AN EARTH-LIKE BEGINNING FOR ANCIENT MARS INDICATED BY ALKALI-RICH VOLCANISM AT 4.4 Ga. Q.-Z. Yin1†, F. M. McCubbin2,3,4†, Q. Zhou1, A. R. Santos1,2,3, R. Tartèse6, X. Li1, Q. Li1, Y. Liu1, G. Tang1, J. W. Boyce5, Y. Lin1, W. Yang1, J. Zhang1, J. Hao1, S. M. Elardo1,2, C. K. Shearer1,2, D. J. Rowland1, M. Lerche9, C. B. Agee1,2,3. 1Department of Earth and Planetary Sciences, University of California, Davis, CA 95616, USA. 2Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131, USA. 3Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, USA. 4State Key Laboratory of Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, 100029, China. 5National Astronomical Observatories, Beijing, Chinese Academy of Sciences, Beijing 100012, China. 6Planetary Science Program, University of California, Los Angeles, USA. 7Department of Earth and Planetary Sciences, The Open University, Walton Hall, Milton Keynes, MK76AA, UK. 8Department of Earth and Planetary Sciences, University of California, Los Angeles, USA. 9Center for Molecular and Genomic Imaging, University of California, Davis, CA 95616, USA. 10McClellan Nuclear Research Center, University of California at Davis, McClellan, CA 95652. USA. (†Authors contributed equally: qyin@ucdavis.edu, fmccubbi@unm.edu).

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 (ZrSiO4), baddeleyite (ZrO2) 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).

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 of 4,333±38 Ma and lower...
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 $\frac{^{207}Pb}{^{206}Pb}=0.971±0.010$, consistently lower than terrestrial common lead composition as noted in [3,15,16].

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

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

**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:**