

The birth of an ocean

Violent earthquakes are ripping apart the Afar Depression in Ethiopia, once described as the cruellest place on Earth. Cindy Ebinger went to investigate.

An average day in the life of an East African rift is tectonically boring: the African and Somalian plates separate at about the same rate as fingernail growth – 0.03 millimetres a day. But occasionally earthquakes and volcanic eruptions remind us of an immense force at work.

In September 2005, Ethiopian scientists detected a burst of earthquakes in a few short weeks in a remote corner of the country; 163 were recorded in geophysical observatories worldwide. These earthquakes, of magnitude 3.9 to 5.6, ripped open a 60kilometre rift measuring over eight metres wide in places. The astonishing speed of this episode surprised geophysicists around the world and our initial reports were met with scepticism. In fact it was the first tectonic episode of its kind since we've used satellite technology to measure ground movement.

The story began when a long-term colleague, Atalay Ayele of the Geophysical Observatory, Addis Ababa, used seismic records to locate a moderate-sized earthquake in the Afar Depression, dubbed 'the cruellest place on Earth' by *National Geographic* magazine. Within days the earthquake activity increased, and by

24 September, the paper pouring from his seismometer in Addis Ababa, 400 kilometres from the epicentre, was no longer churning out thin wiggly lines but was black with activity.

Atalay and colleagues recognised the warning signals of an imminent volcanic eruption, and reports from the ground in Afar confirmed widespread ground shaking and no small amount of panic from the local population. Volcanologists flew over the area. They left the scene just before a vent 60 metres long opened on the eastern flank of the Dabbahu volcano, but not before they witnessed scarps one metre high and fissures half a metre wide forming in front of terrified camel herders.

Field conditions are unforgiving:
daytime temperatures rise to
50°C in the summer.

Volcanic ash darkened the skies for three days forcing as many as 10,000 herders to leave the region. Remarkably, there were no human casualties because there are no two-storey houses anywhere in the affected region.

The rift performance would have continued to an empty audience, without the foresight and intuition of the Ethiopian geoscientists. The large number of earthquakes and surface ruptures did not fit a volcano eruption pattern, and they invited collaborators from the UK, Italy, France and the US to assist



This volcanic vent, half a kilometre in length and 60 metres deep, opened in one day (26 September, 2005).



Derek Keir and Worku Tadesse visiting a seismic station in Afdera.

with monitoring. And that's where our Afar show begins; as I explain below, we are yet to know when it will end.

Over the past decade, former PhD students Nick Hayward and Ellen Wolfenden had studied the pattern of faults and volcanic centres in the area, and had predicted that the rift zones were opening in nearly the same way as seafloor spreading centres lying two or more kilometres below sea level. To see if their prediction was correct we needed a rare burst of earthquake and volcanic activity to expose the processes at work. The urgent messages from the Geophysical Observatory were long awaited. We could directly measure the extremely rare process of magma injection into a continent as it becomes a new ocean basin.

By 14 October we had all the equipment and funding in place for the expedition. Ethiopian researchers Gezahegn Yirgu, Tesfaye Kidane and Atalay met our flights, and they whisked us up and out to the field area on an Ethiopian military helicopter. Gezahegn briefed the UK, Italian and US visitors with information provided by refugees from the area, and we debated a strategy designed to address both the immediate hazard and monitor the ongoing process of plate rupture.

The published locations of the September earthquakes clustered in the general area of Dabbahu volcano, but their position, were only accurate to around 50km. The number of displaced Afar herders suggested a large area of ground shaking. My colleague, Derek Keir, and I were keen to see if buoyant, molten rock (magma) moved along the length of the rift on its rise to the surface. This would answer the question: are the African and Arabian plates being punctured by thin, long sheets of magma that rise from the base of the plate, or are they ripped apart by long cracks that provide conduits for molten rock? The volcanologists supported our plan to monitor a segment of the rift mapped in earlier studies. As Oxford researcher Tim Wright and PhD student Juliet Biggs discovered two weeks later, our intuitive plan was ideal: the entire 60km long Dabbahu segment had ruptured during the September earthquakes. Tim and Juliet compared satellite radar images acquired before and after the earthquakes, detecting up to 8m of opening, with the maximum deformation occurring in the segment's centre, 30km from the active volcanic vent.

In March we returned to the middle of the segment and mapped dozens of newly formed open fissures, massive rock falls, and 5m high cliffs known as faults. The satellite information and field and earthquake studies provided some surprises: despite the nearly continuous earthquake activity, the amount of energy

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Nature, vol. 442. 'Magma-maintained rift segmentation at continental rupture in the 2005 Afar dyking episode'.

released was about ten times too small to explain the deformation seen on the ground and by the satellite radar imagery. The most likely explanation is that molten rock in thin long sheets, called dykes, punctured the plate, triggering earthquakes in the brittle uppermost crust. We think a sheet or sheets of magma 60km long, and about 8m wide shot upwards into the upper crust, probably triggering the entire episode (Wright *et al.*, 2006). Tim's estimates of a magma volume of around 2.5km³ injected in September make it the largest single event of its kind to have occurred on land since the Laki eruption in Iceland in 1783, and the first to occur in the era of accurate satellite measurements.

The ongoing Afar rifting episode is, in effect, a new plate tectonics discovery – understandable given the 100- to 1000-year cycle of tectonic processes. These observations are required to understand the basic physics of plate tectonic processes, and to develop workable hazard mitigation programmes in this harsh, remote place.

The ongoing challenge to our research is the inaccessibility of the region: there are no usable roads within 25km of the volcanic activity, and the nearest electricity is about 150km away. Field conditions are unforgiving: daytime temperatures rise to 50°C in the summer. We deployed one seismometer 87m below sea level

Volcanic ash darkened the skies for three days forcing 10,000 herders to leave the region.

in the hottest permanently inhabited place on Earth: Afdera. Crumbling rocky overhangs provide the only shade on the treeless lava plains, and the black basalt rocks are literally too hot to touch. Ostriches, oryx and gazelles disappear into narrow valleys between lava domes and fault scarps. Away from the ephemeral river beds, the only water comes from traditional distillation pits above hydrothermal vents. Despite its violent performance, the rift zone itself supports the Afar's existence.

Our temporary seismic network continues to record earthquakes and magma intrusions into the plate: another swarm of moderate earthquakes in June 2006 signalled a second catastrophic opening, and demonstrated the need for a permanent network in the area. Our youthful research team watches and waits for Act III of the Dabbahu rift show.

This work was carried out with the aid of a NERC urgency grant. Cindy Ebinger is Professor of Tectonics, Department of Geology, Royal Holloway University of London, email: c.ebinger@gl.rhul.ac.uk, tel: 01784 443890.