Microscale Diversity of H, C, and N Isotopes in Asteroid Ryugu

Larry R. Nittler[1], Jens Barosch[1], Bradley T. De Gregorio[2], Rhonda M. Stroud[2], Hikaru Yabuta[3], and The Hayabusa2-initial-analysis IOM team, Hisayoshi Yurimoto[4], Tomoki Nakamura[5], Takaaki Noguchi[6], Ryuji Okazaki[7], Hiroshi Naraoka[7], Kanako Sakamoto[8], Shogo Tachibana[8,9], Sei-ichiro Watanabe[10] and Yuichi Tsuda[8]

[1]*Carnegie Institution of Washington, Washington DC, USA,* [2]*US Naval Research Laboratory, Washington DC, USA,* [3]*Hiroshima Univ.,* [4]*Hokkaido Univ.,* [5]*Tohoku Univ.,* [6]*Kyoto Univ.,* [7]*Kyushu Univ.,* [8]*JAXA,* [9]*Univ. of Tokyo,* [10]*Nagoya Univ.*

Understanding the nature and origin of organic matter in asteroid 162173 Ryugu is one of the key science goals of the Hayabusa2 sample-return mission. Macromolecular organic matter (MOM) makes up to a few % of primitive meteorites and displays a wide range of H, C, and N isotopic ratios on whole-rock to sub-μm scales [1]. Both its origin (for example, whether in the protosolar molecular cloud or in the protoplanetary disk) and the degree to which it is modified on asteroidal parent bodies is debated, but it may represent the dominant form of C delivered to early Earth. NanoSIMS-based isotopic imaging surveys of both bulk CI, CR, CM, and CO chondrites and purified MOM residues from them [2-6] have revealed that, while bulk samples are typically modestly enriched in D and ^{15}N, relative to the Earth, a small fraction of the material shows much more extreme enrichments and/or depletions in these isotopes. Large ^{13}C enrichments and depletions are also seen in chondrites, both in presolar circumstellar SiC and graphite grains [7], and in rare cases in MOM particles [8].

We have begun conducting similar NanoSIMS surveys of Ryugu samples. Four grains from Chamber A aggregates (A0108) were embedded in S and sectioned with an ultramicrotome equipped with a diamond knife. Relatively thick (250-nm) slices were deposited onto Si wafers for NanoSIMS analysis while adjacent thin sections were kept for coordinated analysis by transmission electron microscopy (TEM) and synchrotron X-ray microscopy (STXM). After the S was sublimated, we applied a thin Au coat to the Si wafers and analyzed them with a NanoSIMS 50L ion microprobe in multicollection imaging mode. Microtome sections were first analyzed for C and N isotopes (as $^{12}C_2$, $^{12}C^{13}C$, $^{12}C^{14}N$, and $^{12}C^{15}N$, plus ^{16}O, ^{28}Si, MgO and secondary electrons) with a 0.4 pA, <200-nm Cs^+ beam. The sections were then re-analyzed at the same magnification with a 1-pA beam and collection of ^{1}H, D, and ^{12}C secondary ions and secondary electrons. Five of the sections were subsequently re-measured for C and N to improve the counting statistics. Total counting times varied but were typically of order ~0.1 s/0.01 μm^2 for each run.

The measurements reveal broadly similar results to similar data obtained on primitive carbonaceous chondrites. The four particles show modest bulk enrichments of D and ^{15}N, with D/H and $^{15}N/^{14}N$ ratios in general agreement with those of CI chondrites. The NanoSIMS images show that much of the C is present as particles typically a few hundred nm in size, but ranging up to 2 μm. As in chondrites, a fraction of these particles show more extreme enrichments or depletions ("hotspots" and "coldspots") which span ranges similar to those recently seen in the least-altered CM chondrites Asuka 12169, Asuka 12236, and Paris [3]. A much smaller fraction of C-rich grains shows ^{13}C anomalies, associated both with presolar grains and organic particles. The bulk and microscale isotopic distributions vary to some extent among the four Ryugu grains, indicating heterogeneity at the 100-μm scale. Planned TEM and STXM measurements of slices from the same grains will help unravel the chemical nature of the organic particles and their relationship to inorganic phases in the asteroid.

References

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