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Evolution of Subduction/Collision Zones from Archean to Present: a Numerical Modelling Approach

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Although the signature of subduction is recognized with some confidence in the Phanerozoic continental geological record, evidence for subduction becomes less certain further back in time. To improve our understanding of plate tectonics on the Earth in the Precambrian we have used 2D petrological-thermomechanical numerical modeling to investigate evolution of (i) oceanic-continental subduction and (ii) continent-continent collision back in geological time. We investigated dependencies of tectono-metamorphic and magmatic regimes for these two major geodynamic settings on upper-mantle temperature, lithosphere thickness, degree of lithospheric weakening and other physical parameters.

For the oceanic-continental subduction setting, we identified a first-order transition from a “no-subduction” tectonic regime at high upper-mantle temperatures more than 200 K above the present-day values (rapid movements of small internally deformable plate fragments) through a “pre-subduction” tectonic regime at 160-200 K above the present-day values (shallow underthrusting of the oceanic plate under the continental plate) to the modern style of subduction. The link between geological observations and model results suggests that this transition might have occurred during the Mesoarchean–Neoarchean (3.2–2.5 Ga). The crucial parameter controlling subduction is the degree of lithospheric weakening induced by emplacement of sub-lithospheric melts into the lithosphere.

For the continental collision setting we identified strong dependencies of tectonic regimes on upper-mantle and Moho temperatures as well as on the effective reology of lower continental crust. At present day conditions weak lower continental crust gives rise to a decoupled continental collision with the formation of a wide orogenic belt with medium-grade metamorphism. In contrast, strong lower crust results in a coupled collision forming narrower orogenic belts comprising ultra-high-pressure metamorphic complexes. Increase of the mantle temperature for more than 100K above present-day values promotes development of hot and narrow convergence zones bounded by lithospheric extension and decompression melting regions. Cases with weaker lower continental crust results in narrow two-sided orogens with deep and hot crustal roots whereas stronger lower crust promotes formation of magmatic belts above hot continental subduction zones. The link between geological observations and model results suggests that the transition from the “hot collision” regime to the modern style of collision might have occurred during the Neoproterozoic when ultra-high-pressure metamorphic rocks first appear in the continental geological record.