NICKEL AND CHROMIUM STABLE ISOTOPE COMPOSITIONS IN UREILITES. K. Zhu (朱柯)[1,2]*, J.-A. Barrat[3], Akira Yamaguchi[4], and F. Moynier[2]. [1]Freie Universität Berlin, Institut für Geologische Wissenschaften, Berlin, Germany [2]Université de Paris, Institut de Physique du Globe de Paris, France. (*zhuke618@foxmail.com) [3]Univ. Brest, IUEM, France. [4]National Institute of Polar Research, Tokyo, Japan.

Introduction: Core formation is one of the most significant stage of planetary formation and evolution, affecting the elemental composition of siderophile (metal-loving) elements. Nickel (Ni) is a major element in chondrites (>1 wt%), and ~90% of its budget is located into the core [1], which can be reconstructed by comparing the Ni stable isotope differences between chondrites and bulk silicate Earth. Klaver et al. (2020) [2] firstly observed the Ni isotope difference between chondrites and BSE, i.e., $\Delta^{60/58}Ni_{Chondrites-BSE}$ = ~0.13‰, and interpreted it by terrestrial core formation. However both *ab initio* calculation [3, 4] and high-pressure experiments [3, 5] show that core segregation may not effectively induce Ni stable isotope fractionation.

Ureilite meteorites mostly represent mantle rocks of an early-differentiated carbon-rich planet [6, 7], after the extraction of various types of magmas [8] and a sulfur-rich iron melt [9]. As such, determining the potential Ni stable isotope difference between ureilites and chondrites could shed light on the core formation effect on Ni isotope fractionation, and further constrain the terrestrial core formation.

Chromium stable isotopes have also been widely used to study planetary differentiation [10-14], however there is a lack of Cr isotope data for ureilites. Here, we report high-precision Ni and Cr stable isotope data (both are using double spike technique) for ureilite meteorites to understand the Earth's core formation and differentiation of the ureilite parent body. The related analytical methods are following [15] and [11-14] for Ni and Cr isotope measurements, respectively.

Results and Discussion: Lack of clear relationships between $\delta^{60/58}Ni$ values and Ni contents and Mg# in the olivine core is consistent with the fact that terrestrial igneous processes do not effectively fractionate Ni stable isotopes, due to the absence of $\delta^{60/58}Ni$ variations between peridotites (0.10 ± 0.07‰) and basalts (0.03 ± 0.16‰) on Earth [2, 4]. The small-scale $\delta^{60/58}Ni$ heterogeneity can be caused by mixing of metal and sulfide (**Figure 1a and 1b**).

Since most of the Ni in ureilites are controlled by the metal phases that accounting for up to 3%vol. in bulk ureilites [16], the origin of the metal must be discussed. Most of these metals have largely fractionated highly siderophile elements relative to CV-CI chondrites, requiring extremely high degrees (>98%) of batch Fe–S melt extraction [16]. Addtionally, during the breakup of the body and immediately after, the carbon must have

reacted with the olivines, producing their characteristic zonings (with Mg-rich rims), according to the reaction: $C + MgFeSiO_4 = MgSiO_3 + CO + Fe$ [17]. Therefore, most of the metal contained in the ureilites should well represent secondary equilibrium with the silicate mantle, instead of represeting the core.
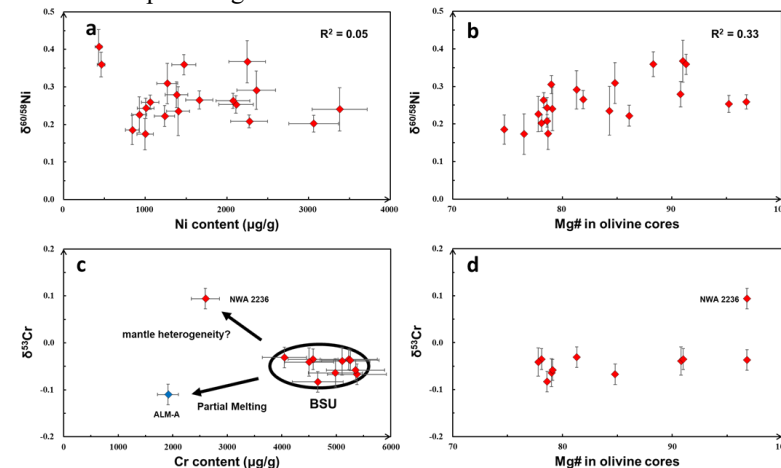

Figure 1. The relationships of Ni-Cr contents (bulk ureilites) and Mg# in olivine cores and $\delta^{53}Cr$-$\delta^{60/58}Ni$ values for ureilites (diamonds).

The Ni stable isotope composition of bulk silicate ureilite parent body (BSU) can be estimated by the average $\delta^{60/58}Ni$ values of all main-group ureilites: 0.26 ± 0.13‰ (2SD), ± 0.03‰ (2SE, N = 22), which is indistinguishable from that of chondrites $\delta^{60/58}Ni$ = 0.23 ± 0.14‰ (2SD) ± 0.02‰ (2SE, N =37; Table S1) [2, 4] (**Figure 2**). Thus, the BSU has the same Ni stable isotope composition as the core of UPB, and core formation process for UPB did not fractionate Ni stable isotopes. This is in agreement with predictions from *ab initio* calculation [3, 4] and high-pressure experiments [3, 5]. Since core formation of the UPB, which must have occurred at a lower temperature [18] than on Earth due to its likely smaller size, did not fractionate Ni stable isotopes, terrestrial core formation should also not fractionate Ni stable isotopes.

As for Cr stable isotopes, except NWA 2236 ($\delta^{53}Cr$ = 0.09 ± 0.02‰ that could be from mantle heterogeneity of UPB), all main-group ureilites show homogeneous $\delta^{53}Cr$ values with average of -0.05 ± 0.04‰ (2SD, N = 10), independent of Mg# in olivine cores (**Figure 1c and 1d**). This suggests a lack of Cr stable isotope fractionation during mantle processes in UPB. However, the $\delta^{53}Cr$ values for ureilites are higher than that of the ureilitic trachyandesite, ALM-A, which has a $\delta^{53}Cr$ value of -0.11 ± 0.02‰ (Figure 1c). The only analyzed

trachyandesitic composition (crustal sample) of the UPB, ALM-A, as an isotopically light Cr relative to the main-group ureilites (mantle rocks), likely reflecting partial melting effect on Cr stable isotope fractionations (exchange of Cr^{2+} and Cr^{3+}).
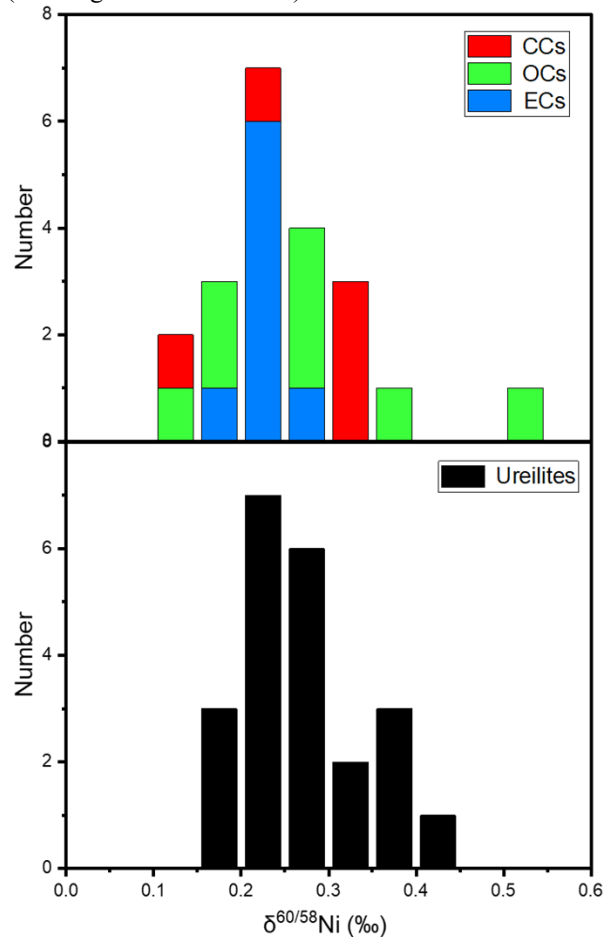
Figure 2. Frequency distribution histogram of Ni stable isotopes for chondrites and ureilites. CC: carbonaceous chondrites, OC: ordinary chondrites and EC: enstatite chondrites. Some of the chondrite data overlap.

Since Cr mostly reside in planetary mantle (relative to crust) due to its compatibility, the average $\delta^{53}Cr$ value of -0.05 ± 0.04‰ (2SD, N = 10) for main-group ureilites (except NWA 2236) should represent that of bulk silicate UPB. Compared to chondrites that have homogeneous Cr stable isotope compositions, with $\delta^{53}Cr = -0.12 \pm 0.04$ ‰ (2SD, N = 42) [14, 19, 20], the bulk silicate UPB possesses isotopically heavy Cr than chondrites that can represent of precursor material of UPB (Figure 3), with $\Delta^{53}Cr_{Ureilites-Chondrites} = 0.07 \pm 0.06$‰ (2SD) or ± 0.02 ‰ (2SE) (**Figure 3**). This Cr stable isotope difference between bulk silicate UPB and chondrites can be attributed to the differentiation of the UPB. This Cr stable isotope shift between ureilites and chondrites can be mostly caused by a sulfur-rich core formation process, similar to the heavy Cr found in enstatite achondrites, instead of Cr evaporation.
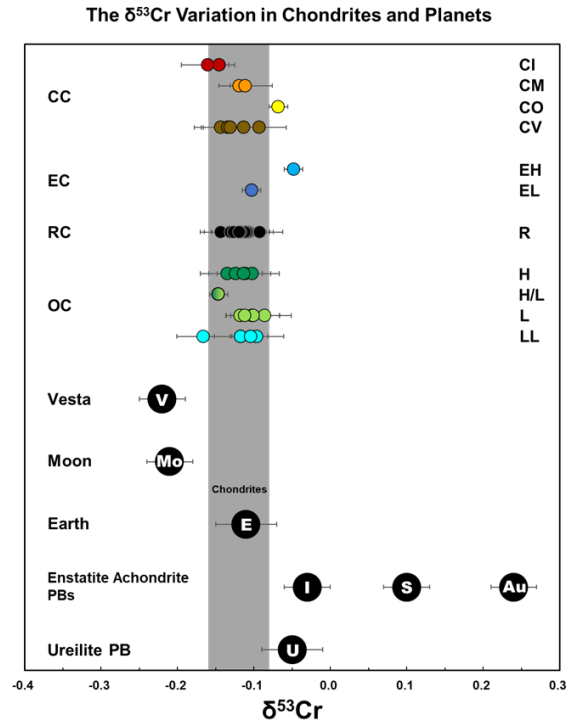
Figure 3. Comparison of the $\delta^{53}Cr$ variations amongst chondrites, achondrite parent bodies (I: Itqiy; S: Shallowater; Au: main-group Aubrites) and the Earth-Moon system.

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