Trace element abundances of glass-bearing inclusions in Chassigny, M. E. Varela[1], E. Zinner, [2] and G.

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Introduction: The Chassigny achondrite belongs to the SNC (Shergottite- Nakhlite- Chassigny) group of meteorites and consists mainly of Fe-rich olivine (Fo_{68}) with anhedral to euhedral shape, suggestive of a cumulate origin [1].

The classical genetic scenario considers Chassigny as a recrystallized cumulate dunite, which possibly formed from a fractionated melt rather than a residual rock after partial melting [2]. The parent magma from which the SNC meteorites could have formed seems to resemble terrestrial tholeiitic magmas (but somewhat poorer in Al_2O_3) [e.g., 3-5].

In the case of Chassigny, the glass-bearing inclusion phase assemblages are consistent with an initial trapped melt that resembles terrestrial boninite lavas with ~1.5 wt% H_2O [6] or with the evolution of a liquid from silica-saturated hawaiitic (with > 0.4 wt% H2O) to trachy-andesite to sodic, alkali-rich rhyolite with P> 4.3 kbar [7]. The parent melt was LREE-enriched with a REE pattern parallel to that of the whole rock [8].

The study of all types of glass inclusions in Chassigny and Nakhla minerals suggests a non-classical scenario with low temperatures prevailing during their formation [9-11]. In Chassigny, the heterogeneous trapping of the mineral assemblages at sub-solidus temperatures suggests a non-igneous origin for the primary glass-bearing inclusions in olivine [9]. Here we report the results of a SIMS study on glass-bearing inclusions in Chassigny olivines that give support to our previous view.

Results: SIMS analyses were performed on a glassy and a multiphase inclusion in PTS L6101(NHM, Vienna). Glassy inclusions have sizes varying from less than 10 to 55 μm in diameter, have a sub-rounded shape and generally occur in clusters (Fig. 1). The major axis of the studied Glass3 inclusion is 55 μm. The multiphase inclusion has a sub-rounded elongated shape, with a major axis of 150 μm and occurs isolated in the host olivine. It consists of glass (glass1 and glass2) plus μm-sized euhedral to subhedral crystals of low-Ca pyroxene (Px2 :$Wo_{3.5}En_{69}Fs_{27.5}$ and Px3: $Wo_{3.3}En_{69.6}Fs_{27.1}$), high-Ca pyroxene (Cpx1: $Wo_{43}En_{46}Fs_{11}$ and Cpx2: $Wo_{41}En_{44}Fs_{15}$) and chromite (Chr: Cr_2O_3: 45.0 wt%, FeO 31.3 wt%, Al_2O_3: 11.6 wt% and TiO_2: 2.89 wt%, Fig.1).

All three glasses G1, G2, and G3 are silica-rich (67.2, 67.2 and 73.6 wt%, respectively) with highly variable alkali contents. The glassy inclusion G3 has Na_2O and K_2O contents of 6.1 and 1.2 wt%, respectively. In the multiphase inclusion, G1 and G2 have different alkali contents, G1 is Na_2O-rich (10.5

wt%) while G2 is Na_2O- and K_2O-rich (7.0 and 5.3 wt%, respectively).

Trace elements (see Fig. 2): In the multiphase inclusion the high Ca-pyroxenes (Cpx1 and Cpx2) have high REE abundances. Cpx1 has a normalized La/Lu = 1 (La and Lu: 11 x CI) and Cpx2 has a La/Lu = 2.3 (La: 14 x CI, Lu: 6 x CI). The low-Ca pyroxene (Px2:) shows a fractionated REE pattern with a La/Lu = 0.067 (La: 0.27 x CI, Lu: 4 x CI). The second pyroxene (Px3) shows a fractionated pattern with the LREEs enriched over the HREEs and La/Lu = 6.2 (La:51.7 x CI; Lu: 8.4 x CI). This pattern is akin to that of an amphibole. A close inspection after SIMS analysis shows the presence of an amphibole-like phase (SiO_2: 50.9 wt%, Al_2O_3:2.24 wt%, MgO: 19.3 wt%, CaO: 11.2 wt%, FeO: 12.6 wt%, Na_2O: 0.33, K_2O: 0.03 wt% and P_2O_5: 1.8 wt%) in between the border of the inclusion and Px3. Although the SIMS analysis was performed far from this amphibole-like phase, we cannot exclude some intergrowth and trace element contamination since REE contents remained high and constant throughout the SIMS analysis of Px3.

Trace element analysis of glasses shows that G3 has a fractionated, LREE-enriched (La/Lu: 44) pattern. The two glasses from the multiphase inclusion show totally different trace element contents. G1 is REE-poor and has a fractionated, LREE-enriched (La/Lu: 1,8) pattern with negative abundance anomalies of Tb (0.24 x CI) and Yb (0.08 x CI). G2 shows a flat pattern slightly enriched in HREE (La/Lu: 0.62) with REE abundances around 3 x CI (Fig 2).

Discussion: Looked at in the classical model view, the glass-bearing inclusions represent assemblages equivalent to those present in terrestrial igneous rocks. From their compositions that of the parent melt can be calculated, assuming that the minerals therein are daughter minerals formed during the cooling of an initially trapped melt. The trace and minor element study of Chassigny and Nakhla constituent phases [8] shows that the parent melt of Chassigny was LREE-enriched and that the whole rock can be explained by closed-system fractionation of a melt similar in composition to the trapped melt in the cumulus pile. The liquid in equilibrium with the late-formed minerals in Chassigny has a pattern parallel to that of the whole rock and to the calculated parent melt [8].

Applying olivine/melt partition coefficients [12,13], all three glasses -G1, G2 and the glassy inclusion G3- turn out to be out of equilibrium with their host olivines. A similar situation is observed between the phases inside the multiphase inclusion: Px2, Cpx1 and G1 are out of equilibrium as are Cpx2

and G2. If all these mineral phases formed from a trapped melt and the glass represents the residual liquid after their crystallization then 1) It is very difficult to explain the existence of glasses with different major and trace element composition inside a single multiphase inclusion and 2) their total lack of equilibrium poses a major problem.

In addition, G1 and G2 – in the classical model considered to be residual liquids in the glass-bearing inclusion - have lower REE abundances than the calculated melt in equilibrium with the early and late phases in Chassigny [8], a geochemical impossibility.

The calculated liquid in equilibrium with both high-Ca pyroxenes is enriched in all trace elements (Fig. 2). The abundances of Nb and Zr are around 400 - 700 x CI; those of Ce, Sm and Sr: 270 - 200 x CI; those of Eu, Gd, Dy, Er, Y and Ti are 150 - 70 x CI and those of La and Lu around 20 - 30 x CI and V: 4 x CI. The liquid in equilibrium with Px2 is also highly enriched in trace elements with abundances as follows: Nb, Zr and Sr: 800 - 600 x CI; Ti: 50 x CI; Ca: 18 x CI, Sc: 5 x CI and V, Mn and Cr: 2.5 - 2 x CI.

The LREE-enrichments in the glassy inclusion G3 matches the La, Ce, Pr and Nd abundances of the calculated melt in equilibrium with the low-Ca pyroxene [8], but G3 has lower abundances in Sm, Gd, Tb, Dy, Ho, Er, Tm and Yb. Glass G3 can be considered as a possible infiltration that has been trapped by the olivine. However, if infiltration did occur, it must have been early in the crystallization sequence [8], thus we should expect the intercumulus melt to have acquired chemical equilibrium with the olivine. However, this is not the case.

Our data are difficult to reconcile with the igneous evolution of glass-bearing inclusions and seem to support the non-classic scenario where Chassigny has formed at sub-solidus temperatures. The possible mechanism involved in Chassigny's origin -as we have previously concluded [9]- considers the formation of the host olivine and the glass-bearing inclusions at sub-igneous temperatures where the constituents of the inclusions were trapped by the growing olivine. Because the trapping of all phases was heterogeneous and took place at relatively low temperatures, equilibrium could not be established, as it is observed. Chassigny could probably have formed by aggregation of precipitates from a fluid (gas) phase- a simple task if the Primary- Liquid- Condensation model [14] was involved. -

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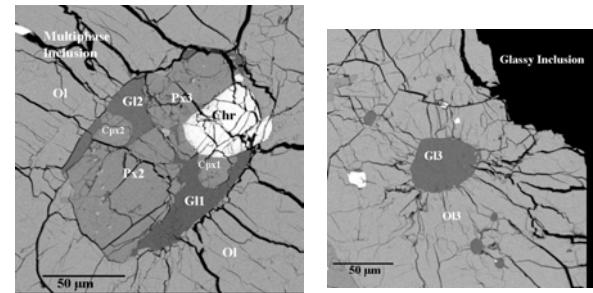
Fig. 1: BSE images of the multiphase and glassy inclusion in Chassigny L6101.
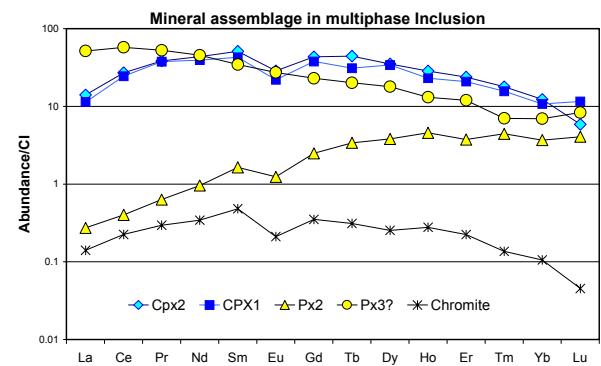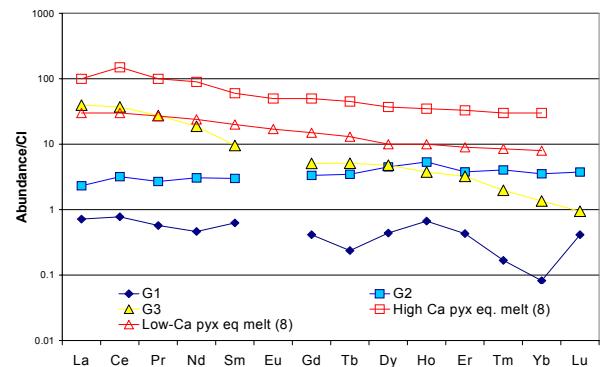
Fig.2: REE abundances of the mineral assemblage in the multiphase inclusion and glasses: G1, G2 and G3. Calculated melt in equilibrium with early and late phases [8] are given for comparison.