Mantle-lithosphere interactions in large, hot collisional orogens: Implications for crustal channels and other flow regimes

CHRISTOPHER BEAUMONT[1], MAI NGUYEN[1,2], REBECCA A. JAMIESON[2] & BONNY LEE[1]
[1]*Department of Oceanography, Dalhousie University, Halifax. N.S., Canada B3H 4J1*
[2]*Department of Earth Sciences, Dalhousie University, Halifax, N.S., Canada B3H 3J5*

Recent interpretations of Himalayan-Tibetan tectonics have proposed that gravitationally driven channel flows of low-viscosity middle crust can explain both outward growth of the Tibetan plateau as the channel tunnels outward, and ductile extrusion of the Greater Himalayan Sequence (GHS) in response to focused surface denudation at the orogenic front. Results from crustal-scale numerical models with self-generating mid-crustal channel flows and subduction-type kinematic basal boundary conditions (Beaumont *et al.*, 2001, *Nature*, **414**, 738-742; Beaumont *et al*., *JGR*, in press; Jamieson *et al.*, *JGR*, in press) are compatible with many first-order features of the Himalayan-Tibetan system. In these models, radioactive self-heating of tectonically thickened crust leads to rheological 'melt-weakening', the development of a broad orogenic plateau, and efficient channel flows when the effective mid-crustal viscosity is $\leq 10^{19}$ Pa.s. In natural systems the level of melting required to reduce the bulk effective viscosity and hence develop efficient channel flows is uncertain but may be < 5% *in situ* partial melt distributed at the scale of the channel flow, within or below the range observed in migmatites. Alternatively, given the uncertainty in the rheology of quartz-dominated rocks above 700°C, it is also possible that comparable viscosity reduction, and hence efficient mid-crustal channel flows, may develop without melting.

The focus of our recent research has been to broaden the investigation of crustal channel flows to models that include the lithosphere and upper mantle, thereby removing the need for the kinematic basal boundary conditions The recent models also include: 1) heating from internal dissipation during deformation as well as radioactive heating; 2) parameterized strain softening and hardening; and 3) the effect of the basalt to eclogite phase transition on the density distribution.

We also want to understand flow regimes in orogenic crust that is sub-critical with respect to the ideal channel flows predicted by the numerical models in homogeneous melt-weakened crust. We regard the latter as an end member, which may be possible beneath super-plateaus in giant collisional orogens. However, such widespread channel flows may not be the best analogues for mid-crustal flows in more common Cordilleran-type and other medium-sized orogens.

In addition to Mode 1, the ideal homogeneous channel flow mode, we also recognize two other flow modes in the numerical model results: Mode 2, heterogeneous channel flow, in which even relatively large-scale blocks of refractory, non-fertile lower crust are detached and incorporated into the channel flow; and Mode 3, the hot fold-nappe mode, in which mid- and lower crust is forcibly expelled outward from the interior of the orogen, flowing up and over stronger lower-crustal blocks that resist detachment and are therefore not incorporated into the flow. In Mode 3 the flow over stronger blocks creates large-scale, highly ductile fold-nappes with overall strong flattening and extensional bulk strain and attenuated lower limbs. This style of flow may be characteristic of crust that has failed to attain sufficiently low bulk effective viscosity for efficient gravitationally-driven homogeneous channel flow. Under these circumstances the process that creates the hot fold-nappes is likely related to the tectonic boundary conditions. For example, collision with a relatively strong crustal block, which acts as a plunger or indentor, can initiate expulsion of fold nappes over the block. This process is particularly favoured when refractory cratonic crust collides and cannot be assimilated into the orogen by the normal weakening processes.

There is also considerable debate concerning the mechanisms by which continental mantle lithosphere, and perhaps lower crust, are resorbed by the sub-lithospheric mantle during collisonal orogenesis. Subduction, ablative subduction, viscous dripping, delamination, and plastic slab breakoff are among the candidate mechanisms. Our recent upper-mantle-scale models exhibit a range of mantle-lithosphere interactions beneath large hot orogens, depending on the mantle lithosphere rheology and temperature. The results are particularly sensitive to the bulk density contrast between lithospheric and sub-lithospheric mantle, with small variations leading to behaviours that range from advancing subduction, with shortening and thickening of the retro-mantle lithosphere, to advancing double subduction, normal asymmetric subduction, breakoff of the subucted slab, or delamination and rollback of the subducting mantle lithosphere. Combinations of these processes are also observed in the models, with transient behaviours apparently related to the mass excess and strength of the subducted lithosphere.

The sensitivity of the model behaviours to mantle density contrasts and other factors will be shown and the implications for the crustal flow regimes examined.