CARBONATE FORMATION TIMESCALES VARY BETWEEN CM1 CHONDRITES ALH84051 AND ALH84034.

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Introduction: Carbonaceous chondrites ALH84051 and ALH84034 rank amongst the most aqueously altered meteorites within the CM group and have been classified as petrologic type 1s. Nearly all primary anhydrous minerals have been replaced by secondary alteration phases, yet these meteorites still possess primitive whole-rock compositions [1,2]. Although elemental transport does not appear to have occurred on the large-scale during the alteration process, local mass transport was clearly an important process. In particular, the formation of carbonates, which are believed to have precipitated from aqueous fluids, occur extensively throughout CM1 chondrites. These carbonate phases, primarily dolomite and calcite, are important secondary minerals that preserve a record of the conditions and timing of their formation.

Here we report new data on the petrography and short-lived radionuclide Mn-Cr systematics of carbonates obtained by nanoSIMS in the CM1 chondrite ALH84051 in a continued effort to constrain the alteration processes on the CM1 parent body. We also compare these data with our previous study of CM1 ALH84034.

Petrography: Carbonates in both sections were primarily dolomite, with rarer calcite. Carbonates in both samples are morphologically similar with small angular to subrounded 20-50 μm individual grains interspersed throughout the meteorite and rare large (up to 300 μm diameter) carbonate agglomerates. ALH84034 carbonates were distributed randomly, though in some areas higher abundances of carbonate grains occur. The distribution of carbonates in ALH84051 is generally similar to ALH84034. However, the thin section of ALH84051 is particularly notable because it contains distinct veins of granular dolomite crystals which crosscut ~3/4 of the width of the sample. We have not observed a feature of this kind previously in any other CM chondrite. The veins, at least in the scope of a two-dimensional thin section, are not contiguous and were interrupted by phyllosilicate matrix grains of varying size and composition.

Previous studies have shown that carbonate grains in ALH84034 exhibit complex zoning when imaged using cathodluminescence (CL) [3]. We examined zoning in multiple carbonate grains on JEOL 5800 SEM in using an Oxford Instruments CL detector. Following CL imaging, compositional zoning in individual carbonate grains was measured via electron probe analysis (EPMA) for Ca, Mg, Mn, Fe, and Sr composition. ALH84051 dolomites possessed similar zoning, with Mn ranging from 0.6 to 1.4 wt% and Fe 2.1-7.2 wt%.

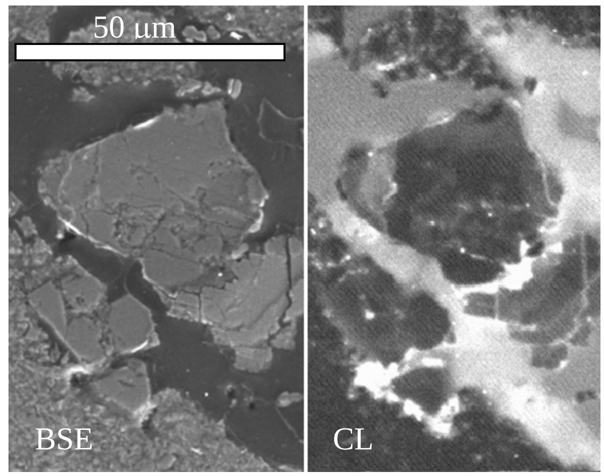

Figure 1. SEM BSE and CL images of an examined ALH84051 dolomite.

Isotopic Compositions: Here, we report measured nanoSIMS Mn and Cr isotopic values for both meteorites. We have previously measured Mn-Cr systematics of dolomites from ALH84034 using the Lawrence Livermore National Laboratory (LLNL) Cameca 3f [3], allowing us to make comparisons between data obtained on the two instruments. The new chromium isotopic and Mn/Cr ratio measurements of carbonate grains from ALH 84034 and ALH 84051 were obtained using the NanoSIMS 50 ion microprobe at LLNL. Secondary ion images were collected by rastering a 90 pA O^- beam over 35-50 μm fields of view. Secondary ions were measured in two magnetic fields; $^{26}Mg^+$, $^{28}Si^+$, $^{44}Ca^+$, $^{52}Cr^+$, and $^{55}Mn^+$ were simultaneously acquired on five electron multipliers in the first magnetic field, and $^{53}Cr^+$ and $^{56}Fe^+$ were acquired on two electron multipliers in the second magnetic field. The mass resolving power was ~6000. A Mn/Cr relative sensitivity factor of 1.12 was obtained from repeated measurements of San Carlos olivine with known Mn/Cr ratios.

The NanoSIMS Mn-Cr isotopic data for ALH84034 are are shown in Fig. 2 and represent a compilation of data from 7 individual carbonate grains. The data show a well defined excess in ^{53}Cr that correlates with $^{55}Mn/^{52}Cr$ ratio consistent with in situ decay of live ^{53}Mn. The regression line for the data define $(^{53}Mn/^{55}Mn)_0$ of 4.27 $\pm$ 0.5 x 10^{-6} indicates that carbonate formation in ALH84034 occurred ~ 6 My before angrite formation. Importantly, these data are consistent with data obtained using the Cameca 3f, which yielded a (^{53}Mn/^{55}Mn)$_0$ of 5.1 $\pm$ 1.5 x 10^{-6} [3]. However, the NanoSIMS data span a range of ^{55}Mn/^{53}Cr ratios 30 times larger than the 3f data and consequently have much smaller uncertainties. These results demonstrate the power of the NanoSIMS for high spatial resolution Mn-Cr dating of dolomites.

The NanoSIMS Mn-Cr data for ALH84051 are shown in Fig. 3, which represents a compilation of three individual dolomite grains. Like ALH84034 carbonates, there is a distinct ^{53}Cr excess that correlates with Mn/Cr ratio. Surprisingly, however, the slope of the regression line is significantly steeper for ALH84051 with a calculated initial ^{53}Mn/^{55}Mn = (9.4$\pm$ 3.6) x 10^{-6}. These data indicate that, despite the similarities in petrology and mineralogy of the two meteorites, carbonate formation occurred significantly earlier in ALH84051. Relative to angrite differentiation, carbonates in ALH84051 formed ~ 11 My earlier than angrite differentiation.

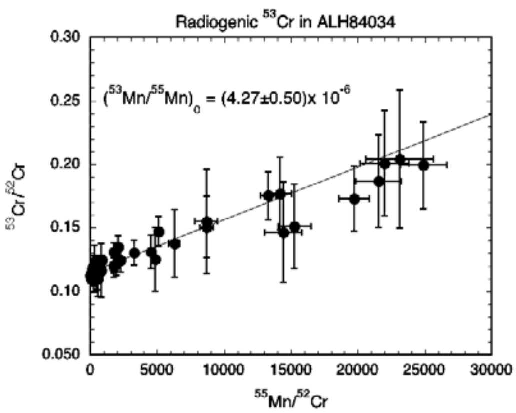

Figure 2. ^{53}Cr/^{52}Cr vs. ^{53}Mn/^{52}Cr ratios in ALH84034. Seven carbonate grains (undifferentiated here) included.

Discusion: Previous studies [i.e. 4] of CI chondrites have shown that the NanoSIMS is a powerful technique for high spatial resolution analysis of Mn-Cr analyses of carbonates. Here we have applied the NanoSIMS for the first time to study dolomites from CM chondrites, which have lower Mn contents than those in CI chondrites. Our results show that high spatial resolution of the NanoSIMS provides significant advantages for analyzing small, complex carbonate grains and provides data which are comparable with or even superior to data obtained using conventional SIMS.

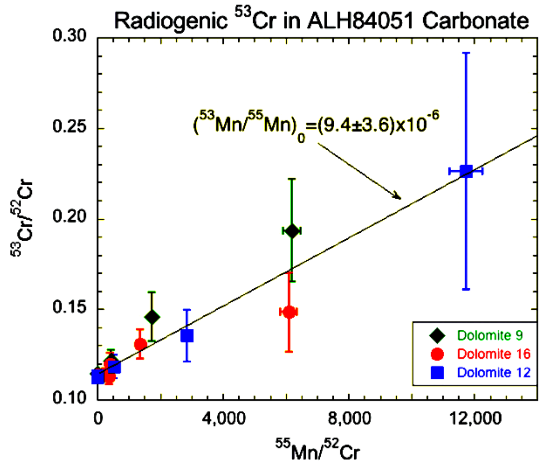

Figure 3. ^{53}Cr/^{52}Cr vs. ^{53}Mn/^{52}Cr ratios in ALH84051. Three carbonate grains are included in the graph.

The results from dating of carbonates in ALH84051 are unexpected. We had previously speculated [5] that the most highly altered CM chondrites experienced alteration for longer than weakly altered CMs and hence contained younger carbonates. Our new data show that extensive alteration apparently also occurred very early in solar system history, suggesting that as long as sufficient fluid is available advanced alteration can occur extremely rapidly. Indeed our new data for ALH84051 carbonates have an initial ^{53}Mn/^{55}Mn ratio which is only slightly lower than that of calcites in the weakly altered CM2 chondrite Y791198 [5]. Assuming the both ALH84034 and ALH84051 come from the same parent body, it appears that aqueous activity was occurring at different locations in the same asteroid over a time period of around 5 My, a remarkably extended period that needs to be considered in thermal models for asteroidal alteration. For ALH84051, we can distinguish no apparent difference in age between vein and other carbonates, although additional studies are needed. Nevertheless, the very young age of the vein carbonates clearly shows veining on the parent body may be a much earlier occurrence than hitherto indicated [i.e. 6].

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