SEARCH FOR PLANETARY FRAGMENTS IN CHONDRULES FROM THE ALLENDE CHONDRITE.

M. Chaussidon[1], C. Rollion-Bard[1], A. Gurenko[1] and T.-H. Luu[1], [1]CRPG-CNRS, Nancy Université, BP 20, 54501 Vandoeuvre-lès-Nancy, France (chocho@crpg.cnrs-nancy.fr).

Introduction and objectives: Recent results acquired over the last years, either on Hf-W differentiation ages of magmatic iron meteorites, or on U-Pb crystallization ages of CAIs and chondrules or on ^{26}Al crystallization ages of chondrules [see 1 for review and refs therein] conduct to a change in paradigm for the accretion history of planetesimals and planets in the early solar system. Some planetesimals of 100-1000 km size accreted and differentiated nearly contemporaneously with the condensation of type B CAIs, while the parent bodies of chondrites accreted late, ≈ 4 to 5 Myrs after CAIs. These facts are in agreement with the latest models which use turbulence to promote the formation of clumps of particles that can become dense enough to collapse by gravitational instability, thus destroying the prerequisite for a hierarchical growth of planetesimals [2-4]. ^{26}Al ages of chondrules show that they formed mostly between ≈1.2 and ≈4 Myrs after CAIs with most numerous peaks of formation between ≈2 and ≈3 Myr after CAIs [5]. In addition, ^{26}Al model age suggests for one Al-rich chondrule that its precursors were formed as early as 0.9 Myr after CAIs, while the last melting event recorded for this chondrule was late [5]. Thus there is absolutely no chronological impossibility for fragments of early accreted and differentiated planetesimals to be present in the accretion disk when chondrules formed. Dust produced during collisions between early formed planetesimals, if in the micrometer-centimeter size range, would be coupled to the gas, would escape accretion to the Sun and could be transported through the disk [6]. The objective of this work is to search for the presence of such fragments in the Allende CV3 chondrite.

Potential planetary fragments in chondrules: Potential candidates (perhaps not the only ones) for these fragments are the clasts made of Mg-rich olivines and metal (±spinel) discovered in type I chondrules from CV chondrites [7]. These clasts have a granoblastic texture and, based on textural arguments, they are akin what would be expected for fragments of the mantle crystallized in the magma ocean of a planetesimal undergoing metal-silicate differentiation [7]. In addition, in many cases these Mg-rich olivines have oxygen isotopic compositions which are not at equilibrium with the other phases of the chondrules (pyroxene, mesostasis) indicating that they are relict phases which predate the chondrule melting event and were thus present among the chondrule precursors [8]. In such clear cases the oxygen isotopic variations observed among the different type I chondrules can be understood as due to partial melting in a common nebular gas (during chondrule formation) of olivine aggregates having different Δ^{17}O values. This gas has an isotopic composition (δ^{18}O=+3.6±1‰, δ^{17}O=+1.8±1‰) plotting in the three oxygen isotope diagram close to the intersection between the YR and the TFL lines [8, 9]. The distribution of the Δ^{17}O values of the relict olivines are not random and show several modes from ≈ -8.5±0.5‰ to +2.7+0.5‰ [9]. However these Δ^{17}O values have been measured using "classical" approaches by ion probe (as are most of the ion probe measurements published) and have a precision (±0.5‰ - ±1‰) which is not sufficient to ascertain whether two sets of relict olivines in two different chondrules could be fragments of the same parent body.

Approach:

Our approach is to study with high precision the isotopic composition (O and Mg) and the minor elements contents of a set of type I chondrules from Allende, chondrules in which the relict character of the Mg-rich olivines can be established from their Δ^{17}O values. The three simplest criteria that these olivines must fulfill in order to be potential fragments of the mantles of disrupted parent bodies are:

1) The olivines from a single parent body must share the same Δ^{17}O value (global melting of this body must homogenize the oxygen isotopes to a single Δ^{17}O value).

2) The olivines must be older (at least slightly older) than the chondrule melting event.

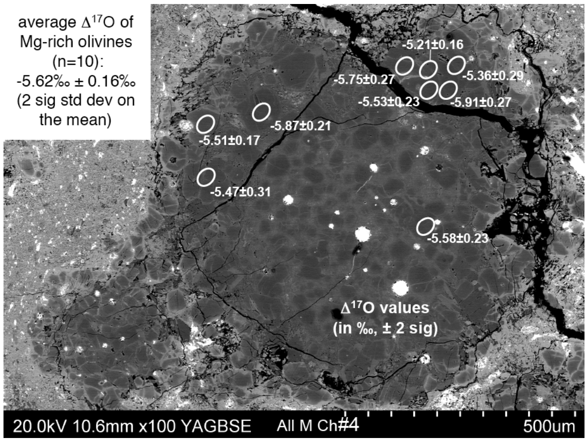
3) The olivines from a single parent body should share a similar systematic in their minor element contents, reflecting the history (accretion, differentiation, ...) of their parent body.

We have developed high precision O and Mg isotopic measurements using our ims 1270 and ims 1280HR2 multi-collector ion microprobes in CRPG Nancy. The Mg isotope composition (^{26}Mg excesses) can be tentatively used to infer ^{26}Al model ages for the olivines since they contain only traces of Al. In addition, minor element concentrations have been measured with high precision using a Jeol Jxa 2800 electron probe at MPI in Mainz following the procedure developed by [10]. We choose to analyze selectively chondrules or isolated olivines in which numerous (up to

20) ion probe spots of ≈ 25 µm diameter could be made in Mg-rich olivines. This allowed to check the isotopic homogeneity and, when isotopically homogeneous, to calculate mean Δ^{17}O and δ^{26}Mg* values and a standard error on the mean. This approach has been tested on terrestrial and extraterrestrial standard olivines and precisions on the level of ±0.01‰ to ±0.1‰ (2 sigma), depending on the samples and the analytical sessions, were obtained on the mean Δ^{17}O and δ^{26}Mg* values. Note that the precision which can be reached for δ^{25}Mg and δ^{18}O is much poorer (a factor of 5 to 10 worse or so) because of instabilities of mass fractionation.

Results, implications and open questions: Forty chondrules and isolated olivines from Allende were analyzed. The first major result is that the Δ^{17}O values of the Mg-rich olivines are homogeneous within errors in a given chondrule (with one significant exception) allowing calculation of mean values for Δ^{17}O of Mg-rich olivines in a given chondrule (Fig 1).

Fig 1: Δ^{17}O values in different Mg-rich olivines in an Allende chondrule.



The second major result is that the means which are calculated in this way do not show a continuum of Δ^{17}O values but only a limited number of values (e.g. 9 chondrules have Δ^{17}O values of -5.56±0.09‰). The third result is that some of the olivines have slightly negative δ^{26}Mg * [11] which would be in agreement, though it is model dependent, with their crystallization in the magma oceans of planetesimals differentiated within the first Myr of the solar system. The last result concerns minor element in olivines. Some systematic can be observed (e.g. MnO versus FeO, Al_2O_3 versus TiO_2) in the olivines sharing a common Δ^{17}O value. Olivines from different chondrules (or different isolated olivines) which can be paired from the minor element systematic, do share the same Δ^{17}O values. In addition, the systematic observed for minor elements seem consistent with trends resulting from magmatic differentiation processes (akin those taking place in the mantle of a planetesimal undergoing differentiation).

In conclusion, all these observations are consistent with these Mg-rich olivines being fragments of a restricted number (less than 10 different Δ^{17}O values have been found) of parent bodies.

These results have implications on the dynamic of accretion and on transport processes in the disk and also on the origin of chondrules. They also open a number of questions. (i) What is the real frequency of such fragments in type I chondrules: are the type I chondrules studied "anomalous" ? (Type I and type II chondrules in Acfer 094 exist in which olivine and pyroxene have the same Δ^{17}O values [12]). (ii) How to recognize a fragment if it has the same Δ^{17}O than the chondrule glass ? (iii) Are the olivine + metal clasts the only type of fragments ? (iv) What is the "window" in space and time in the accretion disk for accretion, global melting, differentiation and disruption to take place ?

References:

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