Himalayan-Tibetan Orogeny: Channel Flow versus (Critical) Wedge Models, a False Dichotomy?

Christopher Beaumont[1], Rebecca Jamieson[2]

[1]Department of Oceanography, Dalhousie University, Halifax, NS, B3H 4J1, Canada, chris.beaumont@dal.ca
[2]Department of Earth Sciences, Dalhousie University, Halifax, NS, B3H 4J1, Canada

Two classes of hypotheses supported by models, here termed Channel Flow and (Critical) Wedge, have been central to recent discussions concerning the evolution of the Himalayan-Tibetan orogen. The first type, Channel Flow (see Grujic, 2006; Klemperer, 2006; Hodges, 2006; Harris, 2007 for overviews), provides an explanation of the development of the Greater Himalayan Sequence as a consequence of the extrusion of a weak mid-crustal channel at the surface. In the Beaumont and others models (Beaumont and others, 2001, Jamieson and others, 2006) channel flow develops in the thickened orogenic crust by ductile weakening following thermal relaxation and radioactive heating, augmented by a small component of 'melt' weakening. Channel flow is driven outward from beneath the orogen by the pressure difference between the plateau and the foreland, and the channel is interpreted to have been uplifted and exhumed to the surface by climate-enhanced erosion focused on the flank of the plateau. Exhumation occurs between coeval basal thrust-sense, and overlying normal-sense, shear zones. The channel flow model also predicts the formation of a plateau in regions where the strength of the crust is sufficiently low that it will not support topographic gradients. Where not exhumed the channel 'tunnels' beneath the flank of the orogen. In general, crust in this region is too cold and the viscosity too high for the channel to be injected (Medvedev and Beaumont, 2006). Instead, the channel only advances when the adjacent crust has thickened, thermally relaxed, and weakened sufficiently to join the channel flow. The region between the foreland and the active channel, corresponding to the Siwaliks and Lesser Himalaya, develops as a thrust wedge (Beaumont and others, 2001 Fig.4c) and this wedge is more fully developed when there is a weak near-surface decollement layer in the model (Jamieson and others 2006, Fig. 4, model HT111). The foreland is flexed downward to form a foreland basin. These models are thermo-mechanically coupled and they evolve dynamically subject to prescribed basal boundary conditions and surface erosion, which depends on the product of the local surface slope predicted by the model, and an erosion rate coefficient modulated by a climate scale that varies between 0 (no erosion) and 1 (highly erosive).

In the second, (Critical) Wedge class of models, the Himalaya is interpreted to have evolved as a wedge (Kohn, 2008) which may / may not be critical (Dahlen, 1984), or a variant on this approach including reconstruction of wedges using balanced cross sections (e.g. DeCelles and others, 2001; Robinson and others, 2006), or transport of thrust sheets over a basal ramp-flat system. Many models in this class either use thermo-kinematic models to predict the thermal evolution of the system in response to prescribed velocity fields and surface erosion (e.g. Henry and others 1997; Bollinger and others, 2006; Whipp and others, 2007; Robert and others, 2009) or base their interpretations on this type of model (e.g., Kohn, 2008).

The discussion of the relative merits of these models has in some instances portrayed them as mutually exclusive; it was either Channel Flow, or (Critical) Wedge, or possibly another mechanism that accounts for the large-scale tectonic evolution the Himalayan system (e.g., Robinson and others, 2006; Robinson and Pearson, 2006; Kohn, 2008). Here we present the case that the two types of models are not mutually exclusive and that we should expect the corresponding tectonic styles to coexist in nature.

We first present model results that show how an orogenic system evolves through several phases: 1, Bivergent critical wedges (while the system is cold); 2, Plateau bounded by critical wedges (as the interior of the system becomes too weak to sustain topographic gradients); 3,Tunnelling channel flow; 4, Exhuming channel, and; 5, Waning channel exhumation. During Phases 3-5 the part of the orogen external to the channel develops as a critical wedge. This is entirely consistent with this part of the orogen being too cold for the channel to tunnel into it.
We then show that as erosion rates decrease and exhumation of the channel is suppressed, the critical wedge expands into the orogen to encompass the region of the exhumed former channel. Lastly, we

demonstrate reactivation of the Main Central Thrust as an out-of-sequence thrust when significant focused erosion returns to the flank of the plateau. We conclude that there is no real dichotomy between channel flow and critical wedge styles of behaviour in orogen tectonic models, and most likely in nature as well. The interior plateau region of the orogen will be governed by the flow of hot, weak mid- or lower crust and may develop channel flows or other deformation styles (Jamieson and others, 2007). Beneath the flank of the orogen, channel flow will coexist with, and be juxtaposed against, an external critical wedge (foreland-fold-thrust belt). Depending on the rates of surface erosion and basal boundary conditions this part of the system will behave as a tunneling or exhuming channel system with external critical wedge, as a thrust-sense critical wedge, or as an unstable system subject to gravitational spreading. The system is expected to migrate among these behaviours as external conditions vary.

In regard to the Himalayan-Tibetan system we infer:

1) A first phase of Early Miocene channel exhumation coincided with protracted intense erosion focussed on the southern flank of the orogen;
2) As erosion rates progressively waned from Mid-Miocene onward, channel exhumation ceased and the whole flank of the orogen cooled and became a thrust-sense critical wedge with the tip of the channel tunnelling at the edge of the plateau;
3) The return of more aggressive erosion (~3 Ma) has reactivated, or is in the process of reactivating, the Main Central Thrust as an out of sequence thrust; ahead of a channel now situated beneath the plateau;
4) If this aggressive erosion persists for approximately 10 Ma, the modern channel will be exhumed in a similar manner to that of the first Miocene phase.

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