**RHÖNITE-BEARING INCLUSIONS E201 AND E202 FROM EFREMOVKA: CONSTRAINTS FROM TRACE ELEMENT MEASUREMENTS.** C. Floss[1], M. A. Nazarov[2] and L. A. Taylor[3], [1]Laboratory for Space Sciences, Washington University, St. Louis, MO 63130, USA (floss@wustl.edu), [2]Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow 117975, Russia (nazarov@geokhi.ru), [3]Planetary Geosciences Institute, University of Tennessee, Knoxville, TN 37996, USA (lataylor@utk.edu).

**Introduction:** Inclusions containing rhönite are rare among CAIs and were known only from the Allende meteorite [e.g., 1-4] until [5] reported the discovery of two rhönite-bearing inclusions, E201 and E202, from the Efremovka CV chondrite. Unlike rhönite-bearing CAIs from Allende, these inclusions show little evidence of secondary alteration and, thus, are a good source of information about primary nebular processes. We are investigating the trace element and isotopic systematics of these inclusions in order to better understand their origin.

**Results:** Trace elements, including the REE, were measured by ion microprobe in the constituent minerals of both inclusions. The petrography of these CAIs was given by [5] and preliminary trace elements data for E201 was reported by [6].

*E201*: E201 is a type B1 inclusion whose core consists of subequal amounts of coarse-grained melilite and fassaite, often poikilitically enclosing spinel; however, there are also spinel-free islands of only melilite and fassaite. Minor rhönite and perovskite occur in the core, but no anorthite is present [5]. Surrounding the core is a mantle of mostly gehlenite-rich melilite, which is separated from the core of the inclusion by perovskite/melilite symplectites. The inclusion is surrounded by a thin rim of spinel and diopside. All of the minerals analyzed have modified group II REE patterns, which are depleted in an ultra-refractory component (Fig. 1). The LREE are enriched relative to the HREE and exhibit moderate volatility-controlled fractionations; positive Tm and Yb anomalies are also present [6]. Superimposed upon these patterns are variations typically associated with crystal chemical controls. Thus, melilite has a positive Eu anomaly and a more LREE-enriched pattern than fassaite. A small hibonite-bearing inclusion attached to the surface of E201 shows the same REE fractionations, indicating that it formed from a similar reservoir.

Fassaite in E201 is zoned, with decreasing Ti and Al and increasing Mg from the cores to rims of crystals [5]. Trace element abundances also vary, with REE and Y abundances increasing and Sc and V abundances decreasing with decreasing Ti. These variations are consistent with the trends expected from crystallization of type B melts [7]. One fassaite grain has REE abundances that are significantly higher (by an order of magnitude) than the others [6]. Core melilite REE compositions vary by a factor of five and are inversely correlated with Ak contents, as expected from partitioning experiments [8]. However, REE abundances are lowest in the more gehlenitic mantle melilite. This may reflect rapid cooling of the outer mantle, as [9] have noted that partition coefficients for melilite decrease with increased cooling rate.

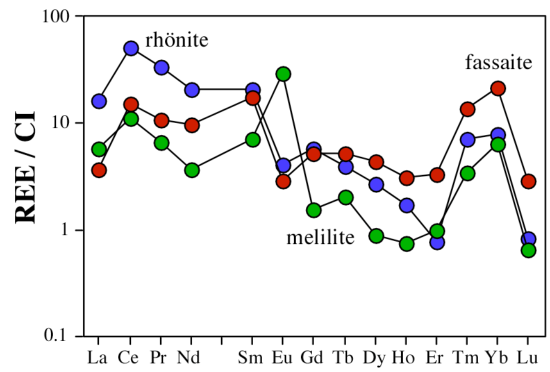


*Figure. 1. Representative CI chondrite-normalized REE patterns for minerals from E201.*

*E202*: E202 is a compact type A inclusion dominated by coarse-grained relatively gehlenitic melilite with minor fassaite, both of which poikilitically enclose spinel. Rounded rhönite grains are associated with fassaite and are surrounded by perovskite/melilite symplectites [5]. A rim containing spinel and perovskite surrounds one edge of the inclusion. The minerals in this inclusion have REE patterns that are largely unfractionated, but show some variations consistent with mineral/melt partitioning (Fig. 2). Melilite REE patterns are flat with small positive Eu anomalies; REE concentrations vary by a factor of three, but are not correlated with Ak contents. Both fassaite and rhönite REE patterns are HREE-enriched with negative Eu anomalies, and show little variation in abundance. REE concentrations are a factor of 5 higher in fassaite than rhönite. Perovskite has a slightly LREE-enriched pattern with a negative Eu anomaly and REE abundances of 600–900 x CI.

Preliminary Mg isotopic analyses suggest that both inclusions have $^{26}Mg$ excesses due to the decay of $^{26}Al$, with $^{26}Al/^{27}Al$ ratios consistent with the canonical value of 5 x $10^{-5}$. Additional measurements are planned to confirm this, and to look for Mg isotopic fractionation in the mantle of E201 that may provide evidence for evaporative loss of Mg.

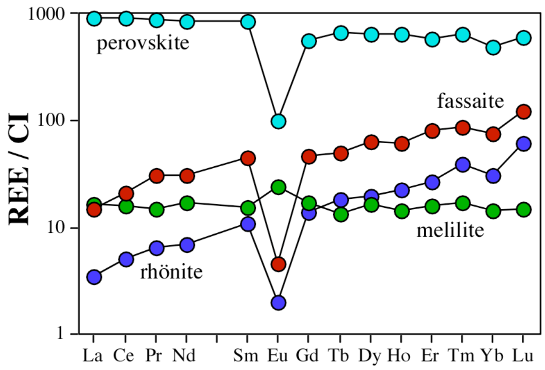


*Figure. 2 Representative CI-chondrite normalized REE patterns for minerals from E202.*

**Discussion:** The presence of rhönite in these inclusions and unusually Ti-rich fassaite in E201 may indicate high Ti/Si in their precursor materials [5], suggesting that the two inclusions originated in a similar region of the solar nebula. However, the trace element data indicate that they have experienced very different histories. In addition to the obvious differences in REE pattern types between the two inclusions, it is interesting to note that rhönite, which in E202 exhibits HREE-rich partitioning similar to fassaite, is in E201 much more strongly LREE-enriched than fassaite.

The modified group II REE pattern of E201 is unusual for type B1 inclusions [10] and indicates that its precursor material condensed after the fractionation and removal of an ultrarefractory component. The fact that an inclusion with similar REE patterns has accreted onto E201 suggests that melting of the E201 precursor material probably occurred in close spatial and/or temporal proximity to the original condensation event. E201 probably cooled rapidly under non-equilibrium conditions, as indicated by the absence of anorthite and the presence of rhönite [5], which is not predicted from equilibrium crystallization of type B CAI melts [11, 12]. Rapid cooling is also suggested by the low REE abundances in the mantle melilite, as noted above.

Spinel-free islands such as those seen in E201 have been interpreted as xenolithic components in some CAIs [13], but such an origin is unlikely in E201. Although the anomalously REE-rich fassaite grain noted above comes from a spinel-free region, two other fassaite grains from spinel-free areas have REE abundances in the range of those from spinel-rich areas. Moreover, [14] showed that REE concentrations for subliquidus fassaite extend to compositions that encompass such grains. Finally, it is not likely that xenolithic components would fortuitously have the same unusual fractionated REE patterns as the host CAI. The spinel-free regions may, however, represent unmolten or partially unmolten remnants of precursor material, which are not in complete equilibrium with the remainder of the CAI.

The origin of E202 is more enigmatic. Although compact type A inclusions are generally thought to have crystallized from liquids, their crystallization histories have been difficult to decipher. REE patterns in the minerals from E202 exhibit variations that are consistent with their formation from a melt, and [5] inferred a crystallization sequence of spinel followed by melilite, rhönite and fassaite for E202. However, melilite REE abundances are not correlated with Ak content as expected for igneous partitioning and fassaite REE and other trace element abundances show no systematic variations from one grain to another. E202 may have experienced later heating [e.g., 15] that obscured original igneous trends in melilite and homogenized fassaite REE compositions. However, the extent of metamorphism must have been limited, because major and trace element compositions in melilite are not homogeneous.

**Conclusions:** Trace element data show that E201 and E202 did not originate in the same part of the solar nebula. Both inclusions crystallized from melts of different precursor materials and E202 may have experienced some later metamorphism. The presence of rhönite in both CAIs could reflect crystallization kinetics [5], possibly coupled with elevated Ti/Si for E201, which contains Ti-rich fassaite in addition to rhönite.

**References:** [1] Fuchs L. H. (1971) *Am. Mineral.* **56**, 2053-2068. [2] Fuchs L. H. (1978) *Meteoritics* **13**, 73-88. [3] Allen J. M. et al. (1978) *PLPSC 9th,* 1209-1233. [4] Podosek F. A. et al. (1991) *GCA* **55**, 1083-1110. [5] Nazarov M. A. et al. (2000) *LPS. XXXI*, #1242. [6] Floss C. (2000) *MAPS* **35**, A53-A54. [7] Simon S. B. et al. (1991) *GCA* **55**, 2635-26455. [8] Beckett J. R. et al. (1990) *GCA* **54**, 1755-1774. [9] Davis A. M. et al. (1996) *LPS. XXVII*, 291-292. [10] Sylvester P. J. et al. (1992). [11] Stolper E. (1982) *GCA* **46**, 2159-2180. [12] Stopler E. and Paque J. M. (1986) *GCA* **50**, 1785-1806. [13] El Goresy A. et al. (1985) *GCA* **49**, 2433-2444. [14] Simon S. B. et al. (1991) *GCA* **55**, 2635-2655. [15] Teshima J. and Wasserburg G. J. (1985) *LPS. XXXVI*, 855-856.