

## NEWS &amp; VIEWS



**Figure 1 | Message from the deep — the flank of the Dabbahu volcano, evidence for extensive dyking below.**

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## PLATE TECTONICS

# Magma does the splits

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**A minor volcanic eruption in Ethiopia was the main visible clue to a massive injection of magma along the Afar rift last year. Such inconspicuous processes could have been crucial in early continental break-up.**

Earth's surface is a mosaic of cool, strong rock plates that are moving continuously at rates of up to 12 centimetres a year. On page 291 of this issue<sup>1</sup>, Wright *et al.* report studies of tectonic events in Ethiopia that provide an unusual insight into what happens in Earth's crust when two of these plates diverge.

Divergent plate movements cause a build-up of tensional stress that is released in a process known as rifting. This consists of periods of large-scale faulting (the slippage of adjacent rock masses at fractures in Earth's crust) and/or volcanic and magmatic activity. The relative contributions of fault movements and magmatic activity are unknown, as are how the deformation processes vary with depth and when exactly rifting episodes occur. Opportunities to observe rifting are rare: separation occurs mostly on mid-ocean ridges and in only a few places above sea level. At any one location, a rifting episode might occur only once every few centuries.

One place where rifting can be observed on dry land is along the East African and Afar rifts in Ethiopia, where the Nubian plate diverges from the Somalian and Arabian plates<sup>2</sup>. The quiet flow and accumulation of magma over a long period — from at least April 2004 to May

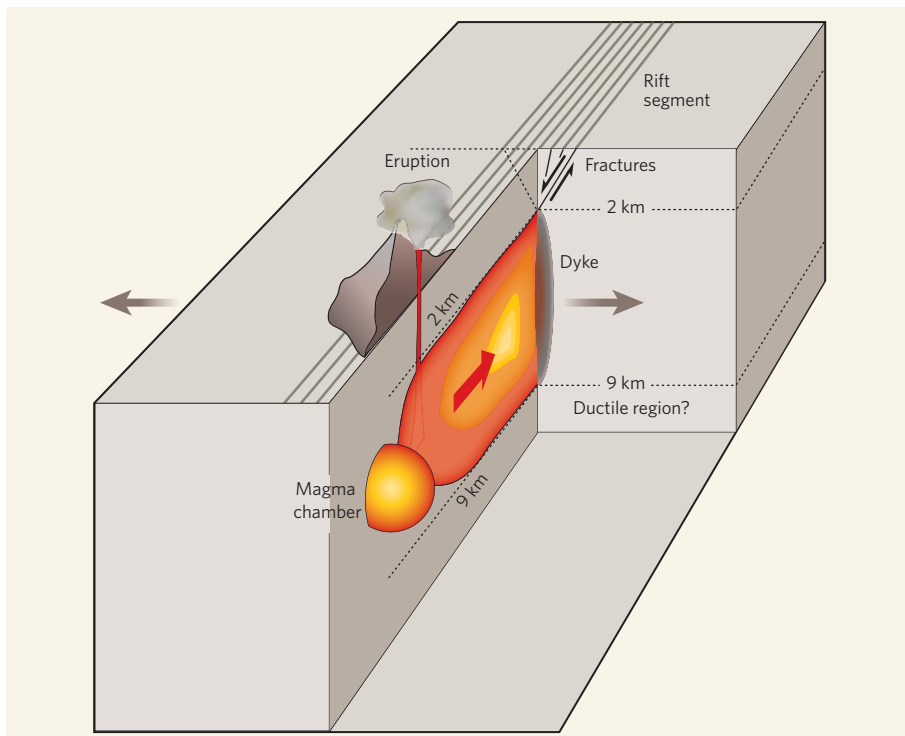
2005 — 5 kilometres below the surface of the Afar rift preceded a series of more than a hundred earthquakes in September 2005, of maximum magnitude 5.6, that were registered across the globe. Continuous earthquake activity, including a volcanic tremor, was observed on 24–26 September at the nearest seismic station in Addis Ababa, around 400 km away. A minor eruption occurred on 26 September along a 500-metre-long fissure on the flank of the Dabbahu volcano in central Ethiopia (Fig. 1), and ground fracturing occurred along a rift segment that was around 60 km long.

Wright and colleagues<sup>1</sup> have revealed the exact course of these events, by interferometric analysis of images acquired by the European Space Agency's Envisat satellite using the synthetic-aperture radar method. They compared images taken from the same location in space before and after the event by 'subtracting' the phase signal of one image from that of the other to form a map, accurate to a few centimetres or better, of the change in distance from the ground to the satellite. By combining observations from ascending and descending satellite passes, as well as direct measurements of offsets in radar amplitude images, the full three-dimensional crustal

deformation field could be evaluated.

The results are clear. Beneath the surface fractures, magma started flowing rapidly from magma chambers 5 km under the neighbouring Gabho and Dabbahu volcanoes. But rather than flowing vertically towards the surface of the Earth, this magma flowed horizontally tens of kilometres, forming a 60-km-long vertical 'dyke' at a depth of 2–9 km (Fig. 2, overleaf). The dyke might also have been fed by a vertical flow of magma from greater depth. These magma flows split the crust laterally by up to 8 metres, relieving centuries of tensional stresses caused by plate divergence. The minor eruption on the side of Dabbahu on 26 September was probably an 'accidental' by-product, a result of the dyke heating an existing isolated pocket of magma in the crust. The inferred average rate of magma flow throughout the process was about 2,000 cubic metres a second, comparable to rates in large volcanic eruptions. The subsurface dyke now has a volume of some 2.5 cubic kilometres, twice the volume of material blown out in the eruption of Mount St Helens in 1980.

Wright and colleagues' study<sup>1</sup> demonstrates that dyking may relieve the tensile stress caused by plate divergence, while allowing



**Figure 2 | Rifting in the Afar in 2005 in simplified cross-section.** Movement on the fractures was mostly limited to the uppermost 2 kilometres of the crust, modelled by Wright *et al.*<sup>1</sup> as slip of up to 7 metres on two inclined fault planes. Farther below, magma did the splitting, forming a dyke that displaced adjacent plates by 2–4 metres in each direction. No source of co-rifting deformation is detected in a possible ductile region below about 9 km; total crustal thickness is about 20 km. The dyke was supplied by magma chambers below the Gabho and Dabbahu volcanoes, and possibly by a deeper source.

only a small amount of magma to reach the surface. Continental break-up starts with normal faulting processes and the formation of characteristic 'grabens', where land sinks down between parallel fault systems as the plates on either side diverge (the Great Rift Valley of eastern Africa, of which the Afar rift is part, is a classic example of such a sunken tract of land). Mantle rock, displaced as a graben forms, moves towards the surface, where the lower pressure causes its partial melting. The resulting generation of magma later leads to the onset of voluminous volcanic eruptions<sup>3</sup>.

But the new observations imply that many grabens and single faults, even at continental rifts, might reflect dyke-induced faulting<sup>4,5</sup>, and might form and evolve through repeated events such as those that occurred in Ethiopia in 2005. An intermediate stage in continental rifting can be envisaged, when melt has begun to be generated in the mantle, but is produced in limited quantities so that most of it is captured inside the extending crust. This period will be dominated by dyking, but characterized by few eruptions.

Another argument for dyking causing early injection of magma into the crust during continental break-up is that it requires less force to dilate brittle crust by upwelling magma than by the slippage of plates in faulting. A stress of some 65 megapascals is needed to initiate slip on a normal fault at a depth of 5 km (ref. 6). In contrast, magma in contact with stretched crust will lead to hydraulic fracturing when

the excess pressure of the magma is about as large as the tensile strength of the crust. This has been inferred to be 1–6 MPa for oceanic crust in Iceland<sup>7</sup>. Thus, any flow of magma into the crust could cause rifting long before the crust is stretched to the degree required for a conventional faulting event.

The study of this rifting episode in Ethiopia increases our understanding of similar events that are taking place on mid-ocean ridges<sup>8</sup>, or where these are exposed on land in Iceland and in Djibouti on the Horn of Africa, where the

Gulf of Aden ridge meets the Afar rift. A smaller-scale rifting episode occurred in Djibouti in 1978 (refs 9, 10). The 1975–84 Krafla episode in Iceland<sup>4,7,11</sup>, however, was more similar to the events of 2005 in Ethiopia in terms of its cumulative widening, the magma volume involved, and the importance of subsurface dyking during its initial four years, when there was little eruptive activity.

The deformation pattern associated with the Ethiopian events<sup>1</sup> suggests that there is a strong vertical variation in the mechanisms that caused them. Faulting seems to have occurred only in the shallowest crust down to a depth of around 2 km, and dyking only in the mid-crust. There is no evidence that the dyke extends below 9 km, indicating that continual ductile deformation processes must prevent the accumulation of tensional stress in this area. A lesson from Iceland is that a rifting episode might consist of many dyking events with an overall duration determined by the period of the magma inflow. More dyking and eruptions might therefore follow in Ethiopia if magma continues to flow to shallower levels. ■

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