A potential impact melt clast in the Renazzo-like (CR) chondrite Pecora Escarpment (PCA) 91082?

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Introduction

The Renazzo-like (CR) chondrites are considered to be some of the most primitive early Solar System materials (see Davidson et al., 2019 and references therein). While they exhibit the full range of aqueous alteration from ~CR2.7 to CR1, there is minimal evidence for significant thermal alteration (the exceptions being shock-heated members). Since the CR chondrites were one of the last carbonaceous chondrite groups to accrete (Sugiura and Fujiya, 2014; Schrader et al., 2017), they may have incorporated material from a variety of sources (including other carbonaceous chondrite groups). Recently, a clast of ultracarbonaceous cometary building block material was discovered in the CR2 LAP 02342 (Nittler et al., 2019) and other xenoliths have been identified in the CR2s QUE 99177 (Abreu, 2013) and NWA 801 (Hiyagon et al., 2016). Impact melts are extremely rare in carbonaceous chondrites (Scott et al., 1992) and have only recently been identified in CV and CM chondrites (Lunning et al., 2016). No impact melts have been unambiguously identified in CR chondrites. Here, we report a potential impact melt clast in the CR2 Pecora Escarpment (PCA) 91082.

Methods

We studied a polished thin section of PCA 91082 (thin section 15), which was characterized to various extents in previous studies (e.g., Connolly et al., 2001; Schrader et al., 2011, 2015). Full section backscattered electron (BSE) and X-ray element images (Si, Mg, Mn, Na, Al, Ca, P, S, Fe, Ni, and Cr) were taken from the study of Schrader et al. (2011). High-resolution BSE, secondary electron (SE), and X-ray element images (Fig. 1) were obtained, and mineral identification was performed via energy dispersive X-ray spectroscopy (EDS), of the entire clast using an FEI Nova NanoSEM 600 scanning electron microscope (SEM) at the Smithsonian Institution (SI) National Museum of Natural History, Department of Mineral Sciences. Major and minor 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 quantitatively 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).

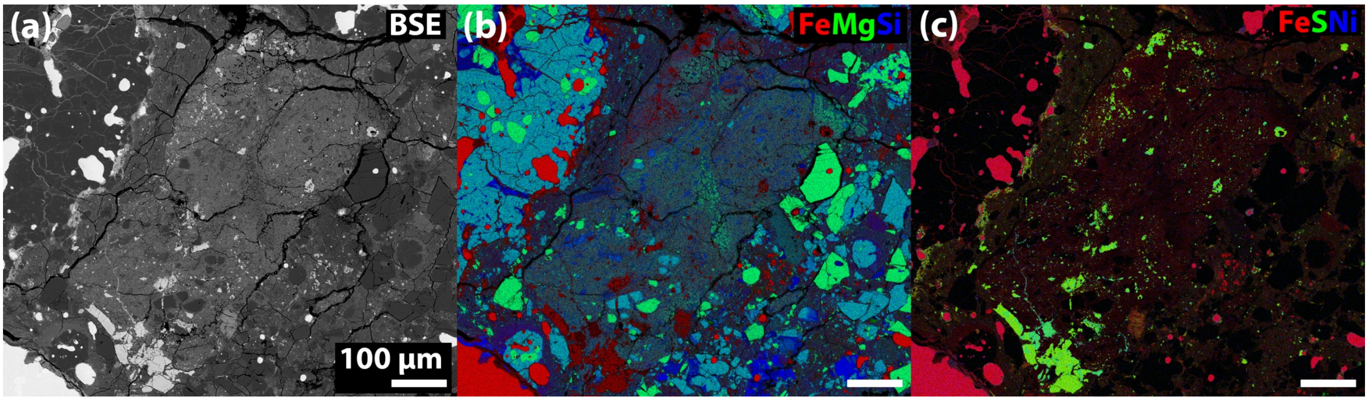

Figure 1. Images of the clast showing (a) backscattered electrons (BSE), (b) combined Fe (red), Mg (green), and Si (blue), and (c) combined Fe (red), S (green), and Ni (blue) showing the distribution of sulfides (green). All panels are shown at the same scale (scale bars are 100 µm).

Results

The clast is ~290 µm by ~640 µm in size, approximately rectangular in shape, and appears brighter in BSE than surrounding matrix due to a slightly higher iron content (Fig. 1). The clast consists predominantly of silicate minerals (olivine and pyroxene), with grains ranging from a few µm to ~45 µm in diameter (Fig. 2a,b). Olivine grains have highly variable Fe-contents (Fa_{1-42}), while larger pyroxene grains exhibit a limited range of Fe contents (Fs_{1-2}). However, EDS indicates the presence of small Ca-rich pyroxene overgrowths at the rims of larger Ca-poor grains (Fig. 2b) that are too small for EPMA analysis. 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; 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) (Fig. 2c,d). One of the larger pyroxene grains appears to have been fractured into three grains, between which sulfide grains have infilled (Fig. 2b).

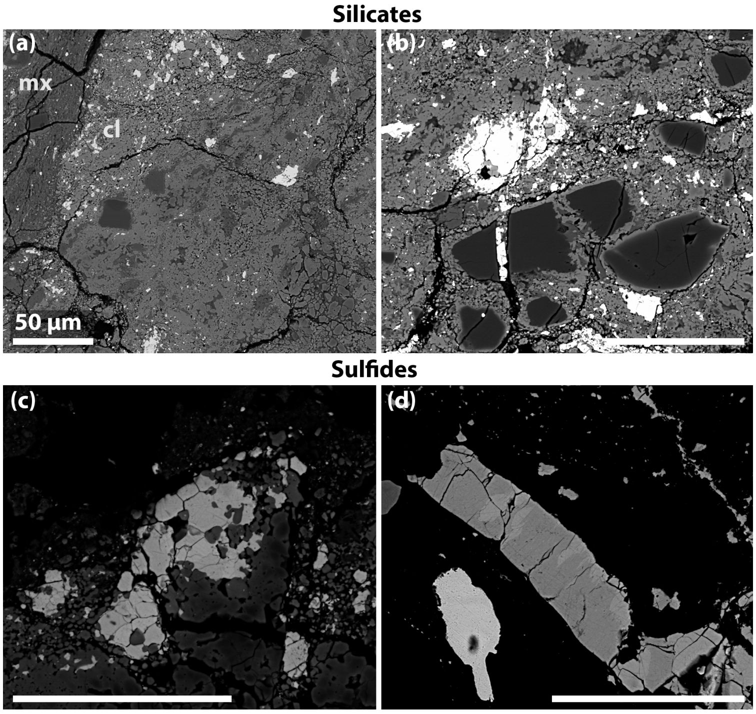

Figure 2. BSE images showing select silicates and sulfides within the clast.

Discussion

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). (2) Large olivine grains possess Fe-rich diffusive rims symptomatic of heating. (3) Sulfide melt veins indicate that the clast has been heated up to at least 950°C to permit sulfide migration (e.g., McCoy et al., 2006).

However, the clast does not possess the same texture as impact melt clasts seen in CV and CM chondrites (Lunning et al., 2016), which are microporphyritic, and appears to be texturally more similar to primitive achondrites. It is possible that the clast formed via impact heating but cooled more slowly than impact melts, which quench.

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 (Schrader et al., 2015). The Ni and Co compositions of sulfides are also consistent with those of PCA 91082 and other CR chondrites (Schrader et al., 2015, 2016). Therefore, the clast appears to be thermally metamorphosed CR chondrite material and not a xenolith. ***This clast adds significantly to the small but increasing number of diverse clasts present within CR chondrites.***

References

Abreu, N.M., A unique omphacite, amphibole, and graphite-bearing clast in Queen Alexandra Range (QUE) 99177: A metamorphosed xenolith in a pristine CR3 chondrite, Geochimica et Cosmochimica Acta, 105, 56–72, 2013.

Connolly Jr., H.C. et al., On the formation of Fe-Ni metal in Renazzo-like carbonaceous chondrites, Geochimica et Cosmochimica Acta, 65, 4567–4588, 2001.

Davidson, J. et al., Re-examining thermal metamorphism of the Renazzo-like (CR) carbonaceous chondrites: Insights from pristine Miller Range 090657 and shock-heated Graves Nunataks 06100, Geochimica et Cosmochimica Acta, 267, 240–256, 2019.

Hiyagon, H. et al., Origin of the eclogitic clasts with graphite-bearing and graphite-free lithologies in the Northwest Africa 801 (CR2) chondrite: Possible origin from a Moon-sized planetary body inferred from chemistry, oxygen isotopes and REE abundances, Geochimica et Cosmochimica Acta, 186, 32–48, 2016.

Lunning, N.G. et al., CV and CM chondrite impact melts, Geochimica et Cosmochimica Acta, 189, 338–358, 2016.

McCoy, T.J. et al., Asteroid differentiation. In Meteorites and the Early Solar System II (eds. D. S. Lauretta and H. Y. McSween). University of Arizona Press, Tucson, pp. 733–745, 2006.

Nittler, L.R. et al., A cometary building block in a primitive asteroidal meteorite, Nature Astronomy, 3, 659–666, 2019.

Schrader, D.L. et al., The formation and alteration of the Renazzo-like carbonaceous chondrites I: Implications of bulk-oxygen isotopic composition, Geochimica et Cosmochimica Acta, 75, 308–325, 2011.

Schrader, D.L. et al., The formation and alteration of the Renazzo-like carbonaceous chondrites III: Towards understanding the genesis of ferromagnesian chondrules, Meteoritics and Planetary Science, 50, 15–50, 2015.

Schrader, D.L. et al., Widespread evidence for high-temperature formation of pentlandite in chondrites, Geochimica et Cosmochimica Acta, 189, 359–376, 2016.

Schrader, D.L. et al., Distribution of ^{26}Al in the CR chondrite chondrule-forming region of the protoplanetary disk. Geochimica et Cosmochimica Acta, 201, 275–302, 2017.

Scott, E.R.D. et al., Shock metamorphism of carbonaceous chondrites, Geochimica et Cosmochimica Acta, 56, 4281–4293, 1992.

Suguira N. and Fujiya W., Correlated accretion ages and $\varepsilon^{54}Cr$ of meteorite parent bodies and the evolution of the solar nebula, Meteoritics and Planetary Science, 49, 772–787, 2014.