Carbon as the primary driver of super-reduced explosive volcanism on Mercury: Evidence from graphite-melt smelting experiments

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Abstract

Multiple volcanic deposits, both pyroclastic and effusive, have been identified on the surface of Mercury. The modeling of volcanic processes on Mercury, particularly with respect to the amount and composition of volcanic volatiles, is hindered by a lack of existing experiments performed at or near Mercurian conditions. Most notable is Mercury's extremely reducing nature (3–8 log units below the iron-wüstite buffer), which is well beyond the range of fO_2s for which existing thermodynamic models are calibrated. The high carrying capacity of sulfur compared to carbon or hydrogen in reduced magmas, combined with remarkably high S concentrations in Mercurian surface materials, has led to the assumption that S is an important driver of volcanic activity on the planet. However, evidence for a primary graphite floatation crust as well as graphite present within Mercury's regolith provide a mechanism for C-rich gas production via magma-graphite smelting reaction. Smelting, in which graphite is oxidized to CO and CO_2 gas and melt oxide species are reduced to metal (e.g., $C_{graphite} + FeO_{melt} = CO_{gas} + Fe^0{}_{metal}$), would also serve to remove O from the silicate melt, consistent with the production of a remarkably reduced surface environment. We carried out experiments to emulate conditions for graphite-induced smelting of three Mercurian magma compositions at high temperatures (ramped from ambient to 1195–1390 °C) and low pressures (8–10 mbar). The compositions of resultant gases were measured in situ via an evolved gas analyzer, and solid run products were analyzed by electron microprobe. Degassing vapor was always dominated by C-O-H species, and S degassing was not detected in any experiments. No significant C releases were measured in experiments using transition metal oxide-free starting silicate compositions, suggesting that transition metal reduction may be required to oxidize graphite to gas. Experiments that produced vapor formed Fe-Si metal alloy blebs, which were always in contact with residual graphite, strongly supporting metal and gas production via smelting between graphite and melt. Our results indicate that CO and CO_2 are likely the most dominant volcanic degassers (and thus drivers of explosive volcanism) on Mercury, and that S degassing plays only a subordinate role, contrary to what has been hitherto assumed.

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