The effect of anhydrous composition on water solubility in granitic melts

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ABSTRACT
The effect of anhydrous composition on the solubility of water in granitic melts was investigated experimentally at 800 °C and pressures from 50 to 500 MPa. Starting materials were ten natural obsidians from various localities worldwide and one re-melted leucogranite from the Himalayas. Most of the experiments were performed in externally heated pressure vessels using Ni-NiO to buffer $f_{O_2}$. All samples were quenched isobarically after reaction for 120–336 h. Water contents of the resulting glasses were determined by Karl-Fischer titration.

The solubility data indicate that Na/K ratio and normative Qz content have only a minor effect on water solubility, whereas the (MCLNK-A)/O parameter, defined as 100·(2Mg + 2Ca + Li + Na + K–Al)/total oxygen, has a major effect. A parabolic law expressed as the mole fraction of $H_2O$ in the melt on a one-oxygen mole basis is proposed to describe the compositional dependence of water solubility in the range 50–200 MPa:

$$X_{H_2O} = X_{H_2O}^0 \cdot (1 + 0.05 \cdot \left[(\frac{MCLNK-A}{O}) – 0.5\right]^2)$$

Minimum mole fractions of water in the melt ($X_{H_2O}^0$) are 0.0521 at 50 MPa, 0.0757 at 100 MPa, and 0.1069 at 200 MPa. The equation fits water solubility data for granitic and phonolitic melts at 100 MPa and 200 MPa to within ±4% relative. The effects of anhydrous composition on water solubility are much more pronounced at 500 MPa than at lower pressures. Thus, the following expression was derived to represent the effects of anhydrous melt composition on water solubility at 500 MPa:

$$X_{H_2O} = 0.1681 \cdot (1 + 0.13 \cdot \left[(\frac{MCLNK-A}{O}) – 0.5\right]^2).$$

INTRODUCTION
Dissolved water has a profound influence on the chemical and physical properties of granitic melts. The addition of a small amount of water to a dry granitic melt decreases the solidus and liquidus temperatures by several hundred degrees (e.g., Tuttle and Bowen 1958), decreases the viscosity of the melt by several orders of magnitude (e.g., Shaw 1972; Dingwell et al. 1996; Schulze et al. 1996), and accelerates not only the diffusivity of melt components, but also the kinetics of crystal dissolution and growth in the melt (Chekmir and Epelbaum 1991; Watson 1994). Therefore, reliable water solubility data are required to model accurately the kinetic and thermodynamic properties of hydrous melts and to predict correctly the behavior of natural magmas. Over the past 25 years, numerous quantitative models have been developed for natural magmas in general, and/or for granitic magmas in particular (Burnham 1979; Nicholls 1980; Silver and Stolper 1985; Papale 1997; Moore et al. 1998; Yamashita 1999; Zhang 1999). All of these formulations predict the pressure and temperature dependence of water solubility. However, they often do not account for the effect of anhydrous melt composition, and all of them are adversely affected by an insufficient quantity of data, and by errors in the experimental determinations of water solubility. Published $H_2O$ solubility data for melts of granitic composition are widely scattered, and systematic discrepancies are observed between results obtained in different laboratories (Kadik et al. 1972; Khitarov and Kadik 1973; Shaw 1974; Silver et al. 1990; Blank et al. 1993; Moore et al. 1998; Yamashita 1999). As discussed by Holtz et al. (1992, 1995) and Zhang (1999), imprecision in the data is mainly due to difficulties in the experimental and analytical techniques used to measure water solubility.

For the present study, we applied experimental and analytical procedures that were successfully tested in previous investigations of $H_2O$ solubility in feldspathic and quartzofeldspathic melts (Behrens 1995; Holtz et al. 1992, 1995). Solid starting materials for the experiments were ten natural obsidians and one re-melted leucogranite, which cover a wide range of anhydrous composition. The Fe contents of these materials were low (<5 wt% $Fe_2O_3$) and they contained only minor amounts of microlites (<2 vol%). The goal of the present work was to determine the chemical parameters that control $H_2O$ solubility in natural granitic melts. Studies on simple synthetic granitic analogs, such as albitic or haplogranitic melts, have shown systematic dependencies of $H_2O$ solubility on melt composition.