Monazite control on Th, U and REE redistribution during partial melting: experiment and application to the deeply subducted crust

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Declaration

The work presented in this thesis was carried out during my time in the Australian National University. I certify that this thesis is my own work except where otherwise acknowledged. Some of the ideas presented have benefited from discussions with my supervisors and other colleagues, but all interpretations and conclusions are my own.

Aleksandr S. Stepanov

Dedicated to my family and science

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Abstract

Rare earth elements (REE), Th and U are elements with similar geochemical properties. In crustal rocks these elements are hosted by the light REE (LREE) phosphate mineral monazite. Piston-cylinder experiments were conducted to constrain monazite solubility and monazite/melt partitioning in hydrous granitic melts at conditions relevant to anatexis at crustal conditions and in subduction zones. Monazite has strong preference for LREE and Th; REE heavier than Nd have decreasing compatibility in monazite, and U is less compatible than LREE and Th. New experimental data and reconciliation with previous studies led to a new formulation of LREE solubility in granitic melts as a function of temperature, pressure, monazite composition and water content in melt.

The behaviour of monazite during high-pressure and ultra-high pressure (UHP) metamorphism was studied using a suite of rocks from the Kokchetav massif, Kazakhstan. Detailed petrographic and geochronologic study of the samples from the UHP Kokchetav complex was combined with investigation of trace element geochemistry and mineral inclusions of garnet, monazite and zircon. These data demonstrated that (a) on prograde evolution rocks did not experience a linear increase of pressure and temperature (P and T), but had stages of almost isothermal increase of pressure and heating stage with a small increase of pressure, (b) exhumation produced a close association of UHP gneisses with rocks that experienced metamorphism at lower PT conditions and/or along different paths from typical UHP rocks.

The geochemistry of the UHP gneisses of the Kokchetav complex is a perfect target for the application of the new experimental data, because these rocks experienced metamorphism and melting at the highest PT conditions recorded in crustal rocks. Bulk rock geochemistry of the UHP gneisses shows pronounced depletion in LREE, Th and U, and a smaller degree of depletion or enrichment in other elements that are often considered as incompatible. The variation in composition of UHP gneisses is explained by a new petrological model, which takes into account the fact that restites are composed of residual assemblage together with a residual melt. It is demonstrated that together with the residual mineral association, the degree of melting and melt extraction efficiency play an important role in controlling of trace element behaviour.

Polyphase inclusions trapped in garnet were found in samples of some UHP gneisses. The original composition of inclusions was obtained by high pressure rehomogenisation experiments. The experiments demonstrated that polyphase inclusions represent former melts of variable compositions, varying from high temperature high-LREE melts formed at peak conditions to low-LREE melts formed during exhumation. These inclusions are the first natural examples of melts formed by melting of sediments at subarc depth. This partial melting led to the complete dissolution of monazite and a strong depletion of LREE, Th and U in the UHP gneisses. Melt inclusions and bulk rock geochemistry provide evidence for the release of high LREE melts from melting of crustal metasediments. Partial melting is thus an important process changing the physical and chemical properties of deeply subducted crustal rocks.

Foreword to the Internet edition

I would like to thank three reviewers for thorough and detailed assessment of this work. Corrections were made whether possible and number of uncorrected issues will be improved or changed in publications produced from this manuscript. The text is still based on NIST values from Pearce et al. (1997) and concentrations will be corrected for new NIST values in journal versions of the chapters. However to the best of my knowledge these issues do not affect validity of observations and conclusions presented in this work.

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