THE NEODYMIUM AND HAFNIUM ISOTOPIC COMPOSITION OF NWA 7034, AND CONSTRAINTS ON THE ENRICHED END-MEMBER FOR SHERGOTTITES. R.M.G. Armytage[1], V. Debaille[1], A.D. Brandon[2], C.B. Agee[3] [1]Laboratoire G-Time, CP 160/02, Université Libre de Bruxelles, Ave Fr. Roosevelt 50, 1050 Bruxelles, Belgium. (*email: rarmytag@ulb.ac.be) [2]Earth and Atmospheric Sciences, University of Houston, Houston, TX, 77204, USA [3]Institute of Meteoritics, University of New Mexico, Albuquerque, NM, USA

Introduction: Shergottites are the largest group of martian meteorites currently represented in our collection. On the basis of their bulk incompatible trace element compositions and Sm-Nd systematics, shergottites form a compositional continuum that can be subdivided into enriched, intermediate, and depleted subgroups. However, the broad variety of textures exhibited by the shergottites, and indices of differentiation such as Mg# do not correlate with these subgroups, making it difficult to explain the compositional continuum in terms of simple crustal assimilation and fractional crystallization [e.g. 1,2]. In addition the correlation between the initial ε^{143}Nd and γ^{187}Os in shergottites is hard to replicate using the crust as an end-member [3]. The favoured interpretation in recent times based on ^{142}Nd-^{143}Nd systematics has been is that the compositional variation reflects mixing between distinct, ancient mantle source regions, likely established during magma ocean solidification, though this requires a protracted magma ocean on Mars [1-3].

Despite the dominance of shergottites in our collection, recent rover and orbital data of the martian surface have highlighted how unrepresentative shergottites actually are of the crust [4]. Until the discovery and identification of NWA 7034 (and its pairs e.g. NWA 7533) as martian regolith breccias [5-8], the crustal end-member in shergottite mixing models was somewhat hypothetical and usually defined based on shergottites themselves. Modelling of the trace element profiles in NWA 7533 carried out by [6] suggested that the crust could be the enriched end-member for the shergottites.

To investigate the relationship between NWA 7034, representing the crustal reservoir, and the enriched end-member for shergottites, we collected ^{147}Sm-^{143}Nd, ^{176}Lu-^{176}Hf and high precision ^{142}Nd data on NWA 7034. As NWA 7034 is a polymict breccia [7], three separate fragments were measured for each isotopic system to assess the heterogeneity.

Method: The three fragments (~0.1g) were digested in HF-HNO$_3$ in Parr Bombs due to the possible presence of zircons [6]. Aliquots to measure spiked Sm-Nd and Lu-Hf, and trace elements were both removed from the initial dissolution. Ion-exchange chromatography was used to separate Hf and Nd for isotopic analysis. The Nd isotopic data was collected on a TritonPlus, while the Hf isotopic ratios and the spiked aliquots were measured on a NuPlasma HR, both at ULB.

Results: Although there is some variation in the trace element profiles among the three aliquots, there is no resolvable variation in the Nd isotopic composition and the average μ^{142}Nd=− 47 ± 5(2SD) and ε^{143}Nd= −17.5 ± 0.3(2SD) are in good agreement with previous data [5,8-9] for this sample. The Hf isotopic data show a bit more variation with ε^{176}Hf ranging from −66 to −58.

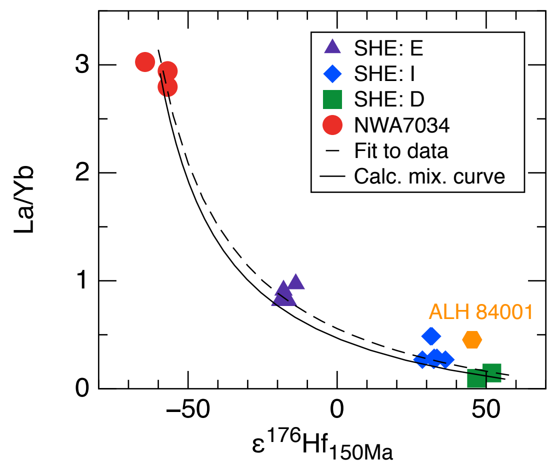

Fig. 1 La/Yb versus ε^{176}Hf for NWA 7034 and shergottites calculated to a common age. Literature data from [2,10-13]

Discussion: As in [5], for ε^{143}Nd$_{150Ma}$ vs La/Yb NWA 7034 plots as the enriched end-member on a two component mixing hyperbola for shergottites, with the calculated mixing curve (between NWA 7034 and the depleted shergottite Tissint) plotting nearly on top of a hyperbola fit to the data. The Lu-Hf systematics tell the same story (Fig. 1), despite the larger variation in the measured ^{176}Hf/^{177}Hf ratios for NWA 7034. The sources of the shergottites also appears to show this coupling as NWA 7034 falls on a hyperbolic mixing curve fit through it and the shergottites (Fig. 2). However, a calculated mixing curve between NWA 7034 and the DMM (depleted martian mantle) composition of [1], does not accurately model the shergottite ^{146}Sm/^{144}Nd-^{176}Lu/^{177}Hf source trend. While the ratios of NWA 7034 fit as an end-member, the concentrations of Nd and Sm or Hf and Lu would have to be a factor of three greater, in the case of the former, or a factor of three smaller for the latter. This rules out any simple binary mixing with the crust as the enriched source. Even a more complex mixing scenario as modeled in [10] requires an enriched end-member that is the residue of magma ocean crystallization. Therefore the ^{147}Sm/^{144}Nd-^{176}Lu/^{177}Hf systematics of the shergottites appear to be inconsistent with the “crust”, as represented by NWA 7034, being the enriched end-member. However, as NWA 7034 clearly falls on the mixing curve for the shergottites it is likely to also represent some degree of mixing of the same mantle reservoirs that have generated the shergottite sources.

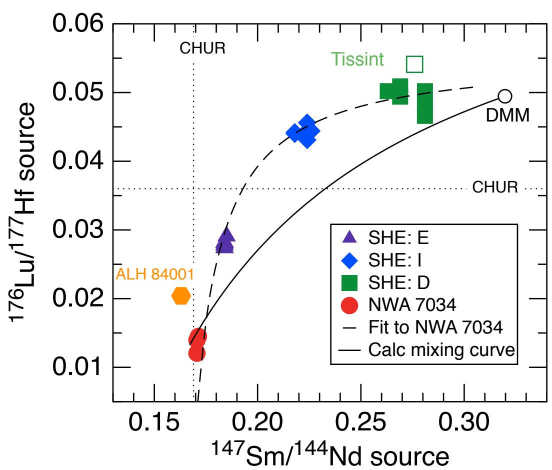

Fig. 2 Calculated ^{147}Sm/^{144}Nd and ^{176}Lu/^{177}Hf source ratios for shergottites and ALH 84001. The measured ^{147}Sm/^{144}Nd and ^{176}Lu/^{177}Hf ratios for NWA 7034 are plotted representing a crustal source. DMM is the depleted mantle composition from [1]

The extremely low μ^{142}Nd = – 47 of NWA 7034 is consistent with early differentiation, during the lifetime of the short lived ^{146}Sm ($t_{1/2}$ = 103 Ma [14]), of a silicate reservoir with a low Sm/Nd ratio. In coupled ^{142}Nd-^{143}Nd space of the shergottite sources evolved to ε^{143}Nd$_{150Ma}$, the μ^{142}Nd composition of NWA 7034 plots just off the shergottite regression line (SRL, r^2 ~0.99), and including it in the regression reduces the fit to r^2 ~ 0.7. In Fig. 3 the bulk Mars initial μ^{142}Nd is taken to be non-chondritic [15], allowing the SRL to be interpreted as an isochron at ~4.5 Ga, which argues for relatively late contemporaneous formation of the shergottite sources [2,15], or as a mixing line. The fact that NWA 7034 plots off the SRL could be a function of its regolith nature. As such, the coupled Nd systematics of NWA 7034 unfortunately place little constraint on whether the SRL is a mixing line or a isochron. If its position below the SRL is interpreted as significant, it highlights the fact that NWA 7034 is not the end-member of the shergottite mixing trend, and it points to the crustal source being formed 30 Myr after solar system formation, ~ 30 Myr prior to the formation of the shergottite sources.

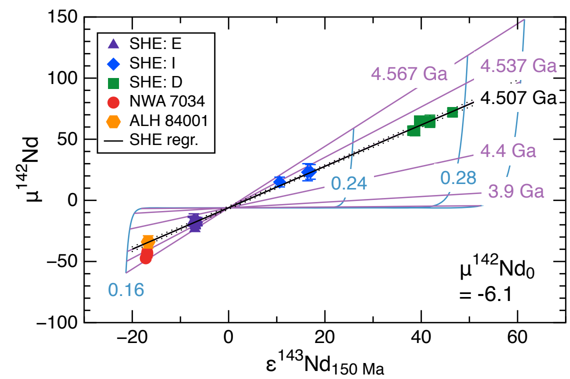

Fig. 3 Coupled μ^{142}Nd-ε^{143}Nd$_{150Ma}$ for the shergottite sources and NWA 7034. The purple lines are isochrons and the blue lines are constant ^{147}Sm/^{144}Nd ratio.

One of the strongest pieces of evidence against the crust as the enriched end-member for the shergottites is replicating the correlation between their initial ε^{143}Nd and γ^{187}Os [3]. Unfortunately, due to its nature as a polymict breccia, the Os isotopic systematics of the NWA 7034 meteorite have been significantly affected by the admixing of impactor material [16], impeding efforts to address this constraint.

Conclusions: The ^{147}Sm-^{143}Nd, ^{176}Lu-^{176}Hf and ^{142}Nd systematics in NWA 7034 argue against the crust, with the composition of NWA 7034, being the enriched end-member reservoir for the shergottites source, despite some compositional resemblance.

References: [1] Borg L. E. and Draper D. S.(2003) *Meteoritics & Planet. Sci., 38*, 1713-1731. [2] Debaille V. et al. (2007) *Nature 450*, 525-528 [3] Brandon A. D. et al. (2012) *Geochim. Cosmochim. Acta*, *76,* 206-235. [4] Mc Sween Jr. H.Y. et al. (2009) *Science, 324*, 736-739. [5] Agee C. B. et al. (2013), *Science, 339*, 780-785 [6] Humayun M. et al. (2013), *Nature, 503*, 513-516. [7] Santos A. R. et al. (2015), *Geochim. Cosmochim. Acta*, *157,* 56-85 [8] Nyquist L.E. et al. *Meteoritics & Planet. Sci., 51*, 1-16 [9] Kruijer T.S. et al. *LPS XLVII,* Abstract #2115. [10] Debaille V. et al. (2008) *EPSL, 269,* 186-199 [11] Blichert-Toft J. et al. (1999) *EPSL, 173,* 25-39 [12] Lapen T. et al. (2010) *Science, 328,* 347-351 [13] Meyer. C. *The Martian Meteorite Compendium* [14] Meissner F. (1987) *Z. Physik* A. 327, 171-174. [15] Borg L.E. et al. (2016) *Geochim. Cosmochim. Acta*, *175* 150-167 [16] Goderis S. et al. *Geochim. Cosmochim. Acta*, *191* 203-215