ASTEROID POND MINERALOGY: VIEW FROM A COGNATE CLAST IN LL3 NWA 8330.

M. Zolensky[1] and L. Le[2], [1]ARES, NASA Johnson Space Center, Houston, TX 77058, USA (michael.e.zolensky@nasa.gov), [2]Jacobs ESCG, Houston, TX 77058 USA.

Introduction: All asteroids surfaces imaged at the cm-scale reveal the presence of pond deposits [1-4]. These ponds are important because it is likely all asteroid sample return missions will sample them, being the safest (very flat) places to touch down. Therefore, it is essential to understand the differences between the material at the pond surfaces and the host asteroid. Fortunately, some fine-grained cognate lithologies in chondrites show sedimentary features indicating that they sample asteroid ponds.

Vigarano: A strange clast in Vigarano (AMNH 2226-7), was first identified by Johnson et al. [5] (Figure 1a). The clast consists mainly of micron-sized grains of olivine, arranged into layers with varying composition and porosity. The densest (most Fe-rich) olivine grains are in sections of layers with the lowest bulk porosity, which appear bright in BSE images (Figure 1a). The most remarkable aspect of the clast are crossbeds. Johnson et al. concluded that this and other similarly fine-grained clasts in the CV chondrites were formed by strictly nebular processes. However, Tomeoka and Kojima [6] proposed that Vigarano 2226-7 was due to a sedimentation process involving a large quantity of liquid water on, or within, the parent asteroid. They pointed out the similarity of the bands to "dish structures" commonly observed in siltstones and sandstones. Some workers were critical of this model because of the amount of water required, and lack of a gravitational basis for waves of water in an asteroid, although Phil Bland and coworkers have proposed a somewhat similar origin for highly-aqueously-altered meteorites such as the CM chondrites [7]. Nevertheless, the formation mechanism of these cross-bedded features in the Vigarano clast through some type of asteroidal sedimentation process has remained an attractive possibility. We proposed that this clast formed by the processes of electrostatic grain levitation [8] and subsequent seismic shaking [9,10]. We then described a similar clast in another Vigarano sample, and in a section of Allende – all CV3 chondrites. Were these clasts to be found in other meteorites? It took 15 years to find another one.

NWA 8330: We have now found the first of these sedimentary clasts in an ordinary chondrite, LL3 chondrite NWA 8330 (section MZ3, Figure 1b). The clast in 8330 measures approximately 1cm across. It is identical to that in Vigarano in most essential respects. The clast consists mainly of fine-grained olivine, with lessor low-Ca, troilite, Fe-Ni metal, and accessories. There are graded, sometimes cross-bedded, layers where the quantity of Fe-rich olivine and metal increases as porosity decreases. The cross beds are apparent as brighter lines in Figure 1b. Boundaries between layers are sharp, and in one place layers are finely- and regularly-spaced. Within each layer mineralogy and porosity gradually vary. The range of olivine compositions in the clast matches that of the host (i.e. the clast is cognate), but the clast olivine is greatly biased towards Fe-rich compositions (Figure 2), which we propose is due to seismic shaking and percolation probably combined with electrostatic levitation of fines from the topmost surface. The presence of zoned olivine in the clast indicates that it has not been significantly affected by metamorphism.

Implications: Based on our observations of the clasts in NWA 8330, Vigarano, and Allende, samples collected from the surfaces of ponds on unequilibrated asteroids will *significantly* differ from the bulk asteroid by being finer-grained, metal poor, and Fe-poor. It should also be possible to place limits on the masses of the host asteroids for Vigarano, Allende and NWA 8330 from the olivine grain-size distributions in the cognate clasts we have described.

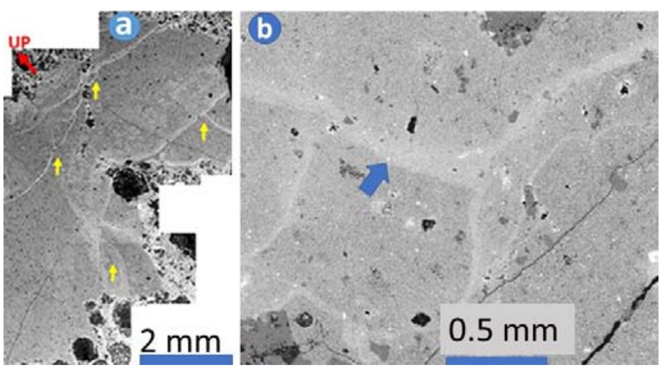

Figure 1. (a) BSE image of a fine-grained cognate clast in Vigarano (CV3), exhibiting cross-bedding resulting from pond formation processes. Crossbeds are indicated by yellow arrows. The original top of the pond bed is indicated by "UP". (b) Similar image of the clast in NWA 8330, with a sharp lower layer boiundary indicated by a blue arrow.

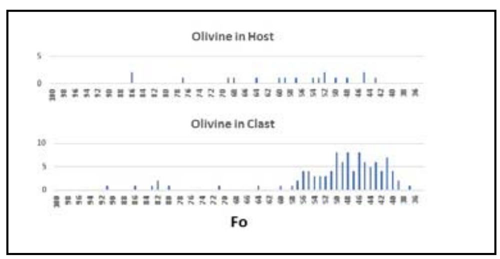

Figure 2. Compositional variation of olivine in (top) the NWA 8330 host meteorite (LL3) and in (bottom) the cognate fine-grained clast. The range of compositions is essentially identical, but there is a striking predominance of heavy, Fe-rich olivine in the clast.

References: [1] Veverka et al. (2001) *Science* **292**, 484-488; [2] Robinson et al. (2001) *Nature* **413**, 396-400; [3] Cheng et al. (2002) *MAPS* **37**, 1095-1105; [4] Miyamoto et al. (2007) *Science* **316**, 1011-1014; [5] Johnson et al. (1990) *GCA* **54**, 819-831; [6] Tomeoka and Kojima (1998) *MAPS* **33**, 519-525; [7] Howard et al. (2011) *GCA* **75**, 2735-2751; [8] Schwan et al. (2017) *GRL* **44**, 3059-3065; [9] Zolensky et al. (2002) *LPSC XXXIII*; [10] Richardson et al. (2005) *Icarus* **179**, 325-349.