An updated calibration of the plagioclase-liquid hygrometer-thermometer applicable to basalts through rhyolites

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ABSTRACT

An updated and expanded data set that consists of 214 plagioclase-liquid equilibrium pairs from 40 experimental studies in the literature is used to recalibrate the thermodynamic model for the plagioclase-liquid hygrometer of Lange et al. (2009); the updated model is applicable to metaluminous and alkaline magmas. The model is based on the crystal-liquid exchange reaction between the anorthite (CaAl2Si2O8) and albite (NaAlSi3O8) components, and all available volumetric and calorimetric data for the pure end-member components are used in the revised model. The activities of the crystalline plagioclase components are taken from Holland and Powell (1992). Of the 214 experiments, 107 are hydrous and 107 are anhydrous. Four criteria were applied for inclusion of experiments in the final data set: (1) crystallinities <30%; (2) pure-H2O fluid saturated; (3) compositional totals (including H2O component) of 97–101% for hydrous quenched glasses and 98.5–101 for anhydrous quenched glasses; and (4) melt viscosities ≤5.2 log10 Pa·s. The final data set spans a wide range in liquid composition (45–80 wt% SiO2; 1–10 wt% Na2O+K2O), plagioclase composition (An17–95), temperature (750–1244 °C), pressure (0–350 MPa), and H2O content (0–8.3 wt%). The water solubility model of Zhang et al. (2007) was applied to all hydrous experiments. The standard error estimate on the hygrometer model is 0.35 wt% H2O, and all liquid compositions are fitted equally well. Application of the model as a thermometer recovers temperatures to within ±12°, on average. Tests of the hygrometer on anhydrous piston-cylinder experiments in the literature, not included in the regression, show that the model is accurate at all pressures where plagioclase is stable. Applications of the hygrometer are made to natural rhyolites (Bishop Tuff, Katmai, and TobaTuff) with reported H2O analyses in quartz-hosted melt inclusions from the literature; the results show agreement. Applications of the hygrometer/thermometer are additionally made to natural rhyolites from Iceland and Glass Mountain, California. The updated model can be downloaded either as a program in Excel format or as a MatLab script from the Data Repository.

Keywords: Plagioclase-liquid hygrometer, hygrometer, thermometer, plagioclase, liquid

INTRODUCTION

The composition of plagioclase in magmatic liquids is strongly sensitive to temperature and dissolved water concentrations, and therefore plagioclase has the potential to be used as either a hygrometer or thermometer in volcanic rocks (e.g., Kudo and Weill 1970; Mathez 1973; Glazner 1984; Marsh et al. 1990; Housh and Luhr 1991, Sisson and Grove 1993; Panjasawatwong et al. 1995; Danyushevsky et al. 1997; Putirka 2005, 2008). Recently, Lange et al. (2009) developed a thermodynamic model for the plagioclase-liquid exchange reaction involving the anorthite (CaAl2Si2O8) and albite (NaAlSi3O8) components, in which all published calorimetric and volumetric data on the standard state reaction were incorporated into the model to independently constrain the effects of temperature and pressure. This allowed available phase-equilibrium experiments in the literature to constrain the effect of melt composition, including dissolved water, on the exchange reaction, thus permitting a plagioclase-liquid hygrometer to be developed. Application of the Lange et al. (2009) model is restricted to plagioclase more calcic than An35, and therefore cannot be applied to most rhyolites, owing to the compositional limitation of the experimental data set upon which that model was calibrated. The 2009 hygrometer was calibrated on 71 plagioclase-liquid experiments, of which 45 were hydrous and 26 anhydrous. Three filters were applied to that phase-equilibrium data set: (1) crystallinities <30%; (2) pure-H2O fluid saturated; and (3) compositional totals (including H2O component) of 97–101% for hydrous quenched glasses. The water solubility model of Moore et al. (1998) was applied to all hydrous experiments. The standard error estimate on the hygrometer model is 0.35 wt% H2O, and all liquid compositions are fitted equally well. Application of the model as a thermometer recovers temperatures to within ±12°, on average. Tests of the hygrometer on anhydrous piston-cylinder experiments in the literature, not included in the regression, show that the model is accurate at all pressures where plagioclase is stable. Applications of the hygrometer are made to natural rhyolites (Bishop Tuff, Katmai, and TobaTuff) with reported H2O analyses in quartz-hosted melt inclusions from the literature; the results show agreement. Applications of the hygrometer/thermometer are additionally made to natural rhyolites from Iceland and Glass Mountain, California. The updated model can be downloaded either as a program in Excel format or as a MatLab script from the Data Repository.