REAPPRAISAL OF METASOMATIC PROCESS CONDITIONS OF ALLENDE CV3 CHONDRITE USING THERMODYNAMIC AND SCHREINEMAKERS ANALYSES. C. G. Ganino[1] and G. Libourel[1,2], M. Delbo, P. Michel, [1]Geoazur, OCA, Université de Nice – Sophia Antipolis, CNRS/IRD, 250 rue Albert Einstein Sophia Antipolis 06560 Valbonne France, ganino@unice.fr, [2]Lagrange, OCA, CNRS, Boulevard de l'Observatoire CS 34229 F-06304 NICE Cedex 4.

Introduction: Petrologic and geochemical studies of chondrites have multiplied evidences for metasomatic processes during the early Solar System formation (see [1] for a review). Chondrite groups have been affected by (fluid-assisted) thermal processes to different degrees and metasomatism can be highly variable even within a single chondrite group. For this reason the precise environment (i.e., nebular vs asteroidal) allowing conditions for these metasomatic processes is still debated. Among the carbonaceous chondrite groups, the CV (Vigarano-type) and CO (Ornans-type) chondrites are the groups with stronger evidence of metasomatic alteration. Brearley and Krot [1] showed very recently that in the oxidized subgroup of the CV chondrites, all constituents (CAIs, AOAs, chondrules, and matrix) have been affected by iron-alkali-halogen metasomatism which is referred as responsible for the formation of a wide range of secondary minerals, of which the great majority is anhydrous. This process is supposed to have occurred at relatively low temperatures (<550 K) from aqueous solutions, consistent with an asteroidal environment. On the other hand, Allende contains dark intrusion whose formation is also debated. Sometimes attributed to a complex multistage alteration process in the presence of an aqueous solution [2], the formation of dark inclusions in Allende faces the lithium isotopes analyses that revealed no evidence of greater levels of aqueous alteration [3]. On the basis of equilibrium assemblage phase study we propose here alternative conditions of formation for both Allende matrix and dark inclusions.

Analytical procedure: A major difference between metasomatism in chondrites and terrestrial metasomatism is the scale on which metasomatism operates. The sometimes called micrometasomatism [1] observed in most chondrites is the result of the highly heterogeneous character of these meteorites at very small scale. Here we have restricted our study to the well-known and precisely described Allende CV3 chondrite. A polished thin section was characterized using FEG-SEM ZEISS SUPRA equipped with a Brucker EBSD analyser and EDX detector system. Our study focussed on the matrix of Allende, and on a dark inclusion about 0.35 mm-large and ~1 cm-long (figure 1).

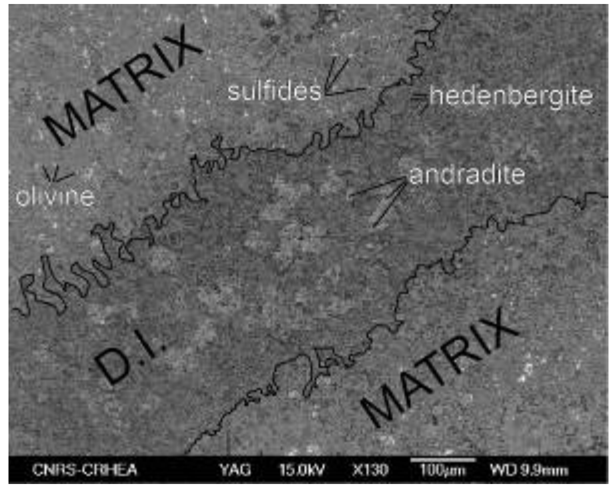

Figure 1: SEM image (YAG) of the andradite, hedenbergite, magnetite-rich and sulfide depleted Dark Inclusion (D.I.) observed in Allende.

Mineralogy of Allende matrix and dark inclusions: The matrix of Allende is abundantly documented and consists of very fine-grained Fe-rich olivine, Ca-poor and Fe-rich clinopyroxene, Fe-rich spinel, and Ni-bearing troilite (figure 2). Dark inclusions in Allende are described as composed of ferroan diopside, hedenbergite, wollastonite, andradite, and kirschsteinite. Wollastonite, andradite, and minor kirschsteinite are usually localized in the central zone of dark intrusion [1]. We observed such distribution in the dark inclusion we studied. Mostly composed of small (≈2µm) acicular iron-bearing olivine (≈Fa_{50}), and hedenbergite, the Dark Inclusion presented in this work contains abundant andradite, nepheline, ± sodalite, hedenbergite and coarsest andradites (≈30µm) are localized at the center of the Dark Inclusion (figure 1). Iron-oxides (magnetite) are present in the dark inclusion and sulfides are very rare. Contrary to this, iron-sulfide (pentlandite/pyrrhotite) are common in the matrix (figure 2). No hydrated mineral was found making us propose that the vein had not experienced an intense aqueous alteration.

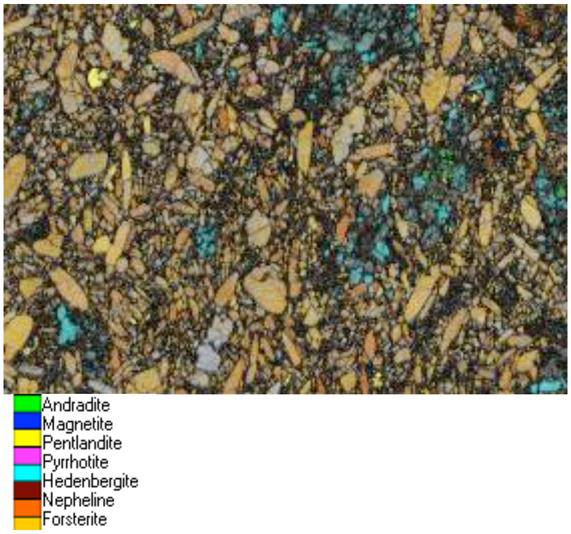

*Figure 2 : SEM - phase map from EBSD analysis of a the matrix of Allende (scale : 100µm*60µm).*

Major elements composition: The composition of the dark inclusion differs from that of the matrix by a significant depletion in Mg-Fe, a strong enrichment in Al-Ca-Na and a strong depletion in S (figure 3). The hypothesis of a leaching as proposed by Brearley and Krot [1] provides the simplest explanation to such chemical heterogeneity, however the behavior of elements strongly differs from the proposed Fe-alkali-halogen metasomatism. Here, Mg-Fe and S were depleted and/or Al-Ca-Na were enriched.

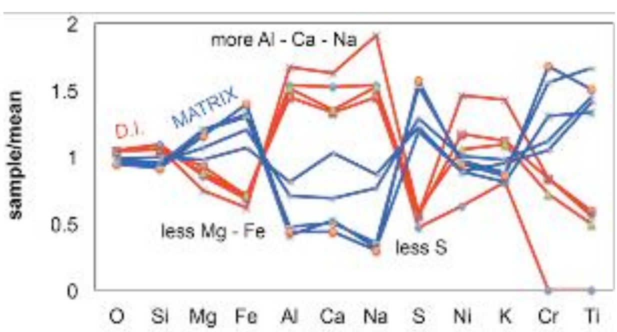

Figure 3: Composition of matrix (in blue) and Dark Inclusion (D.I. in red) normalized to mean composition of our analysis (SEM, backscattered electrons analyses of surfaces). Elements are sorted by decreasing abundance.

Redox state: The dark inclusion we studied experienced different redox conditions and was formed by a different process than the anoxic alteration of Allende parent body. Here, we interpret the presence of andradite and magnetite as an evidence for higher oxidation conditions in the Dark Inclusion (with inferred fO_2 slightly above the FMQ buffer curve) than in the matrix in which iron sulfides dominates. Application of oxidation - sulfidation phase equilibria [4] indicates that andradite is stable over a wide range fO_2 and fS_2. In contrast, hedenbergite is restricted in stability to relatively low fO_2 and low fS_2.

Equilibrium assemblage phase modeling: We performed a thermodynamical study of the equilibrium assemblage phases for the composition of Allende matrix and dark inclusions as well as a new Schreinemakers analyses in the system Ca-Fe-Si-O (free of H_2O). We will show that both approaches allow us to constrain the stability field of main of the observed parageneses in both the matrix and dark inclusion of Allende, including the following phases: andradite, wollastonite, ferroan olivine, hedenbergite, kirschteinite, magnetite. Our combined study of equilibrium assemblage phase in Allende matrix and dark inclusions shows that (1) earth-orientated thermodynamical database success in reproducing the mineralogy observed in CV chondrites in reasonable temperature range, (2) more oxidizing conditions are necessary for the formation of dark inclusions than for the formation of the matrix. (3) If aqueous fluid-rock interaction at low water-rock ratio and low temperature (<200°C) can not be ruled out, this study shows that aqueous fluids are not proved as necessary to reproduce the observed phases. The formation of secondary minerals is the result of higher temperatures than generally proposed.

References: [1] Brearley A. J. and Krot A. N. (2013) *in Metasomatism and the Chemical Transformation of Rock, Springer*, 659-789. [2] Krot A.N. et al. (2000) *Geochemistry International* 38, 351-368. [3] Sephton M.A. et al. (2006) *Meteoritics & Planetary Science* 41, 1039–1043. [4] Hu J. et al. (2011) *Am. Min.*, 96, 599-608.

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