**REFRACTORY INCLUSIONS IN THE UNIQUE METEORITE FROM AMUNDSEN GLACIER (AMU 17290) IN ANTARCTICA: IMPLICATIONS FOR EARLY SOLAR SYSTEM PROCESSES**

I. Baziotis[1], A. Papoutsa[1], S. Xydous[1], D. Michailidis[2], P. Karkanas[2], J. Karner[3], S. J. V. VanBommel[4]; M. Anand[5,6], P. D. Asimow[7]. [1]Department of Natural Resources Management and Agricultural Engineering, Agricultural Univ. of Athens, Iera Odos 75, 11855 Athens, Greece, ibaziotis@aua.gr; [2]Malcolm H. Wiener Laboratory for Archaeological Science, American School of Classical Studies, Athens, Greece; [3]Geology & Geophysics, University of Utah, Salt Lake City UT 84112; [4]McDonnell Center for the Space Sciences, Department of Earth and Planetary Sciences, Washington University in Saint Louis, Saint Louis, MO, USA; [5]Planetary and Space Sciences, The Open University, Milton Keynes MK7 6AA, UK; [6]Department of Earth Sciences, The Natural History Museum, London, SW7 5BD, UK; [7]California Institute of Technology, Division of Geological and Planetary Sciences, Pasadena, California 91125, USA.

**Introduction:** Meteorites, especially carbonaceous chondrites, represent the most primitive objects in our solar system. Hence, they preserve records of early solar system processes, especially in their refractory inclusions. Such inclusions are thought to preserve nebular gas condensation of nebular gas of nearly solar composition [1], whereby refractory elements such as calcium, aluminum, and titanium combined with other lithophile elements form a sequence of solid minerals.

Here, we report preliminary textural and compositional data for a polished thin section of the newly recovered carbonaceous chondrite from Amundsen Glacier (AMU 17290). Despite extensive aqueous alteration, indicated by abundant phyllosilicates throughout the meteorite, we have identified refractory minerals such as hibonite and perovskite that constitute the first report of Ca-Al-rich inclusions (CAIs) in this meteorite.

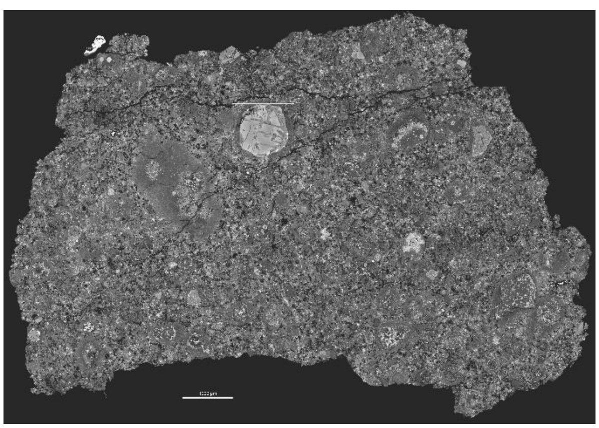

**Figure 1:** *Scanning Electron Microscopy backscattered electron image mosaic of Amundsen meteorite (AMU17290). Note a large fayalitic olivine (white rectangle) and the high matrix to chondrule ratio in this sample.*

**Materials and Methods:** AMU 17290 was recovered by the Antarctic Search for Meteorites (ANSMET) expedition in the 2017-2018 season. This is the only meteorite that has been recovered to date from the Amundsen Glacier in Antarctica. It is a CM2 carbonaceous chondrite [2]. So far, 534 CM2 carbonaceous chondrites are listed in the Meteoritical Bulletin database, some of them paired. We carefully examined polished section AMU 17290 #9 for petrographic relations and mineral chemistry. We have used (to date) reflected light microscopy at the Agricultural University of Athens (AUA) and Scanning Electron Microscopy (JEOL JSM-IT300LV) at the American School of Classical Studies at Athens. Electron microprobe analysis at AUA is in progress.

**Petrography:** Carbonaceous matrix makes up over 70% of the section, with most of the balance being ~300-400 μm chondrules. Many chondrules are either partially or fully surrounded by fine-grained accretionary rims. Only a few chondrules retain rounded shapes; most occur as broken fragments. There is one isolated, large (~1 mm in diameter), equant, relatively fayalitic olivine ($Fo_{75}$) crystal, surrounded by a thick rim of phyllosilicates (Fig. 1). The chondrules are silicate-dominated, composed mainly of olivine and clinopyroxene. The inter-chondrule matrix contains assemblages of refractory oxide-dominated minerals; we did not observe CAI material within the chondrule fragments. The observed CAIs are classified as fluffy type A and spinel-pyroxene-rich, which are common in CM2 carbonaceous chondrites [3]. Although the fluffy type A definition typically requires the presence of melilite, here (as in some other CM2 chondrites from Antarctica, such as GRV 050179) heavy alteration may have removed melilite [4]. We have observed mainly two different types of CAIs (Fig. 2). The first one is hibonite-bearing (Fig. 2a), and the second is perovskite-bearing (Fig. 2d,e,f). In one irregular CAI, we observe coexisting hibonite and perovskite crystals (Fig. 2b). Both perovskite and hibonite are in contact with spinel, but there are no particular textural indicators of the sequence of mineral growth (Fig. 2f). We identified gypsum (Fig. 2d) in an olivine-rich and Cr-spinel nodule, and calcite in a well-rounded perovskite-rich CAI (Fig. 2e); both, we presume are products of parent-body aqueous alteration.

**CAI Formation:** In general, CAIs respresent remants of solar nebula condensates. The prevailing view favours their formation at low pressure ($\leq 10^{-3}$ bar) and high temperature (>1300 K). In AMU 17290 we observe a CAI with coexisting hibonite and perovskite, while corundum is absent. In a "condensation with partial isolation" (CWPI) scenario (in the literature this is also known as the "fractional condensation" model [5]), this phase assemblage indicates a temperature lower than the corundum-out univariant line, ~1751 K at $10^{-3}$ bar (Fig. 3 and in [6]). Above $10^{-3}$ bar in the solar composition, CWPI predicts that hibonite should form first, followed by perovskite (Fig. 3).

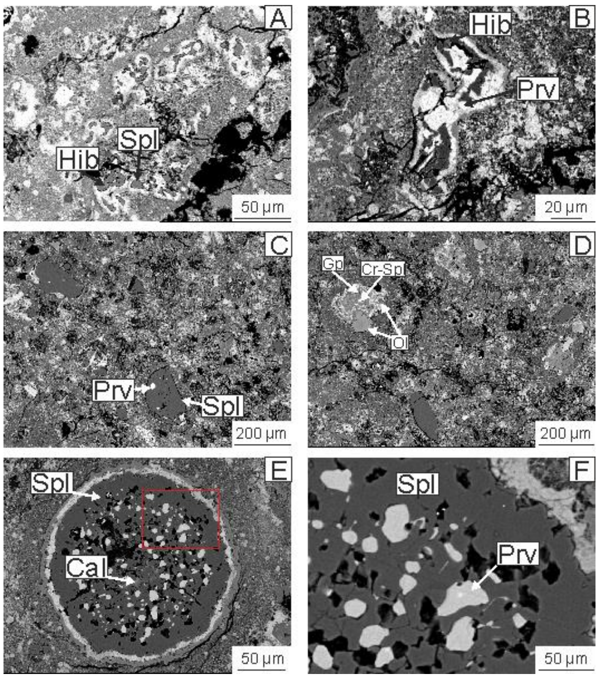


**Figure 2**. (a) *Irregularly shaped CAI with hibonite. (b) Irregularly shaped CAI with both hibonite and perovskite. (c) Broken fragment of spinel-rich nodule with perovskite inclusions. (d) Olivine-rich nodule with cr-spinel showing alteration indicated by gypsum and phyllosilicates. (e) Spinel-type rounded nodule (200 µm wide) with perovskite inclusions and calcite. The nodule is also surrounded by a fine-grained rim. (f) Enlarged area of (e).*

At lower pressure, corundum is expected to be the first phase, but failure of corundum to nucleate may cause deviation from the predicted equilibrium sequence, allowing formation of corundum-free inclusions at pressure below $10^{-3}$ bar [6]. Melilite enters next, followed by spinel at a lower temperature, ~1430 K. At pressure below $6{\times}10^{-7}$ bar, spinel does not form at all [6]. An alternative model scenario consistent with the observed relations is simultaneous or nearly simultaneous formation of hibonite and perovskite at gas pressure ~$10^{-7}$ bar and temperature ~1400 K followed by pressure increase to reach the stability field of spinel.

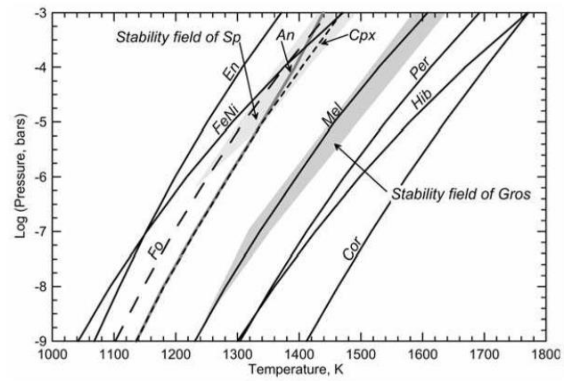


**Figure 3**. *Temperature (in K) vs log pressure (in bars) showing the mineral stability for the case of condensation from a gas of solar composition from Petaev and Wood [4].*

AMU 17290 is the first meteorite recovered from Amundsen Glacier. Despite extensive aqueous alteration it retains some intact CAIs. However, in our preliminary study, we have not yet observed any melilite. Thus possible hypotheses at this point, include: (1) melilite may not have formed because it failed to nucleate before spinel sequestered the available Al remaining after hibonite formation, (2) melilite and other phases may have condensed as separate objects, (3) melilite may have formed but subsequently been consumed by a peritectic reaction with vapor to form spinel, (4) melilite may have formed but subsequently was entirely replaced/removed during aqueous alteration, and (5) melilite is still present but we have not sampled it yet. Continued study is under way to explore these possibilities.

**Acknowledgements:** This research received support from European Social Funds and the Greek State (call code EDBM103). US Antarctica meteorite samples are recovered by the Antarctic Search for Meteorites (ANSMET) program, funded by NSF and NASA, and characterized and curated by the Department of Mineral Sciences of the Smithsonian Institution and the Astromaterials Acquisition and Curation Office at NASA Johnson Space Center.

**References:** [1] Connelly J.N. *et al.* (2012) *Science* **338**:651–654. [2] Antarctic Meteorite Newsletter (2018) **41**(2). [3] Lin Y. *et al.* (2006) *Meteorit. Planet. Sci.* **41**:67–81. [4] Dai D. *et al.* (2015) *Earth Moon Planets* **115**: 101-114. [5] Krot A.N. *et al.* (2004) *Meteorit. Planet. Sci.* **39**:1517-1553. [6] Petaev M.I. & Wood J.A. (2005). In Chondrites and the protoplanetary disk (Vol. 341, p. 373).