COMPOSITION OF NORTHWEST AFRICA 7533: IMPLICATIONS FOR THE ORIGIN OF MARTIAN SOILS AND CRUST.

M. Humayun[1], B. Zanda[2], R. H. Hewins[2,3], and C. Göpel[4], [1]National High Magnetic Field Laboratory and Dept. of Earth, Ocean & Atmospheric Science, Florida State University, Tallahassee, FL 32310, USA (humayun@magnet.fsu.edu), [2]Muséum National d'Histoire Naturelle and CNRS, 61 rue Buffon, 75005 Paris, France (zanda@mnhn.fr); [3]Dept. of Earth & Planetary Sciences, Rutgers University, 610 Taylor Rd., Piscataway, NJ, USA (hewins@rci.rutgers.edu); [4]Institut de Physique du Globe de Paris, 1 rue Jussieu, 75238 Paris cedex 05, France (gopel@ipgp.fr).

Introduction: Our knowledge of Martian composition is largely derived from Martian meteorites that originated from the depleted Martian mantle [1], and from chemical data remotely obtained by spacecraft missions [2-3], which sample distinct aspects of Martian chemistry [4]. Agee et al. [5] have described the first Martian meteorite (NWA 7034) that is a crustal rock matching the *in situ* compositions measured by the APXS and GRS instruments [e.g., 2-3]. Since SNC meteorites assimilate crustal material during emplacement, an LREE-enriched composition of the Martian crust has been inferred from the mixing end-member of the enriched SNCs [6]. Here, we report the chemical composition of matrix and individual clasts from NWA 7533, an impact-melt breccia paired with NWA 7034 [7], analyzed by laser ablation ICP-MS analysis.

Samples and Analytical Methodology: Polished mount NWA 7533-3 (MNHN, Paris) is comprised of two types of clast: fine-grained clast-laden impact melt rocks and coarse grained rock clasts, within a fine-grained interclast matrix, as described in [7]. The section, NWA 7533-3, was analyzed by LA-ICP-MS using a New Wave UP193FX (193 nm) excimer laser ablation system coupled to a Thermo Element XR at the Plasma Analytical Facility, FSU. A total of 73 elements, including all major elements [8], S and Cl, were determined simultaneously in low resolution mode using methods previously described [8-9]. Standardization utilized 6 MPI-DING glasses, 3 USGS silicate glasses, NIST SRM 610, SRM 1263a steel, the iron meteorites North Chile (Filomena) and Hoba, and a pyrite (for S). Beam spots were 50-150 µm ablated at 50 Hz, using either spot or raster mode. LA-ICP-MS analyses of SNC meteorites are described in [10].

Results: The composition of interclast matrix and fine-grained clast-laden impact melt rocks in NWA 7533 are similar and are grouped together as FGM, here. The composition of FGM is basaltic, with 45 % SiO_2, 12 % MgO and 3.2 % Na_2O+K_2O, plotting within the range defined by Gusev soils on a Na_2O+K_2O vs. SiO_2 plot [4] similar to NWA 7034 [5]. The most noteworthy feature of the FGM is the high siderophile element abundances. Fig. 1 shows a Ni vs. Mg plot adopted from [4] comparing the compositions of the matrix and clasts from NWA 7533 with SNC meteorites and Gusev crater rock and soil analyses. In the NWA 7533 FGM, Ni is 500-600 ppm, a factor of 5 higher than SNC meteorites at the same MgO content. The FGM also contains Ir ranging from 10-60 ppb, compared with <1 ppb for the same MgO in SNCs [10], correlated with Os, Ru, Rh and Pt in chondritic ratios. FGM is enriched in Ge/Si, but not in Ga/Al.

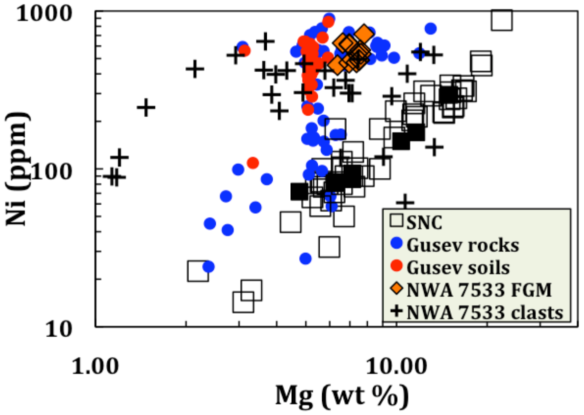

Fig. 1: NWA 7533 coarse clasts and FGM compared with SNCs, Gusev rocks and soils; black squares [10].

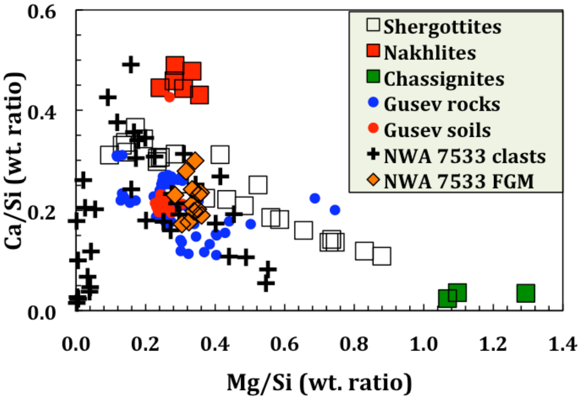

Fig. 2: Ca/Si vs. Mg/Si comparing the trend in SNCs and Gusev rocks and soils [4] with FGM and coarse clasts from NWA 7533.

The NWA 7533 FGM overlap the Gusev soils in major element composition (Fig. 2), indicating a close genetic link between Martian soils and the fine grained matrix and clast-laden impact melt rocks in NWA 7533. It is, therefore, likely that these lithologies are impact melt compacted soils.

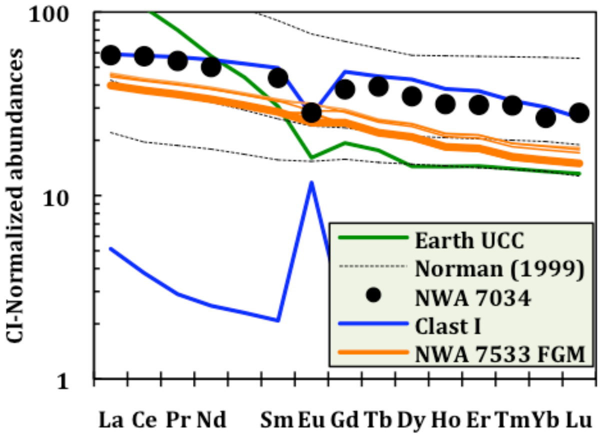

Fig. 3: REE patterns for NWA 7533 (matrix, n=6, and Clast I, n=2) compared with NWA 7034 [5], Earth's upper continental crust (UCC), and estimates of Martian crust REE derived from SNCs [6].

The REE pattern of NWA 7533 FGM have uniform slopes without Eu anomalies (Fig. 3). Coarse-grained clasts show igneous patterns with strong Eu anomalies, both positive and negative, with two analyses of Clast I, a large K-feldspar-bearing clast, shown in Fig. 3. The NWA 7034 bulk REE pattern [5] is 50-90% higher than the NWA 7533 matrix and closely matches the REE pattern of the mafic portion of Clast I.

Discussion: Next, we consider chemical evidence for a meteoritic component, links between FGM with Martian soils, and the origin of the Martian crust.

Meteoritic component in the Martian soils. A ubiquitous meteoritic contaminant is observed in all FGM analyses, and in many of the coarse clasts from NWA 7533 (Fig. 1), indicating that many of the coarse clasts originated from impact melts, as well. The excess Ni in Martian soils has previously been interpreted in terms of a meteoritic component, but considerable ambiguity in its origin remains [12]. The refractory siderophile elements, Os, Ir, Ru, Rh and Pt, require a chondritic source for the excess siderophiles. The excess Ni is equivalent to ~4-5% CI chondrite in the NWA 7533 breccia. However, the meteoritic material is not represented by a single metallic component, but the Ni and Ge have been oxidized and merged with the silicate components, while the refractory siderophiles may be in nuggets. Our interpretation of NWA 7533 also extends to the Martian soils observed at Gusev crater. The origin of siderophiles in NWA 7533 may include material from the southern highlands, or it may reflect meteoritic input to more modern soils. Dust storms are likely to distribute meteoritic material from the southern highlands to all Martian basins.

Chemical link between NWA 7533 and Martian soils. The NWA 7533 FGM are compositionally similar to soils from Gusev Crater in all major element ratios and Ni abundances, perhaps more Mg-rich. NWA 7533 FGM has an Fe/Mn ratio of 47±3 which is higher than Fe/Mn of 40±5 for SNCs, but in range with Fe/Mn of 51±7 for *in situ* measurements of Martian soils [4], due to Fe-oxides in the FGM [7] and, by inference, in Martian soils. In Fig. 2, the cpx-rich nakhlites plot above the SNC trend while the soils plot below the SNC trend in a complementary fashion. This implies a relative depletion of Ca in Martian soils, a feature shared by NWA 7533 FGM. The FGM is also depleted in Sc, while nakhlites are enriched in Sc, indicating that the soils reflect a cpx depletion of magmatic origin in their protolith (Martian crust) rather than loss of Ca during aqueous alteration of the source region [11]. However, there are key differences between Martian soils, all of which are enriched in S, Cl and Zn relative to the rocks, and NWA 7533 FGM which lacks these enrichments. The chemical uniformity of FGM reflects an origin as ancient Martian wind-blown dust.

Origin of the Martian Crust. Fig. 3 shows estimated Martian crustal patterns inferred from LREE-enrichment in shergottites [6]. The NWA 7533 FGM REE pattern is consistent with a low degree partial melt of a fertile garnet peridotite source. It agrees well with an end-member of ~20% crustal contamination of shergottite magma [6], with the exception that the NWA 7533 REE pattern is steeper in the HREE. The Martian mantle is inferred to have refractory incompatible elements (Ba, Th, U, Nb) at ~2 x CI [6, 11]. These elements are enriched 45-48 x CI implying ~4-5% partial melting of a fertile source for Martian crustal origin. If the whole mantle of Mars is melted to an average melt fraction of 4-5% it implies an average crustal thickness of 45-60 km, consistent with geophysical estimates of Martian crustal thickness [13].

References: [1] Treiman A. H. et al. (2000) *Planet. Space Sci., 48*, 1213-1230. [2] Gellert R. et al. (2006) *JGR 111*, E02S05, doi:10.1029/2005JE002555. [3] Taylor G. J. et al. (2007) *JGR, 111*, E03S10, doi:10.1029/2005JE002645. [4] McSween H. Y., Jr., et al. (2009) *Science, 324*, 736-739. [5] Agee C.B. et al. (2013) *Science Express*, doi 10.1126/science.1228858. [6] Norman M. D. (1999) *MAPS, 34*, 439-449. [7] Hewins R. H. et al. (2013) *LPS XLIV*, this volume. [8] Humayun M. et al. (2010) *JAAS 25*, 998-1005. [9] Gaboardi M. and Humayun M. (2009) *JAAS 24*, 1188-1197. [10] Yang S. et al. (2013) *LPS XLIV*, this volume. [11] Newsom H. E. et al. (2007) *JGR, 112*, E03S12, doi:10.1029/2006JE 002680. [12] Yen A. S. et al. (2006) *JGR 111*, E12S11, doi:10.1029/2006JE002797. [13] Zuber M. T. et al. (2000) *Science, 287*, 1788-1793.