THE SHERGOTTITE AGE PARADOX. L. E. Nyquist[1], L. E. Borg[2], and C.-Y. Shih[3]; [1]Code SN41, NASA Johnson Space Center, Houston, TX 77058 (e-mail: nyquist@snmail.jsc.nasa.gov), [2]National Research Council, Code SN41, NASA Johnson Space Center, Houston, TX 77058, [3]Lockheed-Martin Engineering and Sciences Co., 2400 NASA Road 1, Houston, TX 77258.

The radiometric ages of Martian meteorites present a paradox because Martian surface units are predominantly old whereas the Martian meteorites, particularly the shergottites, are predominantly young ($\leq$ 1.3 Ga). Fig. 1 compares the number of samplings of Martian surface units as inferred from Martian meteorites to the percentage of the Martian surface of various ages as determined from crater counts [1]. Here, meteorites with the same values of exposure and crystallization ages are grouped together to represent single events, using exposure ages from [2]. The three nakhlites and Chassigny probably were ejected ~10 Ma ago by a single impact into 1.3 Ga terrain, and are represented by a single symbol in Fig.1, whereas a separate impact ~15 Ma ago into much older, ~4.5 Ga terrain [3,4] is shown for orthopyroxenite ALHA84001. For the young basaltic and lherzolitic shergottites with ages <0.33 Ga, we have further subdivided the three ejection events suggested by [2] to account for the older crystallization age of QUE94201 relative to the other basaltic shergottites [5]. Alternatively, if all the shergottites were ejected in the three impact events identified by [2], the ~2.6 Ma event must have ejected material with a range of crystallization ages from ~165 Ma to ~330 Ma.

The above assignment of exposure ages to Martian surface impacts suggests that at least 3 of 5, and possibly 4 of 6, meteorite-yielding impacts occurred on young terrain. Gladman et al. [6], who compared measured exposure ages to expected transit times from Mars, preferred a model in which all Martian meteorites were ejected independently, in which case 6 of 11 meteorites would be derived from terrain <330 Ma old. However, Mouginis-Mark *et al.* [7], who considered possible source craters for SNC meteorites exclusive of ALHA84001, argued for a single impact, positing that the entire exposure age spectrum resulted from secondary break-up in space. Bogard [8] did not distinguish between the exposure ages of lherzolitic and most basaltic shergottites, and suggested that the exposure age data allowed simultaneous ejection of the nakhlites/Chassigny and ALHA84001, i.e., three events if basaltic shergottite EETA79001 was ejected separately, or only two if secondary break-up in space was responsible for the young exposure age of EETA79001. For those models exclusive of the single-impact model, ~33-66% of the meteorite-yielding Martian impacts occurred on terrain $\leq$ 330 Ma old; the single impact model requires that impact to be on young terrain also. Young volcanic terrain is rare on Mars, comprising ~2% of the surface area (Fig. 1). Thus, young shergottites appear to be over-represented by a factor of ~15-30. A possible explanation is that shergottite basalts actually are present within a larger surface area, but are not recognized from orbital photography. Indeed, spectral reflectance data suggest that basaltic shergottites may be common lava types on the Martian surface [9].

How might young basaltic shergottites be

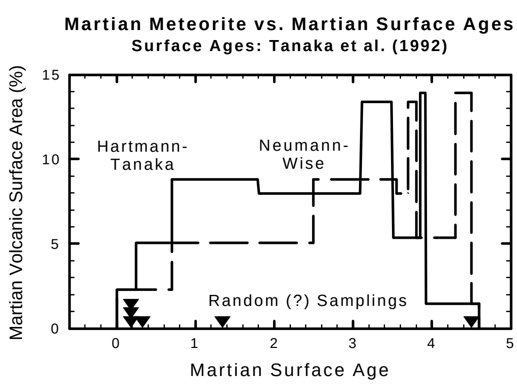

Figure 1. Comparison of apparent time of sampling the Martian surface to the relative area of Martian stratigraphic units. Martian surface ages from [1].

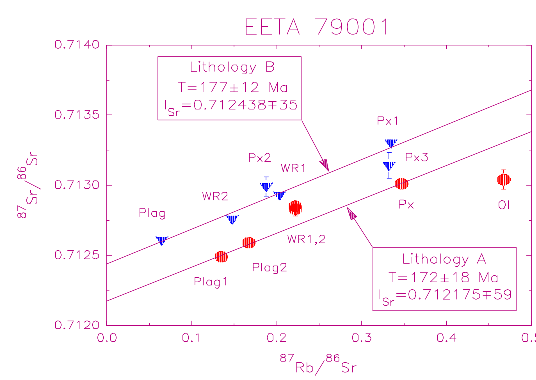

Figure 2. Rb-Sr isochrons for EETA79001 lithologies A and B.

hiding within older, compositionally similar, terrain? One possibility is that most meteoritic shergottites derive from an impact melt [4,10] produced by cratering in old "shergottite" terrain. Isotopic evidence for mixing of crustal- and mantle-derived components, and Sr-isotopic heterogeneities on a cm-scale within EETA79001 and Zagami are consistent with this hypothesis, as well as other possible explanations. Figures 2 and 3 show internal Rb-Sr isochrons for these shergottites [5,11], whereas Fig. 4 shows comparable data for a monzonite from the upper melt zone of the 65-km-diameter Manicouagan crater [12]. Rocks in this zone have an hypidiomorphic granular texture, mineral grain sizes $\geq$ 1 mm, and clast contents of <2% [13]. The analogy between the Rb-Sr isotopic data for this impact melt rock and that of the basaltic shergottites Zagami and EETA79001 is striking. The Sr-isotopic heterogeneity among the Manicouagan melt rocks (#117, 241, 417, and 408, Fig. 4) is consistent with remelting of the target rocks [12]. The isotopic analogy also extends to the K-Ar system. K-Ar ages of shock-metamorphosed Manicouagan anorthosites are ~70-90 Ma older than the ~214 Ma Rb-Sr (or K-Ar) ages of the monzonite [14]; ^{39}Ar-^{40}Ar ages of shergottites exceed the Rb-Sr ages as is well known [15].

Lest sampling pre-existing impact melt by a second impact be considered an *ad hoc* suggestion, we note just this possibility for Crater 3 of Mouginis-Mark et al. [7] located near the summit caldera of Olympus Mons. This crater is on some of the youngest terrain in the Tharsis region, considered the likely source region of the SNCs by [7]. Crater 5, preferred as "the" source crater for SNCs [7,16] is on older terrain, leading to the speculation that Crater 3 might be the source of shergottites and Crater 5 the source of nakhlites/Chassigny.

In spite of similarities between the Sr isotopic systematics of the shergottites and the Manicouagan impact melt rocks, other explanations of the shergottite data may nevertheless be possible. Mineralogical-petrographical studies of the shergottites have led to suggestions that their petrogenesis involved multiple magma pulses and/or chambers [17,18]. Sr-isotopic evidence of magma recharge of a crustally contaminated magma, as in the case of the shergottites, has been presented [16]. The presence of shallow-level "shergottite" intrusions periodically recharged from below, and occasionally excavated from above, may account for isotopic heterogeneities in the shergottites and present an alternative explanation of the shergottite age paradox. Lack of geologic control leaves open basic questions about the Martian meteorites, underscoring the need for spacecraft return of documented Martian samples. Such samples would permit absolute age dating of Martian surface units as well as many other types of studies.

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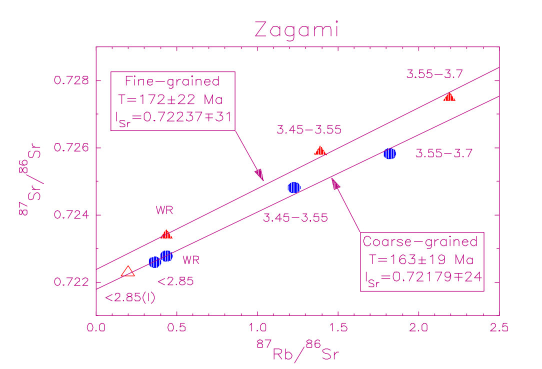

Figure 3. Rb-Sr isochrons for Zagami coarse and fine-grained samples.

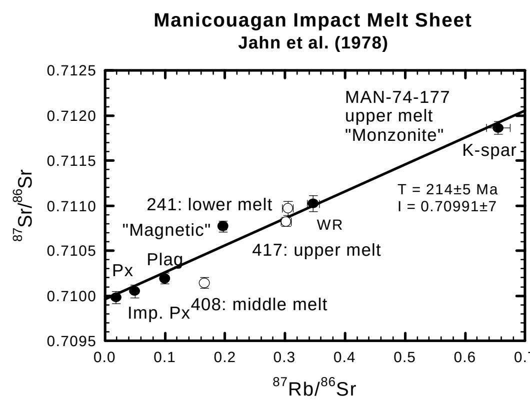

Figure 4. Internal Rb-Sr isochron for a melt rock from the upper melt zone of the Manicouagan melt sheet.