GROUND-TRUTH TESTS OF MARS MAGMATIC EVOLUTION THROUGH TIME. H. Y. McSween[1] and J. W. Head[2], [1]Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996-1410, mcsween@utk.edu, [2]Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912.

Introduction: Orbital spectroscopic analyses of martian volcanic terrains of different ages have been interpreted to reflect compositional evolution of magmas. These changes may have important implications for planetary evolution. Temporal changes include decrease in modal low-Ca pyroxene/total pyroxene [1,2,3] and decrease in K contents [3,4] from Noachian to Hesperian time (Fig. 1), and decrease in SiO_2 and FeO*and increase in Th (Fig. 2) [5] from Hesperian to Amazonian time. Are these patterns consistent with ground-truth data from Mars rover analyses and martian meteorites?

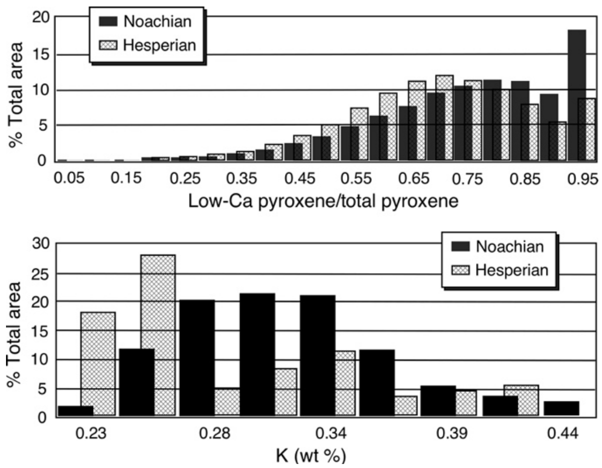

Fig. 1. Temporal changes in the compositions of magmas inferred from remote-sensing VISNIR, TIR, and GRS data. Adapted from [3].

The following ages are assigned to martian meteorites and igneous rocks analyzed at rover landing sites:

- Pre-Noachian (>4100 Ma): NWA 7034 and its pairs are the only samples of this age [6].
- Noachian (4100-3700 Ma): Igneous float rocks [7,8] derived from Gale crater (Curiosity rover) walls likely predate crater formation in Late Noachian. Volcanic float rocks from Endeavour crater (Opportunity rover) [9] are Early Noachian. ALH 84001 (~4100 Ma) straddles the Noachian boundary.
- Hesperian (3700-3000 Ma): Igneous rocks in Gusev crater (Spirit rover) [10,11] and Jezero crater (Perseverance rover) [12,13] are Early to Middle Hesperian based on crater ages.
- Amazonian (<3000 Ma): Radiometric ages for shergottite, nakhlite, chassignite, and augite basalt meteorites span the Early to Late Amazonian period [data summarized by 13].

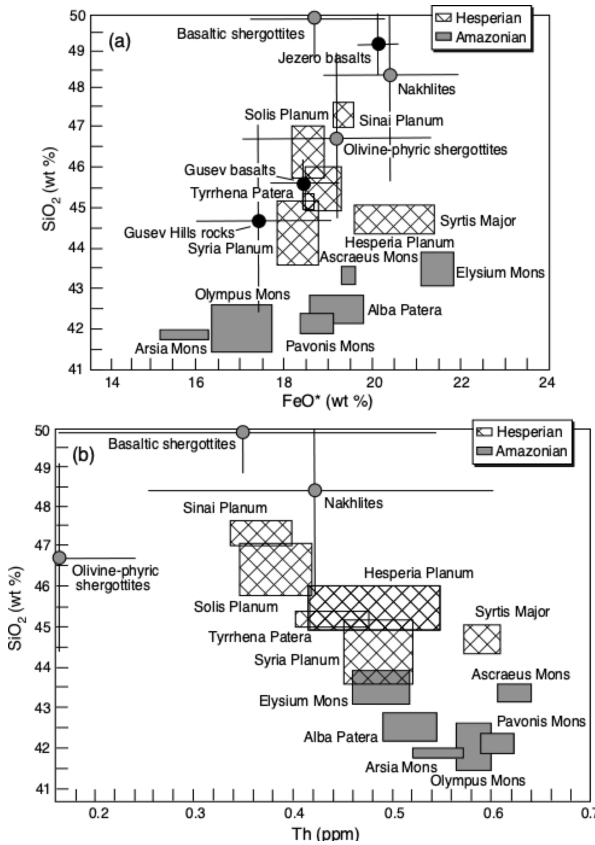

Fig. 2. Temporal changes in the compositions of magmas inferred from remote-sensing GRS data [5], compared to Mars rover and meteorite data.

Comparison of datasets: A decrease in the ratio of low-Ca pyroxene to total pyroxene with time is not supported by surface samples, as judged from modal and calculated normative data (Fig. 3). Pre-Noachian and Early to Middle Noachian samples have high contents of low-Ca pyroxenes [6,9], but high-Ca pyroxene occurs almost exclusively in Late Noachian Gale crater rocks [7,8]. Early Hesperian plains basalts in Gusev crater and alkaline igneous rocks in the Columbia Hills show low-Ca/total pyroxene ratios [15]. Ratios for Hesperian lavas in Jezero vary from 0 to 1 [12,13]. Middle Amazonian nakhlites are dominated by high-Ca pyroxene, but Early Amazonian augite shergottites and Late Amazonian shergottites contain subequal amounts of low-Ca and high-Ca pyroxenes [14].

A decrease in K contents of magmas with time appears to be on firmer ground. The compositions of martian meteorites and rover APXS-analyzed igneous rocks are shown in Fig. 4. The ancient (Pre-Noachian, Late Noachian, and Early Hesperian) rocks are clearly more alkaline than Amazonian meteorites (and Bounce Rock, a float rock similar to shergottites analyzed at Meridiani by the Opportunity rover). Although Fig. 4 combines K and Na oxides, a similar pattern would be observed if only K were plotted.

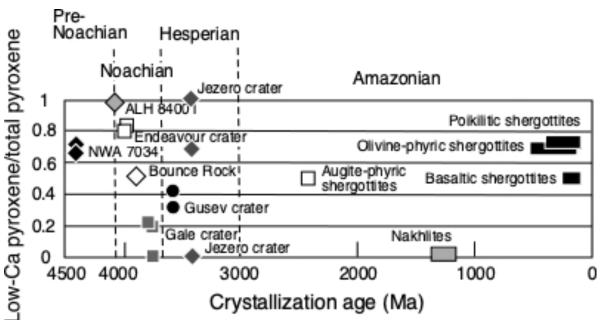

Fig. 3. Temporal variations in Low-Ca/total pyroxene ratios in rover-analyzed rocks and meteorites.

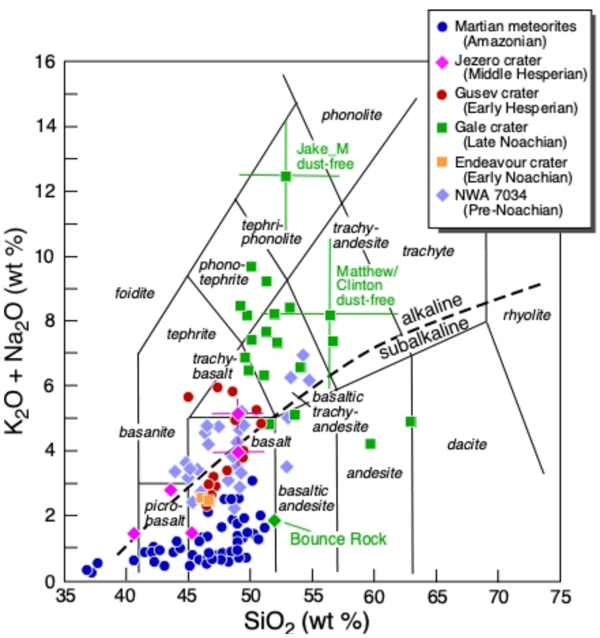

Fig. 4. Changes in the compositions of igneous rocks of various ages analyzed by Mars rovers and occurring as martian meteorites. Adapted from [14] and [16].

A decrease is silica abundance from Hesperian to Amazonian time is obvious from inspection of Fig. 4, if ultramafic meteorites are considered, and the trend is strengthened if Noachian rocks from Gale crater are included. Perhaps this suggests that remote-sensing has sampled more ultramafic compositions than have the launch sites for Amazonian-age meteorites.

It is noteworthy that although Hesperian Gusev rocks have APXS-analyzed silica contents in agreement with GRS values, Hesperian Jezero basalts do not, and silica in martian meteorites is consistently higher than any GRS Amazonian unit measurements (Fig. 2). Because most Amazonian terrains are dust-covered, the orbital GRS analyses may be contaminated.

Neither the proposed decrease in FeO* abundance nor increase in Th with time is supported by rover and meteorite analyses (Fig. 2). However, the GRS iron trend is hardly convincing. Although the GRS-derived Th analyses indicate a clear trend, the meteorite Th abundances are consistently lower than GRS Amazonian data (Fig. 2). Variable enrichment or depletion in incompatible trace elements in martian meteorites of all ages also may cast doubt on a temporal Th trend.

So are the variations real?: Ground-truth data appear to support the purported temporal evolution in alkalis and perhaps silica in martian magmas, although differences between GRS- and APXS-measured data for silica in Amazonian rocks are worrisome. A decrease in FeO* is not convincing, nor is the purported Th increase, as enriched and depleted meteorites formed throughout martian time. Although the variation in low-Ca/total pyroxenes inferred from orbital data is not consistently supported by analyses of surface rocks, that does not mean the trend may not be not real. The surface rocks considered here represent ~9 launch sites for meteorites (known to be chronologically biased) and 4 rover sites – perhaps an unrepresentative sampling.

These results underline the need for 1) higher-resolution combined crater-dating and remote sensing studies, 2) additional robotic missions targeted to a wider array of crustal ages, and 3) sample-return missions targeted to key landing sites to ensure more confidence in the age implications of igneous compositions.

References: [1] Mustard J.F. et al. (2005) Science, 307, 1594. [2] Poulet F. et al. (2007) *JGR, 112,* Eo8S02. [3] Rogers A.D. and Hamilton V.E. (2014) *JGR, 120,* 62. [4] Taylor G.J. et al. (2007) *JGR, 111,* E03S06. [5] Baratoux D. et al. (2011) *Nature, 475,* 338. [6] Santos A.R. et al. (2015) *GCA, 157*, 56. [7] Stolper E, et al, (2013) *Science*, 341,1239462. [8] Schmidt M.E. et al. (2018) *JGR, 123*, 1649. [9] Mittlefehldt D.W. et al. (2018) *JGR, 123,* 1255. [10] McSween H.Y. et al. (2004) *Science, 305*, 842. [11] McSween H.Y. et al. (2006) *JGR, 111,* E06S04. [12] Farley K.A. et al. (2022) *Science*, 10.1126/science.abo2196. [13] Wiens R.C. et al. (2022) *Sci. Adv., 8*, eabo3399. [14] McSween H.Y. (2015) *Am. Mineral., 100,* 2380. [15] McSween H.Y. et al. (2008) *JGR, 113,* E06S04. [16] Udry A. et al. (2020) *JGR, 125*, e2020E006523.