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PLANETARY SCIENCE

Volatility in Martian magmas

Harry Y. McSween

The geochemistry of the Martian surface has largely been determined by the eruption of magmas to form basaltic rocks. A new line of argument has chlorine as an influential agent in that process.

The volatile constituents of magmas exercise a wholly disproportionate influence on magma behaviour. Although they are present in only tiny quantities, these elements and compounds with low boiling points profoundly affect thermodynamic properties and crystallization patterns, and the characteristics of magmatic flow and eruption. When we speak of magmatic volatiles, we normally mean water and carbon dioxide. But other volatile species might well be important, especially on planets other than Earth. Hence the interest in a proposal, reported in *Chemical Geology* by Filiberto and Treiman[1], that chlorine is one such player.

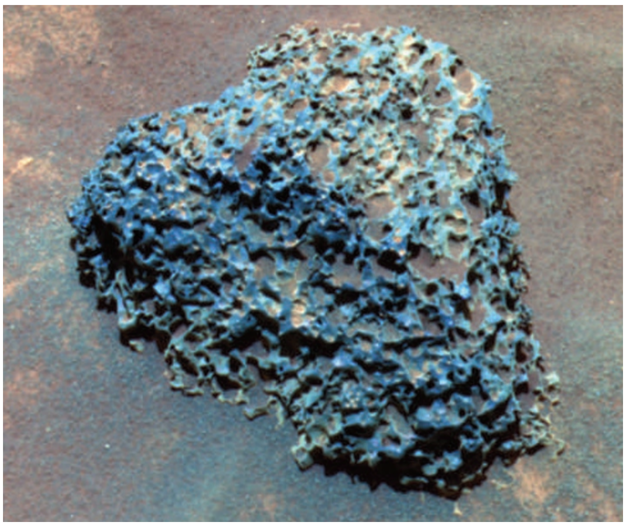

Figure 1 | Volatile traces on Mars. **The vesicular nature of this basaltic rock, photographed on the plains of the Gusev crater, is evidence of the pervasive presence of gas bubbles and so of volatile agents. (Pancam image by the Spirit rover from sol 740.)**

Mars is thought to be richer in volatile elements than Earth[2], and has been seen as a good place for further study. The Mars Exploration Rover Spirit has encountered and analysed numerous basaltic rocks during its five-year trek across the Gusev crater. These rocks are produced by volcanic activity, and the abundant vesicles found in some of them (Fig. 1) testify to the presence of significant quantities of volatiles. But until now, water has been assumed to be the main volatile agent, as for instance was the case in the hydrous crystallization experiments performed on a sample of Gusev basalt[3].

Filiberto and Treiman[1], however, propose that chlorine may have a central role in the generation and evolution of Martian basalts. They have carried out experiments demonstrating that the effects of chlorine on basalt phase equilibria are similar to those of water. The addition of chlorine shifts the liquidus — the stage at which crystals begin to form — to lower temperatures and enlarges the stability field of pigeonite, a form of pyroxene that is a common constituent of basalts. This is notable because the pressure under which the two minerals olivine and pigeonite first appear together is assumed to correspond to the depth at which magma is generated, and that depth is significantly shifted towards the surface if chlorine is the volatile species.

No chlorine-containing minerals have been identified in rocks of the Gusev crater, but that is no surprise because Spirit does not have instruments to do this. Conversely, although high levels of chlorine have been measured chemically by one of Spirit's spectrometers, there is the possibility that those measurements are a reflection of the ubiquitous presence of Martian dust, which contains halides including chlorine.

The broader picture must take account of the fact that much of what we infer about magmatic volatiles on Mars derives from studies of certain Martian meteorites rather than rocks still on Mars. These meteorites — basaltic achondrites, which show the distinctive features of processing by volcanic activity — are remarkably anhydrous, leading some geochemists to speculate that the mantle sources for these magmas must also have been dry. That view has been challenged[4] by the need for dissolved water to explain the calcium abundances and soluble-light-element zoning patterns in pyroxene crystals of some Martian basaltic meteorites. In this model, the magmas lost all their water as they were ejected from Mars, aided by the planet's low gravity.

The water contents of Martian meteorites, however, remain a contentious subject. The most persuasive argument for a role for chlorine is based on the absence of water in nominally hydrous daughter minerals (apatite and amphibole, both of which contain chlorine) in melt inclusions trapped in some Martian meteorites[5].

Filiberto and Treiman's thought-provoking paper[1] will serve a good purpose in prompting renewed debate about volatiles in Martian magmas. But to my mind it is doubtful that magma-borne chlorine would dominate on Mars. The channels and valley networks on Mars were surely eroded by water, and magmas must have delivered that water to the surface. Volcanic rocks in the Gusev crater are estimated to be billions of years old, comparable in age to some of the channels. The existence of hydrogen, which was mapped at high latitudes by Mars Odyssey's Gamma Ray Spectrometer[6], and which presumably is in the form of subsurface water ice, also points to the outgassing of water from magmas on a global scale.

Finally, however, there is a possible terrestrial connection to Filiberto and Treiman's line of investigation. They point out that lavas in certain tectonic environments on Earth can have a chlorine content of up to 0.7% by weight, and they propose that its effect in terrestrial magmas might be similar to that suggested for Mars. Experimental evidence[7,8] supports the idea that water is required to produce two different magmas characteristic of two different tectonic circumstances: so-called andesitic magmas in plate subduction zones, and alkaline magmas in intraplate settings. Filiberto and Treiman speculate that partial melting and fractional crystallization in chlorine-rich terrestrial systems might mimic the effect of water, an idea that merits further testing. ■

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