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Earth and Planetary Science Letters 237 (2005) 873–892

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The water–basalt system at 4 to 6 GPa: Phase relations and second critical endpoint in a K-free eclogite at 700 to 1400 °C

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Received 13 February 2005; received in revised form 1 June 2005; accepted 3 June 2005

Available online 8 August 2005

Editor: S. King

Abstract

The phase diagram of a K-free mid ocean ridge basalt–H₂O system was determined between 4 and 6 GPa to constrain compositions of the liquid phases as liberated from an eclogite during deep subduction and to elucidate mass transfer processes at convergent plate margins. Diamond trap and conventional multi-anvil experiments were combined with a recently developed technique, in which the liquid phases, quenched from high-pressure, high-temperature conditions, are directly laser ablated in a frozen stage and analyzed by ICP-MS. Results show that at 4 GPa a fluid containing ~80 wt.% H₂O coexists with residual eclogite up to 850 °C while a hydrous melt appears at 900 °C, indicating a solidus located between 850 and 900 °C. At 5 GPa the solidus lies between 1000 and 1050 °C but terminates at a second critical endpoint between 5 and 6 GPa. At 6 GPa a supercritical liquid, with a solute content continuously increasing with temperature, forms the volatile bearing phase. Low-temperature H₂O-rich fluids and supercritical liquids have a nepheline- to quartz-normative, peralkaline character due to incongruent dissolution of clinopyroxene. The hydrous melts and high-temperature supercritical liquids evolve from rhyolitic to trachytic/andesitic with increasing liquid fraction. The melting reaction at the solidus changes from eutectic (4 GPa) to peritectic (5 GPa) with garnet changing from the reactant to the product side. With increasing melt fraction, the system becomes cotectic with about equal amounts of clinopyroxene and garnet consumed, the residual mineralogy being dominated by garnet. Most *P–T* trajectories calculated for subduction zone environment do not cross the hydrous K-free MORB solidus, therefore, the liquid phase released from the igneous portion of the subducting oceanic crust will change from fluid to supercritical liquid around 6 GPa. This change, however, is most probably associated with the change from fluid-like to melt-like properties of the mobile phase, with important consequences on trace element partitioning that will also change from fluid- to melt-like.

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Keywords: eclogite; MORB; fluid; hydrous melt; supercritical liquid; subduction zones; HP experiments

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1. Introduction

Considerable efforts have been devoted towards characterizing magmas and fluids produced from the subducting oceanic (igneous) crust at depths where eclogite is the stable mineral assemblage. Experimental [1,2] and geophysical [3] studies have shown that large masses of water are liberated from the downgoing plate as hydrous minerals break down at pressures up to 10 GPa. It is widely assumed that melts produced during partial melting of a subducting slab are intermediate to acidic in compositions, ranging from andesites to rhyolites (e.g., [4–7]). It is also well recognized that hydrous fluids originating from subducting and dehydrating oceanic lithosphere promote melting in the mantle wedge and formation of primitive arc magmas, which in turn give rise to basic to acidic magmatic suites in supra-subduction arc settings (e.g. [2,8–10]). The fluids departing from residual eclogite at subarc depths would also metasomatize the portion of the overlying mantle directly adjacent to the subducting crust and thereby play an important role in refertilization of mantle peridotite [11,12].

Despite the obvious significance of eclogite melting and dehydration and hence the composition of the resulting melts and fluids, relatively little is known about the high pressure melting relations of MORB in the presence of water. Experimental studies explored the coexistence of hydrous melts or aqueous fluids in equilibrium with quartz- or coesite-bearing eclogite at near-solidus conditions [2,5,7,13–17] to 3.5 GPa. Potassium-rich eclogites [7,18] were investigated to higher pressures. However, also in these studies, compositions of near-solidus liquids¹ were not determined and the most significant impediment to our understanding of MORB+H₂O systems comes from the scarcity of information on liquid compositions and proportions.

Previous studies have used a traditional experimental and analytical approach, i.e. after the high-pressure experiment, the capsule was mounted in

epoxy, polished and the compositions of the solid phases were obtained by electron microprobe. The identification and quantification of the high-pressure liquid phase is then often not straightforward because, in most experiments, recrystallization and exsolution upon quenching modifies the observable and measurable product. Already simple opening of the capsule leads to a loss of an emulsion of solute-carrying water and dispersed quench phases (for detailed discussion on these problems see [19,20]). The existence and composition of such unquenchable liquid phases were only determined by examining quench precipitates or were inferred from mass balanced constrains. These indirect methods suffer from difficulties in identifying the mobile phases, which in turn introduce large uncertainties in the characterization of the liquid phase.

At conditions corresponding to the earth's crust and uppermost mantle, two types of liquid phases, aqueous fluid and hydrous silicate melt, can coexist in silicate–H₂O systems. However, both the solubility of H₂O in silicate melt [21] and that of silicate material in aqueous fluid [22] increase with increasing pressure. At high pressures, the immiscibility gap between hydrous melt and aqueous fluid closes with temperature at a critical point, giving way to a supercritical liquid. The intersection of the *P*–*T* trajectory of the critical point of this immiscibility gap (a critical curve) with the solidus defines the critical endpoint of the solidus [19], where silicate melt and aqueous fluid converge in composition and become indistinguishable from each other [23,24] and where the dichotomy of fluid vs. melt ends.

The end of a clear distinction of fluid and melt renders the interpretation of experimental results difficult and, thus, in this experimental study we directly determine the composition of the liquid phase in equilibrium with residual eclogite mineralogy using novel experimental and analytical techniques [20]. This allows to define the critical endpoint of the solidus and to construct *T*–*x* sections for the MORB–H₂O system at conditions (700–1400 °C, 4–6 GPa) directly relevant for subduction zone metasomatism. Here we focus on the major element compositions of the phases and on the petrologic aspects of the hydrous basaltic system. The partitioning behavior of trace elements in the MORB–H₂O system at these conditions will be presented elsewhere.

¹ Throughout this study, we use the term liquid as a general term for any long-range disordered and physically liquid phase, i.e., for fluids, melts, and for liquids beyond the second critical endpoint of the H₂O-saturated solidus, which we term more specifically “supercritical liquids”.

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