EXPERIMENTAL STUDY OF MONAZITE SOLUBILITY IN HAPLOGRANITIC MELTS

MAIERZIYAGULI MAIMAITI
Scuola di Scienze e Tecnologie, Sezione di Geologia, Università di Camerino, Via Gentile III da Varano, 62032 Camerino

INTRODUCTION

REEs (Rare Earth Elements) are viewed as 'Green Metals' and used in nearly every car, computer, smartphone, energy-efficient fluorescent lamp, as well as in lasers and more applications. REEs are also extensively used for various technological applications in magnets, automotive catalytic converters and luminescent phosphors (Chakhmouradian & Wall, 2012).

The knowledge of the behaviour of rare earths in felsic systems has considerable economic importance, as some of the most important rare earth deposits are related to granitic magmas. In fact, in granites, most of REEs are contained in accessory minerals; thus the geochemical behaviour of REEs is controlled by the solubility of accessory minerals like zircon, monazite, apatite, allanite, xenotime, thorite, and huttonite (Seydoux *et al.*, 2002). In addition, knowledge about the stability of these accessory minerals in mantle and crustal environments provides important information about the evolution of magmas.

Monazite is one of the most important REEs minerals and occurs in granitic/rhyolitic rocks with compositions ranging from peraluminous to peralkaline. It can also be a significant host for geochemically useful elements such as U and Th, and it can serve as an indicator of magmatic temperatures and petrogenetic relationships in silicic magmas. The stability of monazite can affect the behaviour of REEs and plays the dominant role in controlling REEs abundances in some felsic magma suites.

The aim of the present study is to investigate geochemical behaviour of REEs in different granitic magmas, in particular, the solubility of REEs enriched mineral such as monazite in different granitic melt composition depending on the temperature and alkali ratio as well as to address the role of peralkalinity on solubility. We have determined monazite saturation and solubility in a series of synthetic silicate glasses of granitic composition.

The solubility of synthetic pure La-monazite ($LaPO_4$) in haplogranite (HPG8) based peraluminous to peralkaline granitic melts (agpaitic index [molar (Na+K)/Al] ranges from 0.9-2, keeping Na/(K+Na) ratio constant at 0.623) were determined at experimental conditions from 720 °C to 850 °C, l kbar to 3 kbar, and water saturated conditions. The experiments were run for up to 22 days to attain equilibrium. Additional high temperature, atmospheric pressure experiments were also done for each composition ($HPG8_{0.9}$, $HPG8_{1.5}$, and $HPG8_{2}$) at 1400 °C for 12h, 24h, and 36h.

THE EFFECT OF PERALKALINITY OF MELT ON SOLUBILITY

According to the previous studies, little is known about the mechanism of monazite dissolution in hydrous melts at various conditions and related consequences for monazite-based geothermometry.

The work presented in this study is specifically directed towards understanding how monazite solubility in silicic magmas is influenced by temperature and melt composition. Dissolution experiments were done using synthetic $LaPO_4$. Major and minor elements were determined by electron microprobe.

The solubility of La-monazite at 2 kbar and 800 °C is shown in Fig. 1, where the experimental data have directly compared with those of Montel (1986, 1993), Keppler (1993) and Duc-Tin & Keppler (2015), as their pure monazite had a composition similar to the monazite used in our experiments, and the melt compositions are similar as well.

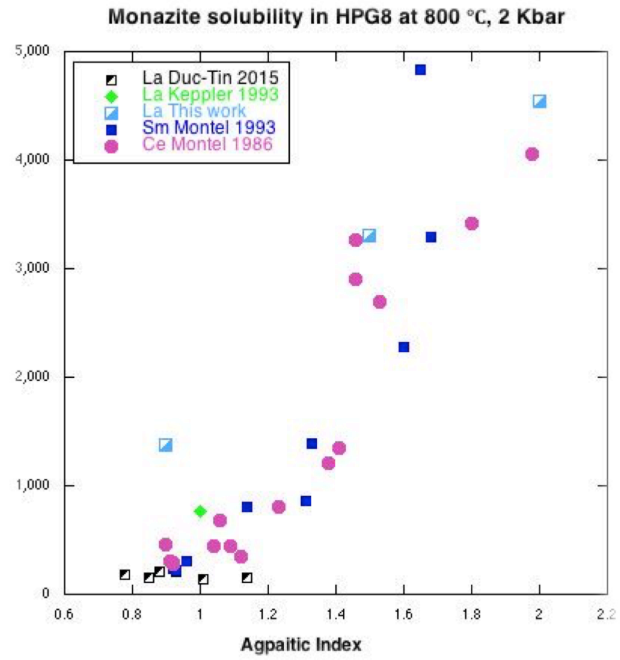

Fig. 1 - Plot of monazite solubility REE (ppm) *vs*. A.I.

The A.I. (Agpaitic Index) shows a little effect on the data of Duc-Tin & Keppler (2015) and Keppler (1993). However, in our experiments, the solubility of $LaPO_4$ increases with A.I. of the melt. This observation is in a good agreement with previous studies Montel (1986, 1993). The solubility data reported in Duc-Tin & Keppler (2015) are much more less with respect to our data. Duc-Tin & Keppler (2015) used synthetic La- monazite in the same HPG8 melt composition, but failed to reach equilibrium even with a run duration of 1-2 months for the metaluminous to peraluminous compositions and all the La- monazite solubility data are very low with respect to our study and previous work done by Montel (1986, 1993). In solubility experiments, in general, it is easier to get low solubility values when the equilibrium is not reached (*e.g*., slow monazite dissolution), but it is difficult to get higher solubility as observed in our results; thus our results indicate a relatively close approach to the equilibrium.

In this study, we used bubble free homogenised melts and fine-grained synthetic monazite which are more reactive than those used in other studies. In addition, in these types of experiments, it is difficult to get solubility values that are too high since the granitic melts had a REE concentration equal to zero. One of the important result of this study is that we provide for the first time the most reliable experimental data of La-monazite solubility in homogenised haplogranitic melts with different degrees of melt peralkalinity.

THE EFFECT OF TEMPERATURE ON SOLUBILITY

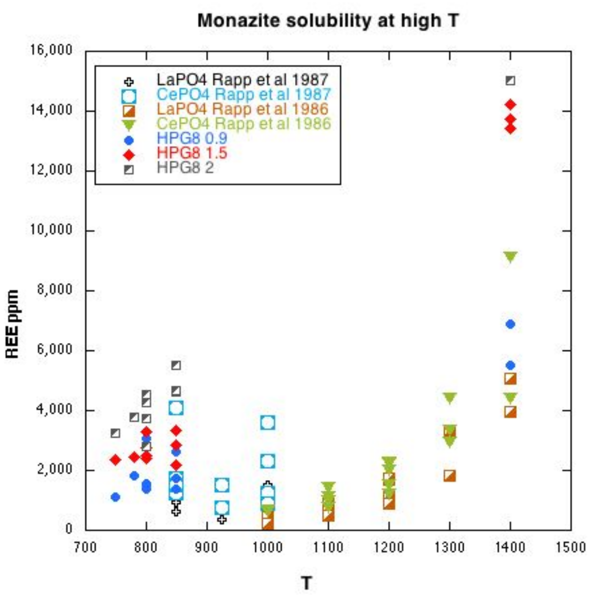

Fig. 2 - Plot of monazite solubility REE (ppm) *vs.* T (°C).

Temperature is another important parameter controlling La-monazite solubility in haplogranitic melt. Previous work on apatite and zircon showed that temperature has some influence on the solubility of accessory phases, with higher solubilities at higher temperatures.

In Fig. 2, the amount of REE in the melt is plotted against temperature. All the experiments indicated a positive dependence of monazite solubility on temperature. The data from this study can be compared with earlier experimental studies of monazite solubility (Montel, 1986, 1993; Rapp & Watson, 1986; Rapp *et al.*, 1987; Keppler, 1993; Stepanov *et al.*, 2012; Duc-Tin & Keppler, 2015).

Our results are in agreement with previous studies showing that temperature is the most important parameter affecting the solubility of monazite in the melt (for constant melt composition) with solubility increasing as temperature increase.

CONCLUSION

This study presents the first experimental data obtained for pure La-monazite in homogeneous HPG8 melt under water saturated conditions in a variety of different melt compositions as well as in a range of P-T conditions. The experimental data presented here indicates that the solubility of monazite is low in peraluminous magmas and increases as melt compositions become more peralkaline. This result can significantly improve the determination of monazite solubility in highly evolved systems and the understanding of magma evolution processes.

The effect of melt peralkalinity is mostly due to an increased depolymerization and stabilization of additional non-bridging atoms in the more peralkaline melts. The experiments at high T showed also the strong increase in monazite solubility with increasing temperature. The results suggest that the solubility of monazite can be useful for estimating temperatures of magmatic processes in granitic/rhyolitic systems, and that increased melt peralkalinity may allow fractional crystallization to produce more LREE-enriched residual melt.

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