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Impact of 3D subduction geometry and crustal rheology on deformation at orogen syntaxes: Insights from thermo-mechanical modelling

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This study investigates upper plate deformation resulting from subduction of a stiff indenter using a fully coupled thermo-mechanical numerical model (DOUAR). The simulations aim to explore the effects of a realistic crustal rheological stratification, strain localization, and surface processes. A range of possible rheological profiles (strength envelopes) have been tested to identify their influence on the resulting pattern of strain localization and associated rock uplift. The models consider two end-member cases of a strong and weak mechanical coupling between the upper crust and lithospheric mantle corresponding to the strong, cratonic lithosphere and considerably weaker, younger (and hotter) continental plate, respectively. The strongly coupled case predicts two oppositely dipping thrust-sense shear zones cutting through the entire crust and the upper lithospheric mantle. The presence of lithosphere-scale thrust faults induces a strong upward Moho deflection associated with narrow bands of localized surface uplift stretched parallel to the trench. In the weakly coupled case, deformation localizes along shallow-dipping retro-shear zones rooting into an underlying ductile lower crust. The rock uplift pattern evolves from a linear trench-parallel band to a localized curved ellipse that is centered above the indenter apex, where vertical surface velocities reach their maximum (7-9 mm/yr). In this case, the initial configuration of the rigid indenter appears to be a key parameter controlling the aspect ratio of the localized area of rapid rock uplift. In particular, a narrow indenter excites a symmetric “bull’s-eye”-like rock exhumation pattern that resembles the concentric pattern of vertical advection observed at orogen syntaxes in such regions as the Himalayan Syntaxes, the South East Alaska (St. Elias region), and the Cascadia Subduction Zone (western USA). We argue that characteristic features of extreme exhumation rates in orogen syntaxes can be reproduced by subduction of geometrically stiffened plate only under condition of mechanical decoupling in the overriding lithosphere.