Experimental calibration of the effect of \( H_2O \) on plagioclase crystallization in basaltic melt at 200 MPa

RENAT R. ALMEEV, 1,* FRANÇOIS HOLTZ, JÜRGEN KOEPKE, 1, AND FLEURICE PARAT 2

1 Institut für Mineralogie, Leibniz Universität Hannover, Callinstrasse 3, Hannover 30167, Germany
2 Géosciences Montpellier, UMR 5243, CC 60, Université Montpellier 2, Place E. Bataillon, 34095, Montpellier cedex 5, France

ABSTRACT

Crystallization experiments were conducted at 200 MPa to determine the effect of small amounts of \( H_2O \) on the liquidus temperature of basaltic melts in which plagioclase is the liquidus phase. The \( H_2O \) concentrations in the quenched glasses, determined by infrared spectroscopy and Karl-Fischer titration, ranged from 0.02 to 4.2 wt% \( H_2O \). The dry liquidus temperature at 200 MPa was estimated from experiments at 1 atm (H\(_2\)O-free) and from the known pressure dependence of plagioclase crystallization temperature. The effect of water (expressed as wt% \( H_2O \)) on the plagioclase liquidus temperature is nonlinear and diminishing with increasing melt \( H_2O \) concentrations. According to our new experimental data, it can be empirically predicted with following equation:

\[
(T_{\text{DRY}} - T_{\text{WET}}) = 76.99 \cdot C_{\text{H}_2\text{O}}^{0.71}
\]

where \( C_{\text{H}_2\text{O}} \) is the water concentration in the melt (wt%), \( T_{\text{DRY}} \), and \( T_{\text{WET}} \) are plagioclase crystallization temperatures in water-free and water-bearing systems, respectively.

The relationship between \( C_{\text{H}_2\text{O}} \) and liquidus temperature worked out in this study is valid for a range of basaltic compositions, ranging from high-alumina basalts to basaltic andesites. The combination of the empirical equation predicting the liquidus depression of plagioclase with previous models predicting the olivine liquidus curve is useful to determine the liquidus temperature in various \( H_2O \)-bearing basaltic systems in which either plagioclase or olivine is the liquidus phase.

Keywords: Crystallization, \( H_2O \), MORB, plagioclase, liquidus, FTIR, KFT

INTRODUCTION

Water is the most abundant and most soluble volatile component of silicate magmas; it dramatically affects their chemical and physical properties. Water suppresses liquidus and solidus temperatures, affects mineral crystallization sequences (e.g., Yoder and Tilley 1962; Hamilton et al. 1964) and thus controls the residual melt evolution (liquid line of descent), leading to the formation of tholeitic or calc-alkaline magmatic series (Grove and Baker 1984; Grove and Kinzler 1986). It is also known that water has a strong effect on crystallization temperatures at low-water contents, and the effect is diminishing with increasing melt water content (\( H_2O^+ \)). For example, the importance of small amounts of water in the crystallization process of \( H_2O \)-poor MORB magmas [containing <0.5 wt% \( H_2O \), mid-ocean ridge basalt (MORB)] has been emphasized in several studies (e.g., Michael and Chase 1987; Danyushevsky 2001; Asimov et al. 2004). Danyushevsky (2001) presented a simple parameterization of the non-linear effect of small amounts of water on the liquidus temperature of olivine in basaltic melts. However, significant discrepancy was observed (Almeev et al. 2007; Médard and Grove 2008) when this empirical model was compared to thermodynamic models such as MELTS (Ghiorso and Sack 1995) or COMAGMAT (Ariskin and Barmina 2004). Recently, the effect of small amounts of water on olivine liquidus temperature in basaltic melts has been experimentally addressed by Almeev et al. (2007) and Médard and Grove (2008). Despite the differences in experimental approaches applied in the two studies (\( H_2O \)-undersaturated conditions at 200 MPa in the former and \( H_2O \)-saturated conditions at different pressures in the latter), both studies reported a nearly identical olivine liquidus depression (\( \Delta T = T_{\text{DRY}} - T_{\text{WET}} \) where \( T_{\text{DRY}} \) and \( T_{\text{WET}} \) are olivine crystallization temperatures under dry and \( H_2O \)-bearing conditions, respectively) in a wide range of \( H_2O \) (up to 10 wt%). This correspondence was explained by the lack of pressure effect on olivine liquidus depression (Médard and Grove 2008). Médard and Grove (2008) also reported that there is no effect of melt composition on olivine liquidus depression.

Among the other main phases crystallizing in basaltic magmas, plagioclase plays a crucial role because it usually prevails in the solid assemblage and affects significantly the residual melt compositions. At the same time, even in nearly anhydrous MORBs, Danyushevsky (2001) has shown that even very low \( H_2O^+ \) may affect plagioclase crystallization, resulting in the compositional change of natural MORB glasses (e.g., to lower FeO and higher Al\(_2O_3\) contents in comparison to dry 0.1 MPa MORB experimental glasses). Danyushevsky (2001) also demonstrated that liquidus temperatures of MORBs corrected for the presence of a small amounts of water are 15–30 °C lower than “dry” calculated temperatures, and that the onset of olivine and plagioclase crystallization can be used as a geohygrometer for MORB if the effect of \( H_2O \) on olivine and plagioclase crystallization is constrained. The crystallization temperature of plagioclase...