Crust in mantle overdrive

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THERE is little doubt that the engine that builds mountain ranges lies in the mantle, fuelled by density differences between cold and hot mantle material and driven by gravity. Most mountain ranges result from thickening of crust where blocks of crust converge towards one another. Through isostasy, the Earth's version of Archimedes' principle, the thickened crust is buoyed up to form a high terrain. What remains the object of much search and speculation is the mechanism by which the convection in the mantle drives the crustal blocks together. A simple and sensible view holds that the cold mantle lithosphere directly beneath the belt must also thicken during convergence, and that this thickened root, being heavier than the surrounding hotter mantle, sinks and draws the neighbouring blocks towards one another (*a* in the figure).

But on page 144 of this issue[1], Makeyeva, Vinnik and Roecker claim that the mantle follows a different agenda. They suggest that instead of converging towards the belt and then flowing downwards, much of the flow in the mantle directly beneath the belt is parallel to it (*b* in the figure), and that in some places mantle actually upwells beneath a region where crustal shortening and thickening continue.

The authors analysed seismograms recorded in the Tien Shan, a major intracontinental mountain range in central Asia. Unlike many large mountain belts (such as the Himalayas or Alps), formed where two continents have collided with one another after a tract of oceanic lithosphere was subducted, the Tien Shan is truly intracontinental. The last oceanic lithosphere disappeared more than 300 million years ago, and the whole region seems to have been eroded to a featureless plain before renewed mountain building began just 30 million years ago.

So the asymmetric processes that characterize subduction zones and collisional belts may not complicate the deep structure of the Tien Shan. Moreover, the range is linear, and if one were to search for an active mountain belt in which variations in structure, and presumably processes, along the belt would be negligible compared with the variations across it, one could not find a better example. Yet the linear topography and surface geology of the Tien Shan conceal large variations in mantle structure along the belt.

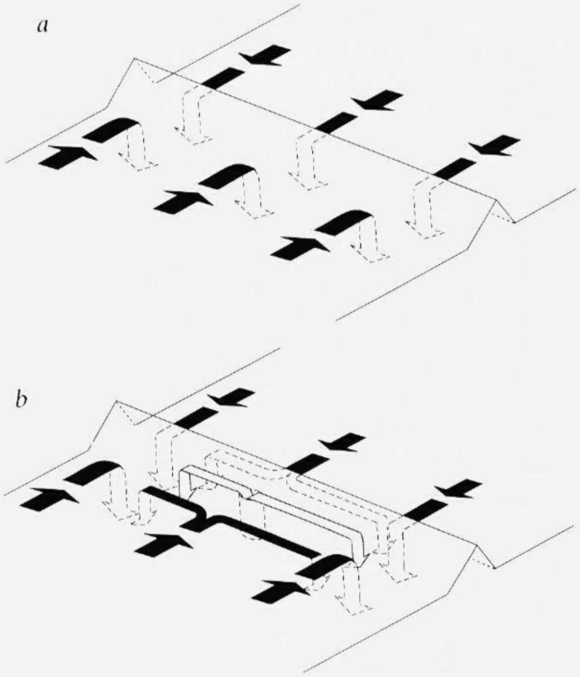
Building upon several years of investigation by Kazakh, Kyrgyz and Russian seismologists, Makeyeva *et al.* claim that the mantle structure beneath the part of the Tien Shan west of the border with China is not underlain by a cold lithospheric root at all, but rather by material with low seismic-wave velocities, and hence presumably relatively hot material. Ultimately, they argue for an upwelling of mantle material beneath this part of the range, but the crucial evidence in their argument is provided by an analysis of seismic anisotropy in the mantle beneath the region.

Anisotropy has, with a few notable exceptions, traditionally served one of two ignominious roles in seismology. Because tedious algebra is needed to describe wave propagation through anisotropic media, anisotropy for many seismologists has been a nuisance that inhibits simple analysis, interpretation and intuitive understanding, and it commonly is ignored. For others, it has been a *deus ex machina*, introduced to rescue a set of otherwise inconsistent observations. But even under these circumstances, it often fails to provide any insights into the interesting processes within the Earth.

Makeyeva *et al.* exploit anisotropy to convert a seemingly exceptional mantle structure beneath the Tien Shan into a rule: one that bears on the significance of anisotropy as a tool, as much as it does on the processes of mountain building.

They show clearly that the faster orientation of the two essentially horizontal polarizations of S (secondary or shear) waves propagating up through the mantle beneath the Tien Shan lies roughly parallel to the belt. This parallelism is common in other active mountain belts. Yet, in the area of the unusually hot mantle material, this orientation deviates markedly from the easterly trend, again making the area exceptional. The casual reader might gain the impression that anisotropy merely provides another entry in a list of anomalies from this area.

As Makeyeva *et al.* state clearly, anisotropy can arise in a variety of situations, and interpreting it in terms of dynamic processes must contain an element of speculation. Nevertheless, citing a number of studies, they assume that the orientation of the faster axis, which



a, Simple pattern of mantle convection that might build intracontinental mountain belts, with linear downwelling beneath a cold lithospheric root. *b*, Circulation pattern indicated by the results of Makeyeva *et al.*, running parallel in places to the chain and with an upwelling plume beneath the chain.

need not lie parallel to the fastest of the three axes[2], lies parallel to the orientation of maximum shear. That assumption makes the rule that the relatively fast axes aligned parallel to mountain belts imply flow in the mantle parallel to them. It follows that the region of anomalous mantle becomes the locus of the upwelling limb of convection parallel to the belt, and that such convective flow characterizes active belts in general.

The application of anisotropy to questions of mantle structure and dynamics is not new in the Earth sciences, but the study by Makeyeva *et al.* illustrates how this wanton, outcast child of seismology can be tamed and put to good use. The inclusion of anisotropy in the toolbag of most seismologists, however, probably will not happen without the smashing of some sacred icons. For instance, there is already a suggestion that much of what has been interpreted as lateral variations of isotropic velocity structure, and hence of temperature in the mantle, might instead be due to lateral variations in anisotropy[3,4].

The variations in mantle structure along the Tien Shan are not exceptional. Even for the most celebrated inference of cold material sinking beneath a convergent mountain belt — the Western Transverse Ranges of California[5,6] — the deep structure is poorly described as two-dimensional. Variations in mantle structure along the Alps are as large as those across it[7], and the vast flat surface of the Tibetan Plateau conceals lateral variations in mantle structure as large as any beneath continental regions[8,9]. Thus, the image of a lithospheric root mirroring the overlying topography of a mountain range may owe its persistence more to belief than to fact.

Makeyeva *et al.* touch only briefly on the process that may cause flow and sense of shear in the mantle to be perpendicular to that observed by geologists in the crust of all mountain belts. The sinking of a linear belt of cold material, the nascent lithospheric root, creates a convective instability, because the material is more dense than its surroundings. The growth of the instability may be faster for flow parallel to the chain than perpendicular to it.

A similar, three-dimensional instability has been observed in numerical experiments of flow at mid-ocean ridges, for convection enhanced by melt segregation and for sufficiently fast spreading[10]. Analysis of corresponding three-dimensional instabilities for lithospheric roots may reveal a similar process beneath mountain belts. Fortunately, these problems do not yet seem to have interested those numerical modellers more interested in simulating complicated situations than understanding simple ones. Thus, the possibility of gaining a simple understanding of the mantle dynamics beneath mountain belts remains open, instead of confused. □

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