Geophysical Research Abstracts
Vol. 17, EGU2015-8239-1, 2015
EGU General Assembly 2015

Decarbonation of subducting slabs: insight from thermomechanical-petrological numerical modelling

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This work extends a numerical geodynamic modelling code (I2VIS) to simulate subduction of carbonated lithologies (altered basalts and carbonated sediments) into the mantle. Code modifications now consider devolatilisation of H_2O-CO_2 fluids, a CO_2-melt solubility parameterisation for molten sediments, and allows for carbonation of mantle peridotites. The purpose is to better understand slab generated CO_2 fluxes and consequent subduction of carbonates into the deep mantle via numerical simulation. Specifically, we vary two key model parameters: 1) slab convergence rate (1,2,3,4,5 cm y^{-1}) and 2) converging oceanic slab age (20,40,60,80 Ma) based on a half-space cooling model. The aim is to elucidate the role subduction dynamics has (i.e., spontaneous sedimentary diapirism, slab roll-back, and shear heating) with respect to slab decarbonation trends not entirely captured in previous experimental and thermodynamic investigations. This is accomplished within a fully coupled petrological-thermomechanical modelling framework utilising a characteristics-based marker-in-cell technique capable of solving visco-plastic rheologies. The thermodynamic database is modified from its original state to reflect the addition of carbonate as CO_2 added to the rock's overall bulk composition. Modifications to original lithological units and volatile bulk compositions are as follows: GLOSS average sediments (H_2O: 7.29 wt% & CO_2: 3.01 wt%), altered basalts (H_2O: 2.63 wt% & CO_2: 2.90 wt%), and metasomatised peridotite (H_2O: 1.98 wt% & CO_2: 1.5 wt%). We resolve stable mineralogy and extract rock properties via Perple_X at a resolution of 5K and 25 MPa. Devolatilisation/consumption and stability of H_2O-CO_2 fluid is determined by accessing the thermodynamic database. When fluid is released due to unstable conditions, it is tracked via markers that freely advect within the velocity field until consumed.

56 numerical models were completed and our results show excellent agreement in dynamics with the original code base. We highlight three significant geodynamic regimes where decarbonation and carbonation processes are driven by the dynamics of subduction. 1) Sedimentary diapirism acts as an efficient physical mechanism for CO_2 removal from the slab. Diapirism is driven by Rayleigh-Taylor instabilities which arise from density driven contrasts at the slab-mantle interface. Otherwise, diapirs are propelled by low density/low viscosity contrasts of partial melts. A unique feature related to diapirism was the emergence of carbonated forearc mantle wedge. We propose that removal of rheologically weak sediments results in heat generation via a shear heating term otherwise not accounted for in thermodynamic and experimental studies. 2) If subduction rates of a young slab are slow, enhanced frictional coupling between the subducting plate and overriding crust occurs. As a result, mafic crust is mechanically incorporated into the lower crust. Near isothermal decompression of injected mafic crust results in significant decarbonation directly into the lower crust. 3) During extension and slab roll-back, interaction between hot asthenosphere and sediments at shallow depths results in small window ($\sim$12.5 Ma) of high integrated CO_2 fluxes (205 kg m^{-3} ma^{-1}).