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Moonmilk in the carbonaceous chondrites [#1367]

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Introduction: The Lewis Cliff (LEW) 85311 carbonaceous chondrite contains objects composed of a meshwork of calcite fibres that are unlike anything previously described from a meteorite. These meshworks are very similar in appearance to 'moonmilk', a variety of finely crystalline needle-fibre calcite that forms by evaporation in terrestrial caves [1]. Here we explore the properties of meteoritic moonmilk, and ask whether it can provide new insights into the history of LEW 85311 and allied carbonaceous chondrites.

LEW 85311: This 200 g Antarctic find is classified as a CM/anomalous CM. It is comparable in petrography and mineralogy to a mildly aqueously altered CMs (**Fig. 1a, b**), but its oxygen isotopic composition plots in the CV-CK-CO field (**Fig. 1c**).

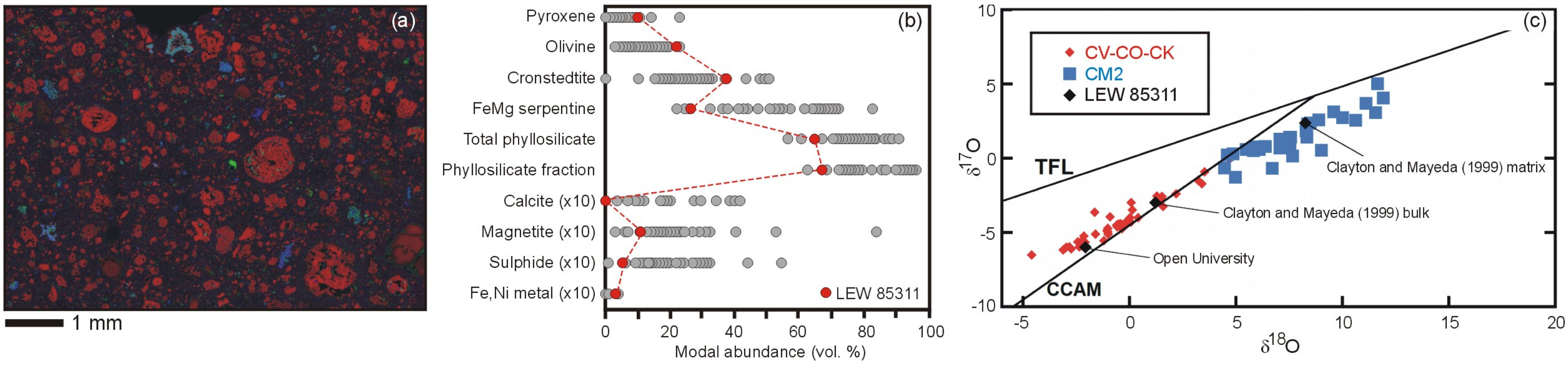

Fig. 1. (**a**) False colour X-ray map of LEW 85311 (red = Mg, green = Ca, blue = Al). (**b**) PSD-XRD modal mineralogy of LEW 85311 compared to other CMs [2,3]. (**c**) Oxygen isotopic analyses of LEW 85311 obtained for this study at the Open University compared with data from Clayton and Mayeda (1999) [4]. Other carbonaceous chondrite groups are plotted for reference.

LEW 85311 moonmilk: Calcite occurs within hundreds of micrometre size objects as a structureless meshwork of ~18 µm x 2 µm fibres. Some of these objects are type I chondrules, and the calcite occupies patches within them (**Fig. 2a**). Calcite is the main constituent of other objects and is usually accompanied by kamacite and its alteration products (tochilinite, schreibersite, P-rich sulphide) (**Fig. 2b, c**)

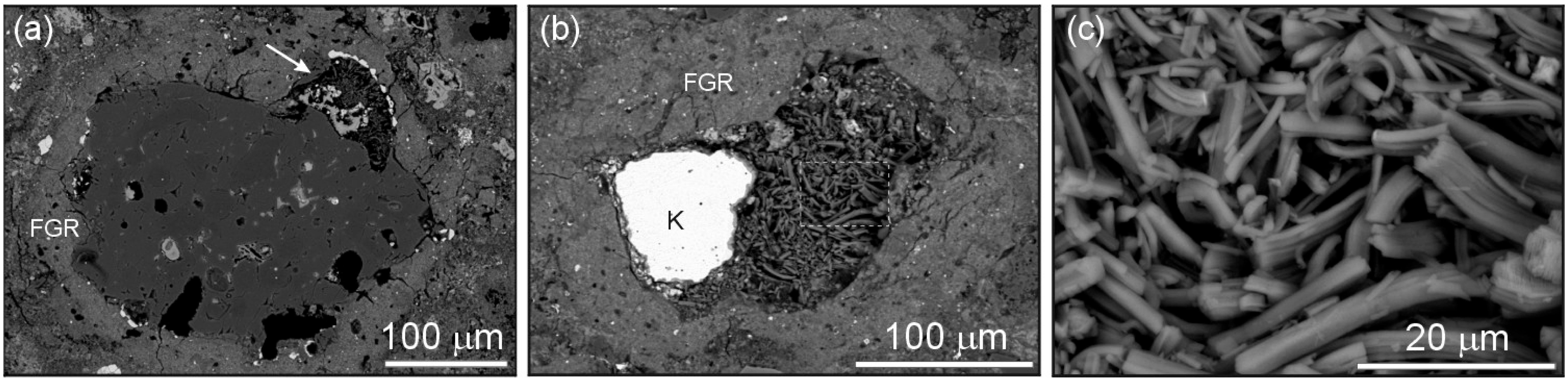

Fig. 2. (a) Backscattered electron image of a type I chondrule enclosed in a fine grained rim (FGR). The arrow indicates a patch of calcite fibres, the outer edge of which is lined by troilite (white). (**b**) Backscattered electron image of an object that is composed of kamacite (K) and calcite, and enclosed in a fine grained rim (FGR). **(c)** Backscattered electron image of calcite fibres in the boxed area of (**b**).

Origin of the calcite fibres: The high porosity of the meshwork (**Fig. 2c**) suggests that calcite formed after its host objects had acquired their fine-grained rim, and also after void space had been created by dissolution. As the calcite is usually associated with kamacite and its alteration products (**Fig. 2a, b**), the void space was likely made by dissolution of a precursor that was rich in Fe,Ni metal. Dissolution of kamacite requires reducing fluids, thus suggesting a parent body environment. The fine crystal size of the calcite and its disorganised meshwork structure indicates that it formed by rapid precipitation from supersaturated solutions, either in the parent body or in the Antarctic ice.

Parent body origin: All of the CMs contain calcite that has formed by parent body aqueous alteration [5]. CM and LEW 85311 calcite are similar in their association with tochilinite, but differ in petrographic context (most CM calcite is in the matrix) and crystal size (CM calcite occurs as 10s-100s µm size crystals suggesting slow growth rates from solutions with a low degree of supersaturation).

Antarctic origin: Carbonates can form by evaporation during Antarctic weathering, and the Lewis Cliff finds have an "above average" abundance of evaporites [6], consistent with the 'Be' classification of LEW 85311. An evaporitic origin for LEW 85311 calcite is consistent with the small size of the calcite fibres and their meshwork structure, but does not explain their association with kamacite and sulphides.

Summary: LEW 85311 has petrographic and mineralogical affinities to mildly altered CMs, but its oxygen isotopic composition is anomalous. If the moonmilk calcite formed by parent body aqueous alteration, conditions of carbonate mineralization in LEW 85311 must have been quite different to the CM parent body(ies). Work to understand the origin and significance of this strange variety of calcite is continuing.

References: [1] Spotl C. (2018) Int. J. Speleology, 47, 127–135. [2] Howard K. T. et al. (2015) GCA, 149, 206–222. [3] King A. J. et al. (2017) MAPS 52, 1197–1215. [4] Clayton R. N. and Mayeda T. K. (1999) GCA, 63, 2089–2104. [5] Lee M. R. et al. (2014) GCA, 144, 126–156. [6] Losiak A. and Velbel M. A. (2011) MAPS 46, 443–458.

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