Samples of Asteroid Surface Ponded Deposits in Chondritic Meteorites. M.E. Zolensky[1], R. Lee[2] and L. Le[3], [1]NASA Johnson Space Center, Houston, TX 77058 USA (michael.e.zolensky@nasa.gov), [2]Lunar and Planetary Institute and Trinity University, San Antonio, TX 78212 USA, [3]Lockheed Martin Space Operations, Houston, TX 77058 USA.

Introduction: One of the many unexpected observations of asteroid 433 Eros by the Near Earth Asteroid Rendezvous (NEAR) mission was the many ponds of fine-grained materials [1-3]. The ponds have smooth surfaces, and define equipotential surfaces up to 10's of meters in diameter [4]. The ponds have a uniformly sub-cm grain size and appear to be cohesive or indurated to some degree, as revealed by slumping. The ponds appear to be concentrated within 30 degrees of the equator of Eros, where gravity is lowest. There is some insight into the mineralogy and composition of the ponds' surfaces from NEAR spectroscopy [2,4,5,6]. Compared to the bulk asteroid, ponds: (1) are distinctly bluer (high 550/760 nm ratio), (2) have a deeper 1um mafic band, (3) have reflectance elevated by 5%.

Thanks to the NEAR spacecraft we also know [2,4,5,6] that: (1) Eros' surface is depleted in S/Si relative to the chondritic value, possibly due to preferential volatilization of sulfide minerals during micrometeorite impacts; (2) Eros' surface Fe/Si ratio is apparently lower than the chondritic value, (3) Eros pond surface Fe/Si ratios are possibly lower than that for the average Eros surface, possibly due to removal of Fe-Ni metal grains by size-sorting or settling [2].

Since images suggest that pond material can be indurated, is it possible that some of this material has survived within meteorites, possibly as foreign clasts? We have previously reported that two clasts within the Vigarano CV3 chondrite could have derived from ponds [7]. This abstract updates our work, reporting discoveries of similar clasts within other chondritic meteorites. Our research aims to permit an understanding of the true nature of asteroid Eros for the first time, and provide a new tool to correctly interpret spectroscopic observations and regolith samples collected by future asteroid missions. Thus, our work provides an important lever to greatly increase the value of Earth-based asteroid studies. In addition, this research will be useful to the Hayabusa asteroid sample return mission as it will assist in the determination of the true nature of an asteroid from its fine-grained regolith.

New Clasts: In addition to the two clasts we previously described within Vigarano, we have now located and characterized similar clasts in Allende (CV3), Cold Bokkeveld (CM2) and Sharps (H3). In addition we have located but not yet fully characterized similar clasts in the following unpaired ordinary chondrites - Y-82055, Y-790149, Y-793535, Y-793472, Y-793374, Y-791863, Y-790448, and Y790199. To locate these additional clasts we performed a survey of all meteorite thin sections available in the JSC (ANSMET) and NIPR Antarctic meteorite collections. It is interesting that we found no clasts in the JSC collection, but numerous ones in the NIPR collection.

As revealed by SEM, microprobe and TEM analyses performed at JSC, the Vigarano, Allende, Cold Bokkeveld and Sharps clasts consist mainly of 5 micron- to submicron-sized grains of olivine (Cold Bokkeveld also contains serpentine). Those in Vigarano, for example, are Fo43-78, with a pronounced peak at Fo50. This is essentially the distribution of olivine compositions in Vigarano itself [8], and since most CVs have distinctive olivine distributions this fact suggests that the clasts are indigenous to the Vigarano host asteroid. Similarly for Allende, Cold Bokkeveld and Sharps, the clasts consist of essentially pure matrix for each material, with the matrix of each of these meteorites being quite different and distinctive. Larger olivine grains up to a few 10s of μm are present in the clasts, and most of these have normal compositional zoning (iron-rich rims, iron-poor cores). The small olivine grains in the clasts are the most iron-rich, since they lack the iron-poor cores.

The most distinctive feature of these clasts are numerous, closely-spaced, sometimes cross-bedded, arcuate bands. Cross-bedding is abundant in the Vigarano clasts; in Allende and Sharps the bands generally form closed loops. The Cold Bokkeveld clast is uniformly fine grained. The bands are apparent in both reflected light and BSE images, because they contain a high proportion of the finest-grained, iron-rich olivine. We define each layer as a "bed", each of which contains within it a "band" with a high concentration of iron-rich olivine. Figure 1 shows a BSE image of the first-discovered Vigarano clast, with obvious arcuate, crossbedding. The entire clast consists of a porous aggregate of olivine grains; the pores in the arcuate bands are almost entirely filled with very fine-grained, iron-rich olivine. From the sense of the crossbedding we can tell which way "up" was, and this reveals that the relatively fine-grained bands are located at the bottom of each bed: the top of each iron-rich band is a transitional boundary, but the bottoms are very sharp. Impact-induced seismic shaking can result in grain-size separation with fine-grained and denser materials "percolating" through a coarse matrix to the bottom [9], just what we observe in the Vigarano clasts. For the Sharps and Allende clasts, we interpret the closed loops to be beds sectioned parallel to the bedding direction (not normal to it as in Vigarano).

Based upon our initial assessment, we propose the following scenario for the clasts. (1) Some process separates fines from the bulk regolith material; this could well have involved electrostatic levitation [3], which could have separated the finest material from coarse accumulations; much work is necessary on this point. (2) An impact generates seismic shaking, forming one bed, with the finest grains percolating to the bottom of the bed. Shaking would be most pronounced at elongated portions of the asteroid, which is where ponds are observed on Eros. (3) Since shaking from subsequent impacts should erase the layering from previous episodes, some process must periodically lithify the beds to some degree to preserve them. Since we appear to be seeing samples predominantly of the bottoms of beds (excepting Cold Bokkeveld), this lithification process is operating most efficiently below the asteroid surface, suggesting impact heating as the cause. Later impacts can then cause degradation, but not total destruction of bases of the previously deposited beds. (4) Slumping, or impact-triggered motions, causes older beds to rotate, and subsequent beds can be deposited on an eroded, flat surface at an angle, creating the crossbeds observed in Vigarano clasts.

Conclusions: We hypothesize that the clasts formed in ponds that experienced seismic shaking. The Eros ponds may have formed the same way. There is a suggestion that the Eros pond surfaces are depleted in iron, based upon the gamma ray spectrum measured at the NEAR landing site [10]. This would be explained by percolation downward of iron-rich olivine and/or dense Fe-Ni sulfides. The latter phases are shown to be preferentially comminuted by multiple lab impacts into chondritic targets [9]. We observe such a downward percolation of metal grains in the clasts.

We believe that we have shown that materials that likely originated in asteroid ponded deposits have survived and traveled to earth within meteorites. We believe that these samples can inform us about asteroidal regolith processes and permit us to better understand the actual nature of bulk asteroids from observations of asteroidal surfaces, and returned samples from the uppermost regolith layers, all of which we now know to be biased in rather unknown ways. We still need to understand the processes that originally segregate and mobilize the fine-grained material in the ponds, and partially indurate the ponded deposits themselves.

References: [1] Veverka et al. (2001) *Nature* **413**, 390-393, [2] Cheng et al. (2002) *MAPS* **37**, 1095-1105, [3] Robinson et al. (2001) *Nature* **413**, 396-400, [4] Veverka et al. (2001) *Science* **292**, 484-488, [5] Nittler et al. (2001) *MAPS* **36**, 1673, [6] Trombka et al. (2001) *MAPS* **36**, 1605-1616, [7] Zolensky et al., (2002) LPSC Abstracts, [8] Krot et al. (1995) *MAPS* **30**, 748-775, [9] Hörz and Schaal (1981) *Icarus* **46**, 337-353, [10] Evans et al. (2001) *MAPS* **36**, 1639-1660.

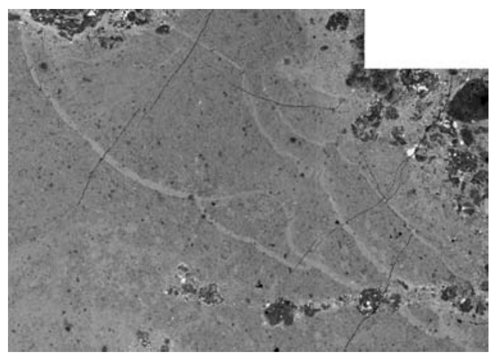

Figure 1 Crossbedded clast in Vigarano; view measures ~1 mm across.

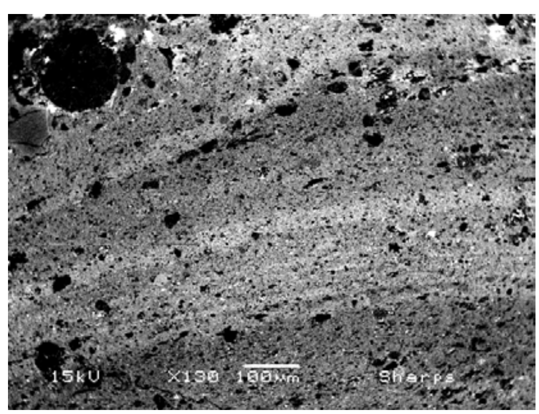

Figure 2 Parallel beds in a Sharps clast; view measures ~1 mm across.