VARIABILITY IN CARBONATE PETROGRAPHY AND NANOSIMS $^{53}$MN/$^{53}$CR SYSTEMATICS IN PAIRED CM1 CHONDRITES ALH 84051, ALH 84049, AND ALH 84034. M. A. Tyra¹, J. Matzel², A. J. Brearley¹, and I. D. Hutcheon², ¹Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, USA (matyra@unm.edu), ²Analytical and Nuclear Chemistry Division, Lawrence Livermore National Laboratory, Livermore, CA 94551

Introduction: ALH 84051, ALH 84049, and ALH 84034 are paired and rank within the CM1 subgroup, which possesses chondrites that interacted and reacted extensively with aqueous fluids. These interactions not only changed the entire mineral makeup of the chondrites, but the fluid compositions as well. Carbonates are common in these CM1 chondrites and preserve the changing characteristics of the fluids from which they precipitated [1].

Here we report petrological and chemical variability within carbonates of this paired set, including zoning, and compare this variability to their Mn/Cr short-lived radionuclide systematics. This builds upon recent work on ALH 84051, ALH 84034, and ALH 83100—all part of this paired set [2, 3]. As different samples represent different areas of the original impactor, analyzing the set as a whole allows a more comprehensive picture of carbonate history in a larger spatial context.

Petrography: Carbonate petrography in sample ALH 84034 and ALH 84051 have been described [2, 4] and the following petrographic description pertains to ALH 84049. This sample contains a carbonate lithology similar to ALH 84034, no agglomerates or veins, but abundant blocky 10-50 μm diameter dolomite and calcium carbonate (probably calcite) minerals. ALH 84049, however, possesses rare carbonates that form pseudomorphic replacements of large chondrules or chondrules fragments (>100 mm diameter). Unlike ALH 84051, carbonates occur randomly throughout the matrix. Rarely, calcite resides in contact with dolomite.

Many analyzed dolomites exhibit extensive zoning, indicating a complex formation history. Fig. 1 shows a typical zoned dolomite in ALH 84049. Zoning is apparent in SEM cathodoluminescence (CL) imagery and via electron microanalysis (EPMA) x-ray mapping. The grain in Fig. 1 shows higher concentrations of Mn correlating with higher CL intensity, but that is not always the case as Fe seems to suppress CL intensity as well. X-ray maps of Fe, Mg, Mn, Ca, and Si show grain extent, phase (e.g. calcite, dolomite, or phyllosilicate inclusions), and zoning more consistently than CL.

To analyze further the chemistry of the paired set, we performed EPMA spot analyses of ALH 84034 and ALH 84034. We discovered that pits created during carbonate EPMA spot analysis possessed disturbed Mn/Cr intensities and these areas were discarded. ALH 84049 carbonates therefore were characterized by multipass compositional x-ray mapping at reduced current and dwell time (20 nA, 25 ms dwell time, 2μm spot-size). Fig. 2 compiles the EPMA spot results in a Ca-Mg-Mn+Fe ternary diagram. Though much of the data overlap, this plot shows that dolomites in ALH 84051 and ALH 84034 vary compositionally within samples and between them. Together, the x-ray maps of ALH

Figure 1. ALH 84049 dolomite. Figure compares BSE, CL, Mn concentration, and Fe concentrations. Zoning in CL apparent and correlates roughly with presence of Mn and lack of Fe.

Figure 2. Ternary diagram. Both compositions overlap, though ALH 84051 average more Ca-rich.
84049 and quantitative spot EPMA analyses show that fluid compositions were variable.

**Isotopic Compositions:** We report ion microprobe Mn/Cr analyses for ALH 84051 and ALH 84049. This data expands the dataset of Tyra et al 2009 [2] and adds new data for ALH 84049. We used the Cameca NanoSIMS 50 instrument at Lawrence Livermore National Laboratory. Secondary ion images were collected by rastering a 70 pA O₂ beam over 15-30 μm² fields of view. Positive secondary ions were acquired in a combined peak jumping, multi-collection mode, simultaneously measuring 55Mg⁺, 28Si⁺, 44Ca⁺, 52Cr⁺, and 55Mn⁺, and then stepping the magnetic field to measure 53Cr⁺ and 56Fe⁺. Secondary ion intensities were corrected for background and counting system dead time. Measured 55Mn/52Cr ion ratios were converted to atomic ratios using a relative sensitivity factor of 0.91 determined from repeated measurements of San Carlos olivine. A mass resolving power of ~3600 was used in order to eliminate potential interferences.

Data for both ALH 84049 and ALH 84051 show excesses in 53Cr that covary with 55Mn/52Cr ratios, which is consistent with in-situ decay of live 53Mn. ALH 84051 carbonate data define a regression line with a slope of (4.68 ± 1.22) x 10⁻⁶ (2σ). This result encompasses seven dolomite grains and 37 regions delimited by 55Mn/52Cr ratio and is significantly different from that reported in [2] (9.4 ± 1.95 x 10⁻⁶), where only 3 carbonates were analyzed.

The NanoSIMS Mn-Cr data for ALH84049 are shown in Fig. 3 and represent seven individual grains, each subdivided into three or four regions based on 55Mn/52Cr ratio. As in ALH 84051, 53Cr excess correlates with 55Mn/52Cr ratio. Regressing the data give a slope of (3.35 ± 0.74) x 10⁻⁶ (2σ). This slope is within error of ALH 84051 and ALH 84034.

**Discussion:** Petrographic variability within the examined paired meteorite set is significant. ALH 84034 is similar to ALH 84049 in aqueous alteration extent and observed carbonate morphologies, with the exception of dolomite-replaced large anhydrous minerals in ALH 84049. ALH 84051 shows significantly more aqueous alteration, and possesses carbonate agglomerates and matrix-bound veins (not fracture fill). In addition, chemical variability is noted with observable zoning in CL, x-ray mapping, and via EPMA spot analysis. These irregularities in carbonate chemistry strongly suggest that carbonates precipitated either from an evolving fluid or from different fluids.

The ion microprobe analyses show that, though fluid chemistry changed, precipitation occurred over a < 5-Myr window. ALH 84051 resides within the reported population, though individual carbonate isochrons vary more widely than the other two samples. Results here are consistent with that reported in ALH 83100 via SIMS analysis (53Mn/55Mn₀ = (5.1 ± 1.7) x 10⁻⁶) [3]. If we consider that (1) our reported isotope compositions are sourced from 3 samples, where original spatial separation on the original impactor is unknown and (2) that analyzed areas represent many cm², the implication that carbonate precipitation on the parent body was confined to a narrow window is bolstered.


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![Figure 3. 53Cr/52Cr vs. 55Mn/52Cr ratios in ALH84049. Seven carbonate grains (undifferentiated here) included.](image-url)