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Effects of high temperature and pressure observed in silicate minerals in Comet Wild 2 samples: Transmission electron microscopy

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http://www.planet.sci.kobe-u.ac.jp/study/list/planet_m/tomeoka.html

Introduction: We received a total of nine Wild 2 samples from NASA JSC for our analysis during the period of February to June, 2006. In this paper, we present the results of mineralogical investigation of those samples using a transmission electron microscope. The results reveal that the nine samples can be divided into three groups: (1) crystalline silicate-rich (three samples), (2) Si-O glass-rich (four), and (3) indefinable (two). This paper focuses on the results of the samples in groups (1) and (2).

The samples used in this study are ultramicrotomed sections (1-23 um in size, 70-100 nm in thickness).

Results: Silicate-rich Particles:

FC13-0-17-1-3: Thin sections consist of lath-shaped to anhedral grains (0.2-1.5 um in size) of low-Ca pyroxene (orthoenstatite) and minor amounts of Fe-rich olivine (Fa30 to Fa50) and high-Ca pyroxene (augite). Minor amounts of grains (0.1-0.3 um) of Fe-Ni sulfide are scattered.

C2115-24-22-1-8: Thin sections consist of lath-shaped to anhedral grains (0.3-2.0 um in size) of Fe-rich olivine (Fa9 to Fa36) and less abundant high-Ca pyroxene (diopside) and Si-O-Al-rich glass. One of olivine grains has a high density (~10^{10} cm^{-2}) of dislocations with Burgers vector b = [001].

C2027-2-69-1-4: Thin sections have a zone texture consisting of a core surrounded by inner and outer rims. The core consists of anhedral grains (0.5-2.0 um in size) of low-Ca pyroxene (clinoenstatite and pigeonite) with a minor amount of Fe-rich olivine (Fa19-24). The inner rim consists of parallel-oriented plates (0.1-0.3 um in width, 0.5-2.0 um in length) of Si-O glass containing minor amounts of Mg and Fe. The outer rim consists of Si-O glass with no other elements, which is probably melted aerogel.

Si-O Glass-rich Particles (C2004-1-44-4-4, C2054-0-35-16-6, C2054-0-35-44-3 and C2054-0-35-53-3): Thin sections consist of arrays of parallel-oriented plates (0.1-0.3 um in width, 0.5-3.0 um in length) of Si-O glass containing minor amounts of Mg and Fe. The plates contain numerous small Fe-Ni metal/sulfide inclusions (5-300 nm in diameter) and vesicles (20-300 nm).

Discussion: Olivines in the three silicate-rich particles differ in Fa contents between the particles and show a wide range of Fa contents within individual particles. In chondrites, olivines with such fine-scale heterogeneity can be observed in the least equilibrated type 3 chondrites. Thus the observations suggest that the degree of thermal metamorphism on comet Wild 2, if any, was extremely low.

The finding of an olivine grain with high-density dislocations is especially significant. Such high-density dislocations are known to be diagnostic of deformation induced by shock at peak pressures higher than 27 GPa (e.g. Ashworth 1985). Thus the finding suggests that the Wild 2 particle has experienced hypervelocity impacts before capture, possibly on the comet.

Pyroxenes show striking differences in structure and composition between particles and within individual particles. Enstatite occurs as orthoenstatite in FC13-0-17-1-3 and clinoenstatite in C2027-2-69-1-4. Orthoenstatite forms through very slow cooling from temperatures above 600 C, whereas clinoenstatite to form through rapid cooling from above 1000 C (Smyth 1974). Therefore, the presence of both types of enstatite suggests that the Wild 2 particles contain materials that have experienced distinct high-temperature and cooling histories.

The core-to-rim texture of C2027-2-69-1-4 suggests that the Mg-Fe-bearing Si-O glass in the inner rim was formed by mixing of melted low-Ca pyroxene and melted aerogel during capture heating.

The four Si-O glass-rich particles exhibit a close similarity in texture and mineralogy to the inner rim of C2027-2-69-1-4. We conclude that the four Si-O glass-rich particles were secondary products formed by interaction between melted cometary silicates and melted aerogel during the capture process.