THE IMPORTANCE OF CLASTIC MATERIAL IN CR CHONDRITES.

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Introduction: The Renazzo-like carbonaceous (CR) chondrites represent some of the most primitive early Solar System materials ([1] and references therein). While they cover the full range of aqueous alteration from ~CR2.7 to CR1, only Graves Nunataks (GRA) 06100 and Grosvenor Mountains (GRO) 03116 exhibit evidence of significant shock-induced thermal alteration (e.g., [1]). Some CR chondrites contain so-called dark inclusions, which are optically dark regions of CR chondrite material that have experienced intense aqueous alteration [2]. Since the CR chondrites were one of the last carbonaceous chondrite groups to accrete [3,4], in addition to containing brecciated CR chondrite material, they may have incorporated material from other sources (i.e., they may contain xenoliths). Xenolithic material may have been incorporated into the CR parent body during or after accretion. Indeed, in the last decade a variety of clast types distinct from dark inclusions have been recognized in CR chondrites, providing valuable information about early Solar System processes [5–8]. These include: (**1**) A xenolithic clast of ultracarbonaceous cometary building block material in the CR2 LaPaz Icefield (LAP) 02342 that supports the idea of inward radial transport of material from the outer protoplanetary disk to the CR chondrite forming region [5]. (**2**) An omphacite, amphibole, and graphite-bearing clast in the CR2 Queen Alexandra Range (QUE) 99177 that may be a metamorphosed xenolith from a large ~760 km wide asteroid [6]. (**3**) Three eclogitic xenolithic clasts were identified in the CR2 Northwest Africa (NWA) 801 and may have formed in a large moon-sized body [7,8]. (**4**) We recently identified a clast in the CR2 Pecora Escarpment (PCA) 91082 that represents heated CR2 chondrite material that was not aqueously altered [9] and likely formed by slower cooling than seen in carbonaceous chondrite impact melts [10,11]. (**5**) Here we report the identification of a clast in the CR2 Miller Range (MIL) 11231, which underwent extensive aqueous alteration followed by heating and furthers our understanding of the alteration history of the CR chondrite parent body.

Results: The clast in MIL 11231 is roughly triangular in shape and is ~870 by ~830 µm in diameter. It is generally enriched in S and has slightly higher Mg- and lower Fe-content than the surrounding matrix. The clast is dominated by Fe,Mg-phyllosilicates, magnetite spherules and framboids, sulfide laths, and carbonates. The clast also contains unusual sulfide morphologies that consist predominantly of pyrrhotite cores with pentlandite rims. Compositionally, the sulfides show evidence for heating; the Fe/S (at.%) of pyrrhotite is ~1, which is indicative of heating after aqueous alteration in heavily aqueously altered chondrites [12].

Discussion: *Origin of the MIL 11231 clast.* The petrographic nature of the MIL 11231 clast is most similar to CI, CM1, CY, and CR1 chondrites [12]. However, the sulfides in the clast are compositionally distinct from those in CI, CM1, and CY chondrites but are consistent with sulfides in the mildly heated, heavily aqueously altered CR1 GRO 95577 [12]. This suggests that the clast likely represents aqueously altered, heated CR1 chondrite material.

Implications for the post-accretionary history of the CR parent body. The CR chondrite parent body accreted too late for ^{26}Al to be a significant heat source [3,4]; the only evidence for substantial heating is attributable to impacts. For example, foliation in the CR2.7 MIL 090657 likely resulted from multiple low-energy shock events [1], similar to what has been seen in CM chondrites [13]. Furthermore, the carbonates in CR1 GRO 95577 are ~8 Myr younger than those in CR2 chondrites, potentially due to later formation as a result of localized heating of water induced by impact activity [14]. The clasts in PCA 91082 (heated, not aqueously altered) and MIL 11231 (aqueously altered, subsequently heated) are products of impact-heating of CR chondrite material with different initial degrees of aqueous alteration. Thus, clasts in CR chondrites provide invaluable insights into the physical and chemical processes occurring in both the protoplanetary disk (e.g., [5]) and in the CR chondrite parent body, including incorporation of xenolithic material from other bodies (e.g., [6–8]) and impact processing of pre-existing CR material [9, this work].

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