

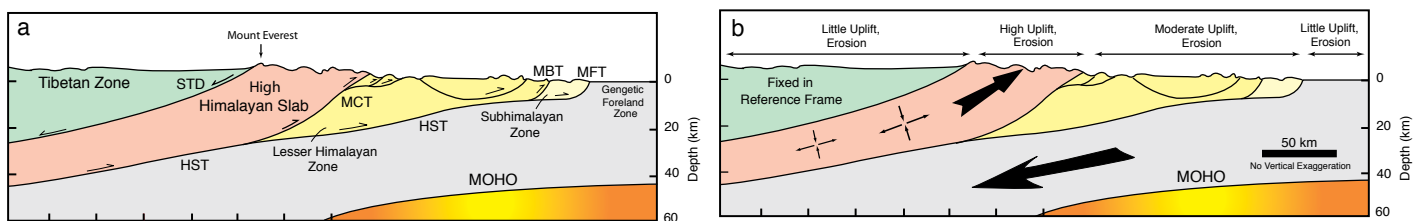


Building the Himalaya: Flow and Extrusion of Mid-Crustal Rocks During Continental Collision

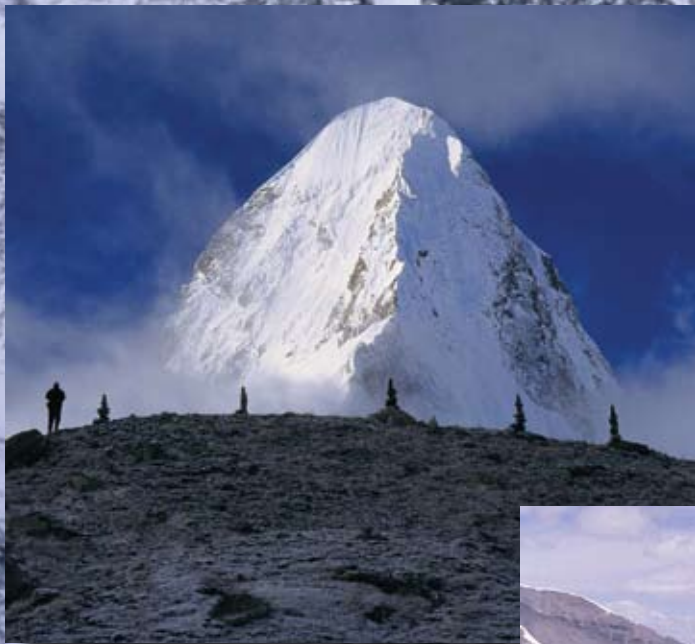
by Rick Law, Professor of Geology

The Himalaya is frequently cited as the classic example of a mountain chain produced by continent-continent collision, with the chain progressively evolving as thrust sheets are stacked up on top of one another during continued collision between India and Asia. But what has been much less commonly talked about is how high temperature flow within the metamorphic core of the Himalaya may itself be an important driving mechanism for uplift and exhumation of these mid-

crustal rocks along with subsequent formation of some of the highest peaks on Earth. That began to change in the late 1980s and 1990s when MIT geologists proposed that rocks forming the metamorphic core of the Himalaya were originally located beneath the Tibetan Plateau and have been squeezed and extruded southwards as a slab-shaped body towards the Earth's surface, driving upwards the crest of the Himalaya [see inset diagram]. Then, starting in 2001, a new generation of more sophisticated computer



Generalized geologic cross section through the Himalaya and southern part of Tibetan Plateau; adapted from Hodges et al. (2001). The Greater Himalayan Slab (GHS) is bounded above by the South Tibetan Detachment System (STDS) and below by the Main Central Thrust (MCT). Top - From bottom left clockwise: Rick Law, Ph.D. student Micah Jessup and Nepalese sirdar Tashi Sherpa at Lukla airstrip; southern edge of Tibetan Plateau and High Himalaya peaks; Lhotse (left) and summit of Everest (right) from Kangshung Glacier; Jessup and Law on trek out from Kangshung Glacier.



models (referred to as channel flow models) were developed by Chris Beaumont and his collaborators at Dalhousie University, Canada, in which southward and upward flow of these rocks from the middle crust under the Tibetan Plateau towards the Himalaya was driven by horizontal gradients in lithostatic (or vertical) load. A common feature of all these models is that the greater the degree of vertical squeezing and shortening of the rocks in this flowing channel, the greater the amount of material that has to be extruded towards the Earth's surface. Also, if surface erosion cannot keep pace with extrusion, the greater the amount of extrusion then the greater the amount of surface uplift - hence explaining why the highest Himalayan

peaks (at least in the Central Himalaya) always coincide with the outcrop position of this channel or slab of mid-crustal rocks.

However, what was missing from these models was any real data on how much vertical squeezing and shortening has actually occurred in rocks during their passage up to the Earth's surface. If the material is deforming by simple shear, a mechanism similar to shuffling a pack of playing cards, then the rocks won't lengthen parallel to the shearing motion, just as a playing card doesn't lengthen when the deck is shuffled. So, in simple shear, rocks from the middle crust won't move very far towards the Earth's surface. However, if the material is both sheared and vertically shortened (referred to as a

pure shear in materials science) then the rocks will lengthen parallel to the shearing motion and move towards the Earth's surface. By the late 1990s, analytical techniques had become sufficiently well developed to quantitatively measure the contributions of simple and pure shear in plastically deformed rocks, opening up the opportunity to begin testing these models for the Himalaya.

Following reconnaissance work by Mike Searle from Oxford University (UK) and me on the north side of Mount Everest in 2000, we received a \$250,000 grant from the National Science Foundation in 2002 to begin

assessing these models in the Everest region of Nepal and southern Tibet. The grant has also provided funds for Virginia Tech student Micah Jessup's Ph.D. research. Micah is a high-altitude climber with previous experience on the km-high vertical granite walls in the Pakistan Himalaya and quickly proved to be a natural fit for the project. The Virginia Tech - Oxford team have so far completed three field seasons under NSF funding in the Everest region, working at altitudes ranging from 3400 m to 6500 m (11000' - 21500') on the south (Nepal), north and eastern (Tibet) sides of the mountain, and in 2004 we were the

Background picture: Tibetan view of Mount Everest (l to r): the N.E. Ridge and the N. Col (lowest part of skyline at right). The banding in the Everest Series rocks can be seen even under the snow. The Lhotse Detachment, the lowest of the South Tibetan Detachment System of faults, separating the Greater Himalayan Slab from rocks of the overlying Tibetan Plateau (see figure page 5), is near the base of the banded rocks. Inset pictures (l to r): Pathangtse rearing up above Kangshung Glacier on Tibet-Nepal border, east of Mount Everest; East Rongbuk Glacier on north (Tibetan) side of Everest; north face of Everest and Northeast Ridge (left skyline) from Rongbuk Glacier; low-tech transport in Rongbuk Valley on north side of Everest. (all photographs by Rick Law.)





Channel Flow, Ductile Extrusion and Exhumation in Continental Collision Zones

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first geologists to get into the remote and rarely visited Kangshung Valley leading up to the east face of Mount Everest. Fieldwork has involved some challenges and steep learning curves, ranging from managing teams of porters for weeks at a time, to handling yaks when their Tibetan drivers disappear off into the mists during the frequent blizzards encountered on the long treks into some of the more remote regions.

Laboratory analyses of the samples collected have conclusively demonstrated that flow within the metamorphic core of the Himalaya has involved major components of pure shear deformation, supporting extrusion and channel flow models for the Himalaya. We are currently working on integrating this flow data with pressure - temperature - time (PTt) information provided by microprobe-based thermobarometry and radiometric dating in order to track the exhumation history of these rocks towards the Earth's surface. Ultimately, we hope to explore potential cause and effect links between the phases of rapid extrusion and exhumation we are beginning to identify in the metamorphic core of the Himalaya and phases of rapid sedimentation that are already well documented in basins, such as the Bengal Fan, to the south.

Processes similar to the Miocene (c. 22-16 Ma) age flow and extrusion we have identified in the Himalaya may also have operated in older mountain belts, although the evidence for their operation has often been obscured by later deformation. Therefore, the geologically young Himalaya could well provide important new insights on processes previously operating in older mountain belts. As part of the project, Mike Searle and I, in collaboration with Laurent Godin at Queens University, Canada, organized a conference in 2004 which was held at the Geological Society of London and was attended by numerical modelers and Himalayan geologists, as well as geologists working



on older mountain belts in the USA, Canada, Greenland, Norway, Italy, Greece and Japan. A follow-up book entitled *Channel Flow, Ductile Extrusion and Exhumation in Continental Collision Zones*, edited by Law, Searle and Godin and consisting of a range of numerical modeling and more field-based studies in the Himalaya, the Hellenides of Greece, and the Appalachians and Canadian Cordillera, was published by the Geological Society in December, 2006.

The next stage of our ongoing collaborative work between Virginia Tech, Oxford and Queens University will be to see if the pure shear driven extrusion processes we have documented in the Everest region have also operated along the length of the Himalaya. To test these ideas, we are currently planning a series of projects ranging in location from Zaskar in the northwest Himalaya of India, through the Annapurna and Makalu/Arun Valley regions of Nepal, to the geologically classic Darjeeling transect of the eastern Himalaya. These projects will offer great opportunities for a new generation of Ph.D. students to gain field experience working in spectacular geologic areas, and will also provide the opportunity for exchange of students between our three institutes, with the students taking advantage of the different laboratory-based facilities offered by Oxford, Queens and Virginia Tech.

From bottom left clockwise: Clare Law and Tashi Sherpa at Base Camp on Nepalese side of Everest; team members for the 2004 expedition including John Cottle (Oxford) and Micah Jessup (back row left), Laura Duncan (Virginia Tech alumnus, B.S. 2004), Mike Searle (Oxford) and Rick Law (front row) plus drivers and sherpas; Rick Law at west face of Nuptse; alpenglow over summit of Makalu on Tibet-Nepal border to east of Mount Everest; yak transport on trek in to Kangsung Glacier; Changtse (left) and north face of Everest from Rongbuk Valley; yak transport and rare alpine vegetation on north side of Everest; Arakam Tse to southwest of Everest; Micah Jessup and Northeast Ridge of Everest from Kangsung Glacier. Photographs by Laura Duncan, Micah Jessup and Rick Law.

