MINERALOGY OF THE SUTTER'S MILL CARBONACEOUS CHONDRITE. Laurence A.J. Garvie, Center for Meteorite Studies, Arizona State University, Tempe, AZ 85287-6004, USA. lgarvie@asu.edu

Introduction: On the morning of April 22nd, 2012, a fireball was observed over Nevada and California, with subsequent recovery of three meteorites on April 24th around Coloma and Lotus in California. These pieces are significant as they are the only to be collected before heavy rains on the 25th and 26th. To date, ~1000 g have been found as 90 small stones. The fortuitous breakup into individual, small meteorites facilitated the distribution and study of multiple individuals.

Initial studies show the stones to be a breccia, with bulk chemistry matching that of CM chondrites [1]. The $\delta^{17}O$ versus $\delta^{18}O$ data of two stones [1] show one (SM43) to be within the CM field, and the other (SM51) between the CM field and Tagish Lake. Despite the isotopic and focused mineralogical and chemical analyses, bulk mineralogical studies were not undertaken. Here I report powder x-ray diffraction (XRD) and thermal gravimetric analysis (TGA) data on seven Sutter's Mill stones.

Materials: XRD patterns were acquired from SM3 (pre-rain), 6, 8, 38, 41, 49, and 65. The stones ranged from relatively soft and friable (SM 41) to hard and porcelainous (SM8). Broken surfaces show brecciation with clast-rich and poor regions. Rounded, mm-sized clasts protrude from broken surfaces of SM3, 49, and 65. SM49 shows well-developed slickenslides. On the whole, recognizable chondrules are relatively rare. Only SM38 has many chondrules, some with Fe-Ni metal, and one to 2 mm with a well-developed 300-µm dust rim. For comparison with Sutter's Mill, XRD patterns were acquired from Murray (CM2), Ivuna (CI1), Bells (C2-ung), Tagish Lake (C2-ung), and Moapa Valley (CM1).

Methods: Each XRD sample was prepared from an ~10 mg chunk (~2 mm piece). The pieces were crushed, mixed with a few ml of methanol and the resulting slurry pipetted onto a low-background single-crystal quartz plate and spread out to form a thin smooth film. This film was dried rapidly under flowing warm air. XRD profiles were acquired with a Rigaku D/Max-IIB diffractometer, with a post-diffraction monochromator, employing Cu Kα radiation. Data were acquired from 5 to 65°, 0.02° steps, and 60 s/step. XRD profiles were acquired from multiple areas of stones. SM3 is essentially anhydrous (see Results) and its background profile was used for the subtraction of the backgrounds from all other patterns.

TGA data was acquired for SM3, 41, Murchison, and Orgueil under flowing He from 20° to 1000° C, with a heating rate of 10°C/min.

Results: The XRD profiles show two distinct mineralogies (Fig. 1) – olivine-rich and clay-rich. SM3, 6, 8, and 49 are olivine-rich, with lesser amounts of enstatite, Fe-sulfides, and magnetite. The olivine peaks match the PDF pattern for Fe-rich forsterite (Fa32). Semi-quantitative mineral analysis using the Easy Quant by Whole Pattern Fitting routine in Jade9 shows these stones to contain ~75 to 80 wt% olivine. SM3 shows small, sharp reflections for oldhamite. Semi-quantitative analysis reveals ~1.5 wt% oldhamite. XRD patterns from several fragments of SM3 show 1 to 2 wt% CaS. No peaks for CaS are present from other stones, possibly because they were soaked with rain. The background-subtracted profiles for SM3 and 6 do not show recognizable diffracted intensity for clays or amorphous materials, whereas SM8 shows weak reflections for clays/amorphous material (Fig. 1).

XRD profiles for SM38, 41, and 65 are similar to each other, with the majority of the diffracted intensity arising from clay/amorphous material. On top of this intensity are reflections from Fe-sulfides, calcite, and magnetite. Reflections for enstatite and olivine are weak and vary in intensity from different regions of sampled stones and come from dispersed macroscopic grains. The majority of the low-angle intensity is centered around ~13.5Å, with a low-intensity sharp reflection ~7.3Å, consistent with high smectite abundance and minor amounts of serpentines. The clay diffraction patterns show the 001 basal reflection followed by weak and broad *hk* diffraction bands (Fig. 1), attesting to their fine-grained turbostratic nature. Approximately 75% the diffracted intensity in SM38, 41, and 65 arises from clay/amorphous material (Fig. 1).

TGA data for the clay-rich (SM41) and olivine-rich (SM3) samples exhibit different curves as a function of temperature. SM3 shows only minor mass loss of 2.5 wt% to 1000° C, whereas SM41 shows ~9 wt% mass loss. The low mass-loss of SM41, compared to Murchison (~15 wt%) and Orgueil (~25 wt%), suggests that the clay-rich SM stones contain an abundant anhydrous amorphous component.

Discussion and Conclusions: While the bulk chemistry of Sutter's Mill is consistent with CM2 [1], the mineralogy determined by XRD is not. The bulk mineralogy of the olivine-rich SM stones is similar to the Belgica-like chondrites [2,3], suggesting that they were CM2 chondrites heated to >700° C prior to being incorporated into the Sutter's Mill parent body. In contrast, the clay-rich SM stones are mineralogically distinct from CM chondrites as they are dominated by smectite-like clays, with trace amounts of 7Å clays. In addition, these stones lack tochilinite, which normally occurs in CM2 chondrites. The XRD profiles of the clay-rich SM stones closely match that of Tagish Lake.

The relationship between the clay-rich and olivine-rich SM stones is obscure. One possibility is that the olivine-rich lithology is the clay-rich lithology heated to high (>700°C) temperatures. However, heated smectite does not decompose to olivine [4,5], unlike serpentine which does [3,6], suggesting that the clay-rich and olivine-rich SM stones are distinct meteorite classes.

No stones were found containing both the clay-rich and olivine-rich lithologies. Further, clasts within each stone have similar bulk mineralogies suggesting that each of the seven stones belong to two distinct meteorite classes and experienced different asteroidal conditions prior to being incorporated onto the Sutter's Mill parent body. These results are consistent with the Sutter's Mill asteroid being a rubble pile of at least two distinct carbonaceous chondrite classes.

References: [1] Jenniskens P. et al. (2013) Science **338** 1589. [2] Ivanova M.A. et al. (2010) MAPS **45** 1108. [3] Nakato A. et al. (2008) Earth Planet Sci. **60** 855. [4] Murad E. at al. (2002) Clay Miner. **37** 583. [5] Gavin P., Chevrier V. (2010) Icarus **208** 721. [6] Gualtieri A.F. et al. (2012) Am. Min. **97** 666.

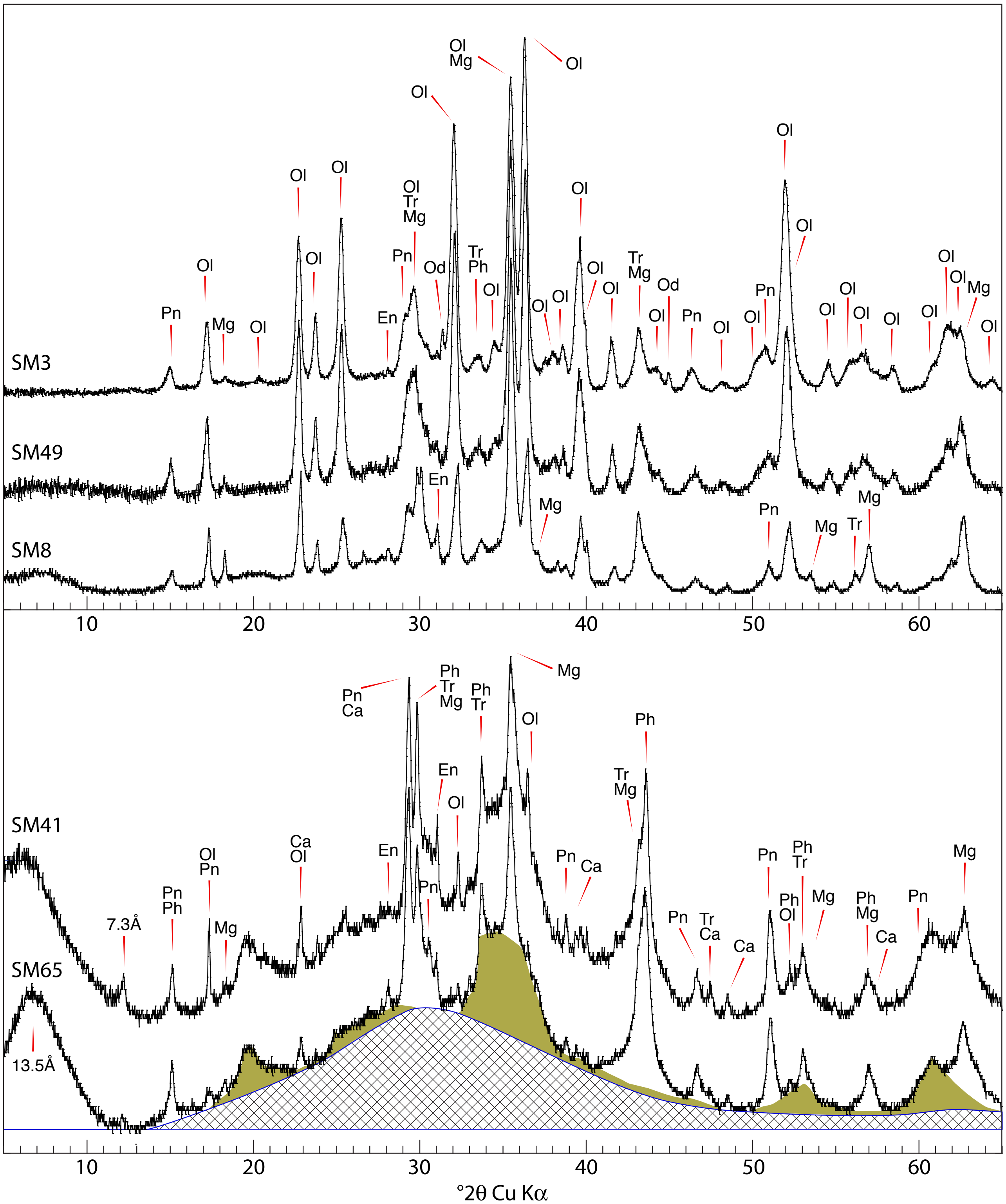

Figure 1: Representative background-subtracted powder XRD patterns of six Sutter's Mill stones. SM3, 8, and 49 are olivine rich, and SM41 and 65 are clay/amorphous rich. The background profile for SM3, which is anhydrous and lacks clays, was used for subtracting the background from the other patterns. The two-dimensional diffractions bands for smectite are shown in SM65 (green - online version, and grey - print version) and remaining intensity from amorphous scattering (cross hatched). Phases marked are Pn - pentlandite, Ol - olivine, Mg - magnetite, En - enstatite, Tr - troilite, Od - oldhamite, Ph - pyrrhotite, Ca - calcite, 13.5Å - 001 of smectite, and 7.3Å - 001 of serpentine.