Chlorine and Cl isotope composition of the martian surface: A perspective from martian regolith breccia sample NWA 7034.

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Introduction: A prominent feature of the martian surface exhibited by the Mars Odyssey Gamma Ray Spectrometer (MOGRS) data is the high and variable abundance of Cl over the mid-latitudes. As shown by Boynton et al. [1], significant Cl enrichment occurs west of the Tharsis Montes and northeast of Apollinaris Patera where the Cl mass fraction exceeds 0.8%. Other areas on the surface have lower abundances (~ 0.2%). The global distribution of Cl correlates positively with H and negatively with Si and thermal inertia [1]. Boynton et al. [1] suggested that some of these high Cl concentrations may result from the deposition of Cl-rich materials such as ignimbrite deposits, which may have been subsequently eroded or associated with the release of Cl through volcanic exhalation. Other possible mechanisms for influencing near-surface Cl distribution are discussed in detail by Keller et al. [2]. Another approach to decipher the nature and origin of the Cl variation on the martian surface is by examining unique martian regolith breccia meteorite NWA 7034. NWA 7034 is considered to be a martian polymict regolith breccia with near surface origins, and contains a variety of magmatic, impact, and lithic clasts. Its bulk composition overlaps with the average martian crust as measured by the MOGRS [1]. Phosphates make up approximately 2 wt.% of the groundmass of this sample with individual clasts having higher modal abundances. The Cl concentration of the bulk groundmass is approximately 0.22 wt.% and the P_2O_5 concentration is 0.76 wt.% [3]. The intent of this abstract is to explore the mineralogical reservoirs of Cl in the martian surface environment by examining the Cl concentration and isotopic composition in apatite from NWA 7034. Companion abstracts addressing the origin of martian mantle Cl isotopic composition within a comparative planetary context and the relationship of the Cl isotope composition of NWA 7034 to other martian meteorites were submitted by Sharp et al. [4] and Shearer et al. [5], respectively.

Analytical approach: Apatite textures and compositions in NWA 7034 were determined using electron microprobe analysis (EPMA). With respect to microbeam isotopic analyses, the intent was to place all analyses within the context of lithologies observed within this meteorite. The δ^{37}Cl values of leachate and residue were measured from bulk samples using conventional magnetic sector mass spectrometry at the University of New Mexico [6]. *In situ* ion microprobe analyses were made on the large radius UCLA Cameca 1270 ion microprobe using a Cs^+ primary beam. Ion beams for mass 35 and 37 were measured simultaneously on Faraday cups with equivalent count rates of 2 to 5×10^7cps for $^{35}Cl^-$. A synthetic Cl-apatite from the University of Heidelberg, with a Cl concentration of 5.5 wt.%, was used as a standard and had a reproducibility of 0.1‰ (n=38). Precision was poorer for low Cl concentration apatites. All δ^{37}Cl values are reported relative to Standard Mean Ocean Chloride (SMOC).

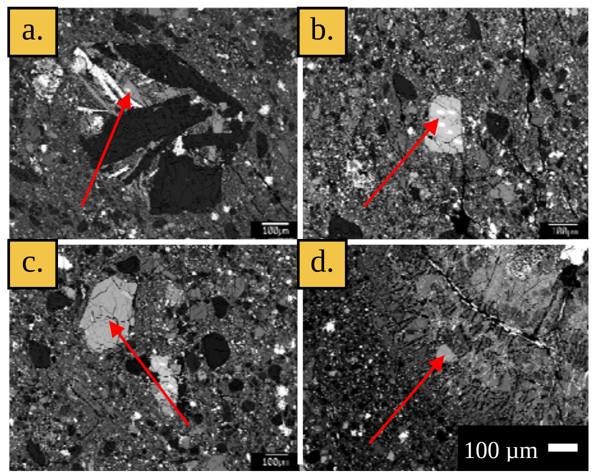

Figure 1. BSE images of apatite in NWA 7034. a. Apatite associated with phosphate-ilmenite clast. b. Apatite associated with matrix with low δ^{37}Cl and high Cl (wt.%). c. Apatite associated with matrix with high δ^{37}Cl and low Cl (wt.%). d. Apatite associated with impact melt clast.

Results: Apatites analyzed in this study occurred in many different lithologies in NWA 7034 (Figure 1). These lithologies included matrix, phosphate-ilmenite clasts, impact melt clasts, and lithic clasts. Although the apatites analyzed exhibit a wide range in grain size, they do not exhibit strikingly different morphologies between lithologies. Apatites associated with the basaltic clasts were not analyzed for this study due to their small grain size. Individual apatite analyses range from +0.1‰ to +9.0‰ δ^{37}Cl (with an average of +1.2‰) for NWA 7034 (Figure 2). There appears to be a slight negative correlation between Cl concentration and δ^{37}Cl values. The matrix exhibits the greatest variation in δ^{37}Cl values, whereas the clasts exhibit a much more limited variation. Bulk rock analysis for NWA 7034 is 1.0‰ (Figure 3) and overlaps with the average value of the ion microprobe results.

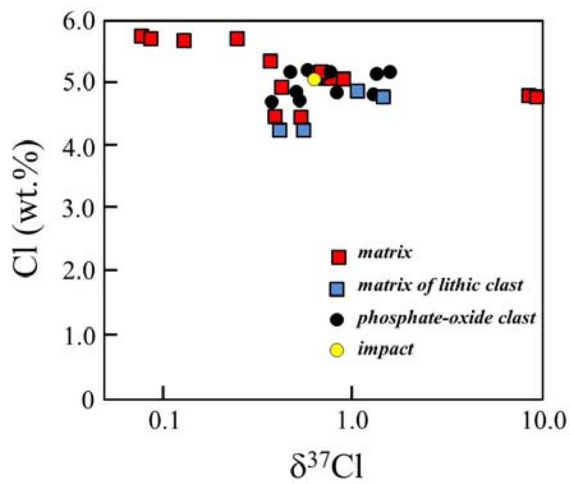

Figure 2. δ^{37}Cl versus Cl (wt.%) for apatite in various lithologies in NWA 7034.

Figure 3 compares the δ^{37}Cl values between NWA 7034 and all other martian basalts analyzed in this study [4,5]. There are several systematic variations among the different martian lithologies (Figure 3): (1) olivine-phyric shergottites appear to be enriched in light Cl with δ^{37}Cl between -1.0‰ and -3.8‰, (2) rocks with a higher crustal affinity (nahklites, chassignites, orthopyroxenites, and NWA 7034) generally appear to be more enriched in heavy Cl, with δ^{37}Cl between +0.1‰ to +9.0‰, (3) basaltic shergottites (Los Angeles, Shergotty, Zagami, NWA 2975) are variable (δ^{37}Cl = -0.1‰ to -3.5‰) and generally lie between these "mantle" and "crustal" signatures.

Discussion:

In many geochemical parameters, the bulk composition of NWA 7034 mimics the bulk composition of the martian crust as portrayed by the MOGRS data. However, with respect to Cl, it is at the lower end of the Cl concentration range. At this lower end, the crystal chemical reservoir for Cl in the martian crust is dominated by apatite. The data from NWA 7034 and other martian meteorites (Figure 3) indicate that the martian crust is enriched in isotopically heavy Cl relative to the martian mantle and that this enrichment is highly variable (δ^{37}Cl = 0 to +9). The enrichments observed in the magmatic clast in NWA 7034 indicate that their parental magmas must have assimilated martian crust during their petrogenesis or that their source must be enriched in heavy Cl. Further, the ancient ages for NWA 7034 and ALH 84001 [6,7] indicate that the heavy Cl-enrichment process must reflect a fundamental, long duration process that shaped the martian crust.

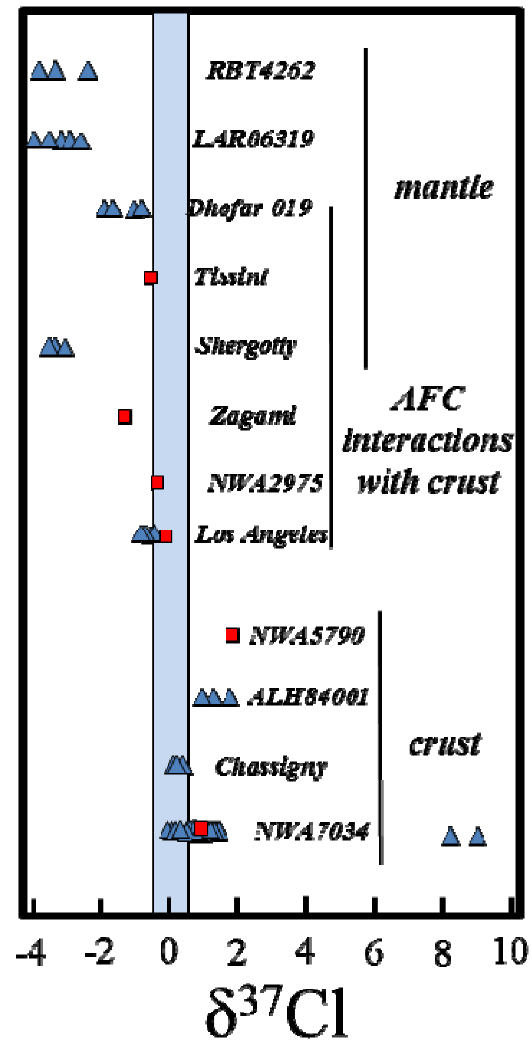

Figure 3. Comparison between NWA 7034 and other martian meteorites. δ^{37}Cl for bulk rock (red squares) and apatite (blue triangles) for a variety of martian rocks. Field for Earth is shown in blue [3]. Suggested fields for the martian mantle, martian crust, and interactions between mantle produced basalts and crust are shown

References: [1] Boynton et al. (2007) JGR 112, E12S99, doi:10.1029/ 2007JE002887. [2] Keller et al. (2007) JGR 111, E03S07, doi:10.1029/2006JE002679. [3] Agee et al. (2012) Science 339, doi:10.1126 /science.1228858. [4] Sharp et al. (2014) 45th LPSC, abs., this meeting [5] Shearer et al. (2014) 45th LPSC abs., this meeting. [6] Sharp et al., (2010) Science, doi: 10.1126/ science.1192606. [6] Humayun et al. (2013) 76th Annual Meteoritical Society Meeting. Abstract #5198. [7] Borg et al. (1999) Science 286, 90-94.