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Metamorphic density controls on early-stage subduction dynamics

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Subduction is primarily driven by the densification of the downgoing oceanic slab, due to dynamic P-T-fields in subduction zones. It is crucial to unravel slab densification induced by metamorphic reactions to understand the influence on plate dynamics. By analyzing the density and metamorphic structure of subduction zones, we may gain knowledge about the driving, metamorphic processes in a subduction zone like the eclogitization (i.e. the transformation of a MORB to an eclogite), the breakdown of hydrous minerals and the release of fluid or the generation of partial melts.

We have therefore developed a 2D subduction zone model down to 250 km that is based on thermodynamic equilibrium assemblage computations. Our model computes the "metamorphic density" of rocks as a function of pressure, temperature and chemical composition using the Theriak-Domino software package at different time stages. We have used this model to investigate how the hydration, dehydration, partial melting and fractionation processes of rocks all influence the metamorphic density and greatly depend on the temperature field within subduction systems. These processes are commonly neglected by other approaches (e.g., gravitational or thermomechanical in nature) reproducing the density distribution within this tectonic setting.

The process of eclogitization is assumed as being important to subduction dynamics, based on the very high density (3.6 g/cm3) of eclogitic rocks. The eclogitization in a MORB-type crust is possible only if the rock reaches the garnet phase stability field. This process is primarily temperature driven. Our model demonstrates that the initiation of eclogitization of the slab is not the only significant process that makes the descending slab denser and is responsible for the slab pull force. Indeed, our results show that the densification of the downgoing lithospheric mantle (due to an increase of pressure) starts in the early subduction stage and makes a significant contribution to the slab pull, where eclogitization does not occur. Thus, the lithospheric mantle acts as additional ballast below the sinking slab shortly after the initiation of subduction. Our calculation shows that the dogma of eclogitized basaltic, oceanic crust as the driving force of slab pull is overestimated during the early stage of subduction. These results improve our understanding of the force budget for slab pull during the intial and early stage of subduction. Therefore, the complex metamorphic structure of a slab and mantle wedge has an important impact on the development and dynamics of subduction zones.

Further Reading:

Duesterhoeft, Oberhänsli & Bousquet (2013), submitted to Earth and Planetary Science Letters