# Earth science: Making a mountain out of a plateau

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# Making a mountain out of a plateau

**A theory proposed last year suggested that nearly-flat surfaces in mountain ranges were formed by the reorganization of river networks. A fresh analysis rebuts this idea, reigniting the discussion of a longstanding problem in Earth science.**

Hugh Sinclair

The origin of low gradient surfaces in mountain ranges have long generated debate. The traditional explanation involves the acceleration of river incision into a pre-existing and slowly eroding low-gradient landscape[1], caused by a change in the underlying geological or climatic controls on the carving of mountain topography. However, a new model has been proposed[2] that invokes the expansion and contraction of river networks during mountain building, and which does not require a change in the underlying controls. Writing in *Geology*, Whipple *et al.*[3] challenge this model, particularly in its application to the mighty river gorges of the Yangtse, Mekong and Salween rivers in southeastern Tibet. The authors defend the conventional idea that these rivers have incised into a relatively low-gradient landscape that is a remnant of a once larger Tibetan Plateau[4].

The formation of mountain landscapes requires the uplift of rock, usually caused by colliding tectonic plates. Rock uplift is then countered by the incision of valleys by rivers and glaciers, and the coupled erosion of hill slopes. In steep mountain regions where rates of erosion are comparable to those of rock uplift, river incision into rock undercuts mountain slopes, forcing the episodic collapse of hill slopes through landslides and debris flows. This drives many mountain slopes towards steep threshold gradients ranging between 20° and 40°, determined by rock strength[5]. In this context, understanding the presence of extensive surfaces with anomalously low slopes provides an ongoing research challenge within many mountain ranges such as the Rockies[6], Himalaya[7] and Pyrenees[8].

The suggestion by Yang *et al.*[2] that many of these surfaces resulted from the inevitable expansion and contraction of river networks — more specifically, from changes in the plan-view geometry of river networks — is therefore an intriguing theory that needs testing.

Crucial to the proposed process is the migration of drainage divides, the ridges that separate neighbouring river catchment areas. The resulting expansion and contraction of catchment areas leads to increases and decreases, respectively, in the amount of precipitation and run-off that feeds the water discharge of main 'trunk' rivers.

Changes in water discharge drive changes in the capacity of a river channel to transport sediment and incise into underlying rock. As one river catchment captures an area of water drainage from another, the river's ability to incise increases, driving erosion. By contrast, the catchment that is the victim of capture loses drainage and so becomes less able to incise. This may cause river channels to accumulate coarse sediment, and reduce the gradient of hill slopes below the threshold for landsliding enabling them to increase their soil cover. This conversion of victim catchments[9] to low-gradient landscapes is the alternative mechanism proposed by Yang *et al*. for the formation of low-gradient surfaces in mountain ranges.

Whipple and colleagues focus the debate around the extraordinarily elongated rivers that drain the eastern margin of Tibet. The unusual geometry of this network, in which parallel river gorges run in close proximity, is thought to result from regional crustal deformation associated with the collision of the Indian continent with Asia[10]. Between these gorges are localized pockets of relatively flat surfaces, conventionally considered to be remnants of a Tibetan Plateau that has been dissected by rivers since about 10 million years ago[4].

Yang *et al*.[2] argued that the elevations of knickpoints (places at which steepening of the river channels occur) in this region are too scattered to reflect dissection of a common plateau, and that the relative gradients of river channels within and marginal to the flat surfaces, imply the capture of one catchment by another. But Whipple and co-workers point out that the knickpoint elevations differ only within a range of about 500 metres, and that this could simply reflect the variability in elevations found on the original Tibetan Plateau. They also argue that evidence for capture of river networks is to be expected in the conventional dissection scenario, as a result of major rivers incising and expanding their valleys into the higher, pre-existing landscape.

Whipple *et al*. use numerical modelling to propose that surfaces formed solely by river capture should be characterized by: a random distribution in elevation; variable topographic relief that depends on the time elapsed since capture began; the presence of drainage divides at their margins that define the principally affected catchment area; and a reduction in relief at increased elevation, because the reduced erosional capacity of the victim's river system will cause a progressive increase in surface uplift at this region. The authors also propose that capture-formed surfaces will feature a remnant, high-relief rim at the upstream part of the catchment. However, such rims are unlikely to be ubiquitous in these surfaces, particularly if the initial reduction of erosion causes a positive feedback that drives capture across all of its bounding drainage divides.

By contrast, remnant surfaces resulting from river incision into a pre-existing landscape should exhibit a relatively uniform elevation and relief that represents the topography of the original landscape. Whipple *et al*. spend little time on the observed variability of the scaling characteristics of the river channels on the surfaces and marginal to the surfaces which is used by Yang et al. as another indicator of drainage capture. But presumably, that's because these differences would also be a response to incision and expansion of valleys into a pre-existing surface.

Despite the caveats mentioned above, the authors' list of diagnostic characteristics for surfaces generated by river capture versus those generated by incision into a pre-existing low-gradient landscape presents a challenge to those who advocate the river-capture mechanism. An outstanding question is whether catchments that experience a reduction in drainage area have sufficient time to lower their hillslope gradients before being fully captured and eradicated by the aggressively incising neighbour. Rates of erosion in the incised gorges of the south-east Tibet region are of the order of 0.1-0.8 mm/yr, but are much slower (~ 0.02-0.03 mm/yr) on the remnant surfaces[4]. So the migration of drainage divides driven by trunk stream incision must be significantly faster than the rate of lowering of hillslopes in the captured catchments. Further testing is needed to determine the conditions under which captured catchments can lower their hillslopes sufficiently to mimic a low-gradient surface that is comparable to a pre-existing landscape. The model of incision into a pre-existing Tibetan landscape also provides challenges, not least how the surface remains relatively uniform across the region despite the high degree of crustal strain advocated by some workers [2,10].

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