The density and compressibility of KAlSi₃O₈ liquid to 6.5 GPa

REBECCA A. LANGE*

Department of Geological Sciences, 1100 N. University Avenue, University of Michigan, Ann Arbor, Michigan 48109-1005, U.S.A.

ABSTRACT

The thermodynamic properties of crystalline and liquid KAlSi₃O₈ are used to calculate the fusion curve of sanidine to 6.5 GPa. New values for the enthalpy and entropy of fusion of sanidine at one bar and 1200 °C (ΔHₛ = 63.0 kJ/mol, ΔSₛ = 42.8 J/mol-K) are recommended on the basis of improved heat-capacity equations for KAlSi₃O₈ crystal, glass, and liquid. On the basis of phase-equilibrium experiments on the congruent melting reaction between 2 and 6.5 GPa, the pressure dependence of the liquid compressibility (K₀' = dK₀/dP, where K₀ = 1/β₀) is constrained to be 12.2 ± 1.0 in a third-order Birch-Murnaghan equation of state (EOS). The metastable, one-bar melting temperature (Tᵢ) is additionally constrained to be 1203 ± 26 °C. Determination of the liquid K₀ allows the density and compressibility of KAlSi₃O₈ liquid to be calculated to 6.5 GPa (2.709 ± 0.014 g/cm³ at 1600 °C). The uncertainty in K₀ of ±1.0 leads to an error in melt density at 6.5 GPa of ±0.52%. With a K₀' = 12.2, the relatively high compressibility of KAlSi₃O₈ liquid at 1600 °C (K₀ = 15.8 GPa) drops rapidly with increasing pressure. The dominant mechanism of compression for KAlSi₃O₈ liquid between 0 and 6.5 GPa most likely involves topological changes and increases in network connectivity with pressure. It is probable that highly compressible liquids, such as hydrous, silica-rich liquids formed by partial melting of a subducted slab, may have K₀ values that exceed 12 (at pressures ≥6.5 GPa).

Keywords: Sanidine, fusion curve, enthalpy of fusion, topology, equation of state

INTRODUCTION

Obtaining an accurate and comprehensive equation of state (P-V-T relation) for magmatic liquids is a major imperative. It is required in order to characterize both their thermodynamic and dynamic behavior at depth (e.g., Stolper et al. 1981). One of the most important parameters to constrain is how melt compressibility (β) or bulk modulus (K = 1/β) changes with pressure, namely K₀' (= dK₀/dP). Currently, most of our information on K₀' for silicate melts (using a third-order Birch-Murnaghan EOS) is obtained from shock-wave (Rigden et al. 1988, 1989; Miller et al. 1991; Chen et al. 2002) and sink/float (e.g., Agee 1992; Agee and Walker 1993; Smith and Agee 1997; Ohtani and Maeda 2001; Sakamaki et al. 2005; Matsukage et al. 2005) experimental studies. However, there is not yet a predictive model for how K₀' varies with melt composition.

In a brief review of the available high-pressure density data for silicate liquids, Lange (2003) postulated that values of K₀' are inversely related to their bulk modulus at one bar (K₀). In other words, the most compressible liquids at one bar are proposed to have the highest K₀' values. However, most of the available data on liquid K₀' values are for compositions (e.g., komatiite, diopside, anorthite, Di₆₄-An₃₆ eutectic) that span a relatively narrow and incompressible range of K₀ (20–25 GPa; Rivers and Carmichael 1987; Secco et al. 1991). In order to test this hypothesis further, experimental determinations of K₀' on relatively compressible liquids (K₀ < 20 GPa) are needed.

In this study, fusion curve analysis is used to constrain the density and compressibility of KAlSi₃O₈ liquid to 6.5 GPa, and thus its K₀' value. Fusion-curve analysis is a comparison between phase-equilibrium experiments on the congruent melting reaction of a mineral at pressure and the calculated melting reaction from measured thermodynamic properties. It thus has the potential to constrain the value of a single thermodynamic property for which direct, independent measurements are not feasible. This was the approach taken by Lange (2003) and Tenner et al. (2005) to constrain the K₀' (10.8 ± 1.5) for NaAlSi₃O₈ liquid, which has a K₀ = 18 GPa at 1673 K.

KAlSi₃O₈ liquid has a one-bar bulk modulus of ~15.8 GPa at 1673 K (Liu et al. 2006), and determination of its K₀' will expand the data set for liquids where both K₀ and K₀' are known. Owing to its high viscosity, density measurements on KAlSi₃O₈ liquid are not readily achieved by other experimental techniques (e.g., shock-wave or sink/float). However, sanidine is well suited for fusion-curve analysis because of the availability of both high-quality experimental brackets on its melting reaction between 2 and 6.5 GPa (Lindsley 1966; Urukawa et al. 1994) and the relevant thermodynamic data (discussed below). Because sanidine melts incongruently below 2 GPa, there are two unknowns to be obtained simultaneously: Tᵢ (the metastable congruent fusion temperature at one bar) and the liquid K₀' value. In this study, the phase-equilibrium data on the congruent melting reaction between 2 and 6.5 GPa are reviewed, which is followed by a discussion of the best available thermodynamic property measurements on sanidine and its corresponding liquid. From this foundation, robust constraints on both Tᵢ and the liquid K₀' are obtained.

PHASE-EQUILIBRIUM EXPERIMENTS AT 2.0–6.5 GPa

Sanidine has long been known to melt incongruently at one bar (at ~1150 ± 20 °C) to leucite (KAlSi₃O₈) plus liquid (Schairer and Bowen 1955). Lindsley (1966) showed that this incongruent reaction extends to 1.9 ± 0.1 GPa, whereas at