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Rheological and geodynamic controls on the mechanisms of subduction, HP/UHP exhumation and PT conditions within crustal rocks during continental collision: insights from numerical models

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Mechanisms of continental convergence are so versatile that it is impossible to elucidate them from conventional set of observations. Additional discriminatory data are needed such as those derived from petrology data, since burial/exhumation dynamics inferred from metamorphic P-T-t paths potentially provides independent constraints on the collision mechanism. While subduction of crustal rocks is increasingly accepted as common phenomenon inherent to convergent processes involving continental plates and micro-continents, the conditions of their formation and mechanisms of their exhumation in the form of high- and ultra-high-pressure (HP/UHP) units remain a subject of controversy. In particular, deep burial and exhumation of continental crust occur in various settings, including subduction of micro-continental terrains carried down with the subducting oceanic lithosphere and transition between the oceanic and continental subduction. Geodynamic inferences from P-T data can be made only after providing a consistent approach to decryption of both pressure and temperature in terms of depth or at least in terms of characteristic geodynamic conditions. Thermo-mechanical thermodynamically coupled numerical models of continental collision provide some elements of solution to this problem through testing various geodynamic scenarios within relatively unconstrained framework which allows for account of non-lithostatic pressure variations and for deviations of temperature from commonly inferred thermal models. We here explore several possible scenarios of subduction and exhumation of continental crust, and their relation to PT conditions and mechanisms of HP/UHP exhumation inferred from conceptual and thermo-mechanical numerical models accounting for thermo-rheological complexity and diversity of the continental lithosphere. Numerical experiments suggest that in most cases both exhumation and continental subduction are transient processes, so that long-lasting (> 10-15 Myr) continental subduction occurs in very specific cases of cold strong lithospheres while in general this process takes less than 5 Myr. During the active subduction phase (simple shear accommodation of convergence) we do not detect significant deviations (+-20%) of total pressure in the subduction channel from lithostatic values , that can be rather lower than the lithostatic pressure, while intra-channel temperatures vary in quite large limits. Hence, large volumes of HP/UHP metamorphic rocks generated and brought to the surface during subduction phase would not record significant deviations from the lithostatic pressure conditions. At the same time, strong non-lithostatic pressures (extensional and compressional) are predicted for some internal parts of the colliding plates that, however, are not prone to yield “extractable” metamorphic material. The experiments also show that high non-lithostatic pressures develop in the former subduction channel at its lock-up , during and after the transition from subduction to pure shear collision or folding, while the metamorphic material generated at this stage appears to be blocked at depth and does not return to the surface (at least if the channel is not unlocked due some external conditions). We suggest that most continental orogenic belts could have started their formation from continental subduction. This process has been generally limited in time while pressures recorded in the HP and UHP material generated at this stage can be largely treated in terms of the lithostatic approximation. In case of subduction of continental terrains embedded in the oceanic lithosphere, it can be shown that their exhumation, resulting in formation of metaphoric belts and domes, may initiate series of slab roll-back and exhumation events associated with remarkably complex and spatially variable P-T-t paths.