Mars: A Perspective from NWA 7533. M. Humayun[1], A. Nemchin[2], M. Grange[2], A. Kennedy[2], B. Zanda[3], R. H. Hewins[3,4], J.-P. Lorand[5], C. Göpel[6], E. Lewin[7]. S. Pont[3] & D. Deldicque[8]. [1]Florida State Univ., Tallahassee, USA; humayun@magnet.fsu.edu. [2]Curtin Univ., Perth, AUS. [3]MNHN & CNRS, Paris, FR. [4]Rutgers Univ., Piscataway, USA. [5]LPGN, Univ. Nantes, FR. [6]IPGP, Paris, FR. [7]ISTerre, Univ. J. Fourier, Grenoble, FR. [8]ENS, Paris, FR.

Introduction:

Meteorites from Mars provide us with the only detailed chronological and chemical constraints on the geological evolution of Mars. Most of the known Martian meteorites are igneous rocks, comprising shergottites ranging in age from 160-600 Ma, or nakhlites/chassignites of about 1.4 Ga. The known exceptions are ALH 84001, a monomict orthopyroxenite breccia of 3.8 Ga age [1], and the newly reported NWA 7034 polymict breccia [2]. This amazing meteorite is represented by a set of five paired stones that are named NWA 7034, NWA 7475 and NWA 7533. An enduring enigma in the Mars-meteorite connection is the lack of samples from the ancient cratered terrain when there are over 60 Martian meteorites that appear to come from younger volcanic terrains. Even ALH 84001, the oldest known Martian meteorite, has among the lowest siderophile element contents of Martian meteorites, i.e., ALH 84001 is a "pristine" rock. Pristine rocks from the Moon are comparatively hard to find in both Apollo collections and among lunar meteorites compared with lunar highlands breccias that contain abundant meteoritic debris [3-4].

NWA 7533 has now been recognized to be a polymict breccia containing mafic and feldspathic clasts in a matrix of alkali basaltic bulk composition [5]. Prior Rb-Sr dating yielded an age of 2.1 Ga [2], and preliminary K-Ar dating yielded an age of ~1.56 Ga [6], inconsistent with an origin from the ancient cratered highlands. In this report, we summarize recent findings on the study of NWA 7533, particularly new compositional and U-Pb zircon dating, and discuss their implications for early Mars.

Analytical Methods:

An uncoated section, NWA 7533 section-3, was analyzed by laser ablation ICP-MS using an ElectroScientific Instruments™ New Wave UP193FX ArF excimer (193 nm) laser ablation system coupled to a Thermo Electron™ Element XR [7-8]. Altogether, 76 peaks for major and trace elements and their interferences were monitored. Spot sizes of 50-150 µm were used, and the laser repetition rate was 50 Hz, with a fluence of >2 GW/cm^2. Raster rates were 10 µm/s. Laser dwell times on a spot were 20 s, resulting in a pit depth of ~100 µm determined by focussing of the optical microscope on the top and bottom of the pit. Relative sensitivity factors obtained from separate standards for many well-characterized lithophile elements agreed to 2-5%, but the accuracy is worse for elements for which only one standard was available, e.g., for NIST SRM 610 (~10-20%).

U-Pb isotope analyses on polished and Au-coated NWA 7533 section-4 were performed on a Shrimp II high-resolution ion microprobe at Curtin University (Perth, Western Australia) under analytical conditions described previously [9]. The beam spot was reduced to 7 µm to effectively analyze the small zircons observed with a primary O^{2-} beam current of 0.5 nA.

Results:

Analyses of 5 zircon grains large enough to obtain one or more spots with no beam overlap yielded a discordia line with an upper intercept of 4,428±25 Ma and a lower intercept of 1,712±85 Ma. Three zircons plotted concordantly on the upper intercept, supporting a very ancient origin of the zircon-bearing, leucocratic lithologies.

Chemical compositions of matrix and clasts from NWA 7533 is presented in figures 1-3, and discussed further below.

Discussion:

The excess Ni in Martian rocks and soils has been interpreted in terms of a meteoritic component [10], or as an indigenous protolith formed by partial melting of an oxidized early Martian mantle [11]. In this study, ubiquitous meteoritic contaminant is observed in the interclast crystalline matrix (ICM), in clast-laden impact melt rocks (CLIMR) analyses, and in many of the coarse lithic clasts from NWA 7533 (Fig. 1), indicating that many of the coarse clasts originated from impact melts. 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. Our interpretation of excess Ni in NWA 7533 also extends to the Martian rocks and soils observed at Gusev crater (Fig. 1). The presence of ancient zircons indicates that the siderophiles in NWA 7533 originate from the southern highlands. Dust storms are likely to distribute meteoritic material from the southern highlands to all Martian basins. We found no evidence to support an early oxidized mantle on Mars.

The NWA 7533 ICM and CLIMR are

compositionally similar to soils from Gusev Crater in all major element ratios (Fig. 2) and Ni abundances, although more Mg-rich. 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. The ICM/CLIMR in NWA 7533 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 [12]. However, there are key differences between modern Martian soils, all of which are enriched in S, Cl and Zn relative to the rocks, and NWA 7533 components which strikingly lack these enrichments (Fig. 3). We infer that the ancient Martian hydrosphere removed these volatiles from the ancient soils lithified in NWA 7533, supporting recent geological evidence for former oceans on Mars [13].

The NWA 7533 matrix 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 [14], 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 [12, 14]. 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 [15].

In summary, NWA 7533 is a polymict breccia containing 4.4 Ga zircons, abundant chondritic impactor debris, and lithified Martian soil modified by interactions with an early hydrosphere.

References: [1] Lapen T. J. et al. (2010) *Science 328*, 347-351. [2] Agee C.B. et al. (2013) *Science Express*, doi 10.1126/science. 1228858. [3] Warren, P. H. et al. (2005) *Meteoritics Planet. Sci. 40*, 989-1014. [4] Korotev R. L. et al. (2009) *Meteoritics Planet. Sci. 44*, 1287-1322. [5] Hewins R. H. et al. (2013) *Meteoritics Planet. Sci. 48* (abstract). [6] Cartwright J. A. et al. (2013) *Lunar Planet. Sci. 44*, abstract#2314. [7] Humayun M. et al. (2010) *JAAS 25*, 998-1005. [8] Gaboardi M. and Humayun M. (2009) *JAAS 24*, 1188-1197. [9] Nemchin A. et al. (2009) *Nature Geoscience 2*, 133-138. [10] Yen A. S. et al. (2006) *JGR 111*, E12S11, doi:10.1029/2006JE002797. [11] Tuff J. et al. (2013) *Nature 498*, 342-345. [12] Newsom H. E. et al. (2007) *JGR, 112*, E03S12, doi:10.1029/2006JE 002680. [13] DiAchille G. and Hynek B. M. (2010) *Nature Geoscience 3*, 459-463. [14] Norman M. D. (1999) *MAPS, 34*, 439-449. [15] Zuber M. T. et al. (2000) *Science, 287*, 1788-1793. [16] Gellert R. et al. (2006) *JGR 111*, E02S05, doi:10.1029/2005JE00255. [17] McSween H. Y., Jr., et al. (2009) *Science, 324*, 736-739.

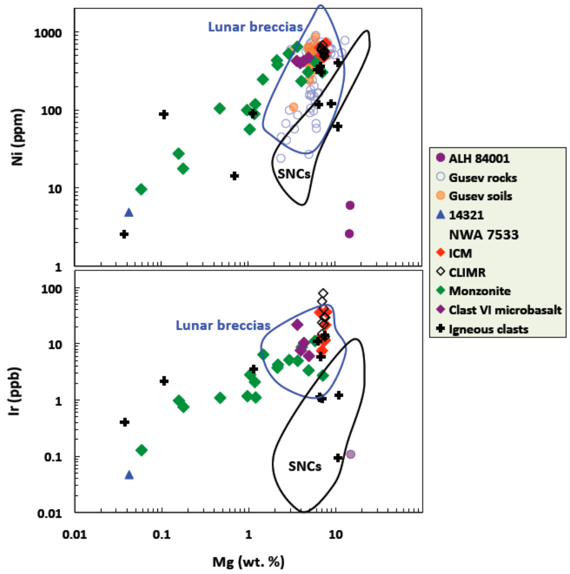

Fig. 1: Siderophile element abundances in components from NWA 7533 compared with SNC meteorites and Gusev rocks and soils [3-4, 16-17].

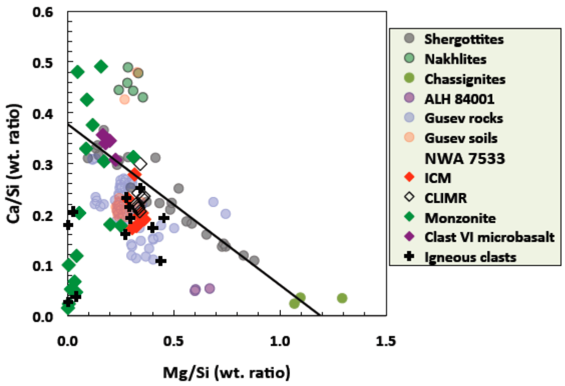

Fig. 2: Major element composition of components from NWA 7533 compared with SNC meteorites and Gusev rocks and soils (modified from [17]).

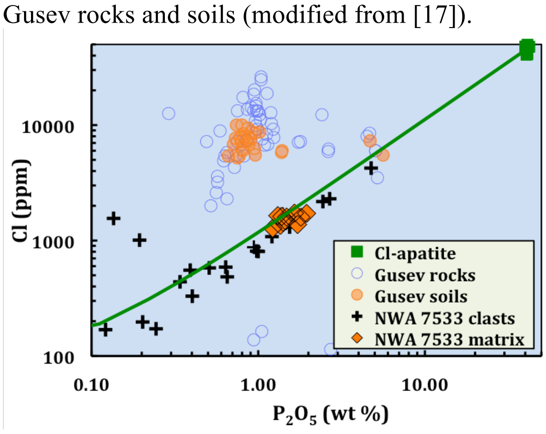

Fig. 3: ICM, CLIMR (matrix) and lithic clasts from NWA 7533 contain Cl only as chlor-apatite (green squares, EMP analyses); Gusev analyses from [16].