Mantle-Lithosphere Interactions in Large, Hot Collisional Orogens and Implications for Crustal Flow Regimes

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Recent interpretations of Himalayan-Tibetan tectonics have proposed that gravitationally driven channel flows of partially molten, middle crust can explain both the outward growth of the Tibetan plateau as the channel tunnels outward, and the ductile extrusion of the Greater Himalayan Sequence (GHS). 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, v414, 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 nature, the level of melting required to reduce the bulk effective viscosity and hence develop efficient channel flows is uncertain but could be < 5% in situ partial melt distributed at the scale of the channel flow, within or below the range observed in migmatites.

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 noted above. We also want to understand flow regimes in orogenic crust that is subcritical 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, widespread channel flows may not be the best analogues for mid-crustal flows in the more common Cordilleran-type and other medium-sized collisional orogens.

In addition to the ideal homogeneous channel flow mode (1) we also recognize two other flow modes in the numerical model results: the heterogenous channel flow mode (2), in which even relatively large scale blocks of refractory, non-fertile lower crust are detached and incorporated into the channel flow, and the hot fold nappe mode (3), in which mid- and lower crust, which is forcibly expelled outward from the interior of the orogen, flows up and over stronger lower-crustal blocks that resist detachment and are therefore not incorporated into the flow (see Jamieson et al., this volume, for a possible natural example). In the third flow regime 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 the necessary 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 older, refractory cratonic crust collides and cannot be assimilated within the orogen by the normal weakening processes.

There is considerable debate concerning the mechanisms by which continental mantle lithosphere and perhaps lower crust are resorbed by the sublithospheric mantle during collisonal orogenesis with subduction, ablative subduction, viscous dripping, delamination, and plastic slab breakoff among the candidate mechanisms. Our recent upper-mantle-scale models exhibit a range of mantle-lithosphere interactions that depend on the mantle lithosphere rheology and temperature. The results (e.g., Fig. 1) are particularly sensitive to the bulk density contrast between the lithospheric mantle and the underlying asthenosphere, 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 lithophere.

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.

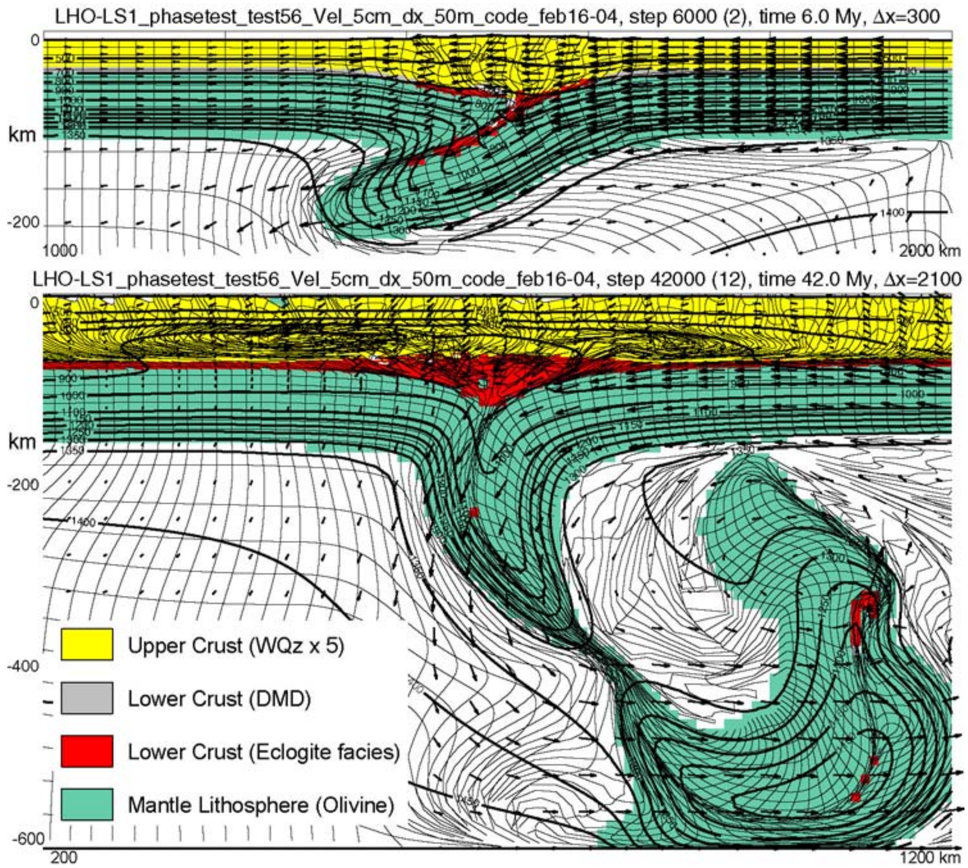

Figure 1: Two stages, 6 and 42My, in the evolution of an upper mantle scale continental collision finite element model (2000x600km) for which convergence at 5cm/y equals 300 and 2100km. Arrows indicate velocity, fine lines are deformed Lagrangian mesh, and medium lines are isotherms (^{o}C). No surface erosion. A crustal channel develops above the eclogitic lower crust. Mantle lithosphere initially subducts then evolves to advancing double subduction and finally breaks off.