Shock and thermal history of ureilites and implications of Zn depletion

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Ureilites are asteroidal peridotites and are the second-largest achondrites after HED meteorites. They were derived from the mantle of a carbon-rich planetary embryo broken by impact. Some workers suggested that the size of the parent body is ~200 km, whereas others suggested a diameter of at least 690 km (e.g., Warren 2012). The ureilite parent body had a heterogeneity in Mg# (=100 Mg/(Mg+Fe), molar) and O, C, and Zn isotopic compositions (e.g., Barrat et al. 2017; Bruiger et al. 2019). The heterogeneity of Zn isotope could have accompanied by volatile depletion by impact events (Moynier et al. 2010; Bruiger et al. 2019). It is likely that the Zn depletion has been related to shock and thermal history of individual ureilite. We studied the petrology and mineral chemistry of 12 ureilites and consider the relationship with thermal history and the degree of Zn depletion. We studied polished thick and thin sections of 12 Antarctic and non-Antarctic ureilites using an FE-SEM equipped with an EDS, an EPMA, and a LA-ICP-MS at NIPR.

The ureilites studied here include unbrecciated rocks or monomict breccias. They are mainly composed of low-Ca pyroxene and olivine with minor carbonaceous materials. Y 980110 and NWA 3222 contain augite grains. Y 981810 contains a few grains of chromite. Core compositions of olivine vary from $Fo_{77.0}$ (ALH-77257) to $Fo_{96.8}$ (NWA 2236). Olivine in three ureilites (A 09317, NWA 2234, NWA 4511) contain thick reduced rims (~40-70 vol.% of olivine) formed due to redox reaction with carbon formed after impact. Pyroxene has varying textures: unaltered crystalline pyroxene (NWA 2236), pyroxene with rims composed of fine-grained pyroxene and interstitial glass (e.g., Y-790981), and aggregate of fine-grained pyroxene with interstitial glass (Y-790981, NWA 4511, NWA 4471). The fine-grained pyroxene aggregate could have formed by preferential melting of pyroxene because the melting point of pyroxene is lower than that of coexisting olivine (Warren and Rubin 2010). There is no clear relationship between the degree of olivine reduction and melting in pyroxene.

Y-790981 and NWA 4511 experienced almost total melting of pyroxene and show large Zn isotopic fractionations (δ^{68}Zn=2.02 and 1.347, respectively) (Bruiger et al. 2019). This may indicate that the impact melting (and volatilization) may be a major cause of Zn isotopic fractionation. However, there is no clear relationship between bulk Zn abundances (~100-300 µg/g) (Barrat et al. 2017) and the degree of shock heating inferred from the textures. This may be due to variable initial Zn abundances before impact. It is important to observe responses to shock metamorphism and heating of individual minerals that carry significant amounts of Zn. There is no significant difference in Zn abundances between unleached and leached samples by nitric acid (Barrat et al. 2016), indicating that the carrier phases of Zn should be silicate and/or oxide minerals. Chromite can be a major carrier mineral of Zn in ureilites (e.g., Goodrich et al. 2014). Y 981810 contains chromite whose Zn is zoned from core to rim (~0.3-0.1 wt.% ZnO). This Zn zoning is related to Fe/Mn ratios (~50-10), suggesting that this Zn zoning formed by reduction during cooling. The fact indicates the depletion of Zn by heating by impact. However, not all the ureilites studied here contain chromite. Further study is needed to determine the Zn abundances of constituent minerals in ureilites.

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