An Open-System Model for Coupled H$_2$O and CO$_2$ Transport in Subducting Slabs

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Subduction zones are sites where carbon and water actively cycle between Earth’s exosphere and interior over geological timescales. However, it is debated how much H$_2$O and CO$_2$ are transferred from subducting slabs to the mantle wedge and eventually to arc volcanoes. To model the H$_2$O and CO$_2$ transport within slabs, we first parameterize the coupled dehydration and decarbonation reactions for representative subducting lithologies based on phase diagram calculations using Perple_X. Such a parameterization allows efficient computation of the H$_2$O and CO$_2$ partitioning between pore fluids and rocks, and captures two important open-system behaviors—infiltration and chemical fractionation. A two-dimensional reactive transport model is then constructed to simulate the chemically open-system behaviors of H$_2$O and CO$_2$ transport within slabs. Model results show that porous flow within slabs must be upward and nearly slab parallel to be able to supply maximum amount of H$_2$O and CO$_2$ at depths directly below volcanic arcs. This finding on the within-slab flow direction is consistent with previous fluid dynamical studies about the effect of compaction pressures on subduction-zone fluid migration. In addition, our models show that infiltration of H$_2$O sourced from hydrated slab mantle (serpentinite) can significantly increase slab surface H$_2$O and CO$_2$ fluxes and redistribute CO$_2$ from slab’s basaltic and gabbroic layers to overlying sediments. As a result, diapiric removal or partial melting of slab surface sediments can promote carbon transfer from subducting slabs to the mantle wedge. In all cases, subducting slabs cannot completely release their CO$_2$ and therefore sequester carbon into the deeper mantle.