Geophysical Research Abstracts
Vol. 19, EGU2017-13042, 2017
EGU General Assembly 2017

Subduction and Slab Advance at Orogen Syntaxes: Predicting Exhumation Rates and Thermochronometric Ages with Numerical Modeling

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The change in plate boundary orientation and subducting plate geometry along orogen syntaxes may have major control on the subduction and exhumation dynamics at these locations. Previous work documents that the curvature of subducting plates in 3D at orogen syntaxes forces a buckling and flexural stiffening of the downgoing plate. The geometry of this stiffened plate region, also called indenter, can be observed in various subduction zones around the world (e.g. St. Elias Range, Alaska; Cascadia, USA; Andean syntaxis, South America). The development of a subducting, flexurally stiffened indenter beneath orogen syntaxes influences deformation in the overriding plate and can lead to accelerated and focused rock uplift above its apex. Moreover, the style of deformation in the overriding plate is influenced by the amount of trench or slab advance, which is the amount of overall shortening not accommodated by underthrusting. While many subduction zones exhibit little to no slab advance, the Nazca-South America subduction and especially the early stages of the India-Eurasia collision provide end-member examples.

Here, we use a transient, lithospheric-scale, thermomechanical 3D model of an orogen syntaxis to investigate the effects of subducting a flexurally stiffened plate geometry and slab advance on upper plate deformation. A visco-plastic upper-plate rheology is used, along with a buckled, rigid subducting plate. The free surface of the thermomechanical model is coupled to a landscape evolution model that accounts for erosion by fluvial and hillslope processes. The cooling histories of exhumed rocks are used to predict the evolution of low-temperature thermochronometer ages on the surface. With a constant overall shortening for all simulations, the magnitude of slab advance is varied stepwise from no advance, with all shortening accommodated by underthrusting, to full slab advance, i.e. no motion on the megathrust.

We show that in models where most shortening is accommodated by subduction, the uplift is highly localized and focused in a shape resembling the geometry of the subducting plate. Strong erosion of the growing orogen can shift the center of uplift towards the orogen flanks facing the trench. In contrast, large amounts of slab advance lead to a less focused uplift with lower maximum velocities and the uplift peak located farther away from the trench. The observed thermochronometric ages follow the uplift pattern, but indicate a significantly deeper and more rapid exhumation for models with a higher underthrusting component.

These variations in amount and style of upper plate deformation may help to deepen the understanding of the different types of orogeny observed at plate corners around the world.