

X-RAY DIFFRACTION AND REFLECTANCE SPECTROSCOPY OF MURCHISON POWDERS (CM2) AFTER THERMAL ANALYSIS UNDER REDUCING CONDITIONS TO FINAL TEMPERATURES BETWEEN 300 AND 1300°C.

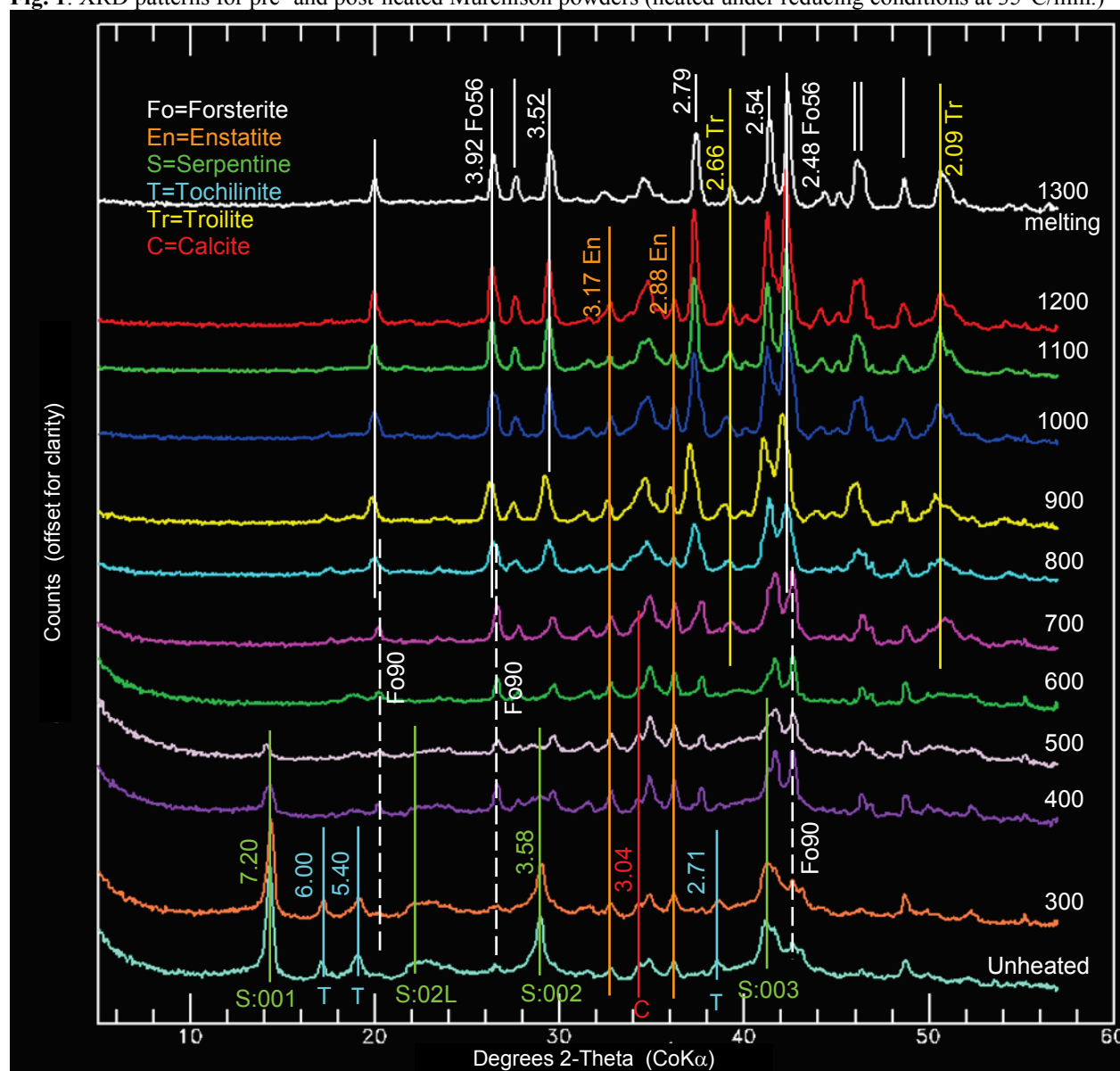
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Introduction: The asteroids Ryugu and Bennu have spectral characteristics in common with CI/CM type carbonaceous chondrites and are target bodies for JAXA's Hayabusa2 and NASA's OSIRIS-Rex missions, respectively [1-3]. Analog studies, based primarily on the Murchison CM2 chondrite, provide a pathway to separate spectral properties resulting space weathering from those

inherent to parent-body, mineralogy, chemistry, and processes [4-6]. Ryugu shares spectral properties with thermally metamorphosed and partly dehydrated CI/CM chondrites [1]. We have undertaken a multidisciplinary study of the thermal decomposition of Murchison powder samples as an analog to metamorphic process that may have occurred on Ryugu. Bulk analyses include thermal

Fig. 1. XRD patterns for pre- and post-heated Murchison powders (heated under reducing conditions at 35°C/min.)



And evolved gas analysis, X-ray diffraction (XRD), and VIS-NIR and Mössbauer spectroscopy; micro- to nano-scale analyses included scanning and transmission electron microscopy and electron probe micro analysis. We report here XRD and VIS-NIR analyses of pre- and post-heated Murchison powders, and [7] in a companion paper report results from multiple electron beam techniques.

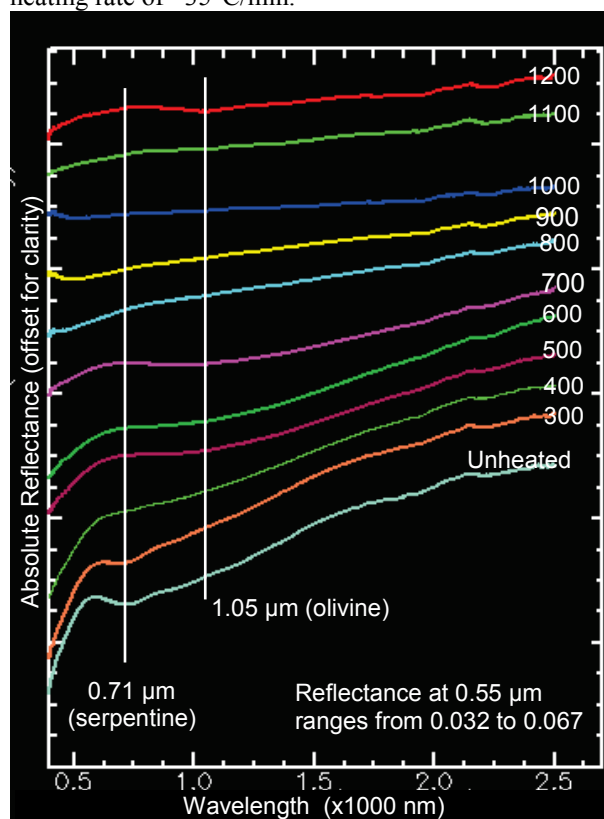
Methods: A whole-rock Murchison sample was dry ground and sieved under ambient conditions to the <45 μm size fraction. Triplicate aliquots were analyzed in a Labsys EVO differential scanning calorimeter furnace/thermal gravimeter (DSC/TG) connected to a Thermo-star quadrupole mass spectrometer, purged with He gas (30 mbar at 10 sccm). Samples were heated from ambient to between 300 °C and 1300 °C in 100 °C steps at 35 °C/min and then rapidly cooled back to ambient temperatures. The instrument configuration and operating conditions are similar to those for the Mars Science Laboratory (MSL)-Sample Analysis at Mars (SAM) evolved gas analyzer. The samples remained as powders for all end temperatures except 1300 °C, and the aliquots for each end temperature were combined after thermal analysis to provide sufficient material for mineralogical and spectral analyses. XRD patterns were acquired on a transmission XRD instrument (CoK α radiation) that functionally approximates the MSL-Chemistry and Mineralogy (CheMin) instrument [8]. Reflectance spectra were acquired on an ASD FieldSpec 3 spectrometer configured with a MUGLite probe (Malvern-PANalytical).

Discussion: Overall, the XRD patterns (Fig. 1) show that the dominant phases for our unheated Murchison powder (serpentine, olivine (~Fo90+), tochilinite (a Fe-Ni hydroxy sulfide), and enstatite) progressively decompose primarily to olivine (~Fo56) and troilite by 1200°C. Total weight loss is ~13 wt.% from TG data. Tochilinite, serpentine, and Fo90 olivine are no longer readily XRD-detectable at temperatures above 400°C, 600°C, and 800°C, respectively. The onset temperatures for discernable peaks for ~Fo56 and troilite are both at temperatures above 700°C. These mineralogical trends with temperature are consistent with evolved gas analysis (EGA) results for evolution of H₂O and SO₂ (not shown). At intermediate temperatures (~400°C to ~1000°C), amorphous phases are likely present, but not readily detected by bulk-sample XRD analysis, during the thermal decomposition of serpentine to Fo56 olivine and tochilinite to troilite.

The VIS-NIR spectra (Fig. 2) show that the pre- and post-heated Murchison powders are all very dark, with the reflectance at 550 nm ranging from ~0.032 to ~0.067, and all powders heated to temperatures between 300°C and 900°C have reflectance values less than that for the unheated Murchison powder (0.058). The spectrum of

the unheated Murchison powder characterized by the typical 0.71 μm spectral feature associated with Fe²⁺, Fe³⁺ charge transfer in serpentine [e.g., 9]. As expected from the XRD patterns, this spectral feature is not readily detected (by 400°C) as the decomposition of serpentine to olivine progresses with increasing temperature. A spectral feature associated with Fe²⁺ in olivine is apparent in the 1200°C sample at ~1.05 μm . The overall positive and generally featureless spectral slope at intermediate temperatures is consistent with the hypothesis that Ryugu may have experienced thermal metamorphism.

Fig.2. Reflectance spectra for powders of unheated Murchison (<45 μm) and products of thermal analysis at final temperatures between 300°C and 1200°C and a heating rate of ~35°C/min.



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References: [1] Kitazato, K. *et al.* (2019) *Science*, 364, 272. [2] Hamilton, V.E. *et al.* (2019) *Nature Astron.*, 3, 332. [3] Clark B.E. *et al.* (2011) *Icarus*, 216, 462. [4] Trang, D. *et al.* (2019) *LPSC 50th*, #2172. [5] Thompson, M.S. *et al.* (2017) *Meteorite Planet Sci*, 52, 413. [6] Thompson, M.S. *et al.* (2019) *Icarus*, 319, 499. [7] Lee, S. (2020) this volume. [8] Blake D.F. *et al.* (2012) *Space Sci. Rev.*, doi:10.1007/s11214-012-9905-1. [9] Cloutis, E.A. (2011) *Icarus*, 216, 309.