

MARTIAN MAGMAS AND MANTLE SOURCE REGIONS: CURRENT EXPERIMENTAL AND PETROCHEMICAL CONSTRAINTS

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Mantle bulk chemical composition has been based on two constraints, SNC meteorites and the moment of inertia. Recently, the moment of inertia has become highly controversial and cannot be considered useful (1, 2, 3). The SNC compositions provide strong constraints (4, 5), but it has not been conclusively proven that SNC's are of Martian origin. It could reasonably be argued that we do not know the composition of Mars! Never-the-less the following discussion is based on the presumption that SNC's are of Martian origin and that the model for the Martian mantle composition based on SNC geochemistry and the assumption of a chondritic bulk composition is accurate. The primary difference between that Martian mantle composition and the Earth's upper mantle is the ratio of Mg to Fe, expressed as the mg# (=atomic Mg/Mg+Fe).

Mantle mineralogy can be calculated from experimental and thermodynamic constraints given the bulk composition. The major mineral mode in the Martian mantle at a pressure of 30 Kbar is (roughly) 50wt% olivine, 25 orthopyroxene 15 Ca-pyroxene and 10 garnet, which is very similar to the Earth's upper mantle (6). A major difference compared to Earth is that garnet is stabilized at lower pressures in Mars (7). A second probable difference which may be important is that the lower mg# will stabilize pigeonite pyroxene relative to clinopyroxene at temperatures below the solidus (8). The presence of pigeonite instead of Cpx could affect partitioning of several trace elements, e.g. REE between source region and primary magmas.

Volatiles in the mantle source region are poorly defined. Sulfur is clearly present in significant abundance (9). The H₂O content is based on SNC's which have yielded two very different conclusions, one that the Martian mantle is extremely dry (10), and the other that it is probably at least as wet as Earth's mantle (11). Experimental and petrochemical arguments require at least a two-stage melting history for at least some SNC source regions (which would give erroneously low estimates for mantle H₂O), and SNC's themselves are highly fractionated (which would yield high estimates). Carbon in the Martian mantle is unconstrained, but arguments based on planetary accretion would suggest that carbon in the Martian mantle is probably greater than in the Earth's (12).

Mantle solidus temperatures are well constrained for a volatile-free mantle at pressures to 30 kbar (230 kms depth)(8, 13). The solidus temperature for a carbonate-bearing mantle is complex (14, 15, 16, 17). At pressures <20 Kbar carbonates are not stable and have little direct effect on solidus temperatures. Above 20 Kbar a very small amount (<<1%) of an alkali carbonate liquid is formed at temperatures <1000°C. At 25 kbar Mg-Fe calcite melts at 1200-1225°C.

Primary magma characteristics are dominated by the iron-rich, low mg# character. At low degrees of melting, magmas will be in equilibrium with garnet at pressures above 15-18 Kbar. Compositions are well constrained for a volatile-free mantle at 25 Kbar, where the melt resembles an iron-rich (23wt% FeO), picritic, alkali basalt at low degrees of partial melting (18). With an increase in the degree of melting the primary magmas will trend toward iron-rich komatiites (13). A carbonate-bearing mantle at pressures above 20 Kbar will possibly form a carbonatitic melt at low degrees of melting, and by 1250°C (possibly 2% melting) the melt will have a large silicate component and may resemble a kimberlite magma (17).

Derivative magmas. Primary magmas will definitely fractionate olivine during their ascent to the surface; thus, decreasing their mg# and increasing SiO₂, Al₂O₃ and CaO contents. Primary magmas produced by small degrees of partial melting would have low initial mg#'s and this fractionation would produce magmas with mg#'s far lower than SNC parent magmas. Thus, it is probable that all SNC parent magmas are produced either by large degrees of partial melting, or that their source region has under gone at least one previous melting event (5, 19). The high H₂O content implied for the Chassigny and Shergotty parent magmas (11) suggests a more

complex history for those magmas and their source regions than has yet been envisioned for Mars. The oxygen fugacity estimated from SNC's is close to the quartz-fayalite-magnetite buffer reaction (11, 20). The viscosity of a generalized SNC parent magma has been measured and ranges from 10 to 200 poise over the 1350° to 1250°C temperature range at one atmosphere pressure (21). Those viscosities are only slightly higher than the 1-3 poise viscosity of the 23 kbar primary magma at 1450°C (6).

CO₂ solubility has been measured in the proposed parent composition of the SNC EETA79001 and found to be similar to the solubility in terrestrial basalts with higher mg#; implying there is little or no mg# effect on CO₂ solubility (22). The very low solubility at low pressure means that CO₂ evolution will provide a driving force for magma degassing on Mars as it does on Earth.

Conclusions which can be reached from the available data are (1) that any Martian magma produced by processes equivalent to those on Earth will have a significantly higher mg# (2) the lower mg# will result in lower liquidus and, in mafic and ultramafic compositions, lower solidus temperatures (3) that Magmas on Mars can have high H₂O contents and hence, erupt explosively, and (4) that magmatism on Mars shows considerable complexity based on just the few SNC samples available.

Future work should include continued study of the phase chemistry of SNC's followed by mineral equilibria calculations, melting experiments on hydrous and carbonated mantle mineral assemblages, measurement of combined CO₂ and H₂O solubilities, and attempts to recreate the line of descent that produced SNC parent magmas. Much more work is needed on the density and viscosity of the iron-rich melts characteristic of Mars for use in fluid dynamic modelling of magma collection, ascent and eruption.

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