FUNDAMENTAL IMPORTANCE OF RETURNED SAMPLES TO UNDERSTANDING THE MARTIAN INTERIOR.
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Introduction: Understanding the formation and evolution of the martian interior is predicated largely on inferences made from the study of martian meteorites. In particular, martian basaltic meteorites (shergottites) have yielded many critical insights regarding the planet's bulk composition, its rapidity of differentiation after accretion, the nature of distinct geochemical reservoirs that remained unmixed until comparatively recent times, and the geologically recent ages of magmatic activity on Mars. They have also provided information that constrains a host of other, nonmagmatic processes. Shearer et al. [this meeting] provided a concise outline of most of these important data.

The mantle sources for martian basalts have been modeled as products of an early magma ocean that differentiated rapidly into two reservoirs [1-5]. These include a reservoir displaying long-term depletions in incompatible trace elements and comparatively reducing oxygen fugacity (fO_2) within a log unit of the iron-wüstite (IW) buffer; and a much more enriched reservoir displaying fO_2 several orders of magnitude more oxidizing. Most workers have concluded that the martian mantle is more Fe-rich than is Earth's; in addition, superchondritic CaO/Al_2O_3 in basaltic meteorite compositions is best explained by early fractionation of (probably majoritic) garnet during magma ocean crystallization. Initially, the enriched reservoir was taken to represent martian crust [4, 6], but we have argued that it can be produced by differentiation within the mantle without the need for a (thus far unsampled) crustal component [5]. Calculated compositions of melts of the depleted mantle, variably mixed with small amounts of the enriched component, appear to account successfully for the mixing trends evident in many types of martian basalt compositional data.

Magma ocean models are based on compositions of the basaltic meteorites. Mars magma ocean models as currently constituted require that all martian basalt source regions be superchondritic with respect to CaO/Al_2O_3 [5]. This is accomplished by invoking fractionation of garnet as an *early* crystallizing phase, sequestering some alumina (garnet crystallization at later stages results in bad mismatches with major and trace element compositions of the meteorites). All subsequent processes of magma ocean crystallization and later melting of the source rocks thus formed are expected not to perturb this ratio [7]. Unlike the case for the Moon, in which most basalts also have superchondritic CaO/Al_2O_3, plagioclase is not a near-liquidus phase for likely magma ocean compositions, so garnet is the most likely agent of bringing about the elevation in this ratio, and it is in fact a near-liquidus phase for candidate magma ocean compositions at relevant pressures [7-9]. Good matches to isotopic and trace element data are also obtained in this formulation. In such a model, which assumes that the magma ocean was extensive and planet-wide, it is simply not possible for there to exist mantle lithologies that do not inherit the elevated CaO/Al_2O_3 ratio after early garnet removal.

However, the few measurements by the Mars Exploration Rovers of surface rocks that have been interpreted as basaltic (from Gusev crater) do not have superchondritic CaO/Al_2O_3 [10]. Fig. 1 plots martian basaltic meteorite compositions (data from [11]) for

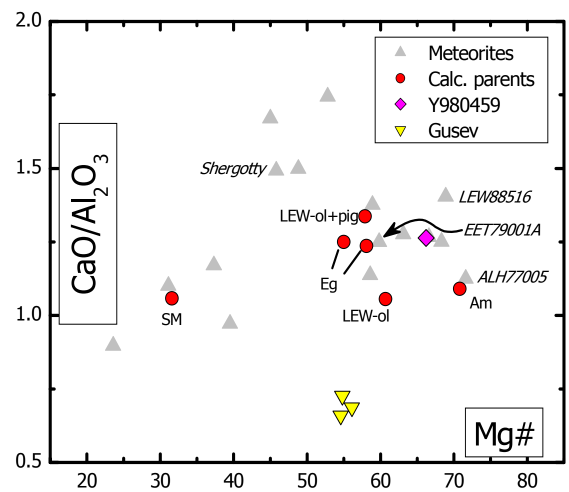

Figure 1. Comparison of martian basaltic meteorites (grey symbols) with Gusev compositions Adirondack, Humphrey, and Mazatzal. See text for discussion

comparison with Gusev data. The Yamato 980459 composition is highlighted, as there is good evidence that it represents a liquid composition [12, 13] and not a crystal accumulate as do almost all the others; if this is true then its composition is of special significance. Also plotted are parental liquid compositions calculated by various authors for Shergotty (SM, [14]), LEW88516 (LEW-ol and LEW-ol+pig assuming olivine and olivine+pigeonite saturation, respectively, [15]), EETA79001 (Eg, [16, 17]), and ALH77005 (Am, [18]). The meteorites for which these parent liquid compositions were estimated are labeled with their names. This diagram illustrates the consistency of superchondritic CaO/Al_2O_3 for martian basaltic meteorites, and that the Gusev compositions are very close to the chondritic value of ~0.80.

At this juncture it is not at all clear whether the reported Gusev compositions actually represent bona fide basalts or whether they instead reflect surface alteration and weathering, which could easily perturb the CaO/Al_2O_3 ratio. If those values truly represent the compositions of basalts on the martian surface, then their compositions require that there be mantle source rocks that *do not* have superchondritic CaO/Al_2O_3, because no phase involved in either melting or crystallization would fractionate Al from Ca. It is reasonable to assume that melting to produce martian basalts occurs in the mantle at pressures below those where garnet would be a stable residual phase, given that the most primitive martian liquid, Yamato 980459, shows multiple saturation with olivine + low-Ca pyroxene below 2.0 GPa under both anhydrous [19] and volatile-bearing [20] conditions. These phases do not perturb CaO/Al_2O_3.

Therefore, basaltic samples returned from the martian surface hold the potential for affecting our understanding of the formation and evolution of the martian interior at the most fundamental level. If basalts with *genuinely magmatic*, chondritic CaO/Al_2O_3 are discovered, then the global magma ocean hypothesis for the formation of the martian interior is almost certainly incorrect, and a different process will be required that allows for the formation of at least two different types of mantle source rocks: one with the chondritic ratio, and another with the superchondritic ratio.

How representative are the basaltic meteorites? There is ample evidence that the martian meteorites represent a biased or skewed sampling of martian igneous lithologies. As has been argued by Irving and coworkers [21, 22], it is likely that the meteorites came from only a few volcanic centers on Mars, possibly all part of Tharsis. For example, the basaltic meteorites' crystallization ages are clustered in three groupings, at ~180 Ma, ~330 Ma, and ~500-575 Ma (data summarized in [11]). They also form clusters in certain geochemical parameters, such as the isotopic and incompatible trace element compositions summarized in Fig. 2. Thus it is quite reasonable to suggest that our sampling of the igneous reservoirs on Mars is incomplete. In fact, it is remarkable that the small and limited sample set has allowed such broad inferences to be made about the nature of the martian interior.

If not a magma ocean, then what? If basaltic samples eventually returned from Mars do in fact have chondritic CaO/Al_2O_3, largely negating the validity of a model invoking a global, extensive magma ocean,

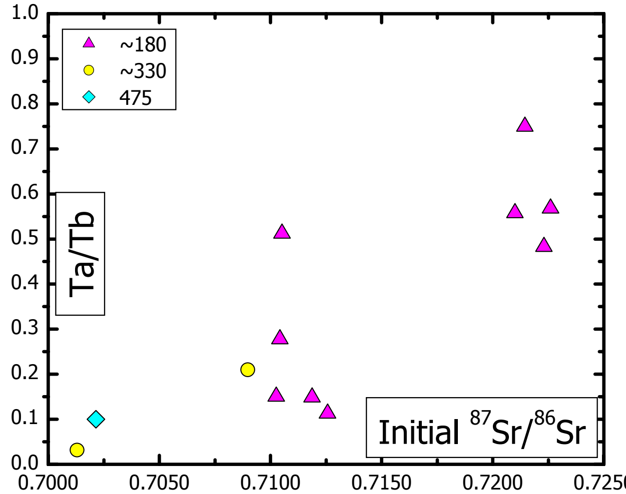

Figure 2. Ta/Tb vs. initial Sr isotopic composition for martian basaltic meteorites of various age ranges. Data summarized in [11].

what sort of model could provide a defensible alternative? One possibility is that a "superplume" early in Mars' history produced the geochemical reservoirs that are unquestionably reflected in the compositions of the basaltic meteorites. In this view, many processes invoked as occurring in a global magma ocean, and especially early garnet fractionation to impart superchondritic CaO/Al_2O_3, may have taken place, but to a more limited extent and only within the plume. Such a feature may operate in a similar fashion to the geophysical models of Kiefer and coworkers [23, 24]. Other mantle regions unaffected by the plume could , at least potentially, retain a chondritic value. Making such a distinction shows that the value of returned basaltic samples would be of critical and fundamental importance in constraining the nature and history of the interior of Mars.

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