

^{26}Al - ^{26}Mg and stable isotopes investigated in ureilites. G. Hublet¹, V. Debaille¹, L. S. Doucet¹, R. Greenwood², A. Yamaguchi³ and N. Mattielli¹, ¹Département des Géosciences, Environnement et Société, Université Libre de Bruxelles, CP 160/02, 50, Av. F.D. Roosevelt, 1050 Brussels, Belgium (ghublet@ulb.ac.be), ²Planetary and Space Sciences, Department of Physical Sciences, The Open University, Walton Hall, Milton Keynes, MK7 6AA, United Kingdom, ³National Institute of Polar Research, Tokyo, Japan.

Introduction:

Ureilites are the second largest group of differentiated meteorites (260 specimens) after the HED (Howardite-Eucrite-Diogenite) meteorite group. These meteorites are currently considered coming from the same parent body called the "ureilite parent body" (UPB) that has not been discovered yet. Actually, it has been proposed that the UPB has been destroyed by a major impact [1,2]. Ureilites are ultramafic achondrites mainly composed of olivine and low-Ca pyroxene (pigeonite). They are highly fractionated igneous rock but have also some primitive characteristic [3] such as heterogeneous values of $\Delta^{17}\text{O}$ suggesting that there could be several UPB. Today, there is a consensus about the ureilite representing partial melting residues. Chemical composition and texture argue that ureilites could be mantle residues of ~15-30% partial melting of the UPB mantle after the extraction of basaltic magma [4,5], even though so high degree of partial melting could not preserve heterogeneous $\Delta^{17}\text{O}$ [6–8]. In opposition, smelting process has also been proposed to explain the formation of ureilites without intensive partial melting [9]. This hypothesis suggested formation of ureilites by low degrees of partial melting that induced smelting without any homogenisation of the UPB.

In this study, Al-Mg systematic and stable O, Fe, Mg and Zn isotopes were investigated in five different monomict ureilites (Yamato (Y-)790981, Y-791538, Y-981750, Y-981810, Asuka (A-)881931) to answer at two major questions: Is there one or more UPB; and what are the asteroid processes that formed ureilites?

Analytical techniques:

All the preparation and chemical procedures were realized in clean laboratory at ULB except for O isotope analyzes that have been measured at Open University following the procedure described in [10]. Around 50 mg of each sample were crushed in an agate mortar for bulk analyze. All sample were dissolved with a concentrated HNO_3/HF mixture (2:1) followed by a step in HNO_3 (+ H_2O_2) to destroy the organic matter and a step in concentrated HCl. All samples and fractions were dissolved again in HNO_3 before the Mg separation procedure. An aliquot of each sample was taken without any purification for the $^{27}\text{Al}/^{24}\text{Mg}$ ratio measurements

and for the Zn, Fe isotope analyzes. For the whole rock data presented here, Mg was separated using cation-exchange resin (Bio Rad AG[®]50W-X12, 200–400 mesh). Mg elution was performed with 1N HNO_3 . The purification was repeated three times in order to insure a perfect separation of Mg and limited interferences with matrix. Elution during the second step used an HNO_3 -HF mixture.

Zn and Fe were separated using a cation-exchange resin (Bio Rad AG[®]1-X8, 100–200 mesh) following the method of [11]. Fe and Zn were collected respectively with HCl and an HNO_3/HBr mixture.

Mg, Fe and Zn isotopes were measured at ULB on a Nu-plasma II HR-MC-ICP-MS. Mg isotope measurements were performed in dry mode using an Apex desolvating system. Measurements were performed in medium resolution in order to avoid the potential isobaric interferences ($^{12}\text{C}^{14}\text{N}$) [12]. The instrumental mass bias was corrected by the sample-standard-bracketing method using DSM-3 as the standard solution.

Fe isotope measurements were performed in dry mode using a Cetac Aridus 2 desolvating system and in medium resolution, applying Ni dropping method. The instrumental mass bias was corrected by the sample-standard-bracketing using the IRMM-14 standard solution.

Zn isotope measurements were performed in wet plasma and low resolution, applying Cu doping method [13]. The instrumental mass bias was corrected by the sample-standard-bracketing method using a "in-house" standard normalized to the JMC-Zn-Lyon standard. Terrestrial reference materials standard BCR-2 and BHVO-2 were measured during the different analysis sessions to control the accuracy of the measurements.

Result and discussion:

Oxygen isotope:

$\Delta^{17}\text{O}$ values in our five ureilites vary between $-0.493 \pm 0.001\%$ and $-1.887 \pm 0.023\%$. This level of heterogeneity indicates that UPB did not undergo large-scale, asteroid-wide, homogenisation and so these results are inconsistent with high degrees of partial melting on the UPB. An alternative explanation is the smelting model for ureilite formation. Smelting process could occur with a low degree of partial melting where extraction of melt is too fast to erase the initial $\Delta^{17}\text{O}$ signature [14,15].

Iron isotope:

$\delta^{56}\text{Fe}$ values in ureilites are homogeneous within the standard error and give a non-chondritic average value of $+0.11 \pm 0.04\%$. This result shows enrichment in heavy isotopes. These $\delta^{56}\text{Fe}$ signatures reflect an efficient extraction of S-rich metallic melt produced during initial metal-silicate segregation [16].

$\delta^{25}\text{Mg}$ and ^{26}Al - ^{26}Mg dating:

The $\delta^{25}\text{Mg}$ values show a homogeneous and chondritic composition with an average of $-0.09 \pm 0.01\%$. No isochron relationship has been observed between $\delta^{26}\text{Mg}^*$ and $^{27}\text{Al}/^{24}\text{Mg}$, even though our five ureilites show various deficit in $\delta^{26}\text{Mg}^*$ compared to terrestrial standard. If these samples are formed at the same time, the $\delta^{26}\text{Mg}^*$ signatures suggest ureilites could come from different parent bodies. On the other hand, this could also be explained by different ages of crystallization for various samples coming from a single parent body. Considering the smelting model, the second hypothesis could be considered. Model age has been obtained using average $\delta^{26}\text{Mg}^*$ and $^{27}\text{Al}/^{24}\text{Mg}$ values of non-CAI-bearing chondrite for the UPB precursor composition, and could suggest a single and common source differentiated around 1.05 ± 0.72 Ma after the formation of the solar system.

Zn isotope and evidence of smelting:

$\delta^{66}\text{Zn}$ values of our five ureilites show heterogeneous signatures ranging from $+0.61 \pm 0.01\%$ to $+1.06 \pm 0.02\%$. These results reflect enrichment in heavy isotopes. Volatilization processes could easily fractionate volatile elements like Zn. [17] suggested that enrichment observed in ureilites could be induced by volatilization process produced by impact process, even though the correlation including shock degree is not clear. In our study, we evaluated the possibility that $\delta^{66}\text{Zn}$ signature could be produced by smelting process during ureilites formation (Fig. 1).

According to the isotope fractionation model [18] based on the Rayleigh distillation equation applied to the smelting process in metallurgic industry, we calculated the variation in $\delta^{66}\text{Zn}$ with the increase in smelting degree. A CI type initial composition was chosen for the UPB precursor. On the basis of this assumption, the $\delta^{66}\text{Zn}$ variability observed in our samples can be explained by a fractionation factor α of 1.0009-1.0011 and a degree of smelting around 50% for the most fractionated values in ureilites.

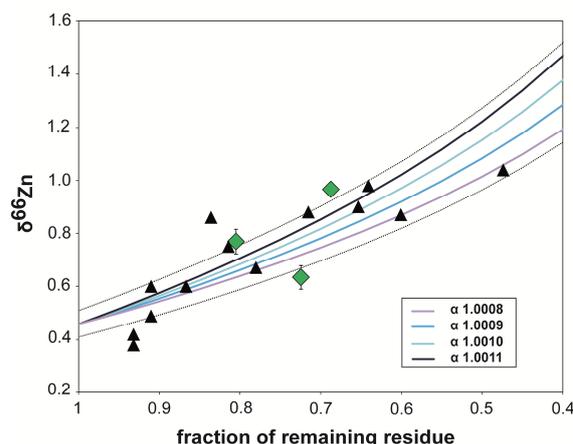


Figure 1: evolution profile of ureilite composition in $\delta^{66}\text{Zn}$ versus fraction of remaining residue considering various fractional factors (α) during smelting. The green diamonds correspond to ureilites analysed in this study. Black triangles correspond to ureilites from the study of [17].

Conclusion:

Combining several isotopic system (Al-Mg, O, Fe and Zn) indicate that that smelting process can reconcile a poorly-differentiated single UPB. On the basis of this hypothesis and considering a chondritic composition of UPB precursor, we can obtain a model ^{26}Al - ^{26}Mg age that suggests a very early differentiation for the UPB. While Fe isotopes are consistent with the early extraction of Fe-S liquid, the impact of smelting on those isotope ratios should be investigated more precisely.

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