12]. Plagioclase compositions set the lower limit for the temperature of 1400°C during loss of Na and K. The oxygen fugacity during the heating and the cooling should be high ( $fO_2 > 10^{-11}$  atm; [13]) sufficient to prevent reducing olivine. To account for the depletion of Na in BLMs (only 3% and 15% of the average Na content of type II chondrules [14] for BLM-1 and BLM-2, respectively) at least 2 hours are necessary [15] even if 1530°C isothermal heating ( $fO_2 \sim 5 \times 10^{-10}$  atm) is assumed.

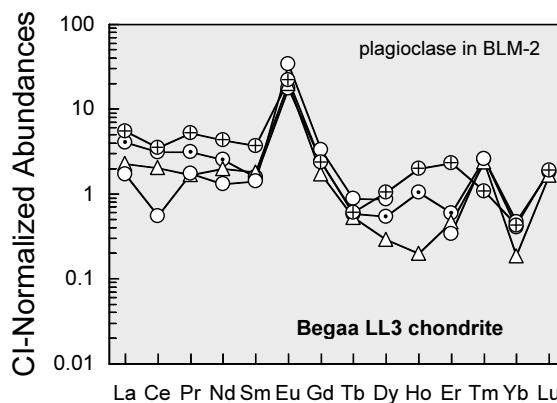
**References:** [1] <http://www.meteorite.fr> [2] Scott E. R. D. (1996) in *Chondrules and the Protoplanetary Disk* (R. H. Hewins et al., eds.), pp. 87-96. [3] Zinner E. and Crozaz G. (1986) *Intl. J. Mass Spectr. Ion Proc.* 69, 17-38. [4] Tissandier L. et al. (2002) *M&PS* 37, 1377-1389. [5] Sheng Y. J. et al. (1991) *GCA* 55, 581-599. [6] Clayton R. N. et al. (1991) *GCA* 55, 2317-2337. [7] Maruyama S. et al. (1999) *EPSL* 169, 165-171. [10] Patzer A. et al. (2004) *M&PS* 39, 61-85. [11] Pack A. et al. (2004) *LPS XXXV*, Abstract #-2062. [12] Hewins R. H. and Radomsky P. M. (1990) *Meteoritics* 25, 309-318. [13] Yada T. et al. (1996) *Proc. NIPR Symp. Antarct. Meteorites* 9, 218-236. [14] Jones R. H. *GCA* 54, 1785-1802. [15] Yu Y. and Hewins R. H. (1998) *GCA* 62, 159-172.



**Fig. 1.** Pyroxene compositions of the Begaa lithic materials (BLMs).



**Fig. 2.** Oxygen isotopic compositions for the Begaa lithic materials (BLMs). Most of the analyzed olivines in the BLMs lie on the terrestrial fractionation line (TFL).



**Fig. 3.** REE abundances of anorthitic plagioclases in one of the Begaa lithic materials (BLM-2).