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Crustal wedge deformation in an internally-driven, numerical subduction model

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The Earth's active convergent margins are characterized by dynamic feedback mechanisms that interact to form an intricate system in which a crustal wedge is shaped and metamorphosed at the will of two large, converging plates. This framework is accompanied by complicated processes, such as seismogenesis and the exhumation of high pressure rocks. To honor the dynamic interaction between different entities and advance on these persisting issues, we model the interaction between the subducting and overriding lithospheres, the mantle and the crustal wedge explicitly, and observe how a crustal wedge evolves in detail within a set of rigid, internally-driven boundary conditions. We model crustal wedge evolution in an intra-oceanic subduction setting by using a plane-strain implicit solid-mechanical Finite Element Model, in which the mechanical conservation equations are solved using the software package ABAQUS. The crustal wedge is modeled as a thick-skinned accretionary wedge of intermediate thickness with a linear visco-elastic bulk rheology. The dynamic interaction between the subducting plate, the overriding plate, and crustal wedge is implemented using a Coulomb frictional algorithm. The interaction with the mantle is incorporated using a computationally favorable mantle drag formulation that simulates induced three-dimensional mantle flow. This results in a quasi-static framework with a freely moving slab, trench, and fault, where a weaker wedge deforms in response to self-regulating, rigid boundary conditions formed by single, frictional bounding faults. The self-regulating evolution of crustal wedge architecture follows three phases; 1) initial vertical growth, 2) coeval compression and extension leading to internal corner flow, and 3) a steady-state taper with continuous corner flow. Particle trajectories show that, as shortening continues throughout the second phase, wedge material is constantly forced upward against the backstop, while extension and ocean-ward extrusion occur on top due to gravitational spreading. This dynamically forced corner flow provides a mechanism for the syn-orogenic exhumation of high-pressure oceanic blueschists. This deformation pattern with a vertical reversal in shear transport direction is similar to that observed in analogue viscous paraffin wedges. Resulting exhumation rates are in the order of millimeters a year, regulated by the frictional parameters and wedge strength. A change in fault frictions lead to subduction erosion instead of accretion, as crustal wedge material is dragged down in a spontaneously formed subduction channel. Subduction erosion is essentially promoted by inter-plate friction, since this determines whether a subduction channel entrance can be formed through down dragging of the overriding plate. This down dragging is also promoted by an increase in relative strength of the wedge compared to the overriding plate. Increased basal wedge drag only slightly increases the amount of subducted material. The type of wedge behavior, accretion or subduction erosion, and its amount considerably influences inter-plate stresses and seismic coupling at the inter-plate fault.