

**THE QUEST FOR THE ELUSIVE LREE CARRIER IN UREILITES: AN ION MICROPROBE STUDY;** Yunbin Guan and Ghislaine Crozaz, McDonnell Center for the Space Sciences and Earth and Planetary Sciences Department, Washington University, St. Louis, MO 63130.

The rare earth elements (REEs) provide one of the most important constraints in exploring the enigmatic petrogenesis of ureilites. It is known that ureilites either have LREE-depleted or V-shaped REE patterns [1,2]. The former patterns have been attributed to the major silicate minerals in ureilites, olivine and clinopyroxene ----the HREE-enriched mineral phases. The simultaneous enrichment of LREEs and HREEs in the V-shaped patterns, however, suggests that component(s) other than olivine and clinopyroxene carry the LREEs in ureilites. Acid leaching experiments indicated that the LREE-enriched component may be associated with a minor phase which is heterogeneously distributed in the carbon-rich veins [e.g., 3]. Although the LREE and HREE enrichments have usually been ascribed to distinct petrogenetic events, recent data [4,5] have raised the question of whether the LREE-enriched component is indigenous to ureilites or whether it was introduced by terrestrial contamination. The latter alternative would also have important implications for ureilite chronology. To evaluate these two possibilities, we have made *in situ* REE measurements of various mineral phases in ureilites, using the Washington University ion microprobe.

With the exception of a preliminary ion microprobe study [6], all previous REE measurements were made on whole rocks or leachates and residues. The few *in situ* measurements [6] showed that no detectable REEs are present in metal and sulfides and that the carbon-rich interstitial areas have higher LREE concentrations than the large olivine and clinopyroxene grains. However it is not clear whether or not the measured LREE abundances in C-rich areas are sufficient to account for the bulk LREE abundances in ureilites with V-shaped patterns. We decided to extend this study to a much larger number of ureilites with known bulk REE patterns and to include in the analysis many additional elements whose association (or lack of) with the LREEs might help in identifying the carrier(s) of LREE enrichments. Here, we examined the thin sections of four ureilites: three of them (Kenna, Novo Urei and Goalpara) have V-shaped bulk REE patterns; the other one (LEW85440) has a LREE-depleted pattern. We focused on the analyses of the major silicates and the fine-grained carbonaceous veins. The analytical methods were similar to those described by Zinner and Crozaz [7]. The primary ion beams used were ~5 nA for carbonaceous veins and ~20 nA for major silicates. The counting times for 20 cycles through the chosen masses ranged from ~30 minutes to ~5 hours. Si was used as the reference element for all measurements. However, it should be noted that the SiO<sub>2</sub> contents of the carbonaceous veins are variable, even in a given ureilite, and that SiO<sub>2</sub> in the heterogeneous volume represented in each ion microprobe analysis can not be reliably determined independently (*i.e.*, with an electron microprobe). Therefore, for C-rich areas, only REE patterns (and not absolute REE abundances) will be presented.

The results show that the REE patterns of olivine and clinopyroxene are as expected from their REE partition coefficients. All olivines and clinopyroxenes have LREE-depleted patterns with little variations in abundances between different grains in the same or in different ureilites. Most of the clinopyroxene analyzed have negative Eu anomalies (Eu/Eu\* ratios range from 0.19-0.51), but no Ce anomalies were found (Ce anomalies, possibly indicating terrestrial contamination, were occasionally observed in the previous ion microprobe study [6]). LREE enrichments in the analyses of reduction rims of two olivine grains in Novo Urei (Fig. 1) are consistent with the suggested origin of these rims by reaction between olivine and carbonaceous materials [3]. However, at this point, we can not exclude the possibility that the "rim" analyses may have been affected by adjacent C-rich veins, given the relatively large primary ion beams used.

Large LREE-enrichments were found in the fine-grained carbonaceous veins of all three ureilites with bulk V-shaped REE patterns. This is consistent with the results obtained by Spitz *et al.* [6]. In contrast, the C-rich areas of LEW85440, which has a LREE-depleted bulk REE pattern, are not, as expected, enriched in LREEs. This is further evidence that LREEs in ureilites with V-

## The Quest for the Elusive LREE: Guan and Crozaz

shaped REE patterns reside in the carbonaceous veins. As in the major silicates, no Ce anomalies were found in the 28 C-rich areas analyzed. In each of the three ureilites with V-shaped bulk REE patterns, the REE patterns in distinct C-rich areas are very similar. However, the LREE patterns show variations among the different ureilites (Fig. 2). Novo Urei and Goalpara have similar LREE patterns, but the La enrichments in Kenna are much more pronounced. Compared to those in Kenna, the carbonaceous veins in Novo Urei and Goalpara contain more Ca and Sr. Good linear correlations between La and Sr and La and Ca are also observed for 10 measurements in C-rich areas of these two ureilites. However, no similar trends are found in the 11 C-rich areas analyzed in Kenna. This suggests that the LREE-enriched component might not be the same in all ureilites. If the LREE carrier in Novo Urei and Goalpara is a Ca, Sr-bearing mineral, it is not present in Kenna and the LREE enrichments in Kenna must be carried by other minor phase(s). Because the LREE signal generally shows little variations as the ion microprobe measurement proceeds, this LREE carrier has to be very fine-grained. Alternatively, the LREE enrichments in ureilites may not be due to a definite minor mineral phase, as already suggested by another study [8], but rather to the absorptions of these elements on the fine-grained carbonaceous materials.

In conclusion, this study confirms that the C-rich areas in ureilites carry the LREE enrichments. The nature of the carrier(s) is still in question. It could be, at least in some ureilites, a very fine-grained Ca, Sr-bearing mineral. Another possibility is that the LREEs are simply absorbed on the fine-grained graphite or amorphous carbon. Reducing reactions between carbon veins and olivine may have introduced LREEs in the olivine reduction rims. At this point, we have no reason to believe that the LREE enrichments are not indigenous to the ureilite parent body.

References: [1] Boynton *et al.* (1976) *Geochim. Cosmochim. Acta* **40**, 1439-1447. [2] Ebihara *et al.* (1990) *Meteoritics* **25**, 359-360. [3] Goodrich (1992) *Meteoritics* **27**, 327-352. [4] Torigoye *et al.* (1993) *Meteoritics* **28**, 450-451. [5] Torigoye *et al.* (1994) *LPS XXV*, 1409-1410. [6] Spitz *et al.* (1988) *LPS XIX*, 1111-1112. [7] Zinner and Crozaz (1986) *Int. J. Mass Spectrom. Ion Processes* **69**, 17-38. [8] Goodrich *et al.* (1991) *Geochim. Cosmochim. Acta* **55**, 829-848.

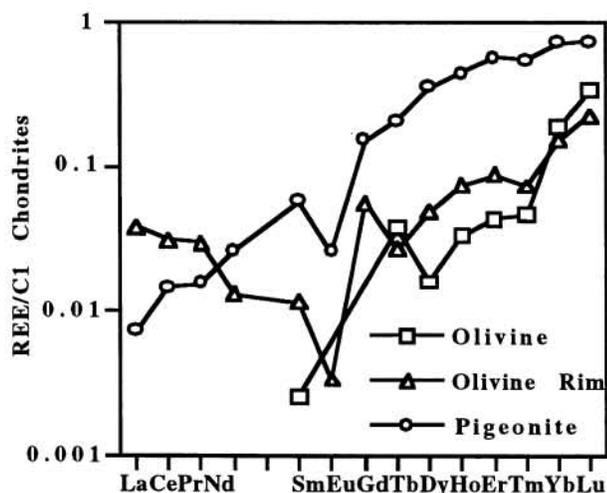


Fig. 1 REE Patterns of Silicates in Novo Urei

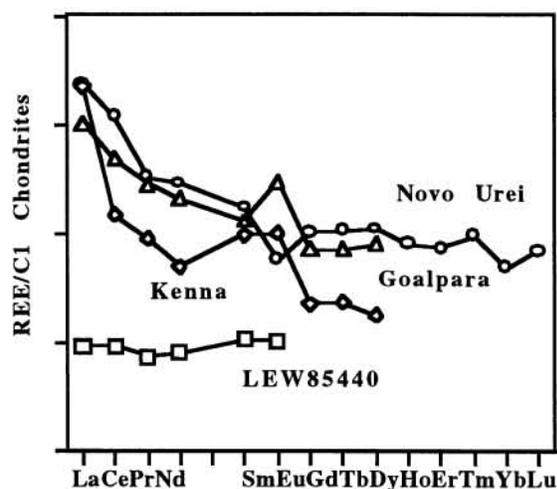


Fig. 2 REE Patterns in C-rich Areas