DELIVERY OF TYPICAL COMETARY DUST TO THE SURFACE OF THE EARTH. T. Noguchi[1], N. Ohashi[1], S. Tsujimoto[1], J. P. Bradley[2], T. Nakamura[3], S. Toh[4], T. Stephan[5], N. Iwata[6], and N. Imae[7], [1]College of Science, Ibaraki University (2-1-1 Bunkyo, Mito 310-8512, Japan), [2]Institute of Geophysics and Planetary Physics, Lawrence Livermore National Laboratory (Livermore, CA 94551, USA), [3]Department of Earth Science, Tohoku University (6-3 Aoba, Aramaki, Aoba-ku, Sendai 980-8578, Japan), [4]High Voltage Electron Microscope Laboratory, Kyushu University (7466-10 Motooka, Fukuoka 819-0395, Japan), [5]Department of the Geophysical Sciences, University of Chicago (5734 South Ellis Avenue, Chicago, IL 60637, USA), [6]Department of Earth and Environmental Sciences, Yamagata University (1-4-12 Kojirakawa-machi, Yamagata 990-8560, Japan), [7]National Institute of Polar Research (10-3 Midori-cho, Tachikawa, Tokyo 190-8518, Japan)

Introduction: Comets are dusty snow balls, formed in the cold regions of the solar system [1]. The Stardust mission revealed that cometary dust particles contain materials formed both in the inner and the outer regions of the protosolar disk [e.g. 2,3,4,5,6]. Although comets have been regarded as one of the important vehicles of exogenous organics to the early Earth, fine-grained particles originated from comets and asteroids are also important vehicles of the organics because they can be decelerated gently in the atmosphere with minimal heating during atmospheric entry due to their small size and low densities [7]. Chondritic porous interplanetary dust particles (CP IDPs) collected in the stratosphere are regarded as particles derived from comets [8]. Recently found ultracarbonaceous Antarctic micrometeorites (UCAMMs) are regarded as particles derived from small bodies formed in the outer solar system [9,10]. Although UCAMMs were found on the ground, and although CP IDPs are much more abundant than ultracarbonaceous IDPs [11], which may correspond to UCAMMs, CP IDPs have not been discovered on the earth's surface. Discovery of CP IDPs on the ground is important to give the direct evidence to the delivery of organics on the past earth by cometary dust. Here we show cometary dust has reached to the earth's surface since at least several thousands years ago to present and that they deliver organic material.

Samples and Methods: Quite porous micrometeorites composed of anhydrous minerals (hereafter CP MMs) with chondritic bulk chemical compositions were identified from residual particles melted and filtered Antarctic blue ice at the Tottuki Point near the Syowa Station [12] and surface snow near the Dome Fuji Station. Procedure of sample collection in the surface snow is described elsewhere [13].

Results and discussion: The major minerals identified by conventional transmission electron microscopy (TEM) at Ibaraki University are low-Ca pyroxene, olivine, pyrrhotite, and high-Ca pyroxene although pyrrhotite is quite rare in the CP MMs collected from ice. Both past and present CP MMs often contain enstatite whiskers on their surfaces. Figure 1 shows an example of the past CP MMs. Abundant acicular and blade-shaped enstatite crystals are dispersed among very porous matrix. We identified crystal structure of one of the crystals that appear on Fig. 1b by preparing focused ion beam (FIB) lift-out method and observed by energy filtered TEM at Kyushu University. Its structure is identical to the enstatite whiskers found in the ultrathin section of the MM. Figure 2 shows an example of the contemporary CP MMs, in which an enstatite whisker protrudes from the porous surface.

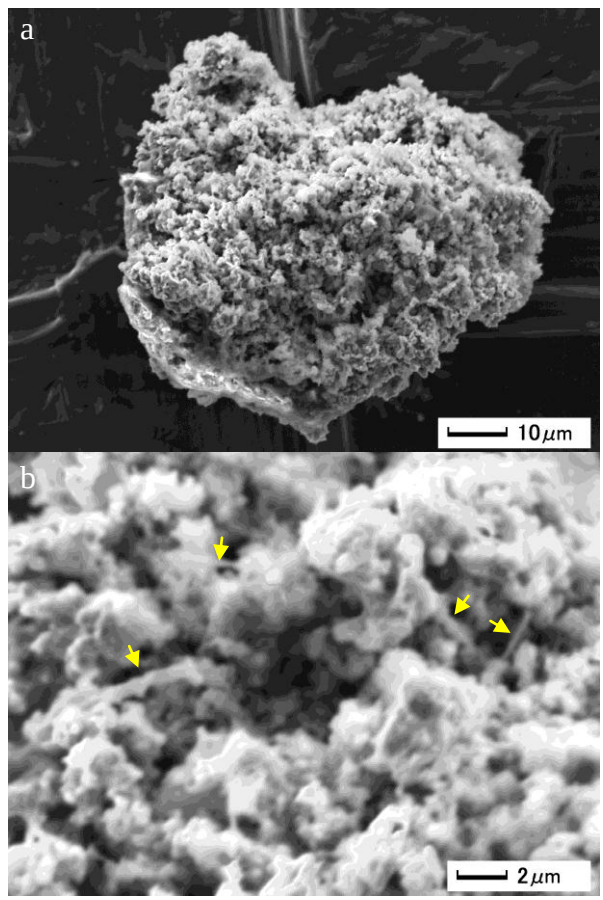

Figure 1 Secondary electron image of a past CP MM collected at the Tottuki Point. (a) Whole image of the CP MM. (b) Many enstatite whiskers (acicular and blade-shaped) exist on the surface of the porous surface of the MM. They are indicated by arrows.

Athough their mineralogy is similar to that of CP IDPs, the effect of terrestrial weathering is remarkable in the CP MMs collected from the Antarctic ice. For example, the abundance of pyrrhotite in the MMs is sustantially lower than that in the contemporary CP MMs. Instead, the past CP IDPs contain abundant poorly crystalline Fe hydroxides, which were probably derived from the pyrrhotite by terrestrial weathering. Their fine-grained mineralogy may have serve to promote terrestrial weathering. Anhydrous silcate minerals are durable to terrestrial weathering because there is no remarkable difference between contemporary and past CP MMs.

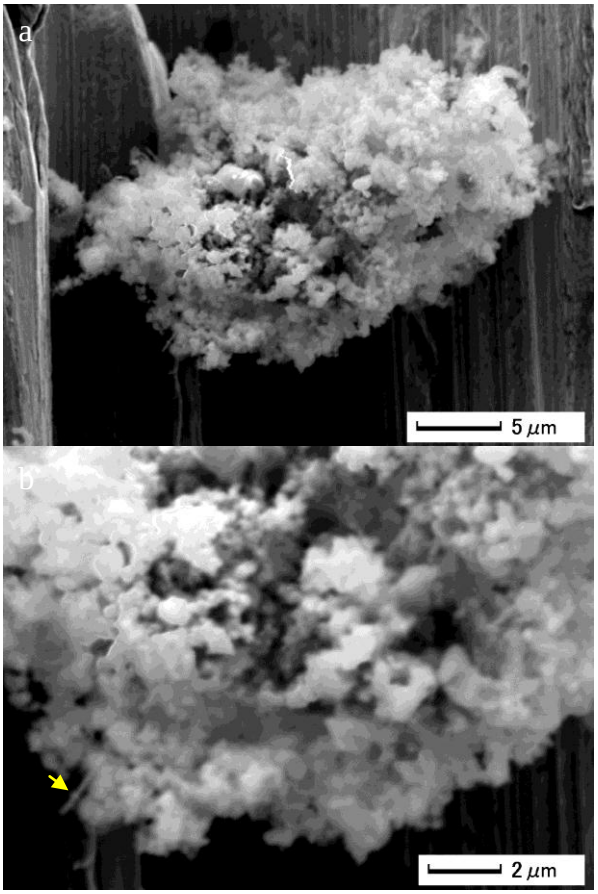

Figure 2 Secondary electron image of a present CP MM collected near the Dome Fuji Station. (a) Whole image of the CP MM. (b) An enstatite whisker (indicated by an arrow) sticks out from the surface.

We reported GEMS (glass with embedded metal and sulfide) -like objects in the past CP MMs based on their texture and bulk chemical composition [14]. We identified Fe metal and Fe sulfide in the GEMS-like objects by using monochromatized spherical abberation corrected (S)TEM at Laurence Livermore Natianal Laboratory. The GEMS-like object in the CP MM shown in Fig. 1 contains both Fe metal and sulfide based on the high resolution imaging and elemental mapping. Terrestrial weathering has reduced metal and sulfide abundances in the GEMS-like ojbects and has depleted Mg (and Ca) in the host amorphous silicate of GEMS-and like objects. The extreme depletion of Mg in some of the GEMS is strongly suspected that Mg is not strongly bound in GEMS. Despite weathering, these data suggest that the objects are typical GEMS. GEMS-like objects in the UCAMMs are enriched in Ni-bearing sulfide and poor in Fe-Ni metal (The amorphous silicate matrices of the objects are essentially Fe-free) [19]. Therefore, UCAMMs may not be the organic material-enriched portions of the CP MMs. (I don't understand this sentence).

Because two important constituents found in CP IDPs (enstatite whiskers and GEMS) are found in the CP MMs, it is clear that CP MMs are contemporary and past CP IDPs have fallen on the surface of the earth.

CP MMs also contain low-iron manganese-enriched (LIME) and low-iron chromium enriched (LICE) olivine and pyroxene, and kosmochlor-rich pyroxene, all of which are found in some CP IDPs and Wild2 particles [2,15,16]. Moreover, two past CP MMs contain hollow organic globules. They are considered as remnants of protosolar disk [17] and identified from carbonaceous chondrites [17], phyllosilicate-rich MMs [13], CP IDPs [18], and Wild 2 particles [19].

Our observations suggest that cometary dust has been falling on the earth's surface and that organic material has been continuously delivered to the earth by the cometary dust throughout its history.

References: [1] Bradley, J. P. (2004) in *Treatise in Geochemistry* (ed Davis, A. M.) (Elsevier-Pergamon). [2] Zolensky, M. E. et a. (2006) *Science* 314, 1735-1739. [3] McKeegan, K. D. et al. (2006) *Science* 314,1724-1728. [4] Nakamura, T. et al. (2008) *Science* 321, 1664-1667. [5] Matzel, J. E. P. et al. (2010) *Science* 328, 483-486. [6] Ogliore, R. C. et al. (2012) *ApJ* 745, L19. [7] Anders, E. (1989) *Nature* 342, 255-257. [8] Ishii, H. A. et al. (2008) *Science* 319, 447-450. [9] Duprat, J. et al. (2010) *Science* 328, 742-745. [10] Dobrica, E. et al. (2012) *GCA* 76, 68-82. [11] Thomas, K. L. et al.(1994) in *Analysis of interplanetary dust*, AIP Conf. Proc. 310, (Eds. Zolensky, M. E. et al.) (AIP Press). [12] Iwata, N. and Imae, N. (2002) *Antarct. Metorite Res*. 15, 25-37. [13] Sakamoto, K. et al. (2010) *MAPS* 45, 220-237. [14] Noguchi, T. et al. *MAPS* 43, A117. [15] Klöck, W. et al. (1989) *Nature* 339, 126-128. [16] Joswiak, D. J. et al. (2009) *MAPS* 44, 1561-1588.. [17] Nakamura-Messenger, K. et al. (2006) *Science* 314, 1439-1442. [18] Busemann, H. et al. (2009) *EPSL* 288, 44-57. [19] De Gregorio et al. (2009) *LPS XXXX* #1130.