The fusion curve of albite revisited and the compressibility of NaAlSi$_3$O$_8$ liquid with pressure

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ABSTRACT

The 1 bar, thermodynamic properties of crystalline and liquid NaAlSi$_3$O$_8$ are used to calculate the fusion curve of albite to 10 kbar. The calculated temperatures (±2σ) of the melting reaction are 1152 (±7) °C at 3 kbar and 1247 (±24) °C at 10 kbar. The location of the calculated fusion curve to 10 kbar is in excellent agreement with phase-equilibrium constraints on the maximum and minimum temperatures of the fusion curve at 3 and 15 kbar, respectively. Calculation of the melting reaction at pressures >10 kbar requires that the pressure dependence of the liquid compressibility ($K'_L = dK_T/\partial P$, where $K'_L$ is the bulk modulus at one bar) be known. On the basis of five half-reversal, crystallization experiments in the literature, which collectively provide minimum temperatures of the fusion curve between 12 and 32 kbar, $K'_L$ (derived from the Birch-Murnaghan relation) is constrained to be ≥10 for liquid NaAlSi$_3$O$_8$. A comparison with other silicate liquids shows that there is a strong, positive correlation between the compressibility at one bar ($\beta_P$) and $K'_L$. In addition, data on the water-saturated fusion curve of albite are used to quantify the effect of small amounts of H$_2$O (≤1 wt%) on lowering the melting temperature of albite (≤68 degrees).

INTRODUCTION

The melting curves of the end-member rock-forming minerals are an essential source of thermodynamic data, particularly for the liquid state. Typically, the one-bar thermodynamic properties of the crystal and liquid are well known, and it is the pressure dependence of the liquid compressibility ($K'_L = dK_T/\partial P$, where $K'_L$ is the bulk modulus at one bar) that may be derived (e.g., Rivers 1985). The example highlighted here is the equilibrium between crystalline NaAlSi$_3$O$_8$ (albite) and liquid of the same composition.

Over the last two decades, there have been numerous attempts to reconcile phase-equilibrium constraints with calculations of the albite fusion curve from thermodynamic property measurements (e.g., Boettcher et al. 1982; Navrotsky et al. 1982; Bottinga 1985; Burnham and Nekvasil 1986; Kress et al. 1988; Wen and Nekvasil 1994; Anovitz and Blencoe 1999). In general, the experiments and calculations do not agree well, owing partly to problems with the phase-equilibrium experiments [e.g., contamination by water, sluggish kinetics, unknown ordering state of the albite; see Kress et al. (1988) and Anovitz and Blencoe (1999) for discussions] and partly to problems with calculations of the fusion curve from available thermodynamic data in the literature. It is the initial slope of the fusion curve (<10 kbar) that has been the most controversial.

For example, Anovitz and Blencoe (1999) and Wen and Nekvasil (1994) calculated albite melting temperatures at 10 kbar (with no adjustments for hypothetical speciation effects in NaAlSi$_3$O$_8$ liquid; Nekvasil, personal communication) that differ from each other by >180 °C. Moreover, the error envelope for the calculated fusion curve in these two studies (based on a propagation of the errors in the thermodynamic properties used to calculate each curve) show little overlap below 10 kbar. Anovitz and Blencoe (1999) presented an error envelope that spans ~200 °C at 10 kbar, whereas Wen and Nekvasil (1994) report one that spans ~120 °C at this pressure and is displaced ~100 °C higher than that given by Anovitz and Blencoe (1999). In Figure 3 of Anovitz and Blencoe (1999), the error envelopes of the two studies are illustrated; in combination, the lowest and highest temperatures permitted for the calculated fusion curve at 10 kbar differ by ~300 °C. Such large errors preclude any efforts to constrain the value of $K'_L$ for NaAlSi$_3$O$_8$ liquid from phase-equilibrium experiments on the albite melting reaction at high pressure.

This study was prompted by these two most recent analyses of the albite fusion curve, and it is shown here that when the best available thermodynamic property measurements are employed, the error envelope (at the 95% confidence level) spans 48 degrees at 10 kbar. The primary cause for the discrepancy in published fusion curves for albite (and the widely variable error envelopes) resides with the volume of NaAlSi$_3$O$_8$ liquid at one bar, which has been measured directly by Knoche et al. (1992) and Lange (1996), with experimental errors that are ≤0.4%. Surprisingly, the volume equations for liquid NaAlSi$_3$O$_8$ used by Anovitz and Blencoe (1999) and Wen and Nekvasil (1994) differ from each other by more than 8% and differ from the measured values by ~3 and ~5%, respectively. Although of smaller magnitude, modifications are also required for the volume of crystalline albite in these studies, owing to a misprint in the reported volume given by Winter et al. (1979) for high albite at 25 °C. It is thus demonstrated that without consideration of the best available thermodynamic data, conclusions regarding the location of the fusion curve, the precision to which it can be calculated, and implications for melt speciation require revision. Perhaps most important, constraints on $K'_L$ for liquid NaAlSi$_3$O$_8$ become feasible within the smaller error envelope.

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