

EVOLUTION OF OLIVINE COMPOSITION IN THE METEORITE FUSION CRUST.

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Introduction: The fusion crust is a blackish layer consisting of quenched melt that generally coats meteorites after being formed during atmospheric entry [1]. Fusion crust forms on all kind of meteorites, but is commonly thicker on iron than on stony meteorites, possibly due to the high heat conductivity of the metal [2]. In iron meteorites, enrichment in Ni and Co in the metal in the quenched fusion crust is observed and interpreted as the result of oxidation. In stony meteorites, the bulk composition of the fusion crust slightly differs from that of the original material, with enrichment in the melt of FeO, TiO₂, Al₂O₃, Na₂O, MnO, and K₂O [1]. However, this may reflect local mineralogy, as no real mixing occurred [3]. Recently fusion crust raised new interest as a possible analogue for chondrule formation [4] and for comparison with micrometeorites [2,1]. Here we present the investigation of the fusion crust of an ureilite A 09368, and for comparison of two H5 chondrites, A 09004 and A 09502, all collected in Antarctica during the 2009-2010 joint Japanese-Belgian mission [5]. These samples have been selected as representative of reduced material, in order to highlight the oxidation processes in the fusion crust. The samples, as petrographic thin sections, have been provided by the National Institute of Polar Research, Tachikawa (Japan) and have been analyzed using scanning electron microscope (SEM) and electron microprobe (EMPA) in the same institute.

Results: In *ureilite*, the fusion crust generally presents three layers, from the interior of the meteorite to the outer part of the fusion crust: (i) olivine intensely fractured, with interstitial melt, appearance of internal porosity, and occurrence of a rim with a higher Mg# than the original olivine, (ii) fragments of relict olivine with extensive overgrowth, suspended in a partially crystallized melt, and large vesicles rimmed by Fe and Ni oxides, and (iii) a microlitic layer, consisting of large (up to 100 μm) acicular crystals of new olivine embedded in a glassy groundmass, with extensive crystallization of skeletal magnetite. The boundary between the first and the second layer is quite sharp, whereas the transition between the second and the third layer is gradational. The chemical evolution of olivine shows a small depletion in FeO and a strong depletion in Al₂O₃, CaO and Na₂O in the fractured olivine, with the overgrown rim being also enriched in NiO, a composition of relict olivine that is similar to that of the porous olivine, with zoning alternating between higher Mg# and lower Mg# than the relict core, and a general enrichment in NiO. In the fusion crust of *H chondrites*, the general features are very similar to those observed for ureilite. However there are some remarkable differences, such as both olivine and pyroxene crystals are intensely fractured in the first layer, the growth rim with higher Mg# than in the original olivine is limited in thickness, relict olivine shows evidence of coalescence, multiple zoning is more common, and the groundmass in the microlitic domain is almost completely crystallized, with dendrites of fayalite and skeletal magnetite. Chemically, new olivine has two distinct populations, as distinguished by their Mg#: (i) slightly higher and (ii) much lower than in the pristine olivine. However, the trend for minor elements is similar for all populations of new olivine, showing enrichment in Al, Cr, Ca, and Ni, and a relative depletion in Mn.

Discussion and conclusion: *Oxidation or reduction?* In ureilite, the olivine that crystallizes from the melt is more magnesian (Fa₇) than the original olivine (Fa₂₀) and only the outer rim begins to be more fayalitic (Fa₁₄). In H-chondrites the new olivine is generally more fayalitic (up to Fa₃₁) and only locally a thin film (< 1 μm) more forsteritic (Fa₁₅) than the original olivine (Fa₁₉) occurs. According to [6], metallic Fe, exposed to oxidation and high temperature, affects the melt composition, producing an olivine and spinel saturated melt. This explains the overgrowth of olivine and crystallization of magnetite after melting and reaction of metallic Fe with atmospheric oxygen in the fusion crust, independently from the original composition of the melt. Enrichment in Fe in olivine, as well as in Ni, is expected due to oxidation of the metal in the meteorite, explaining the concentration of Fe and Ni oxides at the rim of vesicles and the formation of new olivine with a more Fa composition than the original one and enrichment in NiO. The new olivine with higher Mg# than the pristine material can be explained by: (i) oxidation of Fe²⁺ into Fe³⁺, therefore leaving olivine for crystallizing as magnetite, and (ii) reduction due to the presence of C, explaining the occurrence of porosity. Both processes are consistent with formation of fusion crust in ureilite, but the amount of C is negligible in H chondrites, supporting cyclical oxidation of Fe²⁺ to explain the multiple zoning in the overgrown rim of olivine.

References: [1] Genge M.J. & Grady M.M. 1999. *Meteoritics & Planetary Science* 34:341–356. [2] El Goresy A. & Fechtig H. 1967. *Smithsonian Contributions to Astrophysics* 11:391–398. [3] Thaisen K.G. & Taylor L.A. 2009. *Meteoritics and Planetary Science* 44:871–878. [4] Hezel D.C., et al. 2015. *Meteoritics and Planetary Science* 50: 229–242. [5] Yamaguchi A. et al. 2014. *Meteorite Newsletter* 23. Tachikawa, Japan. [6] Longhi J. 1999. *Geochimica et Cosmochimica Acta* 63: 573–585.