RUMURUTI CHONDRITE OPAQUE MINERAL ASSEMBLAGES: IMPLICATIONS FOR PARENT-BODY PROCESSES.

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Introduction: Chondrites recorded complex histories in the early stages of the solar system; distinguishing between nebular and parent-body processes by the effects on chondrite components is essential. Formation conditions of opaque mineral assemblages that occur in CAIs, in chondrules and in chondrite matrix are of significant importance. Oxidized and sulfidized opaque nodules are found in many chondrites (e.g., CR, CV, CK, OC) and there have been extensive discussions of their formation conditions [e.g., 1-5]. In addition to these chondrite groups, sulfide nodules in R chondrites were recently studied [6]. R chondrites are one of the most oxidized and sulfidized chondrite groups and sulfides are a major component. Understanding alteration processes of sulfide assemblies leads to further understanding of the precursors of R-chondrite components and parent body processes. We utilized sulfide-rich opaque mineral assemblies in R chondrites and measured oxygen-isotope compositions in the nodules to identify their precursors and understand their formation. We analyzed the R chondrite Mount Prestrud (PRE) 95404.

Analytical methods: The samples were examined using a VEGA Tescan SEM and the JEOL 8200 electron microprobe at UCLA. Quantitative mineral compositions were obtained by electron probe micro analyzer (EPMA) with 20-s counting times for peaks and 5s counting time for backgrounds, ZAF corrections and a sample current of ~15 nA at 15 kV. Three sigma were used for the detection limits of minor elements.

Secondary ion mass spectrometry (SIMS) analyses were performed on the UCLA 1270 ion microprobe using a primary Cs^+ beam and analyzing negative secondary ions. Samples were sputtered with a primary beam of about 7 nA with impact energies of 20 keV focused to spots with a diameter in the range of 20-40 μm. A normal incident electron gun was used to compensate for possible sample charging. Oxygen isotopes ^{16}O, ^{17}O and ^{18}O were measured simultaneously on a multi-collector system. Three Faraday cups were used for the analysis. A mass resolving power >5000 was used to resolve interference of a singly charged ^{16}OH at mass 17. The magnetic field was regulated by a nuclear magnetic resonance (NMR) sensor throughout the analyses. SIMS data of olive grains were corrected based on the matrix effects correction factor [7].

Results: Opaque mineral assemblages occur as a few 2-3-μm- to 800-μm-size rounded blobs. The main components of these nodules are sulfide minerals. The nodules also contain opaque oxide, Cr-spinel, phosphate, silicate and alteration products of sulfide.

We determimed O-isotope compositions in two opaque mineral assemblages (Fig. 1 and 2). We analyzed large olivine fragments and an altered phase. The chemical formula of the alteration product has not yet been determined. An X-ray element map of this opaque mineral assemblage shows that the composition of the altered phase is a mixture of oxygen and sulfur. This is probably similar to altered phases (jarosite and tochilinite) reported in other R chondrites (LAP 02238, LAP 0364, LAP 031275 [8,9]. It is challenging to distinguish terrestrial weathering products from altered products formed on the asteroid; however, we cannot exclude parent-body alteration from the texture.
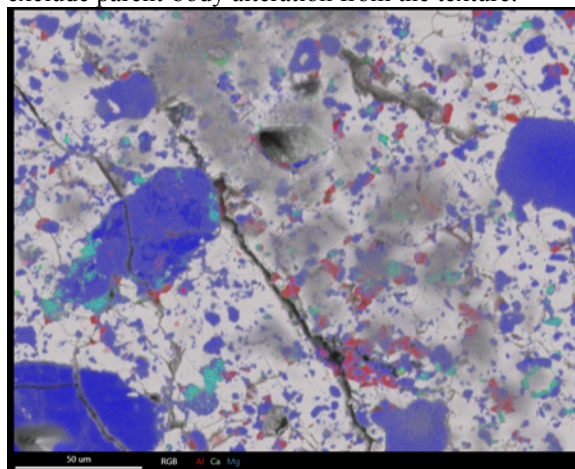

Figure 1: X-ray map on a BSE iamge of sulfide-rich nodule-1. Al (red) Ca(green) Mg (blue). Darker gray areas are oxygen-rich altered sulfide. SIMS spot is located on the altered phase.

The results of the oxygen-isotope measurements are listed in Table 1 and depicted in Fig. 3. The data are reported as per mill deviations from SMOW. Mass-independent isotope fractionations are shown as $\Delta^{17}O$ values ($\Delta^{17}O = \delta^{17}O - 0.52 \times \delta^{18}O$). The O-isotope compositions of silicate grains in sulfide nodule-1 are highly unequilibrated while the O-isotope compositions of the silicate fragment in sulfide nodule-2 are similar to that of equilibrated R chondrites.

Table 1

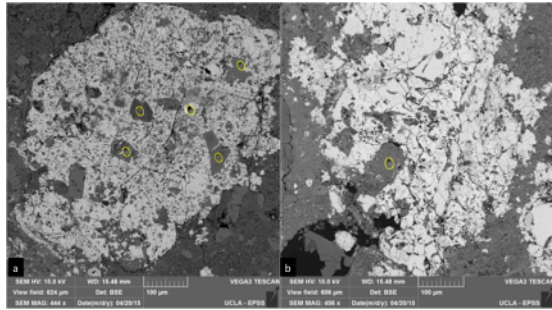| name	$\delta^{18}O$	2SE	$\delta^{17}O$	2SE	$\Delta^{17}O$	phase	Fa
nodule1-1	1.1	0.3	1.7	0.4	1.1	olv	12
nodule1-2	2.5	0.2	1.8	0.2	0.5	olv	16
nodule1-3	-2.5	0.7	-2.4	0.4	-1.1	olv	39
nodule1-4	7.1	0.2	4.0	0.3	0.3	olv	41
nodule1-5	-15.1	0.4	-17.5	0.6	-9.7	sulfate??	-
nodule2	2.4	0.5	3.4	0.5	2.1	px/olv intergrowth	-

Figure 2: BSE images of sulfide nodule-1 (left) and sulfide nodule-2 (right). Yellow ovals are SIMS spots.
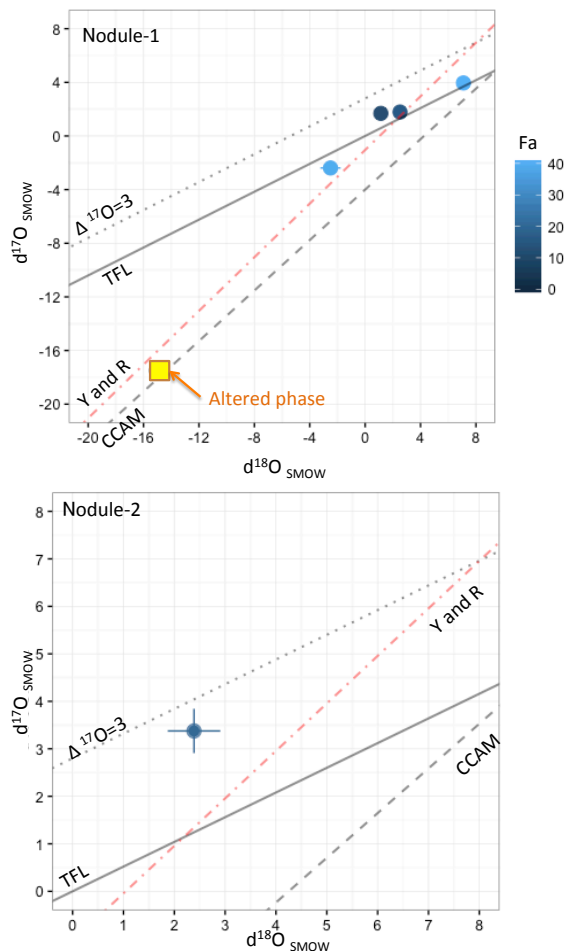

Figure 3: Three oxygen-isotope plots of sulfide nodule-1 and -2.

Discussion: We observed different O-isotopic compositions in the two selected opaque mineral assemblages in PRE 95404. Despite similarities to equilibrated R-chondrite olivine, the olivine grains in nodule-1 that we analyzed have O-isotope compositions that are distinct from equilibrated R chondrites ($\Delta^{17}O=\sim3$). In sulfide nodule-1, the olivine grains and altered phase plot near the Young-Russell line or CCAM line. Olivine Fa values of spot-1 (Fa12) and spot-2 (Fa16) are clearly lower than R-chondrite equilibrated olivine Fa values (Fa 38-40) and oxygen-isotope compositions of the grains are similar to those of ordinary chondrites. Olivine Fa values of spot-3 (Fa 39) and spot-4 (Fa 40) indicate that the Fe/Mg compositions of these grains were equilibrated on the R chondrite parent body; however, these oxygen-isotope compositions may be still inherited from their formation reservoir.

Although mineral compositions of the altered phase were not clearly determined, it is apparent that the major oxide phases in the analyzed spot were formed in ^{16}O-rich reservoirs. This is somewhat unexpected because aqueous alteration either on Earth, on asteroids or in the nebula should elevate the $\Delta^{17}O$ value. For example, terrestrial water is $\Delta^{17}O=0$ and thus sulfide that weathered on Earth should have $\Delta^{17}O=0$. R-chondrite magnetite, which formed due to corrosion of metal on the R parent body, has high $\Delta^{17}O$ ($\Delta^{17}O=+3.8$)[10]. Furthermore, similar mineralogical objects, "cosmic symplectite," is explained as having formed by alteration of pre-existing sulfide by ^{16}O-poor water vapor in the solar nebula; these have an extremely high $\Delta^{17}O$ value ($\delta 1^{7}O=\delta^{18}O>+150‰$) [11]. Water throughout the solar system consistently has ^{16}O-poor compositions; thus it is likely that the analyzed spot had much more ^{16}O-rich oxide prior to additional aqueous alteration. However, further research is required to identify the origin of the alterations.

Formation of the opaque mineral assemblages

The oxide in opaque mineral nodules that we investigated in this study have highly diverse chemical compositions and oxygen-isotope compositions. Therefore, these silicate/oxide grains are unlikely to have formed from an immiscible liquid as proposed for "sulfide chondrules" [6] because that would produce a uniform O-isotope composition. It is more plausible that the fragments we studied were secondary products that were mechanically mixed with sulfide grains. Probably "sulfide chondrules" are the primary source for the sulfide nodules that we studied.

These sulfide-rich nodules were unlikely to have formed in-situ rather than in localized regions such as highly metamorphosed areas or impact melts because there are no sulfide-rich veins or secondary veins in this chondrite. Because the R-chondrite group has heavily brecciated members, the silicate/oxide sulfide fragments are easily found in the matrix. Sulfide blobs produced in a CV-chondrite partial melt experiment [12] seem to be textually consistent with R-chondrite sulfide nodules with oxide fragments.

References: [1] Gooding and Keil (1981) *Meteoritics* 16, 17-43 [2] Blum et al. (1986) *GCA, 53,* 543-556. [3] Grossman and Wasson (1986) *GCA 49,* 925-939 [4] Lauretta et al. (1996) 122, 288-315 [5] Kimura et al. (2011) *MAPS* 46, 431-442. [6] Miller et al. LPS #1496 XLVII [7] Isa et al. LPS #3004 XLVII [8] McCanta and Treiman (2010) #1394. LPSC XLI [9] Steer and Treiman (2014) *LPI Contribution No. 1800, id.5333* [10] Greenwood et al. (2000) *GCA* 64, 3897-3911 [11] Sakamoto N., et al. (2007) *Science,* 317.