

PETROGRAPHIC AND MINERALOGICAL CHARACTERISTICS OF CALCIUM-RICH CARBONATES IN CM CHONDRITES. S. Baliyan^{1,2} and D. Ray¹, ¹Physical Research Laboratory (Planetary Sciences Division, PRL, Ahmedabad, India, 380009, baliyanshivani08@gmail.com), ²Indian Institute of Technology, Gandhinagar, India.

Introduction: Chondrites have undergone various kinds of modifications during the shock, thermal metamorphism, or aqueous alteration, due to which original textures and mineral compositions are likely to be altered. CM-type chondrites host several secondary minerals which indicate the process of aqueous alteration on their parent body. Aqueous alteration is a significant and primordial geological process in the solar system's history. Aqueous alteration causes widespread mineralogy changes, resulting in the formation of hydrated minerals from anhydrous silicates, as well as the precipitation of salts, mainly carbonates and sulfates.

Carbonates represent a minor phase (< 5 %, [1]) although ubiquitously present in CM-type chondrites as individual mineral grains or as veins, or in association with the other mineral phases. Carbonates are formed via precipitation from the fluid phase, generally occupying the voids and gaps, during the earlier stage of aqueous alteration. Typically, the most abundant carbonate is reported as Calcite (0.9-4.2%; [2]). However, complex carbonates including dolomite, breunnerite, and aragonite are also found [3]. The mineralogical-chemical examination of the carbonates can address the chemical evolution of the fluid during aqueous alteration. Thus, carbonates act as an important tool to shed light on the role of micro-environmental conditions and the timescales of their alteration during the early stages of aqueous activity.

Samples: Carbonates from six different carbonaceous chondrites (CM2 type) have been analyzed covering a range degrees of aqueous alteration. All of these carbonaceous chondrites have abundant carbonate minerals which are majorly found as isolated grains in the matrix scattered ubiquitously.

Methodology: BSE imaging and EDS microanalysis were used to identify carbonate grains in the gold-coated samples. Grain sizes of individual carbonates for each sample were noted using BSE images usually along with the longest dimension of the grain. The JEOL SEM used in this study was run at 15 kV and equipped with a Zeiss Sigma Oxford Instruments detector that was controlled by an AZTEC system. A five-spectrometer JEOL FE-

EPMA was used to do quantitative chemical studies of carbonates. The instrument was operated at 15kV and 15 nA to analyze for Ca, Si, Al, Mg, Mn, P, Cr, and Fe, and the analysis was done using a defocused spot beam. Mineral compositions were calibrated using the following standards: calcite (Ca), diopside (Si), olivine (Mg), kyanite (Al), apatite (P), Mn metal (Mn), Fe metal (Fe), and chromite (Cr). Uncertainties (2σ) in our measurement for the most of the elements were better than 5%.

Results and discussion: The highly altered such as Nogoya and Mukundpura and even the moderately altered (Murray) samples show higher abundances of carbonates. All the grains analyzed structurally are found to be calcite and not aragonite. Petrographic evidence points to the presence of at least two distinct populations of Ca-carbonates in all the samples analyzed. The classification technique for various carbonate types is adhered to as stated by Vacher et al., 2017: i) Type 0 Ca-carbonate with no TCI rims (fig 1a); ii) type 1a & 1b (fig 1b), having TCIs interactions with carbonates; iii) type 2, polycrystalline grains having inclusions (fig 1c). These petrographic characteristics infer their correlation to at least two episodes of carbonate precipitation [4].

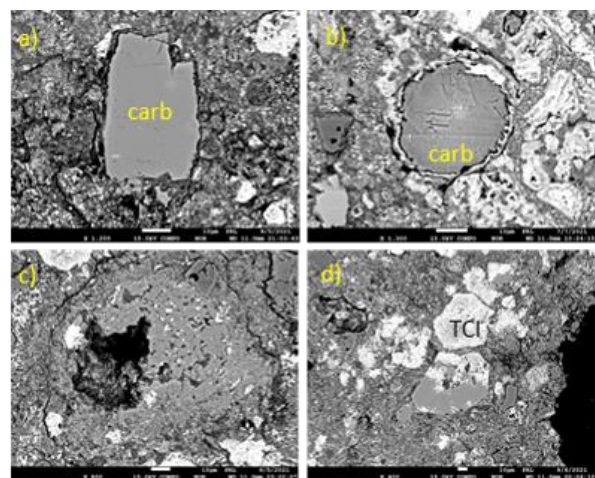


Fig 1: Backscattered electron images of a few carbonate grains a) Image showing a type 0 euhedral carbonate grain, with direct contact to the matrix from CB meteorite; b) Type 1a circular carbonate grain enclosed

by a TCI rim in Murray; c) Inclusion of sulphides in type-2 carbonate; d) A carbonate grain completely replaced by TCI's, while other has started the interaction.

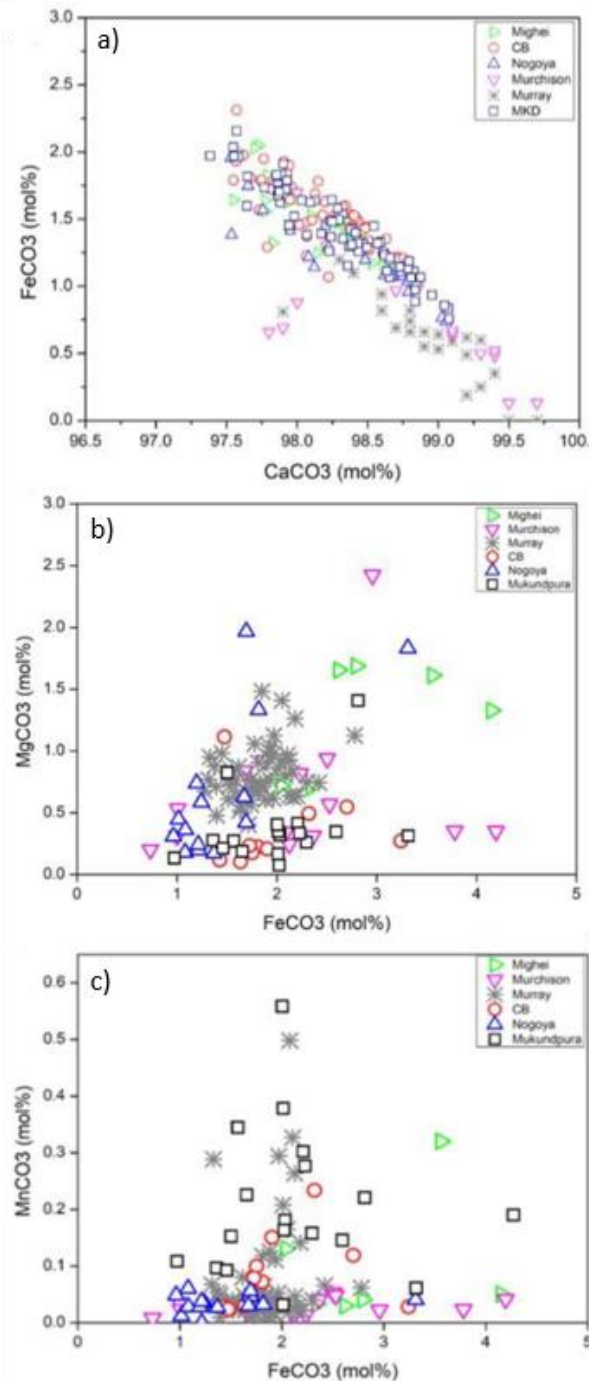


Fig 2: Bivariate plots showing relation between Fe-Ca, Mg-Fe, and Mn-Fe. Compositions are in mol%.

Interaction of TCIs with type 1 carbonates and even partial to full replacement (**Fig 1d**) by TCI suggests that these carbonates have precipitated very early during the aqueous interactions. The petrographic observations suggest that type 0 Calcites are relatively younger and precipitated relatively later than type 1 & type 2 carbonates. However, the absence of TCI interactions with type 0 could also indicate that these carbonates formed under different physicochemical conditions, which do not support the tochilinite formation processes.

During the chemical analysis, the minor element variations in carbonate grains are a reflection of the activity of the ions in the microenvironment, which can be qualitatively inferred through textures from backscattered images. The minor elements particularly FeCO_3 , MgCO_3 , and MnCO_3 are prone to compositional changes in calcite grains. In contrast to what was observed in literature, FeCO_3 does not show much compositional difference between the least altered (CM2.5, CM2.4) and highly altered (CM2.1, CM2.2) samples (**Fig 2**). MnCO_3 does not necessarily show any general trend by comparing within the petrologic types. However, MgCO_3 concentration appears in decreasing order with the increase in aqueous alteration. Differences in ionic activities (Fe^{2+} , Mg^{2+}) of these carbonates may occur due to different precipitation conditions of these grains.

To summarise, both petrography as well as the elemental mapping favors the episodic precipitation during aqueous alteration. CM chondrites carbonates shows appreciable compositional heterogeneity thus supporting for different physico-chemical condition during the formation of carbonates. Thus, carbonates chemistry is consistent with micro-environment concept which can vary in micron-level scale to even tens of mms, and the minor element chemical behavior suggests more than one episode of alteration.

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References: [1] Suttle et al. (2021) GCA, 299, 219-256 [2] Howard, K.T. et al. (2015) GCA, 149, 206-222 [3] Lee et al. (2014) GCA, 144, 126-156 [4] Vacher et al., (2017) GCA, 213, 271-290.