SPECULATIONS ON THE IGNEOUS HISTORY OF MARS: INFERENCES FROM THE SNC METEORITES. John H. Jones, SN4, NASA Johnson Space Center, Houston, TX 77058.

In general, attempts to delineate an a priori sampling strategy for missions to terrestrial planets must be simple. In the case of the Moon, for example, the simplest and most obvious plan -- that to sample both the highly-cratered, high-albedo highlands and less-cratered, low-albedo mare -- has proven very useful. However in the case of Mars, multiple missions and/or roving samplers may prove expensive or infeasible. Thus, we may be limited to collecting samples from a single site, and, consequently, consideration of sampling strategies for a Mars mission is more critical than for the more-accessible Moon.

Based on the orbital and surface photography of the Mars Mariner and Viking missions, four types of martian samples are probably available: (i) basaltic rocks, such as comprise the Tharsis volcanic plateau; (ii) granitic(?) rocks from the heavily-cratered ancient crust; (iii) windblown dust and "loess;" and (iv) sediments and fluvial deposits, formed during the events that produced the martian channels. Here, it will be argued that the samples which will be most informative are a combination of basalts and windblown dust. The logic behind this conclusion is based on three observations. Firstly, evidence from the SNC meteorites argues that basaltic samples will yield information both about the mantle and crust of Mars. Secondly, the global nature of martian windstorms [1] implies that windblown dust can provide a representative sample of the martian crust. Thirdly, dust storms the size of those on Mars should ensure that dust deposits are nearly ubiquitous. Consequently, any sampling venture to collect basalts could also sample dust, and these two dichotomous sample sets should provide constraints on the geological history of Mars.

The latter observations are based on Mariner, Viking and Earth-based imaging and require no explanation. The first observation, based on the chemical and isotopic relations within the SNC suite, will be explored in more detail. Below, it is assumed that the SNC meteorites are martian. The questions that will be addressed are: (i) can the SNC suite be explained within a single petrologic framework? and (ii) do the SNC meteorites give us information about the nature of the martian crust and mantle? The answer to both questions is believed to be yes.

Isotopic systematics of the SNC meteorites. The nakhlites and Chassigny have the simplest isotopic relationships. A variety of isotopic dating methods yield an igneous crystallization age of ~1.3 Æ for these rocks [2]. Within error, Nakhla and Chassigny have the same initial $^{87}Sr/^{86}Sr$ [3,4]. All the nakhlites and Chassigny have cosmic ray exposure ages of about 10 m.y. [2]. These meteorites thus comprise a group of closely-related igneous rocks which crystallized pene-contemporaneously and then were simultaneously exposed to cosmic radiation.

The shergottites are much more complex, and a variety of ages have been proposed for this group. Igneous crystallization "ages" from whole-rock and internal isochrons range from 1300 to ~150 m.y. [2,5], but, regardless of the exact time of crystallization, the event(s) must have occurred relatively recently (≤ 1.3Æ). In contrast, whole-rock Rb-Sr and Pb-Pb analyses of the shergottites yield "ages" of 4.0-4.6Æ [6]. The simplest explanation for the older whole-rock isochrons is that, at the time of crystallization, there was mixing between two isotopically distinct reservoirs that had been separated for ~4.5Æ. If this interpretation is correct, then all whole-rock ages are suspect and igneous crystallization ages are confined to a period of 360 to 150 m.y.

Presently, the only shergottite ages that recur in all rocks and isotopic systems are 150 - 250 m.y. [2]. Various interpretations have been given to this narrow range of ages, but the preservation of igneous zoning trends and the absence of any evidence of thermal or hydrothermal metamorphism argue that these ages reflect igneous events -- not shock or metamorphic resetting [6]. Below, the crystallization ages of the shergottites will be assumed to be ~180 m.y.

Chemical signatures within the SNC suite. The chemistry of the SNC suite has three major points of interest. (i) Shergotty, Zagami and EETA79001 (hereafter, 79001) are quartz-normative, pyroxene - plagioclase basalts which probably do not represent simple mantle-derived magmas [7]. (ii) The nakhlites, Chassigny, ALHA77005 (hereafter, 77005) and 79001(?) plausibly crystallized from mafic (or ultramafic) magmas -- or from the evolved products of such magmas -- which crystallized olivine and calcic pyroxene [7,8]. Whether 79001 should belong to this group is unclear. Although 79001 is quartz-normative, ultramafic xenoliths in 79001A have the same age and initial $^{87}Sr/^{86}Sr$ as their host [9] and could possibly be "cognate" xenoliths from an earlier, mafic precursor to the 79001A magma. (iii) Using the assumption of a 180 m.y. crystallization age, Shergotty and Zagami have negative $\varepsilon(Nd)_I$ while 79001, 77005 and the Nakhla source region have large, positive $\varepsilon(Nd)_I$ [6]. There is a rough correlation between $\varepsilon(Nd)_I$ and $\varepsilon(Sr)_I$ which is suggestive of mixing between complementary reservoirs that have been separated for long periods of time, as has been suggested for some terrestrial basalts [10]. This same type of relationship between the shergottites and the Nakhla source region can also be seen on a $^{207}Pb/^{204}Pb$ *vs.* $^{206}Pb/^{204}Pb$ diagram [6].

A model, with application to martian sampling. The limited amount of evidence that we currently possess suggests that Mars differentiated into a crust and a depleted mantle very early in its history (4.0 - 4.6 Æ ago). The evidence also suggests that there has been igneous activity on Mars within the last 200 m.y. and that the final products of this activity (shergottites) were produced by extensive interaction of mantle-derived mafic magmas with an ancient sialic crust. Nakhlite and chassignite magmas apparently avoided much of this contamination and remained very mafic [8]. The lack of a precisely defined mixing line for shergottite $\varepsilon(Nd)_I$ *vs.* $\varepsilon(Sr)_I$ does not invalidate the general model, but does prohibit simple, two-component mixing. The crust and/or mantle of Mars is probably isotopically heterogeneous.

This model provides a general construct both for sampling the martian surface and for testing the SNC analog. Sampling should begin in the Tharsis region -- the volcanic province that is least cratered and that should represent the most recent igneous activity. The radiometric ages and oxygen isotopes of rocks from Tharsis should be sufficient to address whether SNC's do come from Mars. If they do, then variations in chemical and isotopic compositions of SNC meteorites and **collected basalts and dusts** should allow evaluation of crustal and mantle signatures.

Caveat emptor. Clearly it is difficult to generalize, on the planetary scale, from a few samples of poorly-known provenance which have had a complex petrogenesis. However, the most chronic SNC problem, that of the radiometric ages of the shergottites, is not necessarily the most acute. For example, if one generalizes from the 77005 data of [5] then the time of maskelynitization of the shergottites was less than 30 m.y. ago. Thus, if the whole-rock ages are viewed with suspicion, the only possible times of igneous crystallization (150 - 360 m.y.) are too similar to greatly affect the above conclusions.

In many ways the 1.3Æ Sm-Nd whole-rock isochron of the shergottites is the most difficult observation to relate to the model presented above. Firstly, in the simplest model, Sm-Nd mixing between a crust and a magma from a depleted mantle should yield an isochron that is $\geq$ 4.5Æ -- not less. More complex petrogenetic models can alleviate this problem somewhat, but not in any truly satisfying way. Secondly, there still exists the concordance of ages between the shergottite Sm-Nd whole-rock isochron and the internal isochrons of the nakhlites and Chassigny.

For the present, because there is no evidence for an event at 1.3Æ in the shergottites' Pb-Pb systems [11], it seems most prudent to view the 1.3Æ age as coincidental. The difficulty in achieving an age that is less than 4.5Æ can probably be circumvented by postulating a heterogeneous crust (and/or mantle) -- a conclusion already implied by the $\varepsilon(Nd)_I$ *vs.* $\varepsilon(Sr)_I$ discussion. Presently, it seems that dating systems with parents that are very incompatible during silicate partial melting (U-Th-Pb, Rb-Sr) paint a simpler picture of martian evolution than Sm-Nd.

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