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Numerical modelling of crustal growth at active continental margins: implications for the origin of batholiths

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As the dynamics and melt sources for batholith generation still remain controversial a set of numerical experiments has been performed using a 2D geochemical – petrological – thermomechanical numerical code (I2VIS) to study dynamics of crustal growth at an active continental margin. The petrological – thermomechanical model simulates oceanic – continental subduction, based on finite differences and marker in cell techniques. The model accounts for spontaneous slab retreat and bending, dehydration of subducted crust, aqueous fluid transport, partial melting, melt extraction and melt emplacement in form of both extrusive volcanics and intrusive plutons. A set of numerical experiments has been performed by varying the rheological weakening effect imposed by fluids and melts.

The results indicate that two major tectonic modes of crustal growth exist: (i) plume – absent and (ii) plume – present regimes. Crustal growth in the plume – absent regime is accomplished dominantly by magma emplacement within the lower crust. Melts are extracted from partially molten rocks located atop the slab (i.e. hydrated mantle, sediments and basalts) and are emplaced within the lower crust in form of laterally extending and crystallizing, flattened batholiths of mainly basaltic to andesitic composition. In the case of a plume – present regime subduction of large quantities of sediments results in the formation of buoyant, silicic plumes composed of partially molten sediments and partially molten basalts with some contribution of hydrated mantle. Subsequently these plumes ascend from the slab and intrude into the crust, where they finally crystallize as intrusive bodies (batholiths) within the upper crust. Additionally, extracted melts from partially molten rocks, which are formed both atop the slab and inside the plumes, are being emplaced within the lower crust, where they extend laterally with time until they crystallize. Consequently, two coupled mechanisms contribute to crustal growth in the plume – present model: (1) intrusions of partially molten plumes and (2) the emplacement of extracted melts within the lower crust. Because batholitic intrusions propagate toward higher crustal levels, the plume – present model is more efficient in supplying more voluminous and more silicic magmas compared to the plume – absent regime.

The transition from a plume – present to a plume – absent regime is a direct consequence of the amount of sediments being subducted: subduction of insufficient sediments results in a plume – absent regime. The subduction of sediments is strongly related to fluid – related weakening of the forearc region. Strong weakening promotes plate decoupling, stacking of sediments and therefore results in a large accretion wedge. In this case, insufficient sediments are being subducted and plumes do not form. Small amounts of fluid weakening, on the other hand, result in strong coupling of the subducting and overriding plate in a collision – like subduction setting. In this case, large quantities of sediments are being subducted and sedimentary plumes are formed. In both regimes magmatic addition into the crust causes strong crustal, thermal anomalies, which may explain enhanced localized heat fluxes observed in natural arc settings.