

**Sm-Nd ISOTOPIC STUDIES OF UREILITE NOVO UREI.** C.-Y. Shih<sup>1</sup>, L. E. Nyquist<sup>2</sup>, Y. Reese<sup>3</sup>, and C.A. Goodrich<sup>4</sup>, <sup>1</sup>Mail Code JE-23, Jacobs Technology, ESCG, P.O. Box 58477, Houston, TX 77258-8477, chi-yu.shih-1@jsc.nasa.gov; <sup>2</sup>Mail Code KR, NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX 77058, l.nyquist@jsc.nasa.gov; <sup>3</sup>Mail Code JE-23, ESCG/Muniz Engineering, Houston, TX 77058, young.reese-1@jsc.nasa.gov; <sup>4</sup>Planetary Science Institute, 1700 E. Ft. Lowell, Tucson, AZ 85719, cgoodrich@psi.edu.

**Introduction:** Ureilites are ultramafic (harzburgitic) achondrites composed predominantly of olivine and pyroxenes, abundant carbon (graphites and shock-produced diamonds), some metal and sulfides. These rocks probably represent ultramafic mantles of differentiated parent asteroidal bodies. Age determinations of these rocks by Rb-Sr and Sm-Nd methods have been difficult because of their extremely low abundances of these parent-daughter elements. Nevertheless, Sm-Nd isochron ages were reported for Kenna, Goalpara, MET 78008 and PCA 82506 yielding ages of  $3.74 \pm 0.02$  Ga,  $\sim 3.7$  Ga,  $4.09 \pm 0.08$  Ga,  $4.23 \pm 0.06$  Ga, respectively [1-4]. These "young" Sm-Nd ages may represent secondary metasomatism events [1] related to impacts [5], as indicated by the similarly young  $^{39}\text{Ar}$ - $^{40}\text{Ar}$  degassing ages of 3.3-4.1 Ga for ureilites Kenna, Novo Urei and Haverro [6]. Alternatively, it has been suggested that these rocks may have been contaminated with terrestrial crustal materials and the isochrons do not have any age significance [2,7]. Indications of old  $\sim 4.56$  Ga ages for ureilites were reported from the U-Pb and Sm-Nd model ages for MET 78008 [8]. More reliable evidences for old formation ages of ureilites were reported recently using the short-lived chronometers  $^{182}\text{Hf}$ - $^{182}\text{W}$ ,  $^{26}\text{Al}$ - $^{26}\text{Mg}$  and  $^{53}\text{Mn}$ - $^{53}\text{Cr}$ . The deficits of  $^{182}\text{W}$  in ureilites suggest the metal-silicate segregation occurred very early,  $\sim 1$ -2 Ma after CAI [9]. The  $^{26}\text{Al}$ - $^{26}\text{Mg}$  and  $^{53}\text{Mn}$ - $^{53}\text{Cr}$  studies for a feldspathic lithology [10] and the  $^{53}\text{Mn}$ - $^{53}\text{Cr}$  for olivine- and pyroxene-dominant lithologies [11] in ureilites revealed that they crystallized  $\sim 5.4$  Ma after CAI, i.e., at  $4563.8 \pm 0.5$  Ma relative to D'Orbigny. In this report, we present Sm-Nd isotopic data for a relatively fresh ureilite, Novo Urei, a rare ureilite fall (1886). We compare these data to Sm-Nd data for other ureilites, and discuss Novo Urei's petrogenesis.

**Samples and Analytical Procedures:** Several fragments of Novo Urei weighing 1.67 g were sonicated in ethanol for ten minutes to remove any surface contaminants. The sample was crushed to fine powder. An aliquot of 882 mg was taken as the bulk rock sample (WR). Another aliquot of the bulk rock sample of 793 mg was sonicated first with 2N HCl, then twice with  $\text{H}_2\text{O}$  for 10 minutes to eliminate possible post-crystallization, extra- or terrestrial, contamination. The residue, WR(r), weighed 710 mg and leachate, WR(l), weighed 84 mg. All samples were analyzed following the procedures of [12,13].

**Sm and Nd abundances :** Fig. 1 shows CI-normalized Sm and Nd contents for three bulk rock and leachate samples (red circles) along with the REE patterns of the bulk rock (green squares) by INAA [14] and four clinopyroxene grains (yellow areas) by ion microprobe [15]. The leachate sample WR(l) contains more Sm and Nd, and is LREE-enriched, as previously demonstrated by acid-leaching experiments [1,16]. Both WR and WR(r) samples contain little or probably no LREE-enriched component, as shown by their LREE-depleted patterns and low Sm abundances. They both lie in

the field defined by pure proxene grains in the Sm vs  $^{147}\text{Sm}/^{144}\text{Nd}$  plot (Fig 2). Thus, these Novo Urei bulk rock samples are probably "cleaner" and are better representations of pristine bulk ureilite samples than ureilite 'finds' Kenna and Goalpara.

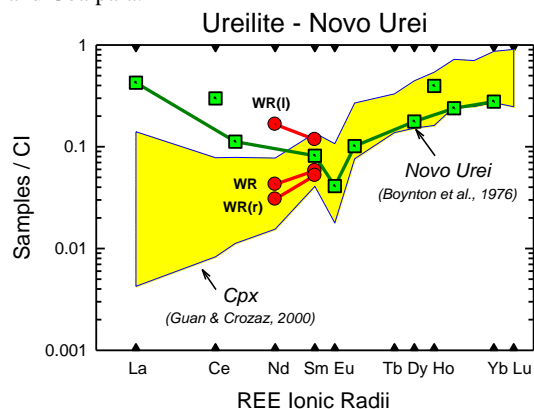


Figure 1. Sm and Nd contents of Novo Urei.

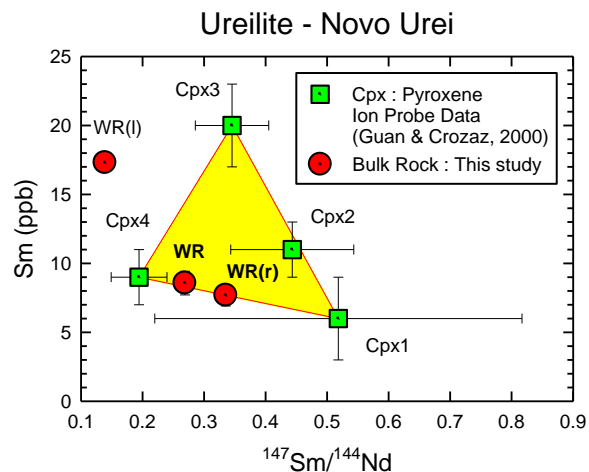


Figure 2. Sm and  $^{147}\text{Sm}/^{144}\text{Nd}$  data of Novo Urei.

We calculate the Sm and Nd abundances of the melt in equilibrium with the Novo Urei WR from its mineral modes, its Sm and Nd contents, and mineral partition coefficients. The calculation yields a LREE-enriched melt of  $^{147}\text{Sm}/^{144}\text{Nd}=0.13$ ,  $\text{Sm}=15 \times \text{CI}$  and  $\text{Nd}=23 \times \text{CI}$ . This melt could represent the missing basaltic crustal LREE-enriched component complementary to the mafic mantles represented by majority of ureilites.

**Sm-Nd isotopic results:** Fig. 3 shows  $^{147}\text{Sm}/^{144}\text{Nd}$  and  $^{143}\text{Nd}/^{144}\text{Nd}$  data for Novo Urei bulk rocks (red circles). The three samples form a linear array (blue line) corresponding to an age of  $4.1 \pm 0.1$  Ga for  $\lambda(^{147}\text{Sm})=0.00654 \text{ Ga}^{-1}$  and initial  $\epsilon_{\text{Nd}}=+20 \pm 2$ . Both the age and initial  $\epsilon_{\text{Nd}}$  are within the ranges

reported for ureilite “finds”, e.g. Kenna  $T=3.74\pm 0.02$  Ga and  $\epsilon_{Nd}=+33$ [1]; MET 78008  $T=4.09\pm 0.08$  Ga and  $\epsilon_{Nd}=+5$ [3] and PCA 82506  $T=4.23\pm 0.06$  Ga and  $\epsilon_{Nd}=+13$ [4]. The bulk rock sample (open square) plotting above the 4.1 Ga isochron is from a different lab [17]. The 4.56 Ga CHUR isochron (red line) lying below the Novo Urei 4.1 Ga isochron is shown for reference. These two isochrons intersect at  $^{147}\text{Sm}/^{144}\text{Nd} \approx 0.51$ . This highly LREE-depleted component was proposed to be the uncontaminated ultramafic end member of the metasomatic process [1] for both ureilites Kenna and Novo Urei. In this scenario [1], two episodes, i.e. 3.7 Ga for Kenna[1] and 4.1 Ga for Novo Urei [this study], of metasomatism occurred on ureilitic parent bodies.

**Petrogenetic model:** The metasomatism model of [1] can be applied to Novo Urei ureilite and is illustrated in its  $^{147}\text{Sm}$ - $^{143}\text{Nd}$  systematics (Fig 4). The blue open square represents the uncontaminated ureilite mantle source rock. It has  $^{147}\text{Sm}/^{144}\text{Nd}=0.51$  corresponding to  $^{143}\text{Nd}/^{144}\text{Nd}=0.52135$  at  $T=4.1$  Ga and an assumed very low Nd abundance of  $\sim 0.01$  ppm. Red open diamonds are two possible LREE-enriched contaminants. One has  $^{147}\text{Sm}/^{144}\text{Nd}=0.115$  and 8 ppm Nd proposed for Kenna in [1] and the other has  $^{147}\text{Sm}/^{144}\text{Nd}=0.13$  and 10 ppm Nd calculated for the melt in equilibrium with the Novo Urei WR. Their respective  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios are 0.51063 and 0.51104 at 4.1 Ga. Calculations show that it requires only  $\sim 0.1\%$  of the LREE-enriched contaminants to match the measured Nd abundance and  $^{143}\text{Nd}/^{144}\text{Nd}$  for the WR of Novo Urei.

A similar approach uses the  $^{146}\text{Sm}$ - $^{142}\text{Nd}$  isotopic data for Novo Urei to test this metasomatism model (see Fig. 5). We obtained an  $^{142}\text{Nd}/^{144}\text{Nd}$  datum only for the WR sample (red circle), which is  $\epsilon^{142}\text{Nd}=+1.5\pm 0.2$   $\epsilon$ -units relative to the terrestrial standard. A similar value of  $\epsilon^{142}\text{Nd}=+1.44\pm 0.21$  was reported for a pyroxene of  $^{147}\text{Sm}/^{144}\text{Nd}=0.3395$  from MET 78008 [8]. The CHUR (blue star) is  $-0.2\epsilon$ -units lower than the earth value. The blue curve shows the evolution of  $\epsilon^{142}\text{Nd}$  over time for the uncontaminated ureilite mantle source having  $^{147}\text{Sm}/^{144}\text{Nd}=0.51$ . The red curves are the similar evolution for LREE-rich contaminants having  $^{147}\text{Sm}/^{144}\text{Nd}=0.115$  and  $0.13$ . At 4.1 Ga, the ureilite mantle source has  $\epsilon^{142}\text{Nd}=+3.8$  and the respective contaminants has  $\epsilon^{142}\text{Nd}=-1.0$  to  $-1.2$ . Again, it requires only  $\sim 0.1\%$  of such LREE-enrich component to match the measured Novo Urei WR datum of  $\epsilon^{142}\text{Nd}=+1.5$ . Metasomatism may play a critical role in the interpretation of ureilite isochron data. The robustness of “young” Sm-Nd ages for ureilites should be further tested by studying more recent ureilite falls.

**References:** [1] Goodrich C.A. *et al.* (1991) *GCA*, **55**, 829-848. [2] Torigoye-Kita N. *et al.* (1995) *GCA*, **59**, 381-390. [3] Takahashi K. & Masuda A. (1991) *Antarctic Meteor.* **XVI**, 66-67. [4] Goodrich C.A. & Lugmair G.W. (1992) *LPS*, **XXIII**, 429-430. [5] Rubin A.E. (2006) *M&PS* **41**, 125-133. [6] Bogard D.D. & Garrison D.H. (1994) *LPS*, **XXV**, 137-138. [7] Torigoye-Kita N. *et al.* (1995) *GCA*, **59**, 4087-4091. [8] Torigoye-Kita N. *et al.* (1995) *GCA*, **59**, 2319-2329. [9] Lee D-C. *et al.* (2009) *EPSL*, **288**, 611-618. [10] Goodrich C.A. *et al.* (2010) *EPSL*, **295**, 531-540. [11] Qin L. *et al.* (2010) *M&PS* **45**, 1771-1777. [12] Nyquist L.E. *et al.* (1994) *M&PS* **29**, 872-885. [13] Shih C.-Y. *et al.* (1999)

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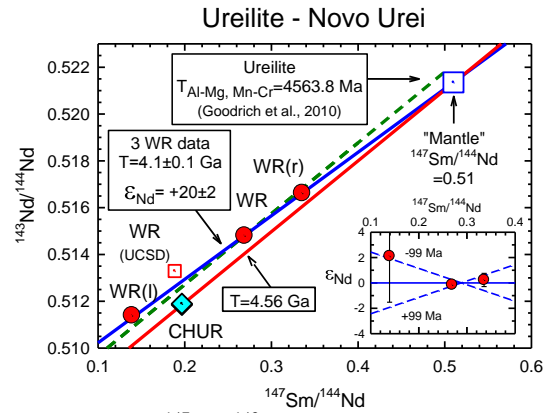


Figure 3.  $^{147}\text{Sm}$ - $^{143}\text{Nd}$  data of bulk Novo Urei.

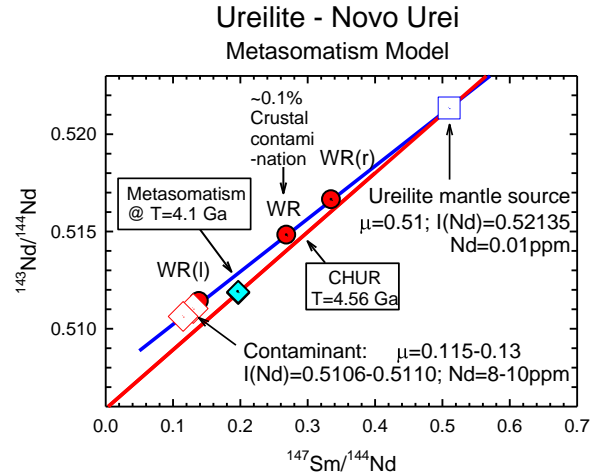


Figure 4.  $^{147}\text{Sm}$ - $^{143}\text{Nd}$  in metasomatism model.

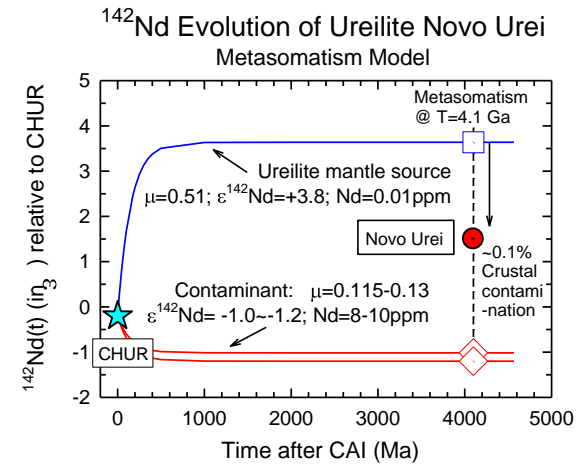


Figure 5.  $\epsilon^{142}\text{Nd}$  vs.  $T(\text{Ga})$  in metasomatism model.