THE NATURE OF GEMS-LIKE MATERIAL FROM ASTEROID RYUGU REGOLITH

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Introduction: GEMS are found in anhydrous, carbon-rich interplanetary dust particles (IDPs) and micrometeorites (MMs) as spheroids of anhydrous Mg-silicate amorphous matrix with kamacite and pyrrhotite nano-inclusions. Organic carbon is present in some GEMS and as mantles on their surfaces. Because GEMS likely accreted at extremely low temperatures in the outer nebula and/or presolar environments, they are considered a proxy for the most cosmically primitive (least altered) meteoritic materials [1]. GEMS-like material is reported in several chondrites e.g. [2,3] and examination of some chondrites shows key differences with GEMS [4,5]. Recently, GEMS-like material has been reported in less-altered lithologies of regolith grains returned from the near-Earth Cb-type asteroid 162173 Ryugu [6].

Samples and Methods: We studied two recently identified highly porous Ryugu grains, A0104-029025 and C0105-039023, to determine if they contain GEMS. Scanning electron microscopy shows A0104-029025 is ~50 µm long with a silica-rich matrix containing remnant olivine (up to ~5 µm across), pyrrhotite, pentlandite, magnetite, Mn-rich Cr-spinel, calcite, and a Fe-Ni-P-bearing phase. Sulfur content shows clear variation in this matrix. C0105-03923 is ~75 µm long, and its silica-rich matrix contains smaller remnant olivine or pyroxene grains, pyrrhotite, pentlandite, magnetite, Cr-spinel, dolomite, calcite, phosphates, and a tiny fragment of the Ta projectile. Both samples were epoxy embedded, FIB-extracted, ultramicrotomed and examined by scanning transmission electron microscopy (STEM).

Results: Both samples contain abundant fine-grained material. Mineral identifications in the TEM sections are based on quantified elemental compositions, to be verified by electron diffraction. C0105-039023 is dominated by compact, well-ordered layer silicates consistent with smectites. The high porosity in this sample is due to many cracks. Accessory minerals and phases include abundant pentlandite and pyrrhotite, minor Fe-oxides, Mg, Ca-rich carbonates, and N-bearing organic nanoglobules. A0104-029025 shows morphology that, at modest magnifications, is similar to GEMS. It has two texturally distinct regions, one with high porosity and the other with lower porosity (Fig. 1). The more porous region is a mixture of poorly ordered, hydrated silicate and finer-grained pyrrhotite. Pentlandite is not observed in the high porosity region. The less porous region has a more diverse mineralogy with pyrrhotite, pentlandite, and an as-yet unidentified platy sulfide (possibly proto-tochilinite). We speculate that the boundary between the regions is a leach front and the lower porosity region is more (aqueously) altered, as evidenced by pentlandite, reduced pyrrhotite grain size, and platy sulfide that may be an oxidation product of pyrrhotite. Metal is absent in both samples.

Discussion: The bulk compositions of TEM sections of both highly porous Ryugu grains overlap those of GEMS, and both contain regions with textural similarities to GEMS, especially A0104-029025. However, the mineralogy of both samples is inconsistent with GEMS in IDPs and MMs. The amorphous silicate matrices are hydrated, Fe-rich, metal (FeNi) is absent, and organic carbon is less abundant than in GEMs. Abundant layer silicates, pentlandite, and carbonates implicate parent body alteration. Like the GEMS-like material observed in some meteorites from asteroids, the GEMS-like material in the Ryugu samples, although morphologically similar to GEMS, was most likely formed by parent body alteration processes including aqueous alteration, shocks, and/or partial rehydration. The context of these two highly porous grains within the range of Ryugu lithologies is unknown. The observation of anhydrous silicates by FE-SEM, however, shows incomplete alteration, and larger grains of anhydrous silicate in A0104-029025 may suggest it is less heavily modified than C0105-039023. The high porosity of both grains suggests sufficient porosity or a low degree of compaction on the parent body to allow aqueous alteration products to form in void spaces.

References: [1] Ishii H.A. et al. (2018) *Proc. National Academy Sci.* 115:6608-6613. [2] Leroux H. et al (2015) *Geochimica et Cosmochimica Acta* 170:247-265. [3] Nittler L. R. et al. (2019) *Nature Astronomy* 3:659-666. [4] Ohtaki K. et al. (2021) *Geochimica et Cosmochimica Acta* 310:320-345. [5] Villalon K. R. et al. (2021) ibid, 346-362. [6] oral presentation, Nakamura T. et al. (2022) *LPS LIII*, Abstract #1753.

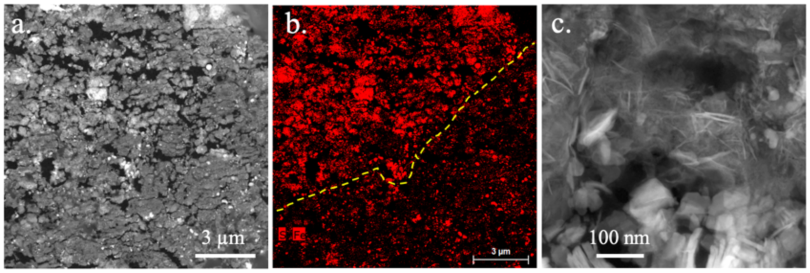

Figure 1. *a) Darkfield (HAADF) image of* A0104-029025. *b) Corresponding map of S+Fe. A dashed line delineates high and low porosity regions. c) Higher magnification HAADF image of low porosity region.*