Study of fusion crust in ureilite and H-chondrites. L. Pittarello[1], V. Debaille[2] and Ph. Claeys[1], [1]Analytical, Environmental, and Geo-Chemistry (AMGC), Vrije Universiteit Brussel, Brussels, Belgium (lidia.pittarello@vub.ac.be), [2]Lab. G-Time, Université Libre de Bruxelles, Brussels, Belgium.

Introduction:

Fusion crust forms during the atmospheric entry of meteoroids. A large part of it is ablated, but commonly a thin layer is preserved and quenched, coating the meteorites surface (e.g., [1]). Fusion crust forms in all kind of meteorites, but generally it is thicker on iron meteorites than on stony chondrites 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 [2]. In stony meteorites, even though fusion crust results from melting, its bulk composition differs slightly from that of the original material [1], because of melt evolution or reflecting the local mineral composition [3]. This difference in bulk composition is obvious for volatiles, which are depleted in the fusion crust with respect to the original bulk composition [1; 3]. Recently fusion crust raised new interest because a possible analogue for chondrule formation [4] and for comparison with cosmic spherules (ongoing work).

Among stony meteorites, ureilites are believed to produce thin fusion crust and entirely consisting of glass [1]. However, sample A 09368, an Antarctic meteorite collected during joint Japanese-Belgian missions to Antarctica and classified as ureilite [5], exhibits a thick and well-developed fusion crust. In this work we focus on this sample, particularly investigating the change in composition of olivine through the fusion crust, comparing the results with those from the fusion crust of two H-chondrites (A 09004 and A 09502; [5]), in the framework of progressive oxidation of the material.

Methods:

The investigated samples were selected (i) because can be considered relatively "reduced" in comparison with other meteorites and (ii) because they exhibit a thick fusion crust that is largely crystallized. Polished thin (35 μm thick) petrographic sections, provided by the National Institute of Polar Science, Tachikawa, Japan, have been preliminary studied with the optical microscope. Micro imaging was performed with a JEOL JSM5900LV field-emission scanning electron microscope (SEM), and compositional data for the investigated mineral phases were measured with a JEOL JXA-8200 field emission electron microprobe (EMPA), equipped with five wavelength-dispersive spectrometers (WDS) and one EDS. Both instruments are at the National Institute of Polar Research, Tachikawa, Japan.

Results:

All three samples investigated exhibit a thick fusion crust, with three, well recognizable layers: Layer 1 is dominated by fracturing and weak thermal alteration, with thin melt veins injected between fragments; Layer 2 varies in thickness and mostly contains relict olivine crystals, with zoning and a thick overgrown rim of olivine, newly crystallized olivine crystals, vesicles, and quenched silicate melt; and Layer 3 consists of large (up to 100 μm) dendritic crystals of olivine and magnetite (Fig. 1).
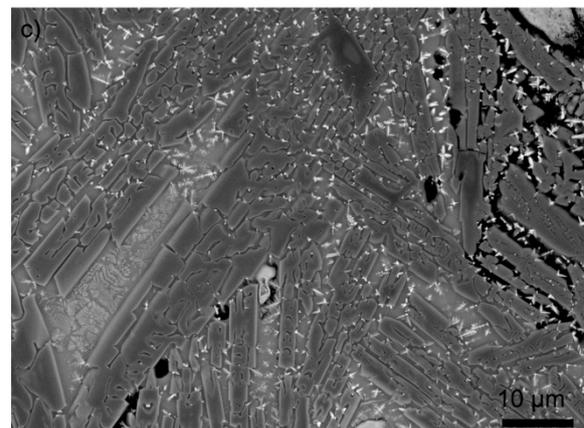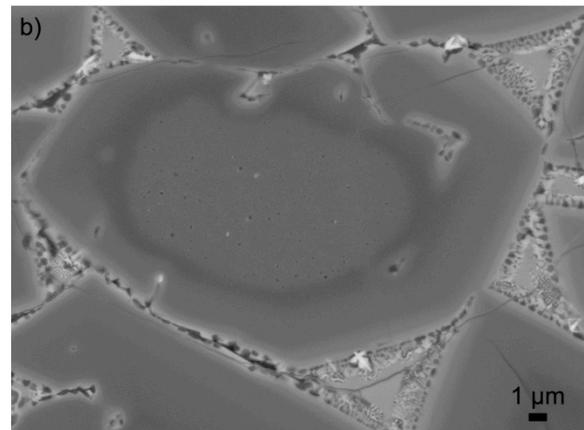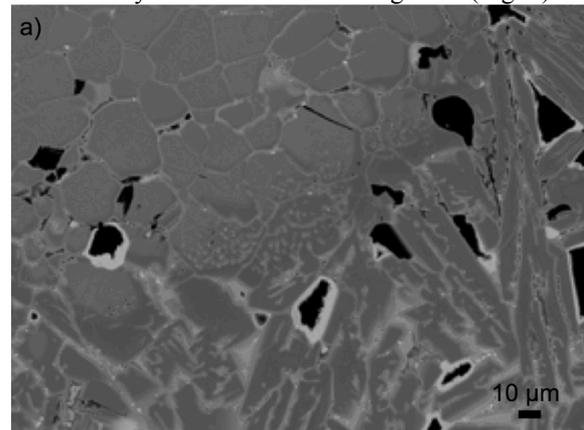
Fig. 1 Features in fusion crust of ureilite and H-chondrites. a) Transition between Layer 1 and 2 in A 09368. b) Zoning, preserved core and overgrown rim in olivine in Layer 2 in sample A 09368. c) Dendritic olivine, magnetite and quenched melt in the transition between Layer 2 and 3 in A 09502. All pictures are BSE-SEM images.

These characteristics are similar to those described in [3] for ordinary chondrites. The transition between layer 2 and 3 is gradual, locally distinguishable only for the size of new olivine crystals (smaller in Layer 3) and for the crystallization of skeletal magnetite in Layer 3. On the other hand, the transition between Layer 1 and 2 is quite sharp, marked by a change in composition and the appearance of a kind of porosity in olivine, just before the crystallization of new olivine (Fig. 1a).

In Layer 1, olivine crystals in the ureilite, are heavily fractured. The average grain size of fragments is less than 20 μm, against an average grain size in the preserved core of the sample. Fractures are locally filled with a silicate melt and metal blebs. The crystals at the border with Layer 2 present porosity, with round vesicles of < 1μm in diameter, and a change in composition, with progressive depletion of Al_2O_3, CaO and FeO, compensated by a relative increase in MgO and NiO. This depletion in Al_2O_3, change in the Fe/Mg ratio, and relative enrichment in NiO represent a general trend that is confirmed between the preserved core of olivine grains and the overgrown olivine in Layer 2 (Fig. 1b), as well as between the dendritic olivine in Layer 3 and the undisturbed olivine in the core of the meteorite. The new olivine in Layer 3 exhibits a thin (< 1μm) outer rim of brighter shade in BSE-SEM images, suggesting higher Fe/Mg ratio than at the core of crystals, but due to the size and the instrumental resolution limit, we could not confirm this change in composition. In H chondrites, the new dendritic olivine, analyzed at the core, is enriched in Al_2O_3, Cr_2O_3, CaO, FeO and NiO with respect to the undisturbed olivine in the meteorite. In Layer 2, a few olivine grains show alternating zoning, suggesting oscillations in the Fe/Mg ratio.

Vesicles are generally rimmed by metal-bearing concretions. Their shape is controlled by the crystals of olivine and their abundance increases outwards. In the melt, skeletal magnetite crystallizes. Microtextures in the melt suggest immiscibility processes between olivine melt and a silica-rich melt. A spherule, entirely consisting of olivine melt has been observed in the fusion crust. The interstitial melt has composition that recalls that of mesostasis in chondrules.

Discussion:

In H-chondrites, no other silicate has crystallized from the melt except olivine, even though the preserved portions of the samples contain pyroxene and plagioclase (Type 5 ordinary chondrites). According to [6], metallic Fe, exposed to oxidation and high temperature, affects the melt composition, producing an olivine and spinel saturated melt. This might explain why an originally chondritic melt crystallizes preferentially olivine, generally enriched in FeO with respect to the pristine olivine. The enrichment in NiO is also consistent with oxidation of the metal. In ureilite, the amount of Ni in the bulk rock is quite low [7]. Therefore, it is important to note that Ni is preferentially included in olivine. The composition of olivine is likely controlled by fO_2 in the melt, as demonstrated in melting experiments [8]. The dendritic shape of crystal is clearly explained by the fast cooling of the assemblage [9].

The change in Fe/Mg ratio within the olivine grains at the boundary between Layer 1 and 2 is likely due to either thermally activated diffusion (< 1 μm scale) or to overgrowth of new olivine at the rim of preserved crystals. The appearance of fine-grained porosity within the preserved grains suggests a reaction to temperature, with volatilization of little amount of Al, and possibly Na trapped in the crystal lattice. Mobilization of Ca is more difficult to occur than for Fe and Mg because it can be accommodated only in M2 octahedral site and is strongly controlled by fO_2 [10]. The enrichment in Ca is, therefore, to be interpreted as evidence of olivine overgrowth.

Conclusions:

In the fusion crust of ureilite and H-chondrite (relatively reduced material), fast crystallization under high temperature conditions of a chondritic melt with relatively high fO_2, due to entry in the Earth atmosphere, and with evolving composition, due to ablation and volatilization of light components, explain the crystallization of olivine, with dendritic shape or as overgrown rim on survived olivine grains, with composition relatively enriched in FeO, CaO, and NiO. The apparent decrease in the Fe/Mg ratio in the new olivine in the ureilite is likely due to crystallization of olivine from a melt enriched in MgO (by melting of other Mg-bearing phases, such as pyroxene) and under high temperature conditions. The combination of these two factors has likely favored the crystallization of more Fo variety.

Multi-zoning in large grains of olivine remains unclear and requires further investigation. A possible explanation is variations of fO_2 and of melt composition and relative temperature due to progressive ablation and solidification of the melt during atmospheric entry of the meteorites.

References:

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