CHRONOLOGY OF DIFFERENTIATION AND MAGMATIC ACTIVITY IN 4-VESTA USING ^{26}Al-^{26}Mg MODEL AGES.

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Introduction: Short-lived isotopic systems like ^{26}Al-^{26}Mg are useful due to their high timeframe resolution during the lifetime of the parent element. As such, they can be considered as the most efficient chronometers for the first few million years (Ma) of the solar system's history. Aluminium-26, now extinct, decays to ^{26}Mg with a half-life of ~0.73 Ma [1]. This chronometer can therefore only date objects that formed within the first ~5 Ma after the formation of the solar system. The major weakness of short-lived radiochronometers is the fact that absolute chronology is no longer possible. To obtain age information the short-lived chronometer must be anchored to a long-lived isotope system such as U-Pb. This results in age variation according to the anchor object used. The anchor value used in this study is the D'Orbigny angrite [2, 3].

Eucrites and diogenites are igneous rocks belonging to a magmatic meteorite series: Howardite-Eucrite-Diogenite (HED) widely believed to have come from the asteroid 4-Vesta. Recent studies have demonstrated an excess in ^{26}Mg in some eucrites [4-6] but usually, these meteorites are considered to be contemporaneous and are dated with diogenites by whole rock isochrons. However, our previous results obtained on seven eucrites and three diogenites (Figure 1) show that not all HED meteorites have an excess in ^{26}Mg [7]. These results suggest that all eucrites do not have the same age and only some of them have known ^{26}Al. Moreover, some diogenites have no excess in ^{26}Mg suggesting that these achondrites formed later. In this case, dating these achondrites with internal isochrons seems more appropriate.

Currently, few studies have presented internal isochrons for eucrites [6, 8]. Here, mineral separation has been performed on five eucrites (Camel Donga (CD), Y-792510, Y-793591, Y-980433 and Y-980318) and three diogenites (Johnstown, Bilanga and Tatahouine).

Besides internal isochrons, we have tested model ages for our data set. This can be done considering ^{26}Al was homogenously distributed in the Solar System [9-11] and a chondritic precursor for Vesta, by combining ^{27}Al/^{24}Mg–δ^{26}Mg* data obtained on mineral separates with a chondritic value [6] and regressing the whole set. In this study, we present the first model ages obtained on eucrites and diogenites that can be compared to ages obtained with internal isochrons.

Methods: All the preparation and chemical procedures were performed in a clean laboratory at ULB. Mineral separation was performed with heavy liquids followed by magnetic separation using a Frantz magnetic separator. After dissolution, a small aliquot of each sample was taken to measure the ^{27}Al/^{24}Mg ratio. Mg was separated from the remainder using cation-exchange resin. Mg isotopes were measured on the ULB MC-ICP-MS Nu-plasma using an Aridus, and some samples were cross-calibrated on a MC-ICP-MS Neptune at UC Davis. Measurements were performed in medium resolution in order to avoid the possible isobaric interference on ^{26}Mg (^{12}C^{14}N) [1]. The instrumental mass bias was corrected by standard-bracketing with DSM-3 and the terrestrial standard BCR-2 was measured repeatedly to establish the terrestrial reference (δ^{26}Mg* = 0.007 ± 0.009 (2σ) n=57).

Result and discussion: Figure 1 presents the results obtained for δ^{26}Mg* on whole rock eucrites and diogenites.

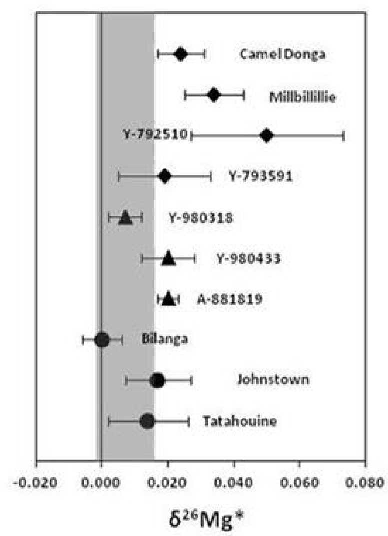

Figure 1: δ^{26}Mg* measurement for basaltic (♦), cumulative eucrites (▲) and diogenites (●). The grey zone corresponds to the terrestrial standard (BCR-2 range value). Errors show in this diagram corresponds to 2 times standard error. The δ^{26}Mg* is reported relative to the DSM-3 standard.

This δ^{26}Mg* anomaly is fully resolvable in Camel Donga (0.024 ± 0.007 (2σ)), Millbillillie (0.034 ± 0.009) and Y-792510 (0.050 ± 0.023) and not fully resolvable compared to the terrestrial field for Y-793591 (0.019 ± 0.014). Two cumulative eucrites, Y-

980433 and A-881819 also show a fully resolvable excess in δ^{26}Mg* and are respectively 0.020 (± 0.008) and 0.020 (± 0.003). The last one, Y-980318 presents no excess in δ^{26}Mg* (0.007 ± 0.005).

For diogenites, Bilanga (0.000 ± 0.006), Johnstown (0.017 ± 0.010) and Tatahouine (0.014 ± 0.012) are in the terrestrial domain within errors.

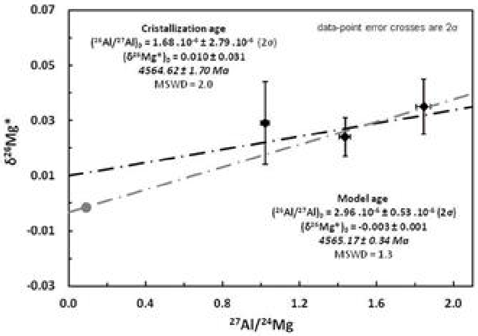

Figure 2: Internal isochron (black line) and model internal isochron (grey line) of CD basaltic eucrite. The chondritic average value is show by (●) symbol (error is include in symbol) and correspond to δ^{26}Mg* value of -0.0015 ± 0.0013 [9].

In general, because of the small number of data point and/or the small spread in Al/Mg ratios, internal isochrons have large uncertainties and $(^{26}Al/^{27}Al)_0$ values can be within error of zero. In order to strengthen those data, we have calculated model ages by using the bulk δ^{26}Mg* value of the solar system at the present day, i.e. non-CAI-bearing chondrite [9, 10]. By doing so, we make the assumption that Vesta started from a chondritic bulk composition and differentiated in a two-stage model. Model age is going to represent the time at which a sample directly differentiated from this chondritic reservoir. Model age can thus be different from the crystallization age. The model and internal isochrons for CD are shown in Figure 2. Model and crystallization ages obtained for CD and Y-793591 basaltic eucrites are shown in Figure 3, as well as for the cumulative eucrite Y-980433 and the Bilanga diogenite.

Previously internal isochron obtained with our data show that basaltic eucrites formed during a magmatic episode at 4564 ± 2 Ma. These data also show that the cumulative eucrite Y-980433 formed at 4560.76 ± 1.17 Ma, and is interpreted to have cooled down slowly, likely deeper in the crust of Vesta. Finally, the diogenites formed after the complete extinction of ^{26}Al and cannot be dated precisely with the Al-Mg isotopic system.

The model ages obtained for the two basaltic eucrites and their crystallization age are similar within the errors (Fig. 3). The crystallization age is systematically younger than the model age, as normally expected. Similar values between crystallization and model ages are observed for the cumulative eucrite but the error associated on both ages is too large to interpret with confidence.

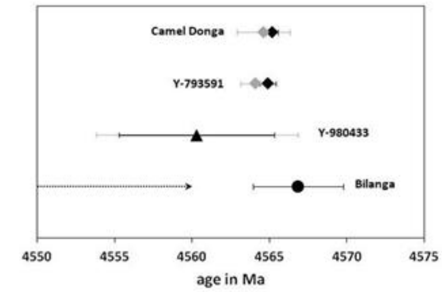

Figure 3: Comparison between crystallization age (grey symbols) and model age (black symbols) for two basaltic eucrites (CD, Y-793591), one cumulative eucrite (Y-980433) and one diogenite (Bilanga). Maximum age for the formation of diogenite ($^{26}Al/^{27}Al$ = 0) is shown by the dotted line. Error bars are 2σ.

Finally, the Bilanga diogenite has a model age that seems older but still similar within the error than basaltic and cumulative eucrites. The crystallization age of diogenites cannot be obtained because they formed after the complete extinction of ^{26}Al. The discrepancy observed among diogenites seems to indicate a more complex history.

Conclusion: The model ages obtained for the basaltic eucrites suggest that the differentiation of Vesta from a chondritic precursor and the magmatic activity at the surface of the parent body occurred in a very limited time period, i.e. < 1Ma. Data for the cumulative eucrite Y-980433 is more difficult to interpret due to the large error, however, both model and crystallization ages converge towards a younger age compared to basaltic eucrites. Finally, data for diogenites show a more complex history and their old model ages needs to be confirmed.

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