PROSPECTS FOR CHRONOLOGICAL STUDIES OF MARTIAN ROCKS AND SOILS. L. E. Nyquist[1], C-Y. Shih[2], and Y. D. Reese[3], [1]Mail Code KR, NASA Johnson Space Center, Houston, TX 77058, laurence.e.nyquist@nasa.gov, [2]Mail Code JE-23, ESCG/Jacobs Sverdrup, P.O. Box 58477, Houston, TX 77058, chi-yu.shih@nasa.gov, [3]Mail Code JE-23, ESCG/Muniz Engineering, Houston, TX 77058, young.reese@.nasa.gov.

Introduction: Chronological information about Martian processes comes from two sources: Crater-frequency studies and laboratory studies of Martian meteorites. Each has limitations that could be overcome by studies of returned Martian rocks and soils.

Chronology of Martian volcanism: The currently accepted chronology of Martian volcanic surfaces relies on crater counts for different Martian stratigraphic units [1]. However, there is a large inherent uncertainty for intermediate ages near ~2 Ga ago. The effect of differing preferences for Martian cratering chronologies [1] is shown in Fig. 1.

Stöffler and Ryder [2] summarized lunar chronology, upon which Martian cratering chronology is based. Fig. 2 shows a curve fit to their data, and compares to it a corresponding lunar curve from [3]. The radiometric ages of some lunar and Martian meteorites as well as the crater-count delimiters for Martian epochs [4] also are shown for comparison to the crater-frequency curves. Scaling the Stöffler-Ryder curve by a Mars/Moon factor of 1.55 [5] places Martian shergottite ages into the Early Amazonian to late Hesperian epochs, whereas using the lunar curve of [3] and a Mars/Moon factor ~1 consigns the shergottites to the Middle-to-Late Amazonian, a less probable result. The problem is worsened if a continually decreasing cratering rate since 3 Ga ago is accepted [6]. We prefer the adjusted Stöffler-Ryder curve because it gives better agreement with the meteorite ages (Fig. 3).

Comparing Fig. 3 and Fig. 1 gives dramatically different impressions of Martian chronology. For example, assuming that suitable habitats for flowering Martian life are most likely to have existed in the Noachian, the revised chronology of Fig. 3 doubles the corresponding time interval from ~4.5 to ~3.5 Ga ago to ~4.5 to ~2.5 Ga ago. Dating Martian basalts returned from known locations would remove the uncertainty on the Moon/Mars scaling factor, and thus on the time interval most conducive to emergence of Martian life.

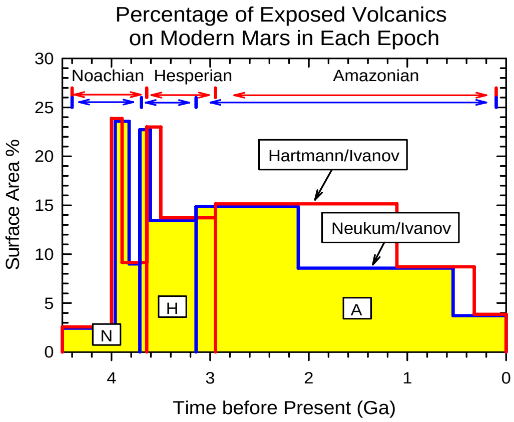

Figure 1. Age distributions for volcanic surface units on Mars using the dating systems of Hartmann/Ivanov (red) and Neukum/Ivanov (blue). From Fig. 15 of [1].

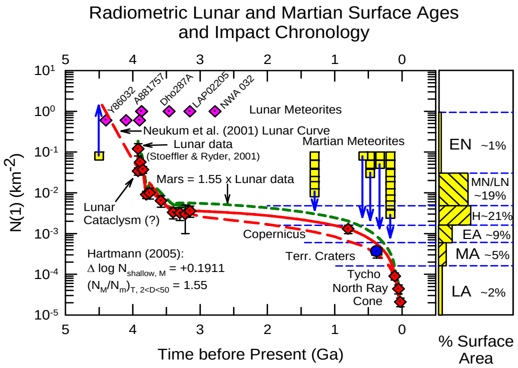

Figure 2. Lunar cratering frequency curve constructed from data summarized by [2] compared to that of Neukum et al. [3] and the ages of some lunar and Martian meteorites.

Chronology of aqueous activity: Crater-frequency chronologies require counting craters within areas with statistically significant numbers of craters. However, the search for Martian life within a returned Martian sample will be done on a micro-scale, as for carbonates in the Martian meteorite ALH 84001 [7]. If a positive result is obtained, chronological methods will need to be tailored to the specific habitat in which evidence is found. For the ALH 84001 carbonates, chemical zoning in carbonate globules resulted in radiogenic parent/daughter elemental fractionation that

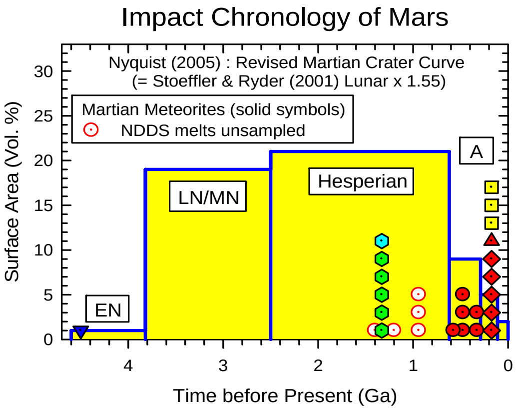

Figure 3. Martian meteorite ages compared to the age distribution of Martian volcanic surface units using a modified Martian crater-frequency curve = (Stöffler-Ryder) x 1.55.

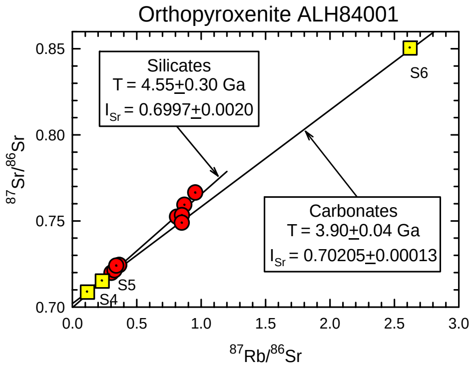

Figure 4. Rb-Sr isochrons for carbonates and host silicates in ALH 84001. Data from Borg et al. [8].

was exploited to determine the carbonate age (Fig. 4).

It is likely that the first Martian sample will be selected to contain evidence of past water. Sulfates are observed from orbit [9] and are present at the Opportunity landing site in Meridiani Planum [10]. To investigate the type of parent/daughter elemental fractionation expected for Martian sulfates, we measured the Rb/Sr ratios of gypsum, kieserite, and jarosite terrestrial analogs courtesy of R. Morris.

Two hypothetical scenarios are illustrated in Fig. 5. For sulfates developed on bedrock of basaltic shergottite composition and 180 Ma old, K-jarosite with ^{87}Rb/^{86}Sr ~1.0 would allow determination of a "precipitation age" as low as ~10 Ma, assuming a single event, or several events closely spaced in time. For ancient terrain (Fig. 5, bottom), a precise age would be expected even in the absence of K-jarosite. In case of apparent protracted sulfate precipitation, individual phases with contemporaneous sulfates would be sought. Ages also would be obtained by additional techniques, for example, laser ^{40}Ar/^{39}Ar dating [11]. Concordant ages by two or more techniques would verify the reliability of the chronometry.

Isotopic tracers for regolith components: Void-filling glasses in EET 79001 ("Lithology C") contain Martian atmospheric gases and S-bearing globules that likely are vestiges of impact-molten Martian regolith [12]. Variations in Sr-isotopic composition observed for lithology C compared to the igneous lithologies A amd B [13] probably reflect the presence of "exotic" Ca sulfides and sulfates in the Martian regolith [12]. Such regolith components are expected as a result of aeolian transport. The ultimate origin of non-mass-dependent S-isotopic fractionation in Martian sulfides may be photolysis in the Martian atmosphere [14]. Isotopic studies of returned Martian regolith could distinguish regolith components of differing origins.

Epilog: Here we avoided conclusions about Martian geochemical evolution from studies of "Martian" meteorites, emphasizing instead topics relevant to the "life" goal of Martian exploration, for which the meteoritic evidence is fragmentary. Nevertheless, a high-priority goal of MSR should be acquiring evidence to rule definitively for or against the Martian meteorite hypothesis, and to acquire igneous rocks whose analysis will complement the meteorite data. Very high analytical precision appears to be required to address some issues of Martian isotopic evolution, as has been demonstrated for meteorites (e.g., [15]). Similar or better precision should be possible for returned rock samples devoid of shock effects.

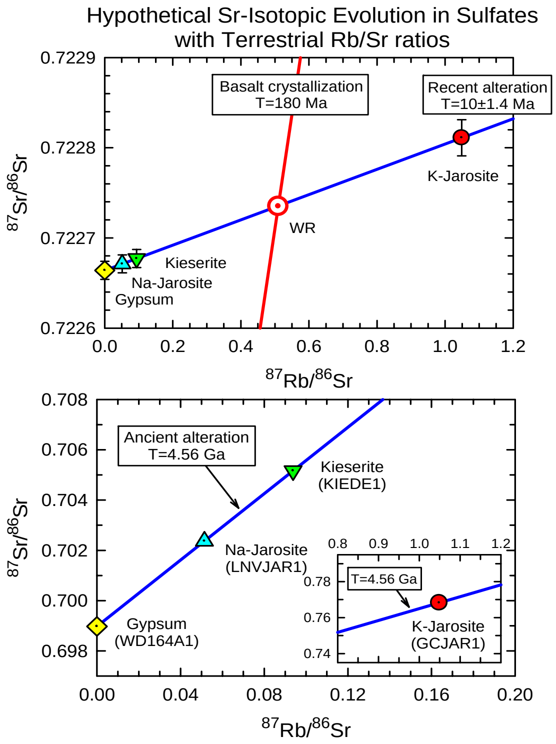

Figure 5. Hypothetical Sr-isotopic evolution in young (top) and ancient (bottom) Martian sulfates using Rb/Sr measured for terrestrial analogues.

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