LETTER

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REPLY TO BAINS ET AL.:

On the plausibility of crustal phosphides as the source of Venusian phosphine

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In their letter, Bains et al. (1) lay out two objections to our model (2) of phosphine production on Venus by explosive volcanism. The first is that phosphides sourced from the deep mantle of Venus would reequilibrate to the lower-pressure, higher oxygen fugacity state of the upper mantle and crust, and thus be largely destroyed. This assumes thermodynamic equilibrium. However, that assumption does not always hold, as the terrestrial rock record shows.

There are many examples on Earth of deep-mantle rock whose original, reduced, oxidation state appears to have been preserved. To give just two, the mineral moissanite (SiC) requires extremely reducing conditions to form and yet is a fairly common constituent of mantle xenoliths (3). The Luobusa ophiolite (4) is a section of ultramafic oceanic plate containing iron silicide–bearing minerals (5), and iron silicides require even more reducing conditions for their formation than do iron phosphides. (From a thermodynamic point of view, the formation of phosphides is easier than carbides, nitrides, and silicides.)

With respect to the dependence on redox state, others (6) have argued that an abundant mantle phosphide source is feasible for Venusian lavas for lithologies more reduced than what we have assumed, in contrast to Bains et al.'s (1) assertion that their conclusion holds even for highly reduced crustal lithologies. Finally, models that go beyond thermodynamics to include reaction kinetics (7, 8) yield abundant (up to 5%) phosphide formation in near-surface high-temperature heating events assuming crustal lithologies like that of the terrestrial mantle, a possibility that cannot be excluded for Venus.

With respect to the second objection, that explosive volcanism is not the dominant mode of volcanism on Venus (1), we must simply point out that both the style and extent of volcanism on Venus are poorly known. In our paper (2), we presented circumstantial evidence from spacecraft observations for explosive volcanism, which we will not repeat here for the sake of brevity.

The source of phosphine in Venus's atmosphere is a difficult problem, in no small part because even the detection of phosphine in the atmosphere is controversial, as we discuss in our paper (2). Confirming or falsifying the original claim of detection (9, 10) is a top priority if proposed mechanisms are to have any relevance to the real Venus. Irrespective of the outcome, determining whether Venus is volcanically active today, and its style of volcanism, remains one of the most important objectives for exploration if we are to understand the planet's evolution. The three missions announced by NASA and European Space Agency earlier this year (11) represent a start to a new era of exploration of Venus that ultimately may answer this and other important scientific questions about Earth's nearest planetary neighbor.

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