SAMARIUM ISOTOPIC CONSTRAINTS FOR AN EARLY COMPACTION AGE OF NORTHWEST AFRICA 7533.

M. Humayun[1], H. Hidaka[2], S. Yoneda[3], C. Göpel[4], B. Zanda[5], and R. H. Hewins[5,6], [1]Florida State University, Tallahassee, FL 32310, USA (humayun@magnet.fsu.edu); [2]Hiroshima University, Higashi-Hiroshima 739-8526, Japan; [3]National Museum of Nature and Science, Tsukuba 305-0005, Japan; [4]Institut de Physique du Globe de Paris, 75238 Paris Cedex 05, France; [5]MNHN-UPMC, 75005 Paris, France; [6]Rutgers University, Piscataway, NJ 08854, USA.

Introduction: NWA 7533 (and paired meteorites) is the first meteoritic regolith breccia to be recognized from Mars [1-2]. The breccia consists of numerous clasts, including igneous-textured lithic or mineral clasts, and fine-grained (<5 µm) clast-laden impact melt rocks in a fine-grained clastic matrix [3]. The abundant fine-grained materials have been interpreted to be Martian soil [1, 3]. U-Pb ages on zircons have yielded a narrow range of 4.43-4.35 Ga upper intercept ages, with a disturbance at ~1.4 Ga [1,4]. U-Pb apatite ages are all reset at ~1.4 Ga [5]. The Rb-Sr age (2.1 Ga) [6] and the K-Ar ages of individual clasts (2.1-1.4 Ga) [16, 7] are all clustered around the U-Pb disturbance age of ~1.4 Ga. The timing of compaction of the breccia is not known but is of great importance to know which part of Mars' history can be accessed from the breccia. The chronologic constraints give rise to an upper and lower bound for the timing of compaction of NWA 7533 (and paired meteorites): (1) an ancient compaction age at ~4.3 Ga, or (2) a compaction age ~1.4 Ga [2, 4]. The case favoring an ancient compaction age is the absence of zircons with ages <4.3 Ga. Since zircons in NWA 7533 occur in impact melt rocks [3] one would expect an age range of 4.4-3.9 Ga, similar to lunar zircons [8], concurrent with the late heavy bombardment (LHB). The case for a ~1.4 Ga compaction age is favored by the abundance of Fe-oxides and the absence of sulfates or clays in NWA 7533 [3], implying a mineralogy consistent with the Siderikian epoch [9], a late Hesperian or Amazonian age. Other arguments are given by [2].

Neutron capture by the reactions $^{149}Sm(n,\gamma)^{150}Sm$ and $^{157}Gd(n,\gamma)^{158}Gd$ in planetary regoliths induce measurable isotope anomalies in lunar, asteroidal and Martian regolith [10-15]. If Martian regolith spanning a period from 4.3-1.4 Ga of Mars history were sampled by the NWA 7533 breccia then significant cosmogenic neutron irradiation of the soil is expected. To study the neutron fluence experienced by the breccia components, we analyzed the Sm (and Gd) isotopic composition of a 100 mg bulk sample of NWA 7533 prepared in Paris.

Analytical Methodology: The sample was dissolved in mixed high-purity $HF-HClO_4$ acids and the REE separated using procedures described [13]. Samarium isotope composition was determined using a Thermo Triton™ *Plus* equipped with 9 Faraday cup collectors in Tsukuba.

Results: Isotopic results for Sm are shown in Fig. 1. Bulk NWA 7533 exhibits a small deficit of -2.23±0.24 (2σ) in ε^{149}Sm, and a corresponding excess of +3.14±0.34 (2σ) in ε^{150}Sm. Results for Gd are not yet available. The black line in Fig. 1 shows the theoretical line defined by neutron capture processes operating on Sm isotopes. Also shown for comparison are aubrites and mesosiderites, both of which are known to have experienced high neutron fluences, and other Martian meteorites.

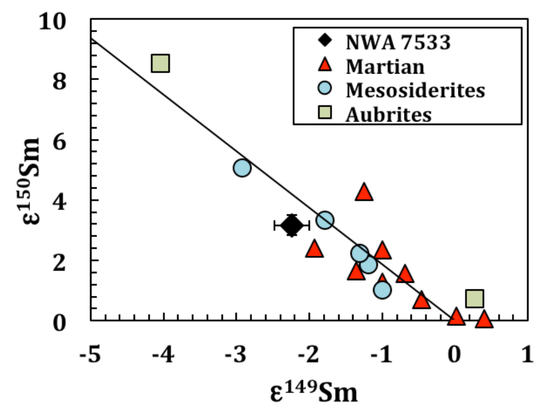

Fig. 1: Sm isotopic composition of bulk NWA 7533 compared with that of other meteorites [12, 14, 15].

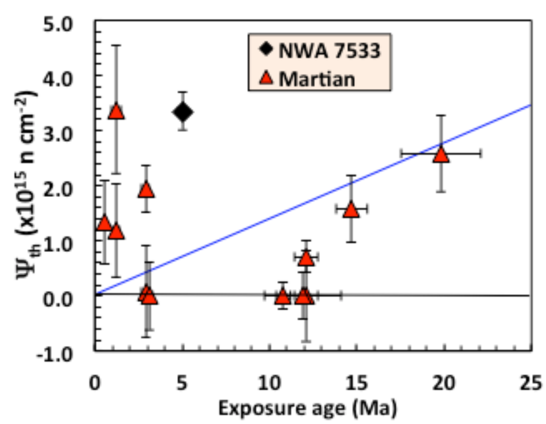

Fig. 2: Thermal neutron fluence of Martian meteorites [14] and NWA 7533 [this study] compared with their cosmic-ray exposure ages [14, 16]. Samples below the blue line are consistent with irradiation in space.

The bulk NWA 7533 breccia has a Sm isotopic composition on the high end of what has been reported for other Martian meteorites.

Discussion: A significant issue for all Martian meteorites is whether neutron irradiation occurred in the Martian regolith or in space during transit to Earth. The extent of the Sm isotopic anomaly depends on the thermal neutron fluence, Ψ_{th}, which is a function of exposure time and shielding depth, with a peak fluence in a meteoroid of radius ~1 m [17]. Fig. 2 shows the estimated thermal neutron fluence inferred from Sm isotopes for Martian meteorites plotted against their cosmic-ray exposure ages [14]. The blue line represents the maximum fluence that the meteorites could have experienced during transit. Hidaka et al. [14] showed that several shergottites must have experienced neutron irradiation near the Martian surface (<2 m) prior to their transit to Earth. Bulk NWA 7533 is plotted on this figure using a ~5 Ma cosmic-ray exposure age [16]. From this, we infer that one or more components within NWA 7533 have experienced a higher thermal neutron fluence than irradiation of a metre-sized body in space would have acquired during ~5 Ma. This irradiation may have occurred either prior to the assembly of the breccia, or more recently on the Martian surface during exposure of the compacted rock. Either way, the thermal neutron fluence experienced over the history of the breccia and its components (Ψ_{th} ~$3x10^{15}$ n/cm^2) is two orders of magnitude smaller compared than the effects observed in the lunar regolith (Ψ_{th} ~10^{17} n/cm^2 [11, 13]). Several factors can contribute to the small size of the neutron fluence. 1. The early Martian atmosphere may have been considerably denser than the atmosphere <4 Ga [18]. 2. The regolith could have been more deeply mixed (to km-depths) prior to the end of the LHB, >4 Ga, effectively diluting shallow (<2m) regolith with deeper regolith or plutonic rocks to under 3%.

The modern Martian atmosphere provides very little shielding (17 g/cm^2, equivalent to ~5 cm depth under solid rock cover) against neutrons, which peak at about 1 metre depth inside regolith (~300 g/cm^2). A thicker Martian atmosphere may have been present prior to ~4 Ga [18], which could effectively shield ancient Martian soil and regolith from neutron irradiation. The current thin atmosphere was likely established by the end of the LHB [18]. Incorporation of regolith exposed near the Martian surface at ~1.4 Ga should have induced significantly larger Sm isotope effects (ε^{150}Sm ~120), comparable to those observed in lunar regolith samples [11, 13].

The lunar regolith exposed today accretes relatively slowly [11], so that a deeper mixing of the Martian regolith could provide effective shielding from cosmogenic neutrons. The mixing depth of the Amazonian regolith on Mars and that on the Moon are likely to be similar, stirred mainly by small impacts that move regolith around within the upper few meters of the surface. However, prior to 4 Ga, large, basin-forming impactors would have excavated material from depths of up to 100 km during the Noachian and pre-Noachian phases of Mars history, producing thick impact melt sheets. During the LHB, gardening of the Martian regolith to depths >>1 metre would dilute any cosmogenic effect produced in the upper metre of the regolith even if the Martian atmosphere provided little shielding. Thus, an alternative means of explaining the pre-transit neutron exposure of NWA 7533 is to have the breccia compaction take place prior to the end of the LHB, > 4 Ga. **Both possibilities for explaining the low ε^{150}Sm in NWA 7533 involve processes that occurred on Mars prior to 4 Ga.** A late compaction age (~1.4 Ga) of the breccia [e.g., 2] is inconsistent with the low neutron fluence experienced by the breccia. Since neutron dosage is a cumulative effect, ε^{150}Sm provides a useful constraint on the compaction age of the NWA 7533 breccia. Thus, the ancient zircon ages provide the best estimate of compaction at ~4.3 Ga, followed by a thermal disturbance ~1.4 Ga. Fluids that were significantly younger than the breccia compaction age would have infiltrated the fractured breccia on Mars prior to the ~1.4 Ga annealing event [19-20].

References:

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