THE D´ORBIGNY ANGRITE: EVIDENCES FOR AND AGAINST A FINAL THERMAL EVENT AT ~1000ºC. Varela, M.E.[1], Hwang S-L.[2], Shen P.[3], Chu H-T.[4], Yui T.F.[5] and Iizuka Y.[5], [1]ICATE-CONICET Av. España 1512 Sur, San Juan, Argentina (evarela@icate-conicet.gob.ar), [2]Department of Materials Science and Engineering, National Dong Hwa University, Hualien, Taiwan, ROC, [3] Department of Materials and Optoelectronic Science, National Sun Yat-sen University, Kaohsiung, Taiwan, ROC; [4]Central Geological Survey, MOEA Taipei, Taiwan, ROC;[5] Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan, ROC.

Introduction Angrites are a small group of rocks as old as the solar system, as indicated by their Pb-Pb ages (e.g, LEW Cliff 86010: 4558.55 ± 0.15 Ma and D'Orbigny: 4563.36 ± 0.34.) [1-2]. The genesis of these rocks is controversial and no consensus has yet been reached. The mineralogical composition of angrites is unusual. All phases are usually out of equilibrium. Ferroan, aluminous and titaniferous augite coexist with anorthite, Mg-rich olivine, Ca, Fe-rich olivine, kirschsteinite, a variety of oxides, phosphates, sulfides and some Ni, Fe metal [e.g., 3-6]. On the base of their textures, angrites are divided into two subgroups: coarse-grained ("slowly-cooled" angrites, e.g., Angra dos Reis, LEW 86010) and fine-grained ("quenched" angrites, e.g., Asuka-881371, D'Orbigny) [7] as a result of different cooling rates.

In the case of D´Orbigny the study of the crystal structure of druse clinopyroxene [8] help to quantify some of the parameters related with the last thermal history of this rock. The random distribution of Fe^{2+} and Mg^{2+} over the M1 and M2 sites suggests a closure temperature of 1000 ºC. However, as pointed out by [8], the high closure temperature (1000 ºC) that indicates an extremely fast cooling rate [9] of clinopyroxene is in contradiction with its grain size (up to 2 mm), perfect prismatic shape and homogeneous chemical composition, implying a slow growth with enough time for chemical homogenization.

Here we present some new evidences –based on SEM and TEM observations- indicating that D´Orbigny was exposed to late high temperature events. The time duration of such thermal events however remain controversial.

Sample and Results: We have studied the PTS D´Orbigny C-N1172 (NHM, Vienna).

The late Fe-Ca veneer: One of the latest events recorded by D´Orbigny produced the practically Mg-free mineral assemblage of Ca-rich olivine, kirschsteinite and titaniferous aluminous hedenbergite, all with atomic Fe/Mg ratios ~ 40 [5]. Olivine in the rock always contains Ca with a core of composition $Fa_{35}La_1$ which is covered by a first zone consisting mainly of Ca-rich olivine (Fa and La denote fayalite and larnite (Ca_2SiO_4), respectively). This zone is covered by a second one dominated by kirschsteinite ($Fa_{66}La_{33}$). Both zones are composed of intimate intergrowths of these two phases but are separated by steep compositional gradients [4-5] (Fig. 1). Because detailed zoning sequences in these phases show slight compositional reversals that cannot be explained by any mineralogic control, [4] invoked the addition of more primitive melts during crystallization of D´Orbigny.

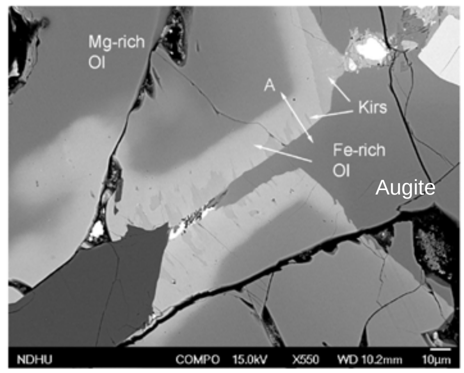

Figure 1: EBSE image showing the two zones surrounding olivines from D´Orbigny and the location of the FIB section (A) for TEM studies.

The co-existing Ca-rich olivine and kirschsteinite indicate a formation temperature of about 1000 °C [10]. At this high temperature the diffusion rates for Fe and Mg in olivine are very high. Therefore, the fact that steep compositional gradients across the plate edge in olivine were preserved, suggests that the late Fe-Ca veneer was the result of a short duration event. This quick cooling event constrains the process invoked by [4]. A TEM study of this area reveals that the reaction zone in olivines is not compositionally zoned in a way one would expect for phases growing from a melt with continuous compositional changes. Conversely, this region shows well-defined areas of Fe-rich olivine and Fe-Ca olivine (Fig. 2), supporting the idea that the Fe-Ca veneer could result from a late stage metasomatic process [5] rather than a magmatic compositional zoning [4].

The silico-phosphate and the Kuratite (Fe-Ti-Al-silicate, see [11] this conference) also belong to this late event. Euhedral kuratite crystals of up to 20 µm diameter was found in multi-phase inclusions in anorthite or enclosed by hedenbergite in association with troilite globules and kirschsteinite [4,5,11]. The crystallization temperature of Kuratite was probably >1000°C, considering the co-presence of Ca-rich fayalite and kirschsteinite [10] and the 900-1100°C stability field of rhönites based on experimental results [12]. Thus, the presence of silico-phosphate and Kuratite assemblage is in accordance with a late thermal event at ~1000 ºC.

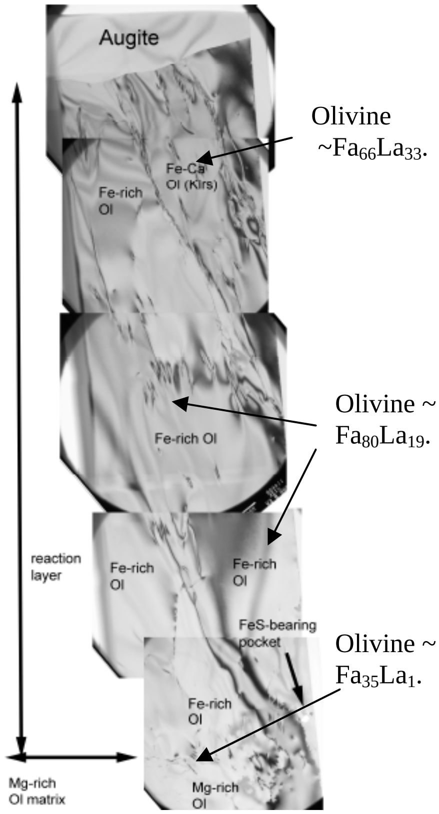

Figure 2: A TEM montage bright field image showing well-developed domains of olvine with different compositions.

Sulfide blebs (Ni-bearing FeS) in glass phase: One of the most unusual aspects of D'Orbigny is the presence of glasses that occur in several modes [13]. The Mn-Cr isotope systematics of the glass and a pyroxene fraction from druses indicate that they formed contemporaneously with the main phases of the angrite D'Orbigny at ~4563 Ma [14]. Glasses filling some of the abundant hollow shells (named glass sphere) contain small (1–50 µm) sulfide blebs (Ni-bearing FeS) associated with small bubbles [13]. Some sulphide globules have metal grains forming a corona decorating the surface of the globule (Fig. 3).

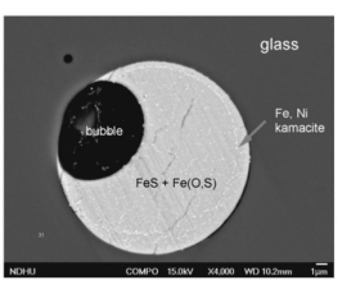

Figure 3: BSE image of a sulphide globule with an Fe-Ni necklace.

A close inspection of these phase assemblage shows that the metal phase is Fe-Ni kamacite. Several of such sulphide globules are dominated by a FeS-Fe(O,S) eutectic microstructures (Fig. 3).

A TEM study of these phase assemblage reveals the presence of an irregular growth front of the FeO/FeS eutectic and the co-existing glassy phase (Fig. 4).

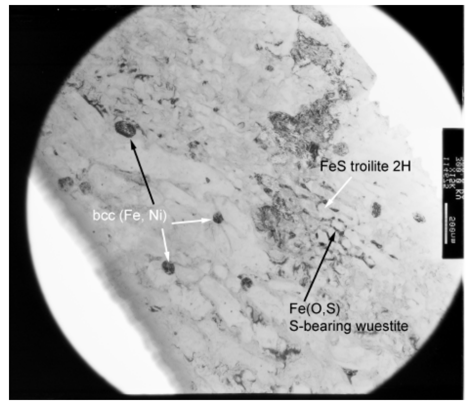

Figure 4: A TEM image showing eutectic microstructure of FeS (troilite, 2H) and Fe(O, S). The spherical inclusions are metallic bcc Fe (10% Ni).

Such FeS (troilite, 2H) and Fe (O, S) assemblage could be formed also near 1000°C, i.e. at the eutectic temperature (~940 C) [15] or under a specified supercooling.

Finally, it should be noted that the evidences considered to define a last short-lived thermal event affecting the angrite D'Orbigny assumes thermodynamic equilibrium. If such phase assemblages were due to kinetic phase change at specified/varied supercooling, supersaturation and short-circuit diffusion, identification of any thermal event becomes controversial. The eutectic texture (FeS-Fe(O, S)) being randomly present in the sulphide globules indicates that the above problems are of concern.

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