mediators of resistance to anti-VEGF therapy — just before the resumption of growth of colorectal tumours and their metastases has been reported for this approach[12] in patients receiving chemotherapy plus bevacizumab.

Finally, although it was initially hypothesized that anti-angiogenic therapy would induce tumour dormancy, this is clearly not the case in the clinic. Thus, following an initial favourable response to chemotherapy combined with anti-VEGF therapy, single-agent anti-VEGF therapy should not be used until there are data from clinical trials to either support or refute this approach. ■

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GEOPHYSICS

Hot blanket in Earth's deep crust

Jean Braun

Studies of rocks from Earth's crust suggest that the lower crust is a good thermal insulator. The knock-on effects of this finding are many — one being the crust's increased potential to generate more magma.

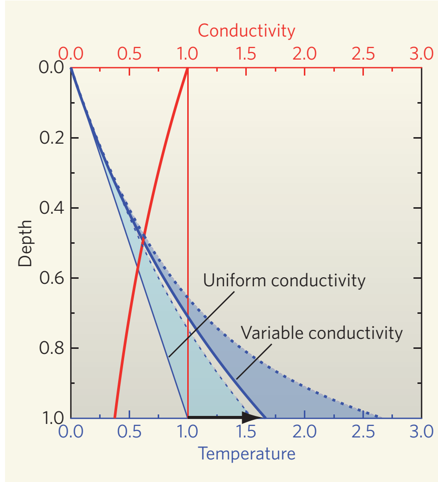

Figure 1 | Thermal conductivity and temperature in Earth's crust. The temperature profile of Earth's crust is shown for two scenarios of conductivity for a crust subjected to a constant basal heat flux: uniform rock conductivity (thin blue line) and variable rock conductivity (thick blue line). Whittington *et al.*[1] show that a non-uniform conductivity across the crust results in an increase in basal temperature, as is indicated by the arrow. The shaded areas show the difference in the crust's response to an instantaneous perturbation in the basal heat flux, such as that caused by a basaltic intrusion or shear heating: the light-blue area denotes the resulting change in temperature for a uniform conductivity; dark blue is for variable conductivity. In the latter case, the reduced conductivity of the lower crust decreases the upward dissipation of the thermal event and enhances heating of the lower crust. The red lines show the two conductivity profiles. The depth scale spans the entire crust (from the surface down to 35–40 km); the temperature scale varies between 0 °C and an upper range of 500–800 °C (this upper limit depends on the assumed contribution from heat production due to radioactivity).

We know little about the temperature of the deepest parts of Earth's continental crust, which can be 30–40 kilometres below the surface. We cannot measure temperature directly beyond a few kilometres down, at the bottom of deep mines or drill holes. Yet temperature governs many geological processes, including the generation of magmas through the melting of rocks in the lower crust and the mechanism by which rocks deform. In the crust, heat from the underlying mantle is mainly transported by conduction. The efficiency of the process is regulated by the crust's thermal conductivity: a high conductivity results in efficient heat flow and a relatively low temperature at the base of the crust; conversely, a low conductivity results in poor conduction of heat and a high temperature at the base of the crust — the lower crust is a good insulator and thus acts as a blanket over the mantle.

Like most materials, rocks become less efficient at transporting heat (their conductivity decreases) as temperature increases, especially in the vicinity of their melting temperature. But measuring thermal conductivity at high temperatures is difficult because, close to the melting temperature, heat is transported not only by conduction but also by radiation. This implies that most existing high-temperature rock-conductivity measurements have been overestimated. Consequently, in many applications, rock conductivity is assumed to be constant throughout the crust. Whittington *et al.*[1] (page 319 of this issue) now provide more accurate data on a variety of crustal rock samples that demonstrate a strong dependence of rock thermal conductivity on temperature. This means that the conductivity of rocks at temperatures existing in the lower crust is much lower — by as much as 50% — than previously recognized. The implication is that the lower crust may be hotter than we thought (Fig. 1).

By using a recently developed technique known as laser-flash analysis, which consists of subjecting one end of a small (10 mm × 1 mm) rock sample held at some temperature in a hot furnace to a laser pulse of heat, Whittington and colleagues were able to measure the time taken for the heat to reach the other end. They then used a carefully calibrated model of heat transport in the sample to extract accurate estimates of its thermal conductivity.

The authors' observation[1] that rock conductivity varies strongly with temperature, and the related realization that the lower crust has a lower conductivity and is thus warmer than we thought, has far-reaching implications for our understanding of fundamental magmatic and tectonic processes (Fig. 2). The conductivity of a rock is more correctly described by its thermal diffusivity — the ratio of conductivity to the product of the heat capacity (the ability to store heat) and density. It is this that controls the rate at which the crust responds to a perturbation in temperature such as is caused by the injection of magma from the underlying mantle or by 'strain heating' in shear zones (Fig. 1).

Reduced conductivity in the lower crust would thus prevent the dissipation of the heat brought into the crust by intrusion of basaltic rock from the mantle; temperatures within and around the intrusion should be higher than we currently predict, and we should expect more rapid and efficient melting of the lower crust for the same amount of heat injected from the mantle. This effect has important consequences for our understanding of arc or andean-type volcanism (that is, volcanism associated with subduction zones). Lower conductivity of magma also helps its ascent through the crust, because it slows down the cooling and 'freezing' that occur by contact with the surrounding, colder rocks.

The deformation of the crust in response to tectonic forces is commonly accompanied by strain localization: that is, by the formation of narrow, ductile shear zones. During deformation at high stress levels, mechanical energy is transformed into heat (a process called strain heating), which is dissipated from the shear zone by conduction. A reduced thermal conductivity at high temperature would limit heat dissipation, resulting in much hotter shear zones than commonly assumed. As

Whittington *et al.*[1] demonstrate, this may even lead to melting inside the shear zone, causing further localization of the deformation within the shear zone. But this result should be interpreted with caution, as strain heating depends strongly on the evolution of stress within the zone, which itself depends on the assumed deformation mechanism and is currently the subject of much debate[2]. Enhanced strain heating could also explain the formation of larger than expected volumes of granitic magmas produced by partial melting of deep crustal rocks[3]. This process, referred to as anatexis, is observed in many mountain ranges, most notably in the granitic belts associated with the Main Central Thrust fault in the Himalayas.

A recent and vigorously debated model for the evolution of large, hot mountain belts, such as the Himalayan–Tibetan system[4], relies on the formation of a ductile, partially molten lower crust that may be extruded at Earth's surface in regions of high precipitation and thus surface erosion. The high-temperature conditions necessary for partial melting of the lower crust are thought to be achieved by increased heat production due to radioactivity, resulting from a thickened crust and/or shear heating. A reduced conductivity in the lower crust would significantly reduce the time necessary for such radiogenic heating to take place, and would potentially lead to higher crustal temperatures. This hypothesis, and many others concerning the dynamics of mountain belts, should now be revisited in view of Whittington and colleagues' new measurements[1] of thermal conductivity.

Also in need of reassessment are most quantitative models of Earth's dynamical behaviour, because heat transport is such an important process inside the Earth. For example, a reduced crustal conductivity would also imply a higher mean temperature in the underlying mantle, especially during the early, 'hotter' stages of the planet's evolution. This, in turn, has direct implications for our understanding of the early Earth's differentiation and the distribution of elements in its various reservoirs (the crust, mantle and core). ■

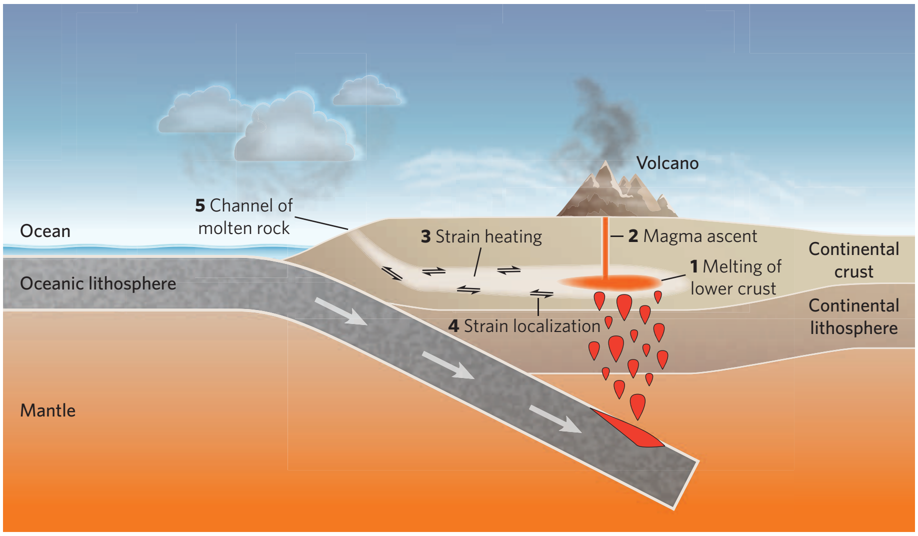

Figure 2 | Implications of a lower crust that is warmer than expected. Whittington and colleagues' observation[1] that the lower crust is a good thermal insulator and is thus warmer than previously recognized has many consequences for magmatic and tectonic processes in convergent plate settings such as subduction zones: **1**, more efficient melting and mixing of the lower crust following mantle-derived basaltic intrusion; **2**, more rapid and efficient ascent of the resulting magma through the crust; **3**, enhanced strain heating during tectonically driven deformation of the lower crust; **4**, enhanced strain localization; **5**, quicker development of a lower-crust channel of molten rock that may be extruded at Earth's surface in regions of high precipitation and thus surface erosion.

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DINOSAURS

Fuzzy origins for feathers

Lawrence M. Witmer

Cretaceous fossil deposits in China are famous for their feathered dinosaurs. But the surprising discovery of a herbivorous dinosaur with a filamentous coat raises fresh questions about the evolution of feathers.

Liaoning Province in northeastern China is renowned for the fossils that document, in often vivid detail, virtually the entire biota that lived over a period of several million years during the Early Cretaceous (about 125 million years ago)[1]. Although exquisite fossils of diverse vertebrates, invertebrates and plants have been recovered, it's the spectacular feathered dinosaurs that have received most attention[2–4] and caused much controversy[5,6]. On page 333 of this issue, Zheng and colleagues[7] present the discovery of a small dinosaur, *Tianyulong confuciusi*, from the Yixian Formation of Liaoning, that promises to send the debate on dinosaur feathers in a totally new direction — and a confusing direction, at that.

Even without preservation of portions of its skin, *Tianyulong* would be a notable find, because its genealogical ties are to a group of herbivorous dinosaurs, called heterodontosaurids, that had undergone their evolutionary radiation 70 million years earlier, making *Tianyulong* a 'living fossil' in its own time. Heterodontosaurids used to be regarded as a fairly obscure group, related to the more famous duck-billed hadrosaurs. But recently, heterodontosaurids have taken centre stage as the most evolutionarily basal branch of the entire great radiation of herbivorous dinosaurs, the Ornithischia (Fig. 1, overleaf), that included not only hadrosaurs but also *Triceratops*, *Stegosaurus* and a host of related animals[8]. Were it not for its skin, *Tianyulong* would be important as a late-surviving twig of this branch of the ornithischian family tree, and the first of its kind known from Asia. But the fossils of *Tianyulong*, splayed on a stone slab, reveal three patches of long filaments reminiscent of structures thought to be the evolutionary progenitors of feathers. The only problem is that *Tianyulong* isn't supposed to have anything like feathers.

Before the 1990s, life was simple: feathers were thought to be an exclusively avian attribute, found in all birds today and extending back to the iconic *Archaeopteryx* in the Late Jurassic, some 150 million years ago. The discovery of very bird-like feathers, complete with shaft and vanes (pennaceous feathers), in some of the predatory theropod dinosaurs found in Liaoning (such as *Caudipteryx* and *Microraptor*) rocked the scientific world[2,4,9], because the feathered dinosaurs were outside the evolutionary group of acknowledged birds. Still, it wasn't completely unexpected, in that these dinosaurs are representatives of the theropod