SNC METEORITES AND THE BULK COMPOSITION OF MARS. John Longhi, Lamont-Doherty Earth Obsvervatory, Palisades, NY 10964 (longhi@ldeo.columbia.edu)

Although igneous rocks such as the SNC (shergottite-nahklite-chassignite) meteorites — the meteorites from Mars — do not provide direct information about their parent body's bulk composition, their compositions do hold important clues that can be employed to estimate bulk composition. For example, because K and La are highly incompatible in igneous processes, their ratio changes little during igneous differentiation; yet K/La may vary during nebular processes because K is moderately volatile, whereas La is relatively involatile. So the Earth, its moon, and the various groups of igneous meteorites have distinct K/La ratios. The average K/La of the SNCs is ~ 600 [1] as compared to the terrestrial value (~350) — both of which are much higher than K/La in lunar rocks and eucrites, but lower than chondritic K/La (~2400). Therefore, numerous authors have concluded that the SNC parent body (Mars) has higher abundances of other moderately volatile elements (alkalis, sulfur) than the earth, and possibly higher abundances of carbon and water. Similarly, Mn/Mg is nearly constant in ordinary and C1 chondrites, and Fe/Mn varies little during igneous processes; so if the silicate portion of a planet has chondritic proportions of refractory elements (Ca, Al, Ti, Mg, REE), then Fe/Mn in basalts can yield Fe/Mg in the bulk silicate. Dreibus and Wånke [1] derived a value of 0.75 for MgO/(MgO+FeO) in this way for the martian crust and mantle. These authors also found that the SNCs were systematically lower in Co, Ni, and Cu than their terrestrial counterparts with similar FeO and MgO concentrations; they surmised that FeS liquids scavanged chalcophile elements out of the early martian mantle and into the core. They derived the bulk sulfur content of Mars and its coupled iron from K/La (above) and other volatile element systematics. Finally, they assumed a Fe/Si ratio for Mars equivalent to that in C1 chondrites (1.71) and apportioned the balance of the Fe not bound with sulfur or mantle silicate to the core. The result is a core with 14.5% S that has a radius approximately half that of the planet [2].

Recent experimental investigations of the DW model for variation of mineral phases and their compositions as functions of temperature and pressure [3,4] have enabled very detailed predictions of the mass distribution with depth from which the moment of inertia factor may be calculated. Calculations [3] show that for a DW core (14.5% S) and mantle (Mg' = 0.75) a reasonable fit to the recently determined moment value of 0.3662 [5] is obtained for a ~ 50 km thick crust (ρ = 3.0 gm/cm^3). However, the bulk Fe/Si for this configuration is much lower (1.32) than the DW prediction, as is the core radius (1420 vs 1690 km). By virtue of Mars not having a C1 Fe/Si ratio, many of the elemental concentrations, especially sulfur, must be recomputed, although the Fe/Mn/Mg systematics and hence the estimate of bulk silicate Mg' appear sound as long as Mars has an ordinary chondrite composition. A direct measurement of core size thus remains essential in order to constrain bulk composition.

Detailed chemical and isotopic measurements reveal complexities in planetary differentiation that will make any reconstruction of Mars' bulk composition difficult. Recent age determinations of shergottites have resolved a long-standing uncertainty in their crystallization ages in favor of ages in the range of 200 to 400 Ma [6]. These young ages, together with 1.3 Ga ages of the Nahklites and Chassigny, require that the SNC source regions maintained more pronounced depletions of incompatible elements than the terrestrial MORB source since primordial differentiation (4.525 Ga) and that the parent magmas of the classical shergottites (Shergotty, Zagami) assimilated a long term light-REE enriched component (crust) [7]. The isotopic evidence indicates little or no mixing between differentiated and primitive mantle or between differentiated mantle and crust during martian history.

Estimated SNC parent magma compositions [e.g., 8] have lower Al_2O_3 concentrations than terrestrial MORB and OIB [7]. These low Al_2O_3 contents are consistent with highly depleted source regions as inferred from the isotopic data. New modeling of polybaric melting reveals that the extent of the depletion in terms of major elements is greater than expected for basalt extraction and may require that the portion of the martian mantle from which the SNC magmas are derived is a magma ocean cumulate. Figure 1 contrasts the results of fractional fusion calculations for various source compositions with the compositions of the SNC magmas. The strings of symbols are compositions of aggregates of melt progressively extracted from an ascending source; the larger individual symbols are the initial source compositions. Numbers indicate the pressures (in kilobars) of initial and final melting. Also shown for reference are the terrestrial PUM composition (large cross)[9], the estimated MORB source (the small tic on the left arm of the PUM cross)[10], and the estimated source of the lunar green glass magmas ( )[11]. The large square indicates the DW mantle composition with 3.0 wt % Al_2O_3. As expected melts derived from this composition (small squares) do not approach the range of SNC magmas. Neither do melts derived from a source that is DW – 2% shergottite (circles), nor DW – 10% shergottite (asterisks), nor a 3:1 γ-spinel + majorite cumulate (ovals)[12]. These sources have 2.85, 2.3, and 1.8 wt % Al_2O_3, respectively (Table 1), whereas PUM and depleted PUM differ by only 0.1 wt % [10]. DW-10 is an extreme model (TiO_2 = 0) equivalent to extraction of a 100 km thick shergottite crust. Its apparent failure rules out basalt extraction as a global differentiation mechanism. It may prove possible to reach the SNC field with a source similar to the spinel-majorite cumulate (SMC) by not adding some the initial high pressure melts to the aggregate melt pool (this is equivalent to episodes of sequential melting [6]) or by initiating melting at much higher pressures. Conversely, it may prove necessary to start with a cumulate source ("**?**") containing even lower Al_2O_3 than the SMC model. The simplest way to produce such a source is by sinking the late-stage pyroxene cumulates of a magma ocean into a barren interior formed by earlier olivine accumulation at the base of the magma ocean.

In any case, source regions with significantly less Al than DW are required for the SNC magmas. This means that extent of planetary differentiation is much greater on Mars than the Earth and that little if any garnet is stable in the SNC source regions. Therefore, calculations of the density distribution will need to be revised accordingly.

Table 1. Model Source Compositions (wt % oxides)

	DW [1]	DW -2% Sh	DW -10% Sh	γ-sp maj [12]
SiO_2	44.47	44.32	43.74	43.01
TiO_2	0.10	0.08	0.01	0.08
Al_2O_3	3.00	2.85	2.28	1.60
Cr_2O_3	0.80	0.82	0.89	0.71
FeO	17.93	17.89	17.69	12.59
MgO	30.25	30.82	32.98	39.96
MnO	0.50	0.50	0.50	0.34
CaO	2.40	2.22	1.56	1.50
K_2O	0.037	0.025	0.007	0.013
Na_2O	0.50	0.47	0.35	0.20

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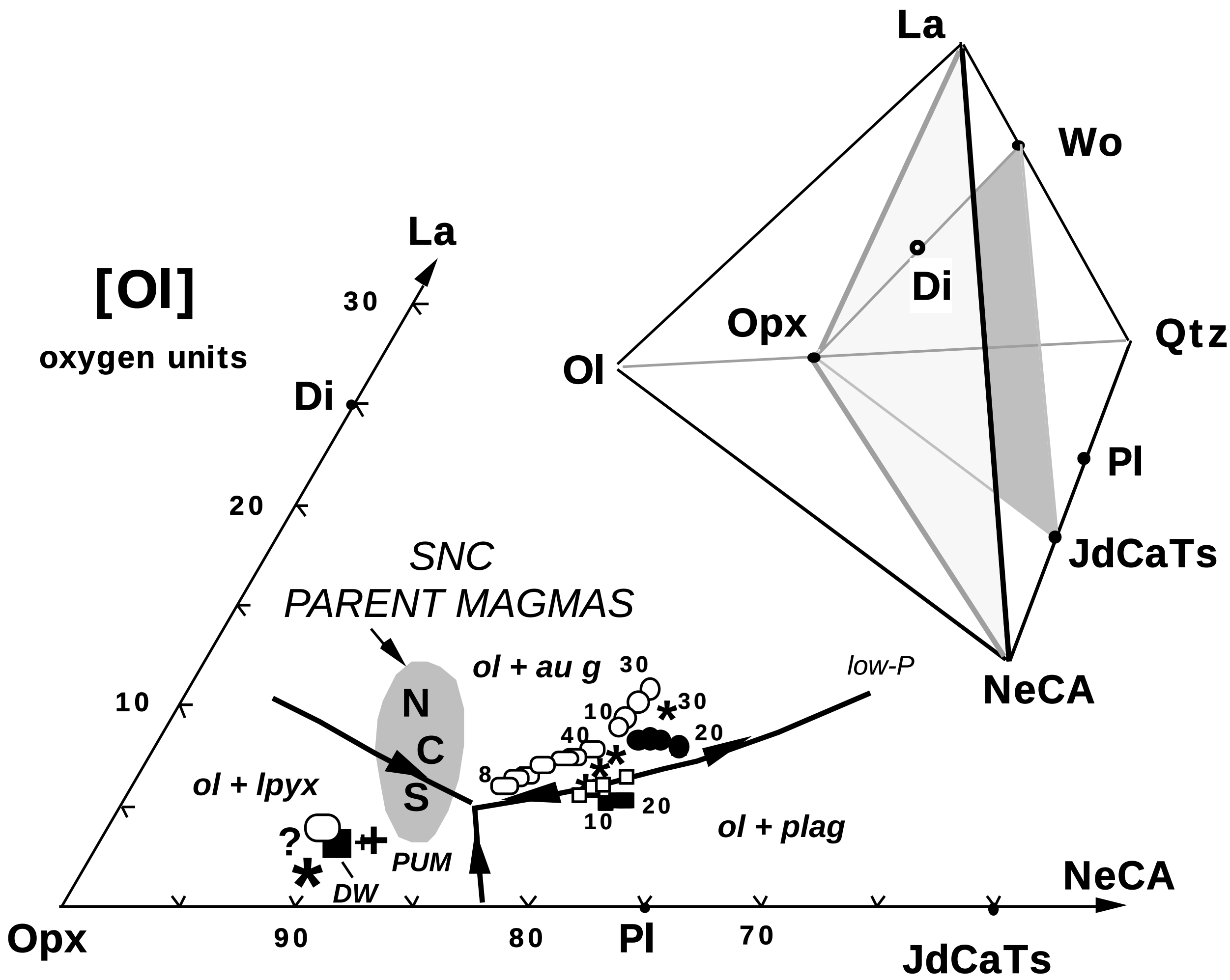

Figure 1. Olivine projection in the system larnite(La)-olivine(Ol)-nepheline+CaAl2O4(NeCA)-quartz(Qtz). Liquidus boundaries and field of SNC parent magma compositions modified after [7,8]. Tracks of symbols are traces of pooled melt compositions generated with a modified version of the polybaric fractional fusion algorithm of [11]. Numbers are pressures of initial and final melting. Compositions of symbols are explained in text. In the current version the heat released during decompression determines the amount of melting and melt is extracted only when weight fraction exceeds an arbitrary porosity limit (here 0.007).