**TIN ABUNDANCES REQUIRE THAT CHASSIGNITES ORIGINATED FROM MULTIPLE MAGMATIC BODIES DISTINCT FROM NAKHLITES.**

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Introduction: Meteorites from Mars lack field context but chemical and chronologic studies have revealed remarkable links between nakhlites and chassignites. A widely held consensus is that nakhlites and chassignites originated from a large, single differentiated flow or shallow intrusive [1-5]. An Ar-Ar study assumed multiple flows based on resolvable age differences between meteorites [6], but did not address the possibility of differential cooling in a large, shallowly emplaced intrusion [1]. REE abundances in pyroxenes from nakhlites and Chassigny led [7] to argue for derivation of these rocks from distinct magmas. Volatile abundances (F, Cl, OH) in chlorapatites indicated that the entire suite of nakhlites and chassignites experienced hydrothermal interaction with a single fluid supporting a single body origin [4]. The discovery of a new chassignite, NWA 8694, extended the Mg# range from 80-54, providing a closer link to nakhlites but revealed the petrological difficulty of fractionating a single body of liquid to yield a series of olivine cumulates with such a large Mg# range [8]. When mafic magmas are emplaced into the crust, crustal assimilation can impart distinct elemental signatures if the country rock has experienced sedimentary or hydrothermal processing [9]. In this work, we used Sn abundances of nakhlites and chassignites to show that these rocks were crystallized from distinct magma batches, providing vital contextual clues to their origin.

Analytical Methodology: The bulk compositions of two chassignites, two nakhlites, eleven shergottites and a martian breccia (NWA 7533) were analyzed using an Elemental Scientific Lasers UP193FX laser ablation system coupled to a high-resolution Thermo Element XR™ ICP-MS at the Plasma Analytical Facility, FSU [10]. Mineral compositions (olivine and pyroxene) were obtained for Chassigny and the pyroxenes from five nakhlites (Nakhla, NWA 817, NWA 6148, MIL 03346, Y 000593 [11]) by the same technique. Bulk analyses were obtained with laser raster mode using a 75 µm spot, scanned at 15 µm s^{-1}, 50 Hz repetition rate, over about 4 mm^2 surface area. Mineral analyses were obtained using the laser spot mode at 50 Hz repetition rate with varying spot sizes (25 µm, 50 µm and 100 µm). The abundances of 69 elements were analyzed at each spot with Sn measured at m/e 120. Three USGS glasses (BCR-2g, BHVO-2g and BIR-1g)

and two synthetic glass standards (GSD-1g and NIST SRM 610) were used as external standards, with As, Mo, Sn, Tl and W calibrated against the synthetic glasses. The analytical precision is better than 5% for major elements, REE and most of the lithophile elements and is better than 10% for As, Sn, Tl and Pb when their abundances are > 0.1 ng/g in samples [12].

Results: From terrestrial igneous rocks, tin (Sn) is known to be an incompatible element displaying a constant Sn/Sm ratio [13]. Fig. 1 shows this relationship for a global suite of mid-oceanic ridge basalt glasses (MORBs) analyzed at FSU (Sn/Sm: 0.25±0.02 [12]) compared with martian meteorites (Sn/Sm: 0.19±0.09, this study, [10]).
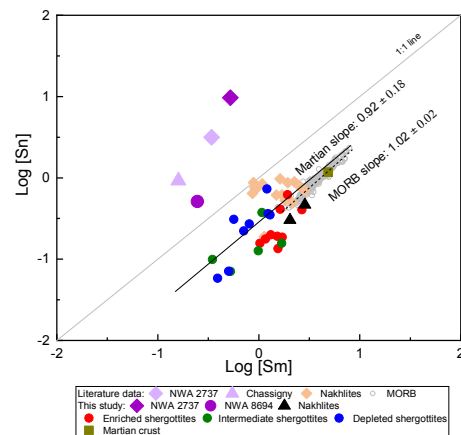
Fig. 1: Correlation between Sn and Sm for martian meteorites (this study) and terrestrial MORB glasses [12]. Nakhlite-chassignite solution analyses from [5].

Martian meteorites define a broader range of Sn/Sm ratios than MORB glasses, likely due to heterogeneous distribution of mineral hosts like phosphates in these coarse-grained meteorites [14]. Solution ICP-MS analyses of bulk nakhlites [5] exhibit a narrower range of tin contents than Sm, but plot on the trend defined by LA-ICP-MS data. Bulk analyses of two chassignites by LA-ICP-MS (NWA 2737, NWA 8694) and of two chassignites by solution ICP-MS (Chassigny, NWA 2737 [5]) plot at distinctly higher and variable Sn contents than the nakhlites. This is very evident for NWA 2737 by both methods in Fig. 2, where Sn content is plotted against Mg# for bulk meteorites, and separately for olivines and pyroxenes.
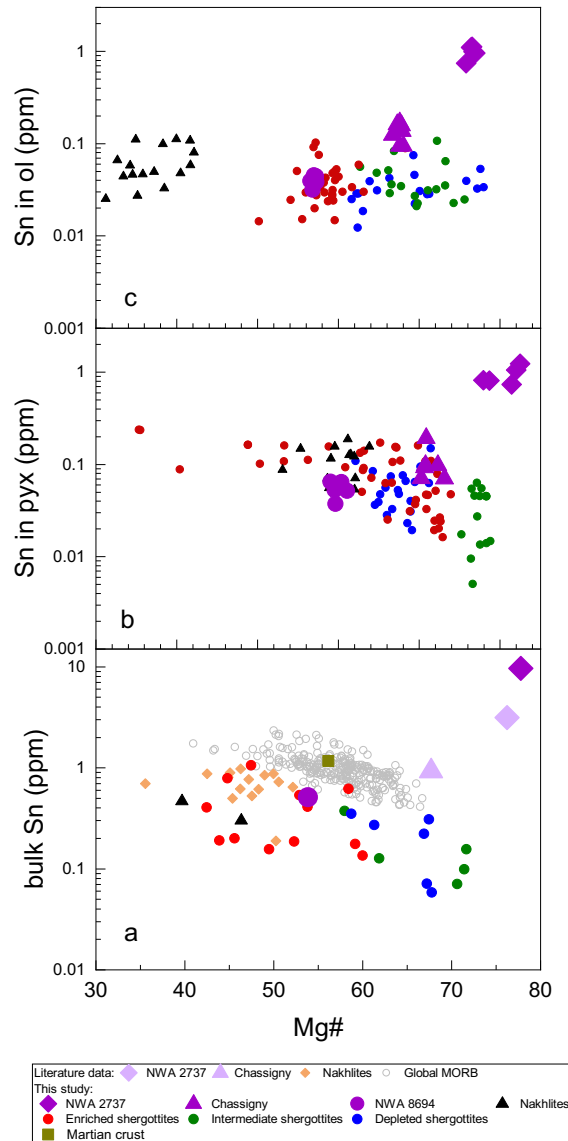
Fig. 2: Tin abundances in martian meteorites plotted against Mg#, with MORB glasses [12] for comparison. Nakhlite-chassignite solution analyses from [5].

Fig. 2 shows that the largest Sn enrichment is in NWA 2737. To make sure that Sn measured by LA-ICP-MS was not due to surficial contamination, olivines from NWA 2737 were analyzed in time-resolved mode with a 100 μm spot size, 50 seconds ablation, at 50 Hz (depth of ~250 μm). We found that Sn is not a surface contaminant, but maintains a similar depth profile to Mg, Si, Ti, Fe, Co, Ni, Zn, Y and Pb.

Discussion: Since the Sn/Sm ratio of a magma remains constant during fractionation, even on the planetary scale (e.g., Fig. 1), it is pretty clear that none of the three chassignites is derived from the same batch of melt. Even NWA 8694 [8] has a higher bulk Sn/Sm

ratio than any of the nakhlites. The high Sn/Sm of NWA 2737 is likely the result of assimilation of tin-mineralized country rocks. Tin is transported by acidic, Cl-rich hydrothermal fluids, and cassiterite (SnO_2) is deposited wherever the HCl is neutralized [15]. The role of a Cl-bearing hydrothermal fluid in creating chlorapatite in nakhlites and chassignites has been shown [4]. However, such fluids would have circulated only after the start of magmatism in the area. This implies that the high Sn was the result of either (i) assimilation of hydrothermal deposits that preceded the emplacement of the nakhlite-chassignite magmas, or (ii) NWA 2737 magma was erupted later in the nakhlite-chassignite emplacement sequence.

The presence of radiogenic Pb in Chassigny olivines [16] and NWA 998 apatites [5] implied that some chassignite and nakhlite minerals had assimilated a radiogenic Pb component from the martian surface. Osmium and S isotopes indicate that some nakhlites also assimilated surficial contaminants [17]. The similarity of radiometric and exposure ages of nakhlites and chassignites [1-6], Cl-rich fluid metasomatism [4], and alteration assemblages [3] speak to a large region sampled by a single impact that dispatched meteorites from multiple igneous bodies [cf. 5, 7, 18].

Assimilation of non-igneous material by martian magmas appears to be far more ubiquitous [9] than previously appreciated. Unique elemental patterns in NWA 2737 provide clues to hydrothermal mineralization of Sn in martian country rocks that have not been directly sampled by meteorites. Searches for mineralized deposits by future missions would be important in finding martian resources for human exploration and habitability.

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