

**Aqueous alteration on the the CI parent body: Mn-Cr ages of secondary carbonate formation**

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**Introduction:** The similarity in chemical composition between the CI chondrites and the solar photosphere is striking and suggests that the material which formed the CI parent body did not experience significant fractionation during nebula processing. Therefore, the CI chondrites are a good proxy for the bulk solar system. However, the CI chondrites are some of the most aqueously altered meteorites. It is important to understand the mechanism, extent and timing of this secondary processing. The timing of aqueous alteration may be examined through the formation ages of the secondary minerals. Carbonate minerals often have high Mn/Cr ratios and so offer an excellent opportunity to apply the short-lived  $^{53}\text{Mn}$  chronometer ( $t_{1/2} = 3.7$  Ma). Several previous studies have examined the timing of carbonate formation on the CI parent body (e.g. [1] [2] [3]). These studies found that dolomites formed early, within a few Ma of CAIs, and are followed by an extended period, up to 14 Ma, of carbonate formation, possibly with a gap between dolomite and breunnerite precipitation [3]. This is consistent with an evolving fluid composition during silicate processing [4]. However, the long duration of carbonate formation, and possibility of a gap between dolomite and breunnerite, is difficult to reconcile with the most likely heat source,  $^{26}\text{Al}$ , due to its short half-life ( $\sim 0.74$  Ma).

The very large isotopic shifts which result from the high Mn/Cr ratios in carbonates may be measured by ion probe. However, accurate determination of a Mn-Cr age is also reliant on an accurate measurement of the Mn/Cr ratio. Secondary ionisation during sputtering results in different elements being detected with varying efficiencies. For most samples this may be corrected through a relative sensitivity factor (RSF) determined by measurement of matrix matched standards. Unfortunately, due to the low and heterogeneous Cr concentrations in carbonates, appropriate carbonate standards are not readily available. Most previous studies have corrected for matrix effects by using one RSF obtained from either silicate standards (e.g. NIST glasses and olivine [e.g. 5]) or, more recently, a synthetic Cr-doped calcite [6]. The use of silicates is problematic as these standards are not matrix matched. While the use of calcite is better, it is only one end-member composition which does not exactly match the matrix of any of the unknown samples of interest.

**Discussion:** We have investigated the problem of Mn-Cr matrix effects in carbonates by using ion implantation, followed by depth-profiling, to determine RSFs over the entire compositional range of carbonates. While our measurement of the calcite RSF is similar to that reported by [6], we find a large range in the RSFs of other carbonates extending well beyond the extent of previously used values. Our results quantifying matrix effects for carbonates of different compositions have significant implications for previous carbonate Mn-Cr ages. Our new Mn-Cr ages, corrected for variable matrix effects, suggest the duration of carbonate formation, and so aqueous alteration, was shorter than previously thought, and is now consistent with an  $^{26}\text{Al}$  heat source.

**References:** [1] M. Endress, et al. (1996) *Nature* **379**, 701. [2] W. Fujiya, et al. (2013) *Earth and Planetary Science Letters* **362**, 130. [3] M. Petit, et al. (2009) *Lunar Planet Sci* **40**, 1657. [4] K. L. Zito, et al. (1998) 61st Meteoritical Society Meeting (A171). [5] P. Hoppe, et al. (2007) *Meteoritics & Planetary Science* **42**, 1309. [6] N. Sugiura, et al. (2010) *Geochemical Journal* **44**, 11.