ALTERATION VERSUS MORPHOLOGY OF ANTARCTIC MICROMETEORITES: A SIMPLE PROCEDURE FOR SAMPLE CHARACTERIZATION. E. Dobrica[1], C. Engrand[2], R. C. Ogliore[3], and A. J. Brearley[1], [1]Department of Earth and Planetary Sciences MSC03-2040, 1 University of New Mexico, Albuquerque, NM 87131-0001 (edobrica@unm.edu), USA; [2]CSNSM, Univ. Paris Sud, Université Paris-Saclay, 91405 Orsay Campus, France; [3]Department of Physics, Washington University in St. Louis, St. Louis, MO 63117, USA.

Introduction: About thirty percent of Antarctic micrometeorites (AMMs) collected in surface snow layers near the French-Italian station CONCORDIA are fine-grained (Fg) particles [1-2]. Among the Fg particles, about 20% are fine-grained compact (FgC) and 10% are fine-grained fluffy (FgF) [2]. The description and classification of Fg AMMs as defined in Genge et al. [3] is based on Cap Prudhomme AMMs (collected from blue ice [4]) that do not contain the FgF particles. The FgF AMMs were later identified in the CONCORDIA AMMs collected from snow [2]. Therefore, robust criteria are essential to classify the different types of AMM more definitively. We are exploring the possibility that the surface morphology of AMMs, may be a useful and simple criterion for distinguishing between different types of AMM. Here we present the results of image analysis of Fg AMMs. The purposes of these measurements are (1) to evaluate the surface structure and sample morphology of the Fg AMMs and (2) to determine if there is a relationship between surface structure and the degree of alteration/ primitiveness of the particles. Therefore, the basis of this study is the hypothesis that the surface structure of a fragment reflects the characteristics, e.g. grain size, morphology, and the porosity of the bulk material.

Methods: AMMs are split into several fragments of which the smallest is deposited on a stub and characterized by SEM, to ensure its extraterrestrial (ET) nature. Secondary electron images were performed on four AMMs stubs (08-33, 08-34, 11-13, and 14-03) using a FEI Quanta 3D field emission gun (FEG) SEM/FIB operating at 5 kV and 20 kV. On each stub there are between 18 to 42 fragments of AMMs collected from snow during the 2006 campaign [1]. Since the samples were fragmented, the exposed surface does not necessarily represent the external surface during atmospheric entry. The proportion of extraterrestrial particles on each stub vary from 48% ET (stub 11-13) to 94% ET (stub 08-33). Forty-six Fg AMMs were identified in these four stubs. The image processing and analysis of the Fg AMM images were performed using ImageJ public domain software program (http://rsb.info.nih.gov/ij) and two different plugins (Facet orientation and Ridge detection) [5-7].

We used the *Facet Orientation* plugin to derive surface orientation and statistics from the topographical secondary electron images [5-7]. The input is a 32 bit, 10 x 10 µm image of each Fg AMM sample in which the pixel values represent distance, z, to a surface. The plugin yields an azimuthal image giving the facets directions in the particle plane (Fig. 1b and 1e). We applied the second plugin, the *Ridge Detection* on the azimuthal images obtained using the Facet Orientation. Each azimuthal image was modified to 8 bit before the application of this last plugin. The Ridge Detection plugin uses an algorithm to extract the line position of curvilinear structures [7] (Fig. 1c and 1f). The lines extracted are not ridges in the topographic sense, i.e., they do not define the way water runs downhill or accumulates [7]. In fact, they are much more than a ridge in the sense that a ridge can be regarded in isolation, while a line needs to model its surroundings [7]. This plugin implements and extends the ridge/line detection algorithm described by Steger [7]. The lengths of all ridges detected on the 10 x 10 µm images were added up for each sample and plotted in Figure 2 as a function of area (the 2D projected area of the entire fragment deposited on the stub).

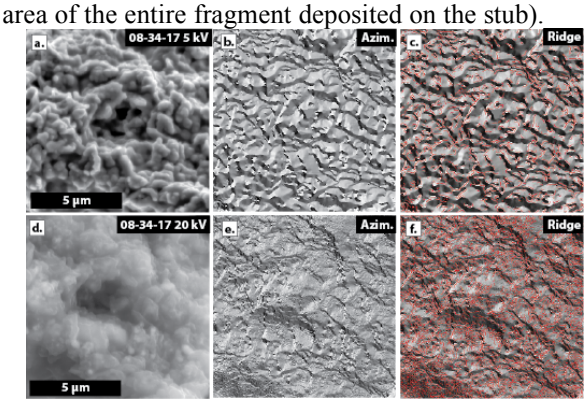

Figure 1. Secondary electron micrographs (10 x 10 µm) of a portion of the surface of AMM 08-34-17 at 5 kV (a) and 20 kV (d), their respective azimuthal images (b and e) and ridge detection highlighted in red (c and f).

We applied the same procedure to samples of the Tagish Lake (C2-ung) meteorite to verify our method. A two millimeter Tagish Lake sample was fragmented and several fragments were then deposited on carbon tape at the surface of a new stub. Detailed SEM observations were performed on about 10 different fragments of Tagish Lake (Fig. 3) and identical image processing and analysis were performed (Fig. 2).

Results: We measured the area and the ridge length of each AMM and Tagish Lake fragment (Figs.

1-2). We observed that the measured ridge length increases with increasing SEM imaging voltage (Fig. 2, AMMs 20 kV - blue circles, AMMs 5 kV – green circles). Additionally, our study shows that there is an anticorrelation between the sample area (the 2D projected area of the entire fragment deposited on the stub) and the ridge length (Fig. 2). We also identified Ca-carbonates and magnetite phases using the SEM in sample 08-34-12 and Tagish Lake, respectively (Fig. 3). So far these minerals were not identified at the surface of the other fragments.

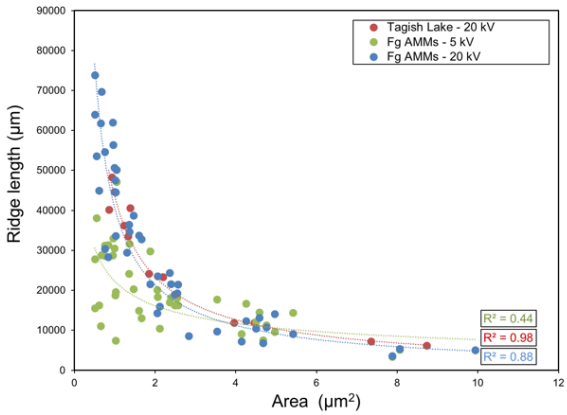

Figure 2. Fine-grained AMMs and Tagish Lake fragment area versus their ridge length measure at 20 kV (blue circles – Fg AMMs; red circles – Tagish Lake) and 5 kV (green circles – Fg AMMs). The power trendlines and their associated R-squared values are displayed for each set of measurements.

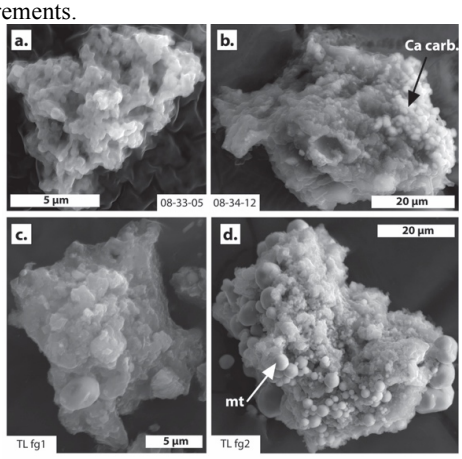

Figure 3. Secondary electron micrographs (20 kV) showing Fg AMMs (a-b) and Tagish Lake fragments (c-d). Sample 08-33-05 (a) and one Tagish Lake fragment (c, TL fg1 - left side micrographs) have the highest ridge lengths and the smallest areas (see Fig. 2). Sample 08-34-12 (b) and a second Tagish Lake fragment (d, TL fg2 - right side micrographs) have the highest areas and the smallest ridge lengths. Calcium carbonates (Ca carb.) and magnetite (mt) framboids were identified in Fg AMMs and Tagish Lake fragments.

Discussion: The characterization and quantification of surface structures of cometary and asteroidal dust particles could be based on several methods. These include stylus profilometry, laser profilometry, white light interferometry, confocal microscopy, atomic force microscopy and SEM [5]. There are significant outcomes from our SEM analysis of the surface structures. At 20 kV, we observe an anticorrelation between the sample area and the sample structure (a.k.a ridge length, Fig. 2), which appear to be susceptible to accelerating voltage. The power trendline of the sample distribution clearly demonstrates that the surface ridge lengths decrease with increasing particle size. This trendline could imply that samples fragment into larger or smaller sizes as a function of their morphology, porosity, and the bulk material. We hypothesize that the ridge lengths reflect the surface characteristics and the underlying mineralogy that is exposed at the surface. Therefore, the more compact the AMMs or meteorite fragments are the lower the ridge lengths and the topographical characteristics, and the larger are the fragments. Additionally, we performed a series of benchmark tests on Tagish Lake meteorite and found an agreement with the results of Fg AMMs. Previous studies of Tagish Lake show the presence of secondary minerals, such as serpentine and calcite, which is suggestive of intensive aqueous alteration on the meteorite parent body in the early solar system [8]. In general, the distribution of the alteration is heterogeneous in carbonaceous chondrites and it can vary at the micrometer scale. We hypothesize that the anticorrelation observed in this study could be produced by the degree of alteration of the fragments. We need to understand what are the fundamental controls that are producing these trends.

Conclusion: Our study suggests the presence of an interesting trend between the sample size (area) and the ridge lengths (morphology) of Fg AMMs and Tagish Lake particles. We are going to explore what textural/mineralogical characteristics cause these differences in ridge lengths and hence might provide a rapid and simple method for establishing the degree of alteration.

Acknowledgements: This work was funded by NASA grant NNH16ZDA001N to E. Dobrica (PI).

References: [1] Duprat J. et al. (2007) *Advances in Space Research*, 39: 605–611. [2] Dobrica E. et al. (2009) *Meteoritics & Planetary Science* 44:1643–1661. [3] Genge M. et al. (2008) *Meteoritics & Planetary Science* 43:497–515. [4] Maurette M. et al. (1991) *Nature* 351:44-47. [5] Chinga G. et al. (2007) *Journal of Microscopy*, Vol. 227, pp. 254–265. [6] Chinga G. (2004) *Journal of pulp and paper science* 30(8): 222-227. [7] Steger C. (1998) *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 20, no. 2, 113-125. [8] Nakamura T. et al. (2003) *Earth and Planetary Science Letters* 207:83-101.