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Progressive lawsonite eclogitization of the oceanic crust: Implications for deep mass transfer in subduction zones

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Lawsonite eclogites are major hosts of H_2O and trace elements and thus key for long-term deep element cycling in subduction zones. Existing cycling models suggest that the subducting oceanic crust transforms to lawsonite-eclogite assemblages; yet the scarcity of lawsonite eclogites in the rock record questions to what extent the oceanic crust transforms to lawsonite-eclogite assemblages during subduction. Here, we use petrological modeling coupled with geodynamic calculations for a typical subduction zone to show that the occurrence of lawsonite eclogites is controlled by the maturation of the subduction zone. We find that lawsonite eclogite does not form in infant subduction zones; with time, the oceanic crust forms lawsonite assemblages, but prograde heating obliterates lawsonite except in rocks exhumed prior to such heating. Lawsonite-eclogite assemblages in the oceanic crust form and survive prograde metamorphism only in mature and cold subduction zones but still necessitate specific characteristics during exhumation to preserve lawsonite. We show that the stability of lawsonite in mature subduction zones is hindered by hybridization between the mafic crust and the overlaying mantle wedge material; by contrast, lawsonite proportion increases with intense seafloor alteration and Ca-Al metasomatism. These latter processes are thus key for enhancing recycling. We argue that lawsonite-driven mass cycling to the deep mantle is important in mature subduction zones, but the role of lawsonite eclogite in carrying mass deep into Earth in the infant stage of a subduction zone is minor.