Cracking the Himalaya

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The collision of India with Asia causes large earthquakes and active faults along the southern margin of the Himalaya. But has localized erosion by monsoon rains created new faults in the interior of the range?

The provocative idea that climatically driven erosion could govern tectonic deformation has instigated a decade of geodynamic models[1–3] and geological studies[4,5] that explore potential climate–tectonic feedbacks. According to this idea, erosion of mass from Earth's surface may determine where tectonic deformation is most rapid. Consequently, heavy precipitation, rapid erosion and active faulting are predicted to be spatially correlated in an active mountain belt, or orogen. Based on local variations in erosion within the Himalayan range, Wobus *et al.* (page 1008 of this issue[6]) deduce the presence of a large, previously undocumented fault that ruptures the surface, and which is interpreted as a response to especially intense rainfall.

One challenge in testing connections between climate and tectonics is that active faults are difficult to locate in the bedrock core of mountain belts: erosion commonly removes features, such as displaced river terraces, that record readily recognizable offsets. Although different types of bedrock may be juxtaposed across a fault, that in itself reveals little about how rapidly the fault slipped, or whether it last ruptured 100 million years ago or a decade ago. As a consequence, few active faults have been identified within the core of mountain ranges, even when it is known that rapid tectonic contraction is occurring across the range.

Wobus *et al.*[6] use an innovative combination of techniques to deduce that there is a major surface-breaking fault within the interior of the Himalayan range. Rather than examine observable offsets of the surface, they use two contrasting measures of erosion rates to demonstrate an abrupt change in rates across a narrow zone. Their approach involves measuring the concentrations of cosmogenic radionuclides and the ratio between argon isotopes ($^{40}Ar/^{39}Ar$) in sediments, which are interpreted to record variations in erosion rates on thousand-year and million-year timescales, respectively. An argon 'cooling age' measures the time since cooling below around 350 °C for muscovite (the mineral dated by Wobus and colleagues), thereby defining an average cooling rate. When divided by a geothermal gradient (temperature change with depth), a cooling rate yields a mean erosion rate.

In mountain ranges where contraction

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Figure 1 **Blue yonder. Steep hillslopes in the rapidly eroding Himalaya north of the newly defined fault[6] and the 'physiographic transition'.**

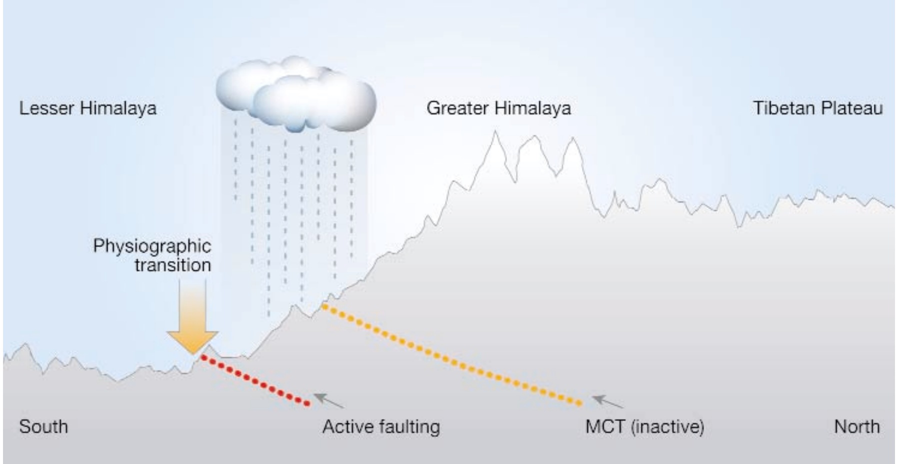

Figure 2 **Topography of the Himalaya at the site of Wobus and colleagues' study[6]. The site lies in the northern Lesser Himalaya, at the physiographic transition just south of the Main Central Thrust (MCT), which marks the boundary between the Lesser and Greater Himalaya. Wobus *et al.* argue that the transition is a consequence of an active fault. The existence of the fault is inferred from the estimated rapid surface erosion, caused by heavy monsoon rainfall, which allows southerly 'channel flow' of the lower crust to reach the surface.**

results from a long-lived continent-to-continent collision, erosion rates are commonly considered as proxies for rates of rock uplift. Consequently, the differential uplift implied by the spatially abrupt change in erosion rates, as identified by Wobus *et al.*, suggests that active faulting has persisted in the core of the Himalaya for millions of years. Moreover, noting that the highest monsoon rainfall occurs near the inferred fault, Wobus *et al.* link fault slip to climatically driven erosion, thereby coupling tectonics with climate.

Throughout the Himalaya, the boundary between two major subdivisions of the range, the Lesser and Greater Himalaya, is traditionally defined by the Main Central Thrust. This is a major, northward-dipping fault along which deeply buried rocks in the north have been thrust southwards over less deeply buried rocks. The fault described by Wobus *et al.* lies in the northern Lesser Himalaya, 5–20 km south of the Main Central Thrust, at a topographic change (termed the 'physiographic transition') where broad valleys and gentle hillslopes are replaced by narrow valleys, steeper rivers, higher mountains and steeper hillslopes (Figs 1 and 2).

The significance of an active fault in this position can be viewed in the context of three perspectives on collisional orogens. First, the traditional view is that, in such orogens, deformation migrates outwards over time, leaving more interior faults as relics, while creating faults at the distal edge of the orogen[7]. Most geologists consider the Main Central Thrust to have been inactive for the past 10 million years, but its footwall (northernmost Lesser Himalaya) may have been undergoing deformation between 6 million and 2 million years ago[8,9]. Wobus and colleagues' results would extend this activity to the present.

Second, collisional orogens have been likened to tapered wedges[10], in which the outward slope has a constant angle, even as the orogen grows, much like the wedge of snow in front of a snowplough. If erosion differentially removes material from the wedge's interior, contraction within the wedge is predicted to restore the original taper. The correlation of active faulting with active erosion on steep Himalayan slopes is consistent with this model.

Third, crustal thickening resulting from the Indo-Asian collision is predicted to have caused partial melting of the lower crust beneath the Tibetan Plateau[11]. Driven by the high potential-energy gradient along the margins of Tibet[12], outward flow of the lower crust ('channel flow') is predicted to emerge at the surface as a fault-bounded zone where erosion is focused and vigorous[2]. Wobus *et al.* suggest that their newly identified fault bounds the lower margin of the channel and that the erosion caused by locally high monsoonal rainfall has concentrated faulting near the foot of the Greater Himalaya (Fig. 2). If so, this is a significant discovery of a zone of deformation that is intimately tied to climatic gradients.

These interpretations are not unequivocal. A more complex structural geometry could juxtapose the contrasting argon cooling ages found by Wobus *et al.*, without surface faulting. In the context of the 'snowplough' model, for example, a steeper step in the sliding surface beneath the wedge could migrate southward with time[13], causing the locus of rock uplift and associated erosion to change. And the apparent match of modern contraction rates across the Himalaya[14] with the measured slip over the past 9,000 years at the southernmost edge of the Himalaya[15] does not require an active fault in the middle of the range.

Furthermore, the spatial pattern of erosion rates is complicated. Wobus and colleagues' cosmogenically determined rates are only high within a few kilometres of the proposed fault and decrease northwards to background rates. In the next valley to the west (the Marsyandi), however, cosmogenic erosion rates are 4–20 times higher again in the Greater Himalaya, north of the physiographic transition and the Main Central Thrust[16]. Although the rates of cooling and erosion inferred from $^{40}Ar/^{39}Ar$ ages by Wobus *et al.* indicate an abrupt increase in long-term erosion rates at the proposed fault, the ages tend to get still younger to the north, implying faster rates. In the Marsyandi valley, rates of bedrock cooling imply a 2–10-fold increase in long-term erosion rates in the Greater Himalaya[5] compared with the ages reported from the Lesser Himalaya just south of the Main Central Thrust[5,6]. Moreover, higher rates in the Greater Himalaya are sustained despite a fourfold decrease in monsoonal precipitation[5], indicating that the coupling of climate erosion and tectonics may be weaker than theory might predict[2].

Nonetheless, the cosmogenic data define an abrupt jump in millennial-scale erosion rates at exactly the same place as the offset in $^{40}Ar/^{39}Ar$ ages[17]. Unless landslides occurred to perturb these short-term rates[16], the spatial coincidence of jumps in erosion rates at very different timescales is strong evidence that there is indeed an active, surface-breaking fault in the core of the Himalayan orogen. The lateral extent of this fault, any causal relationship to climate gradients and its role in proposed flow in the lower crust remain to be explored. ■

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1. Beaumont, C., Fullsack, P. & Hamilton, J. in *Thrust Tectonics* (ed. McClay, K. R.) 1–18 (Chapman & Hall, London, 1992).
2. Beaumont, C., Jamieson, R. A., Nguyen, M. H. & Lee, B. *Nature* **414,** 738–742 (2001).
3. Willett, S. D. *J. Geophys. Res.* **104,** 28957–28982 (1999).
4. Dadson, S. J. *et al. Nature* **426,** 648–651 (2003).
5. Burbank, D. W. *et al. Nature* **426,** 652–655 (2003).
6. Wobus, C., Heimsath, A., Whipple, K. & Hodges, K. *Nature* **434,** 1008–1011 (2005).
7. Armstrong, F. C. & Oriel, S. S. *Am. Assoc. Petrol. Geol. Bull.* **49,** 1847–1866 (1965).
8. Harrison, T. M. *et al. Earth Planet. Sci. Lett.* **146,** E1–E7 (1997).
9. Copeland, P. *et al. J. Geophys. Res.* **96,** 8475–8500 (1991).
10. Dahlen, F. A. *Annu. Rev. Earth Planet. Sci.* **18,** 55–99 (1990).
11. Nelson, K. D. *et al. Science* **274,** 1684–1688 (1996).
12. Hodges, K. V. *Geol. Soc. Am. Bull.* **112,** 324–350 (2000).
13. Bollinger, L. *et al. Tectonics* **23,** TC5015 doi:10.1029/2003TC001564 (2004).
14. Wang, Q. *et al. Science* **294,** 574–577 (2001).
15. Lave, J. & Avouac, J. P. *J. Geophys. Res.* **105,** 5735–5770 (2000).
16. Niemi, N. A. *et al. Earth Planet. Sci. Lett.* (submitted).
17. Wobus, C. W., Hodges, K. V. & Whipple, K. X. *Geology* **31,** 861–864 (2003).