Degassing of alkalic basalts

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ABSTRACT

In order to model quantitatively exsolution of volatiles over the range of basaltic melt compositions found on oceanic islands, I present compositional parameterizations of H₂O and CO₂ solubilities and use these parameterizations to develop vapor saturation and degassing models for alkalic basaltic liquids. Vapor-saturation diagrams generated as a function of melt composition are used to determine the pressure at which the melt was last in equilibrium with a vapor and the composition of the vapor phase based on measured H₂O and CO₂ contents in basaltic glasses. These models allow the calculation of the pressure at which a magma of known initial volatile content reaches vapor saturation and begins to exsolve a vapor phase. The higher solubility of CO₂ in alkalic magmas causes vapor saturation in CO₂-bearing alkalic magmas to be reached at lower pressures than in CO₂-bearing tholeiitic magmas having identical volatile contents. However, if variations in major element and volatile concentrations were linked by variations in the extent of melting, then volatile-rich, strongly alkalic magmas would begin to exsolve a vapor at slightly higher pressures than volatile-poor alkali olivine basalts or tholeiites.

Partitioning of H₂O and CO₂ into the vapor during volatile exsolution is controlled by the difference between H₂O and CO₂ solubilities. As melts become more alkalic, the relative difference between H₂O and CO₂ solubilities decreases, thus diminishing the preferential partitioning of CO₂ into the vapor. Exsolution of volatiles from tholeiites is characterized by strong partitioning of CO₂ into the vapor such that most or all CO₂ is lost before any significant loss of H₂O. In contrast, the combination of higher CO₂ solubility and higher volatile contents (and perhaps higher CO₂/H₂O ratio) in alkalic melts results in less fractionation between CO₂ and H₂O during volatile exsolution.

INTRODUCTION

Volatiles play an important role in the generation and evolution of mantle-derived melts, affecting the extent of mantle melting, liquidus phase relationships, physical properties of melts, and explosivity of volcanic eruptions. Alkalic lavas from oceanic islands provide a wealth of information on mantle heterogeneities with respect to major and trace elements and radiogenic isotopes, but heterogeneities in mantle volatiles remain poorly known. Determining heterogeneities in mantle volatiles is important to characterize mantle reservoirs fully, to understand the role of volatiles in igneous processes in different tectonic environments, and to constrain global cycling of these elements. However, to investigate the underlying mantle volatile concentrations, it is first necessary to see through the window of shallow level processes such as degassing and assimilation.

Recently, Dixon and Stolper (1995) presented a quantitative degassing model for tholeiitic basaltic melts and used this model to gain insight into exsolution of volatiles from oceanic tholeiitic magmas. This study extends their model to alkalic basaltic compositions. I present new compositional parameterizations of H₂O and CO₂ solubilities and incorporate them into mixed H₂O-CO₂ vapor saturation and degassing models for alkalic basaltic melts.

SOLUBILITY MODELS

Review of H₂O and CO₂ solubilities in tholeiitic melts

Calculation of H₂O and CO₂ solubilities in tholeiitic melts using the Stolper thermodynamic model (i.e., the activity of H₂O is taken to be the activity of molecular H₂O in the melt; Holloway and Blank 1994) involves (1) calculation of H₂O or CO₂ fugacities at the P and T of interest; (2) calculation of the mole fractions of molecular H₂O or carbonate ions in the melt in equilibrium with pure H₂O or CO₂ vapor; and (3) calculation of total H₂O or carbon dioxide concentrations in the melt. The advantage of Stolper-type solubility models for degassing calculations is that the activities of both molecular H₂O and carbonate in basaltic melt follow Henry’s law at the low pressures of degassing. Also, the thermodynamic properties determined in the end-member systems can be used to calculate saturation concentrations of H₂O and CO₂ in mixed volatile systems.

Fugacities are calculated using a modified Redlich-Kwong (MRK) equation of state (Holloway 1977). At the