HIGH SILICA CONTENTS IN MARTIAN BASALTS AND ITS RELATIONSHIP TO MAGMATIC WATER. J. B. Balta and H.Y. McSween Jr., Planetary Geoscience Institute and Department of Earth & Planetary Sciences, University of Tennessee, Knoxville, TN 37996-1410, jbalta@utk.edu.

Introduction: Understanding the petrogenesis of martian basalts is hampered by the lack of context for the available samples. While we have a variety of igneous rock types, including basalts and cumulate rocks, from meteorites alone it is difficult to extrapolate to global statements about martian magmatism. However, the exploration of Mars in the last decade has significantly improved our ability to make inferences about global processes. The presence of rovers on the surface has increased the variety of rock types observed, producing analyses of alkaline basaltic rocks, probable pyroclastic material, and images of rocks which are vesiculated [1]. In addition, orbiting spacecraft have dramatically increased our understanding of the geophysical properties of Mars, including establishing composition and density constraints on the martian crust [2, 3]. Finally, continued sampling efforts have expanded the variety of meteorites available and improved our understanding of martian magmatism. Consequently, it is now possible to make large-scale interpretations about global magmatic processes on Mars, including estimates of magmatic volatile abundances and inferences about the history of surface volcanism.

Based on these newly available data, a number of authors have proposed plausible compositions for martian parental magmas, which could have produced many of the meteorites in our collection through crystallization and mixing processes. These compositions include the Gusev alkali basalts [1,4] and three shergottite magmas [5-7]. These represent geochemically depleted, intermediate, and enriched shergottite compositions, spanning the variety of trace element signatures currently observed in shergottites. They also may include magmas that are close to parental to the chassignite meteorites [8]. Consequently, any similarity between these disparate parental magma compositions may be reflective of global processes. Here we consider the crystallization paths of these disparate magma compositions, and suggest that compared to terrestrial basalts, the full collection of martian samples available to us represents silica-enriched magmatism, suggesting an important role for water in their generation.

Why should martian basalts be low in silica?

1. The thick martian crust. During melting of dry peridotitic mantle, there is a correlation between the silica activity of the magma and the pressure of melting caused by the effect of pressure on the stability relations between the melt, olivine (OL), and orthopyroxene (OPX). At low pressures, peridotite melting (or reaction of magmas with solids) consumes OPX and produces OL, as shown by the common occurrence of dunitic channels within terrestrial ophiolites [e.g., 9]. Melting of OL-OPX bearing rocks at low pressure is a peritectic reaction; the magma is more silica rich than either OL or OPX, and consequently OL formation must increase the silica activity of any magma in equilibrium with those minerals. However, at greater pressures this reaction reverses, switching from being a peritectic reaction to a eutectic reaction (a tie-line switch). One net effect of this crossover is a decrease in the silica activity of magmas correlated with increasing average pressure of magmatism, as the high-silica phase becomes a product and the low-silica phase becomes a reactant.

Most terrestrial basalts are produced under thin oceanic crust or at mid-ocean ridges with effectively no crust. As such, melting can continue throughout the mantle, including substantial melting in the low-pressure region where OL is a reaction product. Mars, however, has no plate tectonics, but is instead a large, one-plate body with a crust up to 100 km thick in some places [3]. This depth corresponds to a pressure of 5-10 kbar. Thus, while terrestrial melting can continue close to the surface, melting of the martian mantle must terminate at high pressures. The net effect of this thick crust should therefore be to reduce the silica activity of mantle melts by increasing the average pressure of melting, as there is effectively zero melt generated at low pressures.

2. Proposed martian magmatic volatiles. Various authors have proposed significant roles for several different martian magmatic volatiles in addition to water. Based on high-Cl apatite compositions, [10] argued that martian magmatism was dominated by chlorine rather than water. Alternatively, several authors have considered the possible dissolution of CO_2 in martian magmas, in the context of estimating CO_2 release to the atmosphere [11].

The presence of either CO_2 or Cl during melting produces a decrease in the silica content of the corresponding magma. This effect has been experimentally observed for CO_2 [12, 13], and can be inferred from the increased stability of OPX relative to OL seen in the Cl-bearing experiments of [14]. Cl and CO_2 both complex with cations such as MgO and FeO in magmas, effectively reducing their activity in the liquid phase and causing a corresponding increase in their magmatic abundances. As shergottites have very low volatile abundances by the time they are measured on

Earth, if either of these volatiles were present, they must have degassed prior to collection on Earth. A rock crystallized from a CO_2 or Cl bearing magma would therefore give analyses suggesting silica depletion.

Evidence for high-silica in martian basalts

As martian basalts are iron-rich, direct comparison of wt.% silica with terrestrial basalts will not give a direct comparison of silica content and conversion to silica activities will be complicated. To address this issue, we conducted a series of crystallization calculations using the MELTS algorithm [15] on the martian parental magma compositions discussed above. The calculations were typically started as isobaric cooling and crystallization calculations spanning pressures from the martian surface to within the mantle. To indirectly address the silica activity of the magmas, we specifically calculated the OL-OPX multiple saturation point; the pressure at which the first mineral to crystallize from the magma changes from OL to OPX. [16] showed that for common magmas, this transition was a function only of the silica activity of the magma, and thus will allow for direct comparison of silica activities across disparate compositions. These calculations placed the multiple saturation points for those martian liquids between 9.5-12 kbar. One of those multiple saturation points was determined experimentally by [8] to be ~13 kbar, close to the calculated value.

These calculated and observed multiple saturation pressures are surprisingly low compared to terrestrial basalts. For one example, [17] found multiple saturation experimentally near 19 kbar in terrestrial MORB compositions; other compositions typically give similar values. These multiple saturation pressures therefore require that silica activities in martian basalts are substantially elevated compared to typical terrestrial basalts from either OIB or MORB. Furthermore, the calculations verify that these elevated silica activities are common to all available martian basalts, in both meteorites and measured compositions from the surface, and thus may represent a global phenomenon.

[18] calculated magma compositions from terrestrial partial melting under various pressure conditions using the MELTS algorithm, and consequently also calculated multiple-saturation pressures for their magmas. The only magma they calculated with as low of multiple saturation pressure as those observed in martian basalts had an average melting pressure of 7.5 kbar. For much of Mars, this pressure would sit within the martian crust! Thus, generation of these high silica activities on Mars cannot be linked to low pressures as on Earth. Similarly, the high silica activities suggest that although Cl and CO_2 may be present in martian

basalts, but they cannot exert a dominant influence on the melting process.

Remaining explanation - water

Water, if present during melting of every analyzed shergottite, chassignite, and Gusev basalts, has the opposite effect of the other possible volatiles [e.g., 13]. Hydrogen complexes with silica groups to give Si-O-H species in the melt, effectively reducing the silica activity and causing an increase in total silica content in response. Viewing these basalts after degassing, an observer would conclude that they were systematically elevated in silica activity, exactly as suggested here. Other possible explanations, such as melting of variably enriched or depleted sources or crustal contamination can be ruled out by the variety of magma compositions tested, which include both enriched, intermediate, and depleted compositions. If the silica enrichment were due to these processes, it would likely be correlated with evidence for crustal contamination, such as increased trace element abundances or radiogenic isotopes, which is not observed. Loss of OL due to crystallization could elevate the silica activity, but that would require that no martian magmas sample these anomalously high Mg # olivines, which seems implausible given our current sampling. Thus, the only explanation which appears consistent with the observed characteristics is that martian basalts were originally hydrous, containing water at or above the weight % level, and that the water was degassed prior to arrival on Earth.

References

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