

**Formation of secondary Ca-Fe –rich minerals assemblages in CV chondrites.** C. Ganino<sup>1</sup>, G. Libourel<sup>2</sup>, S. Jacomet<sup>3</sup>, O. Tottereau<sup>4</sup>. <sup>1</sup>Université Côte d'Azur, CNRS, OCA, IRD, Géoazur, 250 rue Albert Einstein, Sophia Antipolis 06560 Valbonne, France, <sup>2</sup>Université Côte d'Azur, CNRS, OCA, Lagrange, Nice, France <sup>3</sup>MINES ParisTech, PSL – Research University, CEMEF – Centre de mise en forme des matériaux, CNRS UMR 7635 Sophia-Antipolis, France, <sup>4</sup>CRHEA, CNRS UPR 10, Sophia Antipolis, France.

**Introduction:** Petrologic and geochemical studies of chondrites have demonstrated that metasomatic processes occurred during the early Solar System formation (e.g. [1] for a review). These processes altered the primitiveness of the oldest and best samples to constrain the early Solar System processes and its evolution [2]. In CV chondrites, all constituents (CAIs, AOAs, chondrules, and matrix) have been affected to various degrees by iron-alkali-halogen metasomatism, which is referred as responsible for the formation of a wide range of secondary minerals (for the most part anhydrous). On the one hand, temperature for this process is still debated and ranges from relatively low temperatures (<300°C) aqueous metasomatic process consistent with an asteroidal environment [3], to very high-temperature (>1000°C) consistent with a nebular process [4]. On the other hand, oxidizing conditions are also very speculative, with supposed oxidizing conditions for some secondary phases abundant in CV<sub>ox</sub> (e.g. andradite) and reducing conditions for secondary phases abundant in CV<sub>red</sub> (e.g. kirschsteinite).

Here we present new results focussing on the stability of Ca-Fe –rich minerals in the matrix and Dark Inclusions in CV chondrites.

**Methods:** Samples from three different subgroups of CV3 chondrites – Allende (CV<sub>oxA</sub>), Bali (CV<sub>oxB</sub>), and Vigarano (CV<sub>red</sub>) – were examined in this work to characterize the occurrence of secondary phase mainly in the matrix but also in some dark inclusions of the Allende CV3 carbonaceous chondrite.

Backscattered Electron (BSE) images and Energy-dispersive X-ray (EDX) spectroscopy chemical maps were acquired with a FEI XL30 ESEM LaB6 (CEMEF) and FEG-JEOL 7000F (CRHEA). Thermodynamical analyses and equilibrium phase assemblage diagrams were computed using Theriak-Domino software [5] and the internally consistent and the most updated thermodynamic database from Holland and Powell [6]. We investigated the effect of evolving chemical composition (especially  $a\text{SiO}_2$ ),  $f\text{O}_2$ , and T on the stable assemblages.

**Results:** Our survey of mineralogy in the CV3 subgroups confirms the ubiquitous occurrence of Ca-Fe-rich assemblages. Hedenbergite-dominated Ca-Fe secondary phases in CV3 subgroups occur under three similar types of textural setting (Fig.1): i) nodules or patches scattered in the iron-rich olivine dominated matrix, ii) fine poly-crystalline veinlets, forming an

imbricated network in the matrix or in dark inclusions, and iii) larger clusters (veins or dark inclusions). Irregular shaped hedenbergite ± andradite or hedenbergite ± kirschsteinite assemblages form veins in matrix that surround not only CAI or dark inclusions but also chondrules. Frequently these assemblages insulate a discontinuous porous central part made of voids or elongated cavities filled with euhedral Ca-Fe crystals. Ca-Fe-rich pyroxenes (i.e. hedenbergite), are by far the most dominant secondary phases, and are frequently found in association with andradite (only in CV<sub>ox</sub>), wollastonite, and/or kirschsteinite (abundant in CV<sub>red</sub>, rare but present in CV<sub>ox</sub>). Calcium-rich phases: larnite (Ca<sub>2</sub>SiO<sub>4</sub>) and rankinite (Ca<sub>3</sub>Si<sub>2</sub>O<sub>7</sub>), indicative of silica depleted conditions, were also documented as inclusions in andradite in Bali (Fig. 2). Finally, we confirm the occurrence of both FeNi metal and sulfides in the reduced and oxidized subgroups.

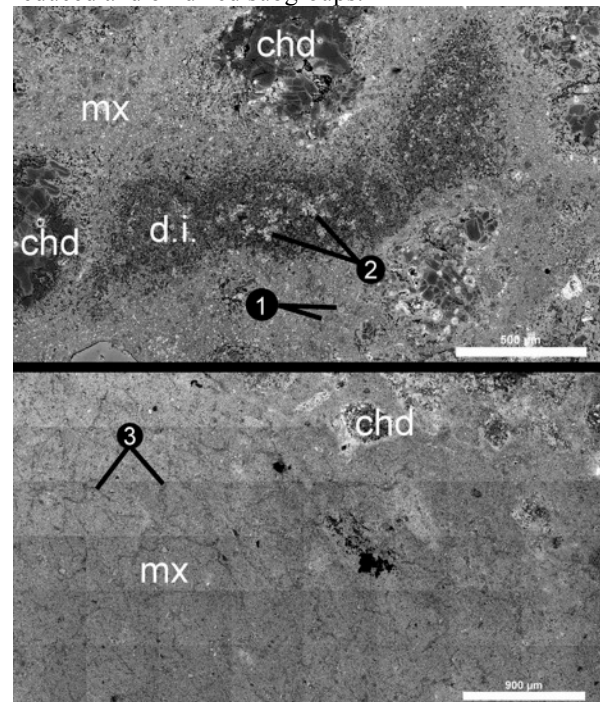


figure 1: (top) SEM image showing the occurrence of secondary minerals (here andradite-hedenbergite associations) as isolated patches {1} or grouped in inclusion {2} in a Dark Inclusion of Allende CV3. (bottom) SEM image showing the occurrence of hedenbergite following a network {3} in the matrix of Allende CV3.

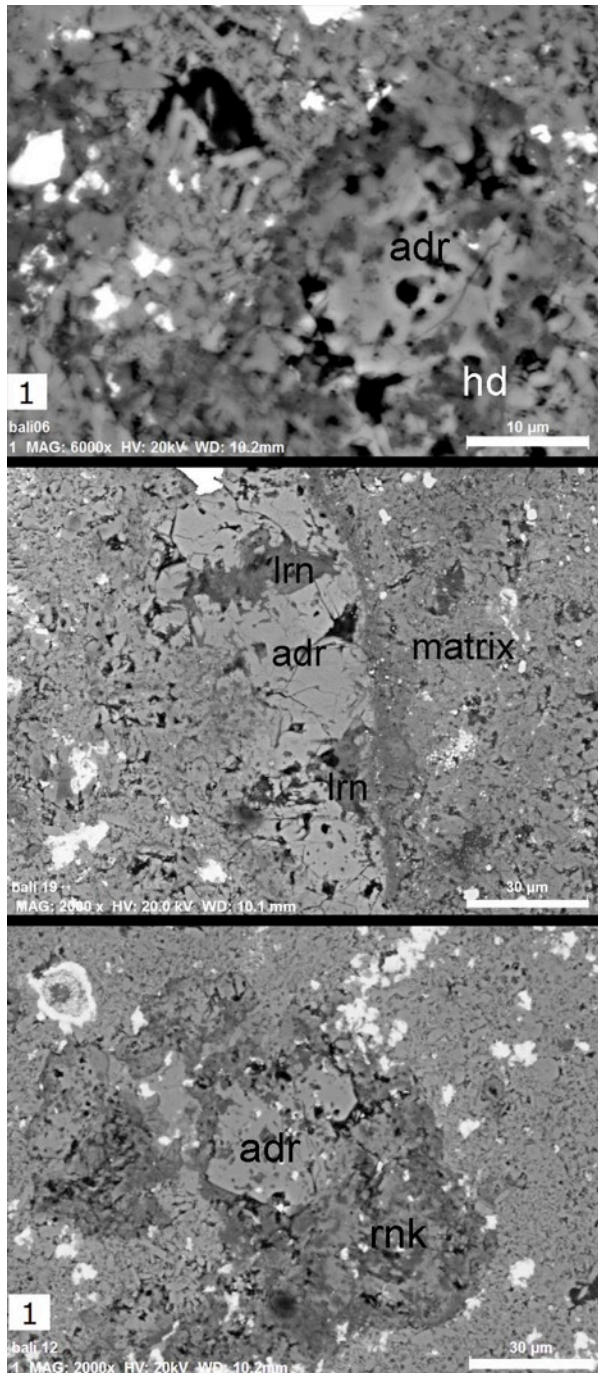


figure 2: SEM images of andradite+hedenbergite (top), andradite+larnite (middle), and andradite+rankinite (bottom) secondary Ca-Fe -rich assemblages in the matrix of Bali CV3.

Using Allende bulk composition simplified to its Ca-Fe-Si-O components as input, our thermodynamic analyses reveals that : i) hedenbergite, kirschsteinite, rankinite, larnite in that order and in different assemblages require significant decreases in the silica activity of the system, ii) kirschsteinite is stable only for IM buffered) redox condition, low silica activity and temperature > 450°C, iii) fayalite + hedenbergite assemblages are stable for Fe-rich system and high silica activity. iv) Andradite is stable at high temperature in oxidizing conditions but also for reducing conditions at lower temperature in low silica activity environments.

The diversity in secondary Ca-Fe -rich minerals assemblages demonstrates the large range of temperature and aSiO<sub>2</sub> in CV chondrites, compatible with a H<sub>2</sub>O-poor Darcy flow percolation of the planetesimal crust [8].

**References:** [1] Brearley A. and Krot A.D. (2013) in *Metasomatism and the Chemical Transformation of Rock*, Springer, 659-789. [2] Libourel et al. (2016) *Icarus* 282, 375-379. [3] Krot A. N., Petaev M. I., and Bland P. A. (2004) *Antarctic Meteorite Research* 17, 154–172. [4] Brenker F.E. and Krot A.N. (2004) *Am. Mineral.* 89, 1280-1289. [5] De Capitani C., and Petrakakis K. (2010) *Am. Mineral* 95, 1006-1016. [6] Holland T.J.B. and Powell R. (2011) *J. Metamorph. Geol.* 29, 333-383. [7] Bonal et al. (2016) 189, 312-337. [8] Fu, R. R., & Elkins-Tanton, L. T. (2014). *EPSL*, 390, 128-137.

**Additional information:** This work was financially supported by BQR from the Observatoire de la Côte d'Azur (OCA) and CSI from the Université de Nice Sophia Antipolis.