Earth science

Continents soldered from below

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A study of melting in the mantle under northern Canada more than one billion years ago shows that the oldest blocks of continent not only break apart but can also be repaired by the gluing action of major melting episodes. **See p.732**

Billions of years of plate tectonics have destroyed much of the evidence about the nature of the earliest continents. The parts of these continents that remain have survived because their composition makes them buoyant and strong, and they float like driftwood on the convecting mantle that has slowly churned beneath them many times over. These ancient continental blocks, known as cratons, were originally thought to be indefinitely stable owing to their strength and buoyancy. However, in the past few years, many studies have cast doubt on this viewpoint and emphasized the break-up and destruction of cratons. On page 732, Liu *et al.*[1] report that cratons not only break apart but can also be fused back together again.

Mantle plumes are columns of hot, buoyant material that rise upwards through the mantle. On modern Earth, plumes are thought to be responsible for rifting (the splitting apart of tectonic plates) and continental break-up[2], and for the erosion of cratons[3]. A large geological structure called the Mackenzie dyke swarm in a craton of northern Canada constitutes the remnants of an enormous plume. This structure comprises a massive collection of vertical slabs of solidified molten rock spanning thousands of kilometres and dating back 1.27 billion years[4].

High-pressure melting experiments on rocks with similar compositions to those of the Mackenzie dyke swarm have shown that the magma that formed this structure originated from depths of less than 100 kilometres below the planet's surface[5]. Therefore, this magma must have erupted through a thin plate. However, geophysical images of the area today reveal a thick plate (about 200 km thick)[6] that is typical of cratons, showing that the plate must have thickened after the development of the dyke swarm. Radiometric dating of mantle samples from the area indicates that the plate had thickened by 600 million years ago[7].

Liu and colleagues combined geodynamic simulations with pressure–temperature calculations for the origin of mantle samples to suggest a mechanism for the thickening of the plate immediately after the dyke swarm formed. They demonstrate in their simulations that the residue from the melting of the plume responsible for the dyke swarm could have helped to repair the damaged craton, essentially filling thin parts of the plate and cementing it from below. This finding indicates that cratons do not simply exist passively for billions of years, but undergo a more complex history than was previously assumed.

Over the past few years, the indestructibility of cratons has been questioned. It has been found that they can be slowly destroyed by chiselling from below by magmas[3], and can crumble from the sides as a result of small-scale mantle convection[8] or the effects of subduction[9] (the process in which one plate dives beneath another). Consequently, in some regions, such as northern China, the cratonic plate has thinned over vast areas[10]. Cratons had previously been thought to resist the effects of hot mantle material from below, spreading the heat to the sides, much as a frying pan does to the flame beneath. In this scenario, the heat would result in blooms of magmatic activity around the margins of the craton, but it would not affect the base of the craton much.

However, Liu and colleagues show that mantle melts can repair and thicken cratonic plates in areas where they are thin, even if these areas are disconnected from the main heat source. This finding is consistent with the upward flow of hot mantle material along channels in the base of such plates[11]. Therefore, this material, which melts as it nears the planet's surface, might preferentially seal the cratons along existing gaps or crevasses in the underside of the continental blocks. If confirmed, this sealing mechanism will change the outlook of many researchers, who have viewed mantle plumes as causing the break-up of continents rather than as a means to stabilize them.

The resealing of continental blocks and thickening of plates also have ramifications for mineral exploration. Many types of mineral deposit are often spatially associated with huge structures known as trans-lithospheric

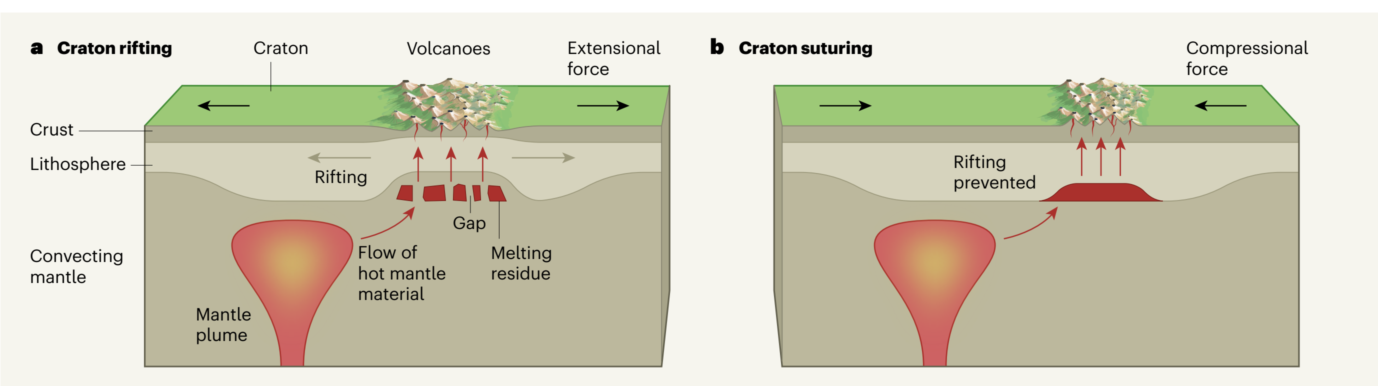

Figure 1 | Rifting and suturing effects of mantle plumes. Liu *et al.*[1] explore how ancient blocks of continent called cratons are influenced by mantle plumes — columns of warm, buoyant material that rise upwards through Earth's convecting mantle. This hot mantle material flows into gaps in the underside of the lithosphere (the rigid layer beneath Earth's crust). It then melts as it approaches the planet's surface, producing abundant volcanism. **a**, If regional forces related to the large-scale movement of tectonic plates are extensional, the craton can undergo rifting (stretching and thinning of the crust and lithosphere), and the residue from the melting of the hot mantle material cannot plug the gaps in the underside of the lithosphere. **b**, However, if these tectonic forces are compressional, craton rifting is prevented, and the authors show that the melting residue can plug the gaps and thicken the base of the lithosphere.

faults that reach from Earth's surface down to the base of the plates, cutting through both the crust and the upper mantle. These faults provide pathways for fluids and melts, which can form mineral deposits in the upper crust when they stop or encounter rocks that contrast, in their chemical properties, with those from which the fluids or melts originated[12]. Clearly, trans-lithospheric faults can serve as pathways only if they are open at the bottom. Therefore, when the resealing process occurs, it will close a time window after which no further mineral deposits can form in these large structures.

Why some mantle plumes break up continents and others stitch them together remains unknown. Differences in regional tectonic states and local forces might play a part in determining whether a plume is destructive or constructive (Fig. 1). For instance, if a plume is located below a continent that is prevented from breaking up because of the relative movements of the surrounding plates, the resealing effect becomes more probable than it would otherwise be.

Another open question is how the frequency of occurrence of mantle plumes, their melting behaviour and their ability to cement continental blocks together have changed over time[13]. Many cratons are made up of smaller blocks that were amalgamated during the Archaean eon more than 2.5 billion years ago. Compared with today, the mantle was then hotter, plumes are thought to have been more frequent, and more of these smaller blocks covered the planet's surface. In those times, the suturing mechanism described by Liu and colleagues might have been common, allowing these smaller blocks to weld together and survive the violence of early Earth.

"The resealing of continental blocks and thickening of plates have ramifications for mineral exploration."

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