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Porous flow assisted plate rheology enables and controls terrestrial subduction: why and how?

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Subduction is a key process for the evolution of Earth's surface and interior but its initiation and variability of tectonic styles remain controversial. Based on high-resolution numerical experiments, we demonstrate that the presence of surface water on Earth controls both initiation and geodynamic regime of subduction via rock strength reduction induced by high porous fluid pressures. We show that although subduction fails to initiate under fluid-absent conditions, it can naturally start when porous fluid is present inside oceanic crust and along the plate boundaries. Fluid percolation localizes along spontaneously forming fractures where high fluid pressure compensates lithostatic pressure, thus dramatically decreasing friction along the incipient subduction zone. We further demonstrate that three main geodynamic regimes of subduction can be identified depending on degree of fluid- and melt induced weakening: retreating subduction with opening of a backarc basin, stable subduction, and advancing, compressive subduction. Retreating subduction regimes require plate decoupling, which results from strong weakening due to both fluids and melts. Spreading centers nucleate either in forearc or in intraarc regions, thus always leaving deactivated paleoarcs on the far side of the backarc basin. The advancing subduction regime results from strong plate coupling caused by reduced fluid-related weakening of the forearc. At the mature stage, this subduction mode is associated with strong subduction erosion and hydrous plumes/diapirs development under magmatic arcs. Mature compressive intra-oceanic subduction may additionally associate with partial fragmentation and subduction of a serpentinized forearc. Stable subduction regime with little variation in the trench position forms at an intermediate plate coupling and shows a transient behavior from the retreating to advancing modes. Crustal growth in arcs depends critically on geodynamic style of subduction. Crustal growth in a stable subduction setting results in the emplacement of flattened intrusions in the lower crust, characterized by a successively increasing mantle component and low magmatic addition rates (10 km3/km/Myrs). Compressional arcs are accomplished by the formation and emplacement of hydrous plumes/diapirs, containing large volumes of partially molten sediments and basalts. Magmatic addition rates are higher compared to stable arcs (40–70 km3 /km/Myrs). Subduction in a retreating arc setting results in intense decompression melting of relatively dry asthenospheric mantle. Large volumes of mafic (oceanic) crust are formed in the backarc region with total magmatic addition rates being as high as 90–170 km3/km/Myrs.