

Removal and replacement of primary metal in ferroan lodranite MAC 88177.

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Introduction: Collectively, acapulcoites and lodranites form a clan of primitive achondrites generally thought to have originated from the same parent body on the basis of similarities in petrology, mineral compositions, bulk compositions, cosmic ray exposure ages and oxygen isotope compositions [1-6], although considerable variation in some of these parameters has shown that the parent body was not entirely uniform [7]. The presence of relict chondrules in several acapulcoites indicates that all were likely derived from chondrite-like precursor materials. The transition from acapulcoite to lodranite is gradual and corresponds to increasing metamorphic grade. Lodranites are generally coarser grained, but petrographic distinction between the two groups can also be made by modal abundances of troilite and plagioclase. Depletion of both these phases and incompatible lithophile trace elements in lodranites is consistent with their restitic origin formed by >10% extraction of basaltic melt [8,9]. Magnesian lodranites (e.g. Gibson, GRA 95209, Y-75274, Y-8002), some of which might also be considered transitional acapulcoites [9], have mineral and chemical compositions consistent with derivation by thermal metamorphism and partial melt extraction from acapulcoites, as would seem logical if samples represented different grades of metamorphism along a linear evolution trend. Ferromagnesian silicates in these lodranites tend to be displaced toward lower fe# (opx fe# 4-6) than the distribution observed in acapulcoites (opx fe# 6-11) (Figure 1). A subset of lodranites, termed “ferroan lodranites” [7] (e.g. FRO 90011, LEW 88280, Lodran, MAC 88177, Y-74357, Y-791491/Y-791493), have ferromagnesian silicate minerals that are too Fe-rich (fe#>10) to have formed as simple restites from any known acapulcoite. Like silicates, metal-sulfide systematics of the ferroan lodranites are also inconsistent with a simple restitic origin. Logically, restitic lodranites should have been depleted in FeS during extraction of partial melts, since melting of the metal-sulfide system initiates at lower temperatures than melting of sili-

cates. Yet, puzzlingly, ferroan lodranites contain significant quantities (1.9-5.3 modal%) of troilite [2,8,10], indicating either (1) metal-sulfide partial melts were retained during basaltic melt extraction or (2) later infusion of metal-sulfide melts has occurred [7]. In this study, we use trace siderophile elements in metals to assess the relative importance of each in creating the observed troilite enrichment.

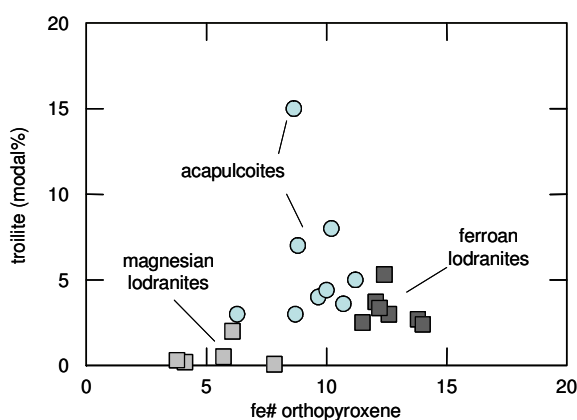


Figure 1. Ferroan lodranites have distinctly higher average fe# of orthopyroxene and modal abundance of troilite. Data compiled from numerous sources.

Methods: We compared the trace siderophile element composition of metals in ferroan lodranite MAC 88177 with seven other acapulcoites and lodranites from the U.S. Antarctic Meteorite Collection spanning a range of metamorphic grades. Antarctic samples are preferred since metals and sulfides are readily altered by terrestrial weathering. Analyses were performed *in situ* on polished thin sections by LA-ICP-MS at the ICP-MS facility of the National High Magnetic Field Laboratory/Florida State University using the methodology of [11] and obtaining similar analytical precision. With proper instrumentation and adequate care, LA-ICP-MS can be a nearly non-destructive technique, with a typical working range of 20-150 μm spot sizes. Due to the scarcity and high scientific value of these specimens, care was taken to

produce only minimal damage at specific points of interest. Metal, sulfide, and silicate phases in these samples were characterized by EPMA at NASA Johnson Space Center prior to LA-ICP-MS analysis.

Results: Fe,Ni-metal comprises <1 modal% of MAC 88177 and contains a range of Ni contents (6-32 wt%). The average composition of metal is more Ni-rich (14.5 wt%) than in any other sample analyzed, and the modal sulfide/metal ratio (4:1) is also higher. Metal is strongly depleted in highly compatible siderophiles (Re,Os,Ir,Pt) relative to other samples, yet contains comparable concentrations of less compatible siderophile elements (As,Pd,Au).

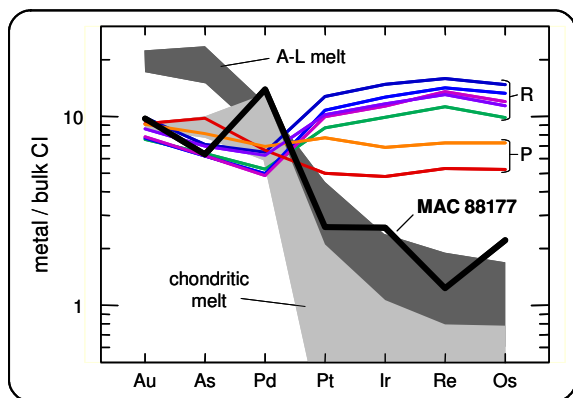


Figure 2. Average metallic siderophile element abundances in MAC 88177 metals compared to metals of primitive (P) and relict (R) clan members normalized to bulk CI chondrite in order of increasing solid metal/liquid metal partitioning at a melt composition of 25 mol% S. Also shown are fields for calculated compositions of low-degree partial melts derived from metals of other clan members (A-L) and chondritic metals.

Discussion: Metal composition in MAC 88177 strongly resembles low degree metallic partial melts (Figure 2). Considering also the low metal and relatively high troilite content, it seems apparent that all or nearly all of the original metal in this sample has been lost and replaced by metallic melts from elsewhere. Presumably this occurred sometime after MAC 88177 underwent extensive partial melting (>20% [8]), when temperatures fell closer to the Fe-Ni-S cotectic (~980°C) low-degree metallic melts from elsewhere in the parent body infused in. It is unclear whether the last stages of removal of refractory metal occurred simultane-

ous with the extraction of silicate partial melts or resulted from through-fluxing by fertile S-rich melts, which could potentially have had a dissolution effect. Samples with comparably high 2-pyroxene temperatures (~1200°C [method of 12]) but more typical fe# of ferromagnesian silicates, such as ALHA 81187 and GRA 95209, contain matrix metals of refractory composition and, thus, appear to have retained much of their original metal content. Future research on metal compositions in other ferroan lodranites yielding lower 2-pyroxene temperatures, such as Y-74357 and Y-791491/Y-791493, will hopefully provide a more detailed history of the metallic system in ferroan lodranites and perhaps yield clues to their genesis.

References: [1] McCoy *et al.* (1997a) *GCA* 61(3):623-637. [2] Nagahara & Ozawa (1986) *NIPR Spec. Issue* 41:181-205. [3] Mayeda *et al.* (1987) *NIPR Spec Issue* 46:144-150. [4] Clayton & Mayeda (1996) *GCA* 60:1999-2017. [5] McCoy *et al.* (1996) *GCA* 60:2681-2708. [6] Mittlefehldt *et al.* (1996) *GCA* 60(5):867-882. [7] Mittlefehldt (2003) *M&PS* 38(Supp.1):A95 [8] McCoy *et al.* (1997b) *GCA* 61(3):639-650. [9] Patzer *et al.* (2004) *M&PS* 39(1):61-85. [10] Miyamoto & Takeda (1994) *JGR* 99(E3):5669-5677. [11] Campbell *et al.* (2002) *GCA* 66:647-660. [12] Brey & Köhler (1990) *JOP* 31(6):1353-1378.