THE OXYGEN ISOTOPIC COMPOSITION OF SAMPLES RETURNED FROM ASTEROID RYUGU: EVIDENCE FOR SIMILARITY TO CI CHONDRITES. E. D. Young[1], H. Tang[1], L. Tafla[1], A. Pack[2], T. Di Rocco[2], H. Yurimoto[3], the Hayabusa2-initial-analysis chemistry team, and the Hayabusa2-initial-analysis core. [1]UCLA, USA (eyoung@epss.ucla.edu), [2]Universität Göttingen, Germany, [3]Hokkaido University, Japan.

Introduction: Samples returned from the Ryugu C-type asteroid by the Hayabusa2 mission have clear mineralogical affinities to CI meteorites [1]. Here we report "bulk" oxygen isotopic measurements of mg-sized grains from two samples from Ryugu, A0107 and C0002, which are the samples collected at the first and second touchdown, respectively. We compare them to CI chondrites measured using the same methods, focussing here on the Orgueil meteorite. As part of this comparison, we also report results of heating experiments on Orgueil samples that shed some light on the sources of potential differences between CI-meteorite and Ryugu samples.

Methods: Analyses were performed at UCLA and at the University of Göttingen. In both cases IR laser-assisted fluorination was used, but with some differences in methods. At UCLA, samples were heated to $\sim 116°$C using an IR lamp while pumping for approximately 5 hours prior to fluorination. At Göttingen samples were pre-heated by applying heating tape to the stainless steel air lock containing the samples. The air lock reached a temperature of 100°C for 24 hrs. At UCLA, analyses of O_2 were performed using a large-geometry gas-source mass spectrometer to resolve mass/charge interferences. At Göttingen, O_2 liberated by fluorination was purified using gas chromatography. The two laboratories obtain similar results for San Carlos olivine and O_2 from air. Analyses from UCLA are colored blue and those from Göttingen are colored red to permit distinction between results from the two labs. Two samples of Orgueil at UCLA were heated to 350°C and another at 250°C for 5 hours while actively pumping in a vacuum furnace and then analyzed for comparison with unheated samples.

Results: All four of the Ryugu analyses plot in the vicinity of CI meteorite samples in oxygen three-isotope space (Figure 1), albeit at the higher end of both δ^{18}O and Δ'^{17}O relative to most analyses of Orgueil (Δ'^{17}O quantifies deviations from the mass fractionation line passing through VSMOW with a fractionation exponent of 0.528). The two A0107 samples of Ryugu measured at UCLA, with masses of 2.58 and 1.50 mg, have an average Δ'^{17}O of $0.575 \pm 0.003(2\sigma)$ ‰ (Figure 2). This is higher than the maximum value for Orgueil from UCLA and Göttingen, and from the literature (Figures 1 and 2). The two C0002 samples of Ryugu measured at Göttingen, with masses of 1.42 and 1.30 mg, yield an average Δ'^{17}O value of 0.306 ± 0.02.

The difference between the two samples is greater than the differences in standards between the laboratories, suggesting that the difference reflects sample heterogeneity, likely due to indigenous differences in phyllosilicate Δ'^{17}O as well as variability in modal abundances of minerals with different Δ'^{17}O values [2] and/or labile water contents (see below). The δ^{18}O values of these samples vary over several per mil, presumably for similar reasons.

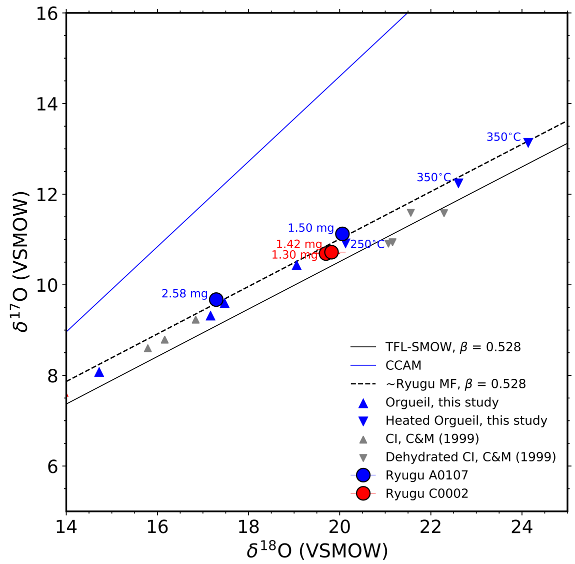

Figure 1: Oxygen three-isotope plot comparing Ryugu mg-sized samples with Orgueil meteorite values from this study and from the literature. C&M refers to [3].

Discussion: Because the Ryugu samples are depleted in interlayer water compared with CI chondrites despite having saponite as a significant constituent [1], we investigated the effects of removing interlayer water from samples of Orgueil for comparison with the Ryugu samples. We are testing the hypothesis that at least some interlayer water in CI chondrite saponite is terrestrial in origin, and that this might explain why both Δ'^{17}O and δ^{18}O of the Ryugu samples tend to be on the higher side of the great majority of CI data (this trend is not universal; the Göttingen laboratory obtained $\Delta'^{17}\mathrm{O} = 0.78$ for the Alais CI chondrite). Interlayer water should be released between $\sim 200°$ and $\sim 350°$C [1] given sufficient time. Our results over 5 hours exhibit mass losses of between 7.5% and 25% (Figure 2). These temperatures are too low for thermal decomposition of carbonates [4, 5]. We cannot exclude the possibility of sulfate decomposition, but note that due to the terrestrial origin of many

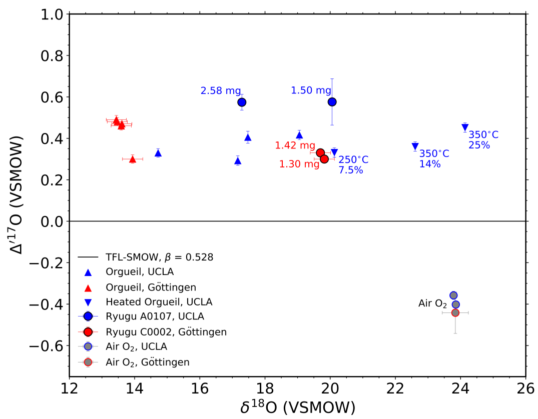

Figure 2: Plot of Δ'^{17}O vs. δ^{18}O showing results of Orgueil heating experiments together with Orgueil meteorite and asteroid Ryugu samples. Percentages represent mass losses due to heating at the indicated temperatures.

sulfates in Orgueil [6], the effects on Δ'^{17}O may be similar to water. With mass loss, Δ'^{17}O increased with increasing δ^{18}O (Figure 2) beyond expectations from a change in mass fractionation law. Converting mass loss to oxygen fraction, assuming it is entirely due to water, the oxygen balance equation becomes

$$\begin{aligned}\Delta'^{17}\mathrm{O}_{\mathrm{meas}} &= \Delta x_{\mathrm{H_2O}}\left(\Delta'^{17}\mathrm{O}_{\mathrm{ah}} - \Delta'^{17}\mathrm{O}_{\mathrm{H_2O}}\right)\\ &+ \left(\Delta'^{17}\mathrm{O}_{\mathrm{ah}} + x^{\circ}_{\mathrm{H_2O}}(\Delta'^{17}\mathrm{O}_{\mathrm{H_2O}} - \Delta'^{17}\mathrm{O}_{\mathrm{ah}})\right)\end{aligned} \quad (1)$$

where $\Delta x_{\mathrm{H_2O}}$ is the *oxygen* fraction lost as water, $x^{\circ}_{\mathrm{H_2O}}$ is the pre-heating oxygen fraction of water, and "ah" refers to the rock component excluding interlayer water. This equation shows that the slope in Figure 3 corresponds to the difference in Δ'^{17}O between interlayer water and the remainder of the rock. Regression of the three points in Figure 3 yields $\Delta'^{17}\mathrm{O}_{\mathrm{ah}} - \Delta'^{17}\mathrm{O}_{\mathrm{H_2O}} = 0.51$ ‰. Assuming the mass loss is due mainly to terrestrial interlayer water, with $\Delta'^{17}\mathrm{O} = 0.0$ ‰, the meteorite has a Δ'^{17}O of 0.51 ‰. This result is consistent with the hypothesis that CI meteorites exhibit variability in Δ'^{17}O values in part due to variable interlayer H_2O of terrestrial origin. We can expect these meteorites to exhibit generally lower Δ'^{17}O values than the Ryugu samples that have little interlayer H_2O. Similar results obtain for δ^{18}O where the component lost by heating has apparent δ^{18}O values 16 ‰ lower than the remainder. This value includes convolved fractionation effects. The heated Orgueil samples have δ^{18}O values reminiscent of samples previously referred to as CY chondrites [7].

Conclusions: Ryugu samples resemble CI chondrites in their "bulk" oxygen isotope ratios at the milligram scale, but may have slightly higher Δ'^{17}O and δ^{18}O values due at least in part to lack of contamination

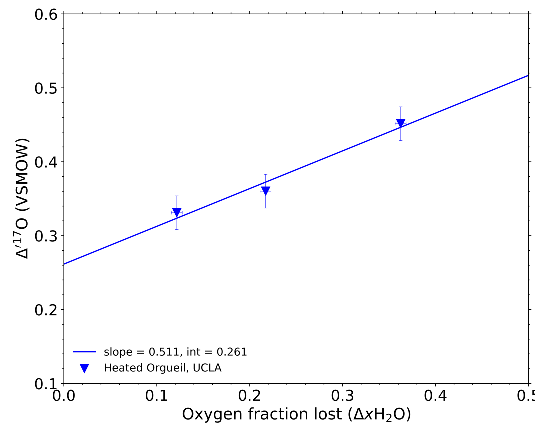

Figure 3: Results of heating experiments in Δ'^{17}O vs. oxygen fraction lost ($\Delta x_{\mathrm{H_2O}}$).

by interlayer water of terrestrial origin.

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