AN EARTH-LIKE BEGINNING FOR ANCIENT MARS INDICATED BY ALKALI-RICH VOLCANISM AT 4.4 Ga.

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Introduction: Much of what we know about the geochemistry of Mars comes from detailed studies of the martian meteorites as well as remote sensing studies from orbital, lander, and rover-based missions [1]. The remote-sensing studies indicate that Mars has a fairly ancient surface [2], however the ages of most meteorites are quite young, typically ranging from 180 Ma to 2.1 Ga [e.g. 3,4]. The exception to the young ages comes in the form of an orthopyroxenite cumulate named Allan Hills 84001, which has a crystallization age of >4.1 Ga [e.g. 5,6]; however, its cumulate nature renders the sample unhelpful for understanding magmatic processes early in Mars' history. Consequently, our picture of the thermal and magmatic evolution of Mars is largely affected by inferences of the conditions recorded by recent volcanism. Furthermore, the younger basaltic martian meteorites, referred to as the shergottites, have largely been a mismatch for the geochemistry of rocks and soils that have been analyzed by orbital, lander, and rover missions [1].

One of the newest additions to the martian meteorite clan, which came in the form of a basaltic clastic rock named NWA 7034 (*aka* "*Black Beauty*", and its paired rocks, e.g. NWA 7533), changes the landscape on both Mars crustal chemistry and chronology [4,7]. This meteorite was described originally as a monomict basaltic breccia, and it has many geochemical similarities to the orbital, lander, and rover mission data sets [1,4,8]. Furthermore, it shares geochemical linkages with the shergottites, providing a modern link between the mission and shergottite geochemical data sets. Consequently, we set out to date individual components within the polymict meteorite to identify any variations in ages among clasts.

We identified a number of U-rich phases in NWA 7034 including zircon ($ZrSiO_4$), baddeleyite (ZrO_2) and, phosphate minerals (apatites, merrilites, monozites), all of which are suitable for Pb-Pb and U-Pb dating. We found the U-bearing phases in a number of petrographic contexts within NWA 7034 including in the matrix of a rounded lithic breccia clast, in a basaltic clast with igneous crystallization texture, and within the bulk matrix of NWA 7034 (e.g. Fig. 1).

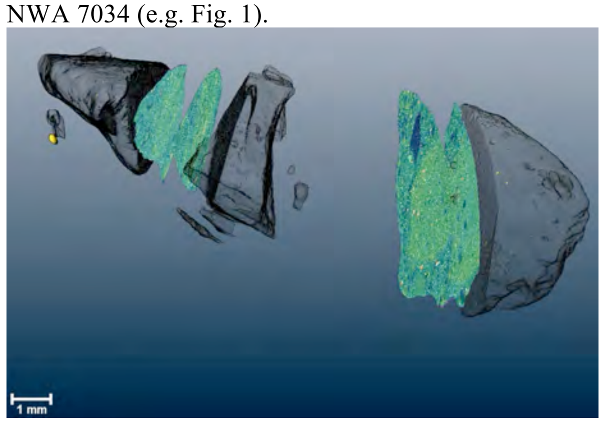

Fig. 1. A 0.6 g fragment of NWA 7034 was subjected to the X-ray CT scan, cut to make 4 petrographic sections (color slices show BSE and X-ray images overlain in situ). Small yellow dots *inside* the far right transparent fragment are martian zircons (terrestrial zircon monitor to the far left (yellow).

We dated the U-rich phases using Cameca IMS-1280HR SIMS, using small beam techniques (2-5 microns) for zircons and baddeleyites following procedures in [9,10], and [11] for phosphates. Initial results were presented at the 76th Meteoritical Society in Edmonton [12] and Goldschmidt 2013 [13]. A parallel effort using NanoSIMS is presented at this meeting by [14]. Here we briefly summarize our finding.

Results: Five zircon grains and one baddeleyite give an average U-Pb age of 4,439±17 (all errors are reported as 2σ) Ma. One zircon grain (F3-2) shown in Fig. 2 is distinctly younger (4,350±13 Ma) than the oldest group, suggesting NWA 7034 polymict breccia records at least two igneous events between 4.35-4.44 Ga. Another five zircon grains gave an average age of 1,410±56 (Ma). Fig. 3 shows an example of concordant upper intercept age of 1,441±37 Ma for Zc#1 grain, a member of the younger group. Zc#1 is the largest zircon grain in our study (~100 μm). A third intermediate group of four zircon grains shows discordant ages with an upper intercept age of 4,333±38 Ma and lower intercept age

1,434±65 Ma (Fig. 4), thus connecting the older and younger age groups. Only zircons in this group were found with petrological context, where the zircon-bearing clast is a basaltic trachyandesite (mugearite) clast, similar to "Jake-M" found by *MSL* [8]. Zircons in this group are very small (Fig. 3 inset). All phosphates give consistent lower intercept age of 1,345±47 Ma (Fig. 5), and martian common Pb isotopic composition of $^{207}Pb/^{206}Pb$=0.971±0.010, consistently lower than terrestrial common lead composition as noted in [3,15,16].

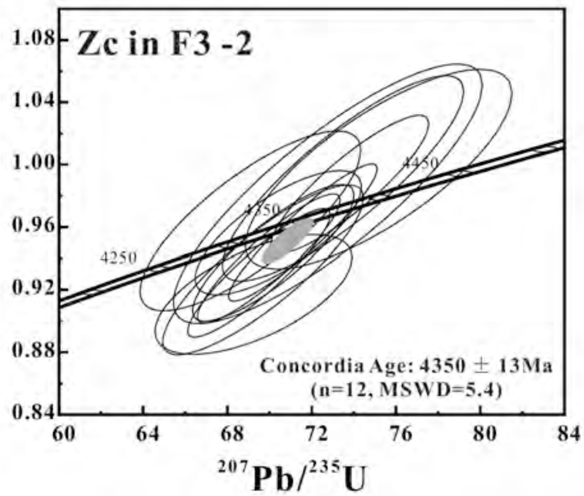

Fig. 2. Concordant U-Pb zircon age for F3-2 grain.

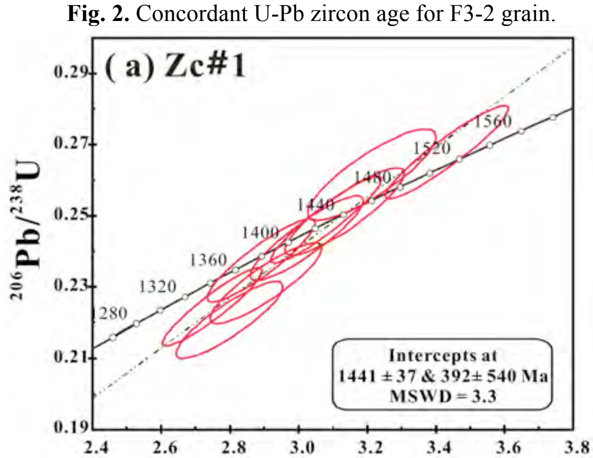

Fig. 3. Upper intercept U-Pb age for Zc#1 (~100μm).

Discussions and Conclusions: We identify four major age groups in NWA 7034: 4.44 Ga, 4.35 Ga, 1.44 Ga for zircons and baddeleyites, and 1.35 Ga in phosphates. We propose NWA 7034 formed at 1.44 Ga, while it contains 4.35-4.44 Ga lithic clasts (basaltic and alkali-rich, trachyandesite clasts). The youngest 1.35 Ga most likely reflect a metamorphic resetting event. The younger formation age of the rock itself at 1.44 Ga permits its origin from the northern hemisphere of Mars. The ~1.7 Ga disturbance age reported by [7] was not seen in our study. NWA 7034/7533 is a polymict clastic rock that records a period of martian crustal history (4.4-1.4 Ga) that has not been sampled by any of the other martian meteorites. Given the old age of the oxidized and evolved igneous clast, Mars underwent crustal building processes at 4.4Ga that were capable of producing volcanic outgassing of both water and CO_2 rich vapors. These conditions are very similar to those implicated for the early Earth and indicate that Earth and Mars may have had a similar geochemical beginning.

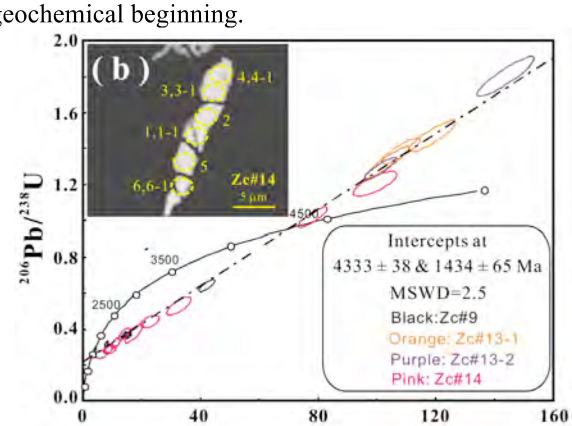

Fig. 4. Discordant ages for a group of four zircons. Note the analyses spots are only ~2 μm.

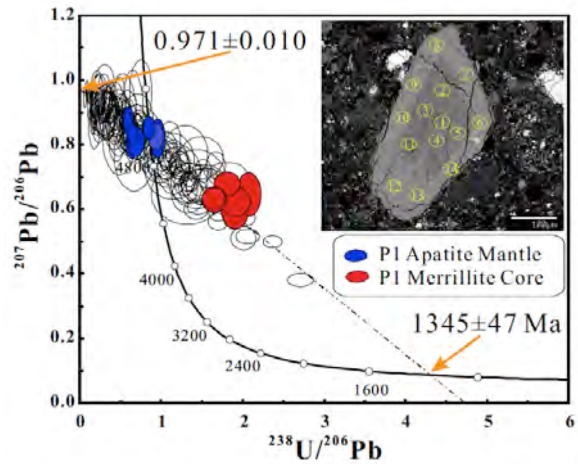

Fig. 5. Tera–Wasserburg concordia diagram for measured total $^{207}Pb/^{206}Pb$ and $^{238}U/^{206}Pb$ for apatites and merrillites (~150 analyses).

References: [1] McSween et al. (2009) *Science, 324,* 736. [2] Hartmann & Neukum (2001) *Space Sci. Rev., 96*, 165. [3] Zhou et al. (2013) *EPSL, 374,* 156. [4] Agee et al. (2013) *Science, 339,* 780. [5] Nyquist et al. (2001) *Space Sci. Rev., 96*, 105. [6] Lapen et al. (2010) *Science, 328,* 347. [7] Humayun et al. (2013) *Nature, 503,* 513. [8] Stolper et al. (2013) *Science, 341,* DOI: 10.1126/science.1239463 [9] Zhou et al. (2013) *GCA, 110*, 152. [10] Liu et al. (2011) *JAAS, 26,* 845. [11] Li et al. (2012) *Gondwana Res. 21*, 745. [12] Santos et al. (2013) *76th MetSoc,* A5284. [13] McCubbin et al. (2013) Goldschmidt, A1721. [14] Tartèse et al. (2014) LPSC (this meeting). [15] Yin et al. (2014) *EPSL, 385,* 218. [16] Borg & Drake (2005) *JGR (Planets) 110*, E12S03.