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Modeling geochemical across-arc variations in the Kamchatka subduction zone – evidence for slab mantle dehydration from thermodynamic and trace element models

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Along and across arc variations in B/Nb and boron isotopic compositions in volcanic rocks are generally interpreted to reflect fluid release from the subducting plate. Decreasing boron concentrations and decreasing δ11B values with increasing slab depth are thought to reflect continuous slab dehydration and decreasing fluid flux from the downgoing plate. However, in some subduction zones, such as in Kamchatka, the across arc B trends are more complex and show reversals in both parameters at slab depths greater than 150 km, which have not yet been satisfactorily explained.

In Kamchatka, three distinct volcanic zones occur with increasing distance from the trench. In the first volcanic front arc lavas show decreasing B/Nb and δ11B values with increasing slab depth, as observed in many subduction zones. This trend is reversed in the second front where B/Nb and δ11B values increase drastically. In the third volcanic chain B/Nb and δ11B is at low values again.

Here we present combined thermomechanical, thermodynamic and geochemical models of the Kamchatka subduction zone that simulates fluid release, fluid migration, boron transport and boron isotope fractionation in a subducted slab passing through a steady state thermal pattern. The model successfully predicts the complex B and δ11B patterns as well as the spatial distribution of arc volcanoes that are both determined by dehydration of the oceanic slab beneath Kamchatka.

In the sub-arc region, at slab depth between 100 and 150 km, water is delivered by continuous chlorite dehydration in the hydrated oceanic crust and the wedge mantle that causes characteristic decreasing B and δ11B across-arc trends. The most important finding of our work is that serpentine breakdown in the slab mantle leads to a focused water release at slab depth of 175 km, which coincides with the position of the second volcanic chain. Moreover, the fluids liberated from the slab mantle are responsible for the increasing B contents and δ11B values in the arc volcanic rocks of the second chain. Our models constrain the presence of water within the uppermost subducted oceanic mantle to about 2.5 - 6 wt.%. Depending on hydration depth, between 25 and 90% of this water is recycled into the deeper mantle.

Our results emphasize that the initial hydration state and the dehydration behavior of the oceanic mantle play a key role in determining water flux and the partitioning of fluid mobile trace elements in subduction zones. Further, we demonstrate the importance of boron and its isotopic composition in across-arc trends for the interpretation of dehydration and fluid migration processes within and above a subducted slab. The comparison of modelled and observed geochemical trends provides evidence that the subducted slab mantle is hydrated underneath Kamchatka. Thus, our models indicate a direct link between dehydration reactions in the slab and the occurrence and chemical characteristics of arc volcanic rocks at the surface.