MOUNTAIN BUILDING

How Earth created heaven

James H. Knapp

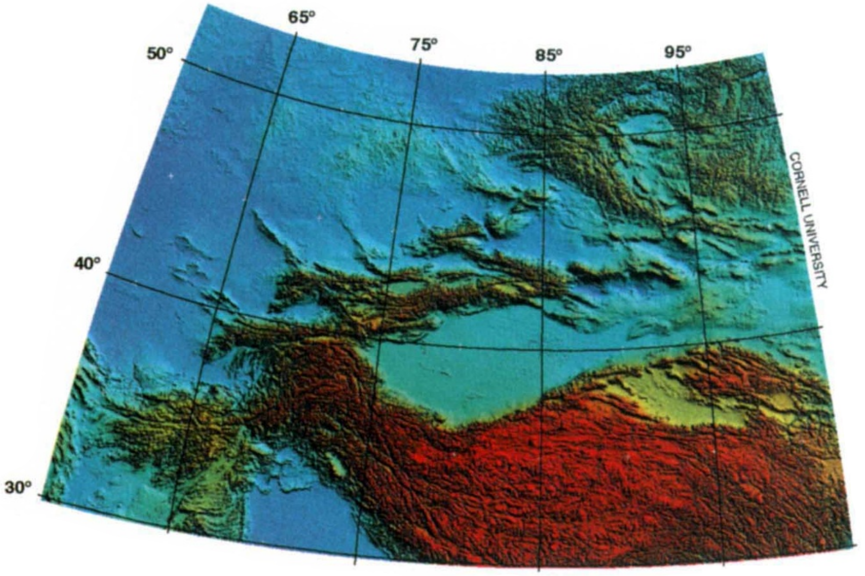
THAT the Earth's surface consists of rigid plates that travel the globe and interact along their boundaries was a central and highly successful tenet of plate tectonic theory in the 1960s. But whereas the oceanic plates fit this model well, their continental counterparts, with their thicker, lighter and weaker crust and upper mantle (together defining the lithosphere), appear to deform at large distances from active plate boundaries. The knowledge that continents deform internally is not particularly new. But on page 450 of this issue[1] Abdrakhmatov *et al.* report surprisingly high modern-day shortening rates across the Tien Shan, or 'Heavenly Mountains', of Central Asia, far from the active collision zone between India and Eurasia.

The satellite-based Global Positioning System has high resolution, and it allows measurement of crustal-scale deformation on a timescale of a few years. Using it, Abdrakhmatov *et al.* found shortening rates of $\sim$20 mm yr^{-1} across the central Tien Shan, in the Central Asian republics of Kyrgyzstan and Kazakstan. Although these rates are moderate compared with measurements from other areas, such as the South Pacific[2], they still account for a large percentage of the total convergence of $\sim$45 mm yr^{-1} between India and Siberia[3], implying that the forces of colliding continents are being transferred far from what was once the Eurasian plate margin.

Moreover, the coincidence of the measured shortening direction with the relative motion of the Indian and Eurasian plates[3] suggests that these forces are transmitted in a geometrically straightforward way, despite the striking heterogeneity of the crust in this area. In fact, the growth of the Tien Shan within a much larger region composed of a complex assemblage of different geological units[4] adds to the enigma. It may be that old scars in the crust from previous episodes of tectonic upheaval make the region relatively weak (in the figure, note the large faults extending northwestward from the range). But only some faults are reactivated, raising the question of how and why the strain is localized where it is. The answer may in part lie in features such as the Tarim Basin (the low area between the Tien Shan and the Tibetan plateau), which could be a preserved block of denser, stronger oceanic crust, caught in the collisional collage.

How the horizontal crustal movements get translated into the lofty peaks of the Tien Shan hinges largely on the steepness of the faults and the depths to which they descend in the crust — factors that are largely unknown in this region. What is apparent is that deformation does not propagate in a regular and predictable fashion away from the plate boundary.

The shortening rates are significantly greater than estimates derived from analysis of either the surface geology[5] or earthquake slip on faults[6]. Such a discrepancy could indicate that the faults in these mountains are creeping instead of causing earthquakes; equally, it could mean that large stresses are building up in the region, posing a considerable seismic threat.



Topographic image of the Tien Shan (centre) and Tibetan plateau (bottom). The Tien Shan is far from the former southern margin of Eurasia (the southern edge of Tibetan plateau), and isolated within the continental interior. Red marks high elevations, blue low.

If these modern shortening rates are representative of the geological past, one is left with the impression that the Tien Shan have virtually leapt skyward. By drawing on geological estimates for the total amount of shortening, and assuming that the present is the key to the past, Abdrakhmatov *et al.* speculate that the deformation may have begun less than 10 million years ago.

A word of caution is in order, however, because the extrapolation of crustal deformation rates from decades to geological timescales (10^4–10^7 yr) remains questionable[7]. In the case of the Tien Shan, deposition of thick sections of sediment in adjacent areas[8] suggests that the mountains were rising many tens of millions of years ago, even before the collision of India with Eurasia. Similarly, thermal histories of rocks now at the surface show that they were rising, cooling and being eroded some 20 to 30 million years ago, implying that the Tien Shan probably has a history at least that long[9].

Even though the topographical evidence of such an earlier phase of mountain building may have been eroded away before the latest uplift, estimates of the total amount of shortening probably include part of that earlier history. These new data may imply that the deformation and ascent of the Tien Shan has accelerated markedly in the past few million years.

On a larger and perhaps more fundamental scale, it is unclear how this crustal shortening is accommodated in the underlying mantle lithosphere. Seismological evidence from the central Tien Shan[10] implies that rather than being a thickened lithosphere floating on a cold, stiff mantle, these mountains may be supported by a relatively hot, weak mantle plume rising from below. If such thermal weakening is a long-lived feature beneath the Tien Shan, it may have played a key role in focusing the effects of continental collision here[11].

As one of the youngest and highest mountain belts in the world, the Tien Shan might be viewed as the tip of a continental iceberg; rising above the Central Asian steppe, they belie an intriguing mystery at depth, whose solution would tell us much about the mechanical nature and evolution of the continents we inhabit. ☐

James H. Knapp is at the Institute for the Study of the Continents, Cornell University, Ithaca, New York 14853, USA.

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