

The Thermochemical Evolution of the Martian Mantle: Alkali Abundances and Their Effects on the Mantle Solidus and Magma Production Rate over Time

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Studies of the martian meteorites suggest that the martian mantle is enriched in alkalis (Na and K) and iron (lower magnesium number) relative to Earth. The Mars primitive silicate mantle is estimated to have 0.5-0.9 wt% Na₂O with a magnesium number of 75-80 [1-4]. In comparison, the primitive silicate Earth mantle has Na₂O of 0.35 wt% and a magnesium number of 89 [5]. Both differences lower the solidus temperature on Mars relative to Earth.

To quantify the effects of composition on solidus temperature, we analyzed experimental melting results for a suite of peridotite melting studies at 1 and 3 GPa with Na₂O between 0.02-0.66 wt% and magnesium number between 75 and 90.5 [3, 6-13]. We calculated multivariable least squares fits to test how changes in total alkali content (Na₂O + K₂O) and magnesium number affect the solidus. The 3 GPa solidus varies between 1430 and 1515 °C, depending on composition. Our parameterization explains 95% of the total data variance, with an RMS misfit of 7 °C. At 1 GPa, the solidus varies between 1195 and 1270 °C. Our parameterization explains 62% of the data variance, with an RMS misfit of 15 °C.

Based on this parameterization and the differences in mantle composition summarized above, the Mars mantle solidus is about 30 °C lower than the Earth solidus at 1 GPa and about 50 °C lower at 3 GPa. At both pressures, the alkali abundance and magnesium number each account for about half of the difference in solidus temperature. Incorporating these differences in solidus temperature into a model of pressure-release mantle plume melting [14] increases plume melt production rate by a factor of 3-10. Clearly, the small differences in mantle composition between Earth and Mars are important and might be the difference between a planet that is still slightly active volcanically and a planet that is magmatically dead at present.

The differences in chemical composition cited above are for the primitive mantle prior to separation of any crust from the mantle. Because Na is incompatible, it partitions into the crust

during volcanism and thus both its abundance in the mantle and its effect on the solidus temperature and the magma production rate decline over time. On the other hand, the magnesium number of the mantle does not change significantly with time, and its effect on the solidus should continue to be important to pressure release melting in mantle plumes on present-day Mars. We recently modeled the thermal and magmatic evolution of Mars using a model that accounts for water loss from the mantle and its effects on the solidus [15]. In our on-going work, the model is being adapted to also track transport of Na into the crust and to parameterize the effects of Na loss from the mantle on the solidus using the results described above.

The Gusev Crater basalts and pyroclastics measured by the MER rover Spirit have Na₂O 2-3.5 wt % , while the much younger olivine-phyric shergottites typically have Na₂O < 1.2 wt % . This may indicate loss of Na from the mantle over time, but differences in other factors such as melt fraction and melting pressure also need to be considered, and the two rock types may represent separate mantle reservoirs [16].

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