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Bend-faulting, serpentinization, and double seismic zones – new insights from reaction-transport modeling

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Double Benioff zones (DBZs) are globally observed parallel bands of seismicity corresponding to planes of internal deformation that occur in subducting plates irrespective of plate age, subduction rate, or stress orientation. Although various mechanisms have been proposed as the trigger for these seismicity planes, the process by which the lower plane of seismicity is formed is still debated. One of the more favored methods is the dehydration of various minerals within the altered, subducting oceanic lithosphere; specifically, the dehydration of metabasalts and antigorite/chlorite as the causes for the upper and lower regions of seismicity, respectively.

Here we explore the likely degree of hydration of subducting lithosphere and its consequences for intermediate depth seismicity and formation of DBZs. To do so, we have developed a reaction transport model that resolves for the circulation of seawater as well as serpentinization of cold oceanic lithospheric mantle. The 2D porous flow model has been developed using finite elements and is based on Darcy flow; serpentinization is implemented using experimentally determined reaction coefficients. We find that bend-faults forming during plate bending at the outer rise are likely to be highly serpentinized. Background serpentinization away from faults is most intense around the 270°C isotherm where the rate of serpentinization is at its maximum.

In a series of 2D, along- and across-trench numerical experiments, we demonstrate that the degree of hydration increases with plate age. The across trench simulations show a prominent band of high serpentine contents around the 270°C isotherm. The depth of the 270°C is plate age dependent as plate cooling models show. As a consequence, the depth at which maximum serpentinisation is favored, i.e. the 270°C isotherm increases with plate age. Strikingly the location of this band of high serpentine content correlates reasonably well with the observed dominant spacing of DBZs observed worldwide for different plate ages. Deviations from this correlation can be related to 3D effects during serpentinization, which have been explored in a series of along trench numerical experiments. The striking correlation between the depth to the 270°C prior to subduction and the observed separation of DBZs holds for many subduction zones worldwide with various plate ages. Our numerical experiments provide therefore a quantitative link between plate hydration during plate bending and the occurrence of DBZs.