IDENTIFICATION OF A THERMALLY METAMORPHOSED CLAST IN THE RENAZZO-LIKE (CR) CHONDRITE PECORA ESCARPMENT (PCA) 91082.

J. Davidson[1,2] and D. L. Schrader[1,2], [1]Center for Meteorite Studies, 781 East Terrace Road, Tempe, AZ 85287-6004, USA, [2]School of Earth and Space Exploration, 781 East Terrace Road, Tempe, AZ 85287-6004, USA (jdavidson@asu.edu).

Introduction: The Renazzo-like (CR) chondrites are some of the most primitive early Solar System materials (see [1] and references therein). While the CR chondrites cover the full range of aqueous alteration from ~CR2.7 to CR1, there are few members that exhibit evidence for significant thermal alteration. The exceptions being the shock-heated CRs Graves Nunataks (GRA) 06100 and Grosvenor Mountains (GRO) 03116 (e.g., [1] and references therein). Since the CR chondrites were one of the last carbonaceous chondrite groups to accrete [2,3], they may have incorporated material from a variety of sources, including other carbonaceous chondrite groups (i.e., they may contain xenoliths). Recently, a xenolithic clast of ultracarbonaceous cometary building block material was discovered in the CR2 LaPaz Icefield (LAP) 02342 [4] and other xenoliths have been identified in the CR2s Queen Alexandra Range (QUE) 99177 [5] and Northwest Africa (NWA) 801 [6].

The evidence for melt formed by impacts (i.e., impact melts) is extremely rare in carbonaceous chondrites [7]; impact melts have only recently been identified in CV and CM chondrites [8]. The characterization of impact heated material would provide a greater understanding of impact processing in carbonaceous chondrites. To date, no impact-heated CR chondrite material has been unambiguously identified. Here, we report a clast of thermally metamorphosed material in the CR2 Pecora Escarpment (PCA) 91082.

Methods: We studied a polished thin section of PCA 91082 (thin section 15), which was used in several prior studies (e.g., [9,10,11]). Full thin section backscattered electron (BSE) and X-ray element images (Si, Mg, Mn, Na, Al, Ca, P, S, Fe, Ni, and Cr) were used from the study of [10]. High-resolution BSE, secondary electron (SE), and X-ray element images (Fig. 1) were obtained of the entire clast using a FEI Nova NanoSEM 600 scanning electron microscope (SEM) at the Smithsonian Institution (SI) National Museum of Natural History, Department of Mineral Sciences. Mineral identification was performed via energy dispersive X-ray spectroscopy (EDS) on the same instrument. Quantitative element abundances (Na, Mg, Al, Si, P, K, Ca, Ti, Cr, Mn, Fe, and Ni for silicate phases; Fe, S, Si, P, Ni, Co, Cr, Al, and Cu for sulfides) were determined with a five-spectrometer wavelength dispersive JEOL 8900 Superprobe electron probe microanalyzer (EPMA) at SI (operating conditions: 15 kV and 20 nA, ~1 µm focused beam).

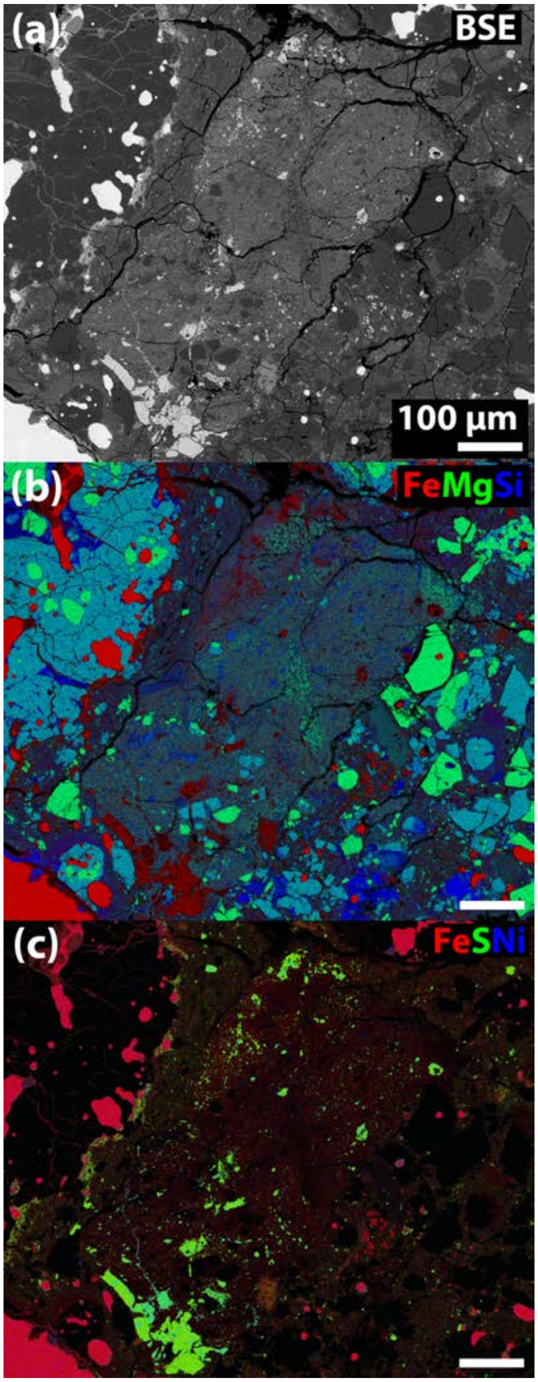

Fig. 1. *Images of the full clast shown as: (a) backscattered electrons (BSE); (b) combined Fe (red), Mg (green), and Si (blue); and (c) combined Fe (red), S (green), and Ni (blue) showing the distribution of sulfides (green). All panels are shown at the same scale (scale bars are 100 µm).*

Results: The clast is ~290 µm by ~640 µm in size and is approximately rectangular in shape. The clast appears brighter in BSE than surrounding matrix due to its slightly higher iron content (Fig. 1). The clast consists predominantly of silicate minerals with fewer opaque minerals. The silicate minerals (olivine and pyroxene) range from a few µm to ~45 µm in diameter (Fig. 2a,b). Olivine grains are unequilibrated and have highly variable Fe-contents ($Fa_{1–42}$), while larger pyroxene grains exhibit a more limited range of Fe contents ($Fs_{1–2}$). EDS indicates that small Ca-rich pyroxene grains are present as overgrowths on the rims of larger Ca-poor grains (Fig. 2b); however, these grains are too small for EPMA analysis. While silicates are unequilibrated, many of the larger silicate grains show evidence for Fe-Mg diffusion at their rims (i.e., Mg-rich cores, Fe-rich rims; Fig. 2a,b). The opaque minerals within the clast are exclusively sulfides (Fig. 2c,d); no Fe,Ni metal or magnetite was observed (Fig. 1c). Sulfides are present as discrete mineral grains (up to ~65 µm in length) and as veins that cross-cut the clast (the longest vein is ~200 µm in total length). One of the larger pyroxene grains appears to have been fractured into three grains, between which sulfide grains have infilled (Fig. 2b).

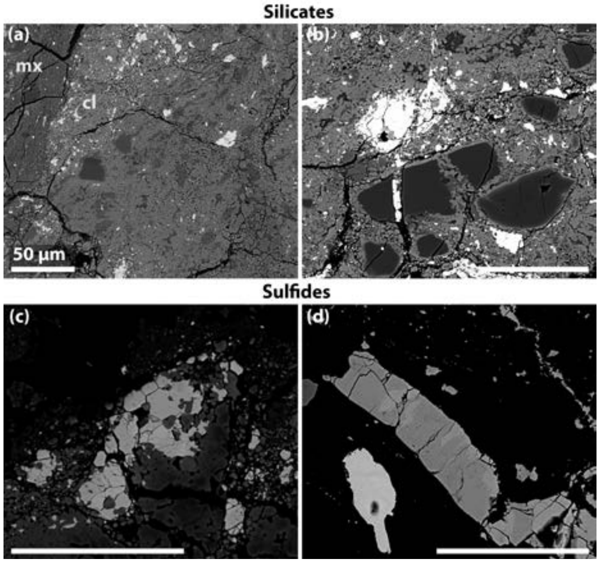

Fig. 2. BSE images showing select silicates and sulfides within the clast in PCA 91082,15. Where mx = matrix, cl = clast. All scale bars are 50 µm.

Discussion: The clast may represent heated material that originated from either the CR parent body or another chondrite parent body, discussed as follows:

Is the clast an impact melt? Multiple observations indicate that the clast has been significantly heated in comparison to the host chondrite: (1) The smallest grains in the clast are much coarser grained than the matrix within the rest of the thin section (a few µm in diameter versus sub-µm) (Fig. 2a). (2) Large olivine grains possess Fe-rich diffusive rims symptomatic of heating (Fig. 2b). (3) Sulfide melt veins indicate that the clast has been heated up to at least 950°C to permit sulfide migration (e.g., [12]) (Fig. 2d). However, the clast does not possess the same texture as impact melt clasts seen in CV and CM chondrites [8], which are microporphyritic. Instead the clast in PCA 91082 appears to be texturally more similar to primitive achondrites. This difference does not preclude an origin via impacts but instead may indicate that the clast formed via impact heating but was not completely melted and cooled more slowly than other impact melts identified to date, which experienced higher degrees of melting and quench cooling.

Is the clast consistent with a CR chondrite origin or is it a xenolith? The Fe/Mn ratios of olivine within the clast are consistent with those of olivine from CR chondrites [11]. The Ni and Co compositions of sulfides are also consistent with those of PCA 91082 and other CR chondrites [11,13]. Therefore, the clast appears to be thermally metamorphosed CR chondrite material and not a xenolith from another chondrite parent body (unless this other body was remarkably similar to the CR chondrite parent body).

Conclusion: The clast appears to represent thermally metamorphosed CR chondrite material that may have formed by slower cooling than seen in impact melts from carbonaceous chondrites. This clast adds significantly to the small but increasing number of diverse clasts present within CR chondrites.

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