

CARBON SOLUBILITY IN MERCURIAN MAGMAS: WHAT WE DON'T KNOW. K. Iacovino¹, J. W. Boyce², N. G. Lunning², F. M. McCubbin², G. M. Moore¹, K. Vander Kaaden¹. ¹Jacobs, NASA Johnson Space Center, Houston, TX. ²NASA Johnson Space Center, Houston (Email: Kayla.Iacovino@nasa.gov)

Introduction: Mercury's *Borealis Planitia* (BP) is interpreted to have formed by flood volcanism and makes up over 6% of Mercury's surface cover [1]. Compositional data retrieved by the MESSENGER spacecraft and subsequent petrologic and experimental studies [2,3] suggest BP is made up of boninitic lava, which is relatively SiO₂- and MgO-rich (~57 and 15 wt%, respectively) and Fe-poor (~1 wt% FeO^T), making BP one of the only known silica-enriched extraterrestrial crustal terranes identified from orbit. Thus, this region represents an important phase in the evolution of Mercury's surface as well as shedding light on previously unknown mantle processes capable of generating Si-rich magmas on extraterrestrial worlds.

As with terrestrial flood basalts, the BP boninites may have played a substantial role in supplying volatiles (chiefly C, S, and H) to Mercury's surface. However, modeling such processes is challenging given the lack of experimental data and subsequent model formulations applicable to BP lavas and to pressure-temperature-*f*O₂ conditions relevant to mercurian boninite genesis (~1300 °C, 1.4 GPa [3]; Figure 1). Oxygen fugacity (*f*O₂) is known to strongly affect H and C solubility [4], particularly at reducing conditions, but no terrestrial model adequately considers this parameter. This is critical for mercurian lavas, which have much lower *f*O₂ than terrestrial, lunar, and martian lavas. Using the new open-source thermodynamic model engine VESICAL [5], we explore how terrestrial volatile solubility models for H, C, and H-C systems predict the volatile carrying capacity of BP boninite.

Applicability of current models: Fig. 1 shows the calibrated model space of seven volatile solubility models. Of these, the thermodynamic MagmaSat model [6] is the most likely to yield results relevant to mercurian lavas as it is parameterized on the largest dataset, resulting in better extrapolation capability than empirical models. It is also the only dataset calibrated at pressures above 1 GPa and is calibrated for both C and H systems. Although not independent of *f*O₂, [6] is not calibrated with experiments at reducing conditions, where H will speciate primarily as H₂ and C as CO and CH₄. MagmaSat predicts pure-C and pure-H solubilities of 3755 ppm C and 1.55 wt% H₂ at 1300 °C and 1.4 GPa. This extremely high volatile carrying capacity is ~2X greater than that of a comparable trachyandesite at the same conditions (similar composition to boninite but ~7 wt% FeO^T, 2.5 wt% MgO, *f*O₂ ~IW+4) and ~23X greater than measured in an experimentally saturated reduced (~IW) basalt at 1.5 GPa and 1450 °C [4].

Oxygen fugacity: Oxygen fugacity has a substantial effect on C solubility in magmas, but this is poorly understood at terrestrial *f*O₂ values (e.g., ~IW+4) that dominate the experimental literature. The terrestrial model of [7] attempts to account for *f*O₂ (via separate terms for Fe²⁺ and Fe³⁺ in the melt) and predicts a 2-fold increase in pure-C solubility in BP boninite at 1300 °C and 1.4 GPa with increasing *f*O₂ from Fe³⁺/Fe^T=0 (4380 ppm C) to 0.6 (5740 ppm C). However, in andesites [7] predicts the opposite relationship between *f*O₂ and C solubility. Notably, this dependence is constrained by a very small database – in large part because *f*O₂ is not reported for the majority of experiments in the literature – at exclusively oxidizing (~IW+4) conditions. At moderately reducing conditions ~IW, C solubility in basalt is diminished to ~200 ppm [4; Fig 2]. This is key to the investigation of mercurian magmas, which are extremely reducing (<<IW) with *f*O₂ possibly as low as

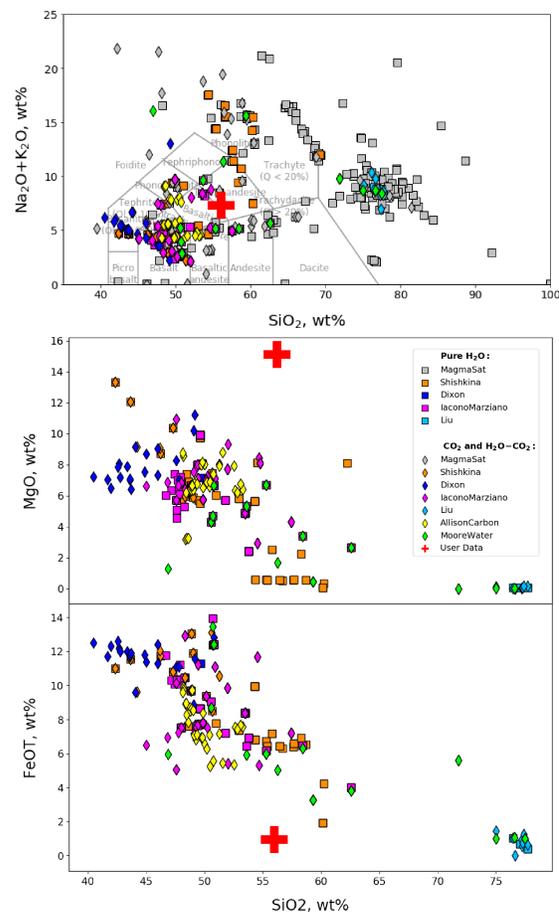


Figure 1 Compositions of solubility experiments used to calibrate all models in VESICAL [5]. References for each model given in [5]. Red plus: BP boninite.

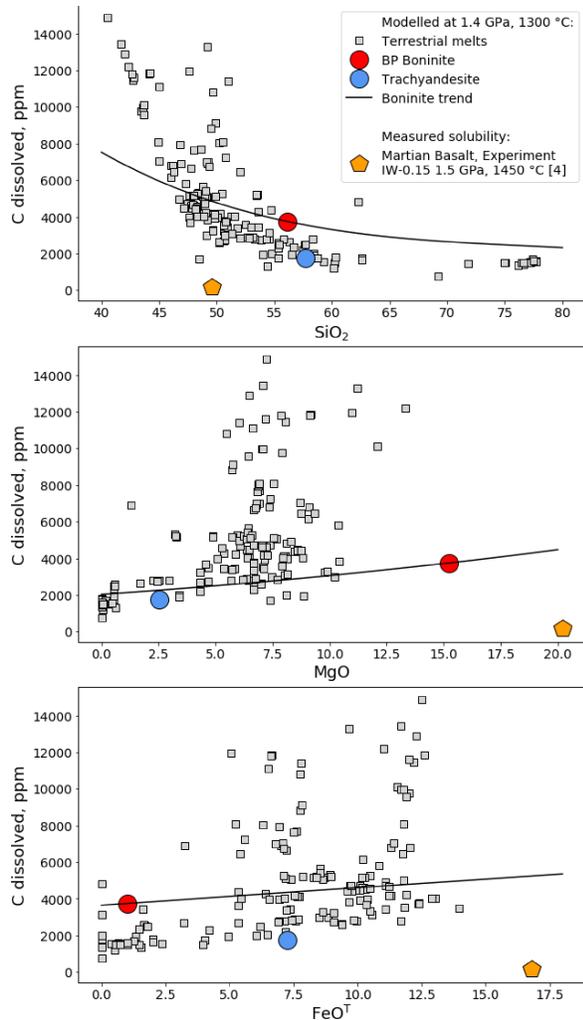


Figure 2 Modelled C solubility in all melts in our database at 1300 °C, 1.4 GPa using [6] in [5]. Red circle: BP boninite. Blue circle: comparable trachyandesite. Orange pentagon: reported C content of saturated martian basalt at IW-0.15, 1.5 GPa, 1450 °C [4]. Black curves: modelled C solubility for BP boninite but with variable SiO₂, MgO, or FeO^T.

ΔIW-7, where CO or CH₄ is the dominant dissolved C species, depending on H content. Additional experiments should be performed at extremely reducing conditions and with variable H contents such that solubility at low fO_2 can be fully explored.

Composition: While the treatment of fO_2 by current terrestrial models is inadequate, we can use them to examine the effect of composition independent of fO_2 . BP boninite has significantly lower FeO^T and higher MgO than any composition in our database of melts shown in Fig. 1. To understand the role of composition on C solubility in boninite, we modelled the pure-C solubility at 1300 °C and 1.4 GPa for fictitious melts bearing the same composition as BP but varying either MgO (100 melts from 0–20 wt% MgO), FeO^T (100 melts from 0–18 wt% FeO^T), or SiO₂ (200 melts from

38–75 wt% SiO₂). These are illustrated in Fig. 2 (black curves) plotted along with BP boninite (red), a comparable trachyandesite (light blue), and all melt compositions in the experimental database of [5] (squares). C-solubility for all melts drops with increasing SiO₂, but our model predicts that BP boninite retains a relatively high C solubility compared to other intermediate melts, in part due to the high MgO content.

Uncertainty: It is difficult to assess quantitatively the error on any estimate of solubility given the large number of parameters and a poor understanding of the interaction of those parameters. However, we can examine the data presented here to illustrate the very high uncertainty in solubility estimates for mercurian melts. BP boninite falls well outside of the range of existing model calibrations, particularly with respect to FeO^T and MgO, which we have shown may have a significant effect on C solubility. Notably, this is also true for studies at reducing conditions, which primarily focus on basalts. Thus, any model estimate is an extrapolation and may affect C solubility estimates by several thousand ppm. Moreover, experiments on intermediate melts are the least well represented in the literature, which results in significant disagreement between models for andesites, trachyandesites, and likely for boninites as well. Finally, because highly reducing experiments are not included in terrestrial models, their application to Mercury introduces significant error on the order of >1 wt% C.

Future work: To understand the volatile budget and migration of volatiles within the planet Mercury, new solubility experiments must be performed at compositions (incl. fO_2), pressures, and temperatures relevant to mercurian mantle and crustal processes. Combined with other experiments at moderately reducing conditions (e.g., for lunar and martian basalts), a model engine such as [5] could be used to construct a new predictive model applicable to a range of compositions, pressures, and temperatures relevant not only to Mercury but to other planetary bodies as well. Boninitic magma from *Borealis Planitia* is a prime target for study, since it represents voluminous eruptive activity on Mercury's surface that may have been associated with significant volatile outgassing.

References: [1] Head J. W. et al. (2011) *Science* 333, 1853. [2] Nittler, L. R. et al. (2011) *Science* 333, 1847. [3] Vander Kaaden K. E. and McCubbin F. M. (2015) *GCA*, 173, 246–263. [4] Li et al. (2017) *JGR:P*, 122, 1300–1320. [5] Iacovino K. et al. (in press) *Earth & Space Sci.* (pre-print: 10.31223/X5D606) [6] Ghiorso M. S. and Gualda G. A. R. (2015) *Contrib. Mineral. Petrol.*, 168, 1–30. [7] Papale P. et al. (2006) *Chem. Geol.*, 229, 78–95.