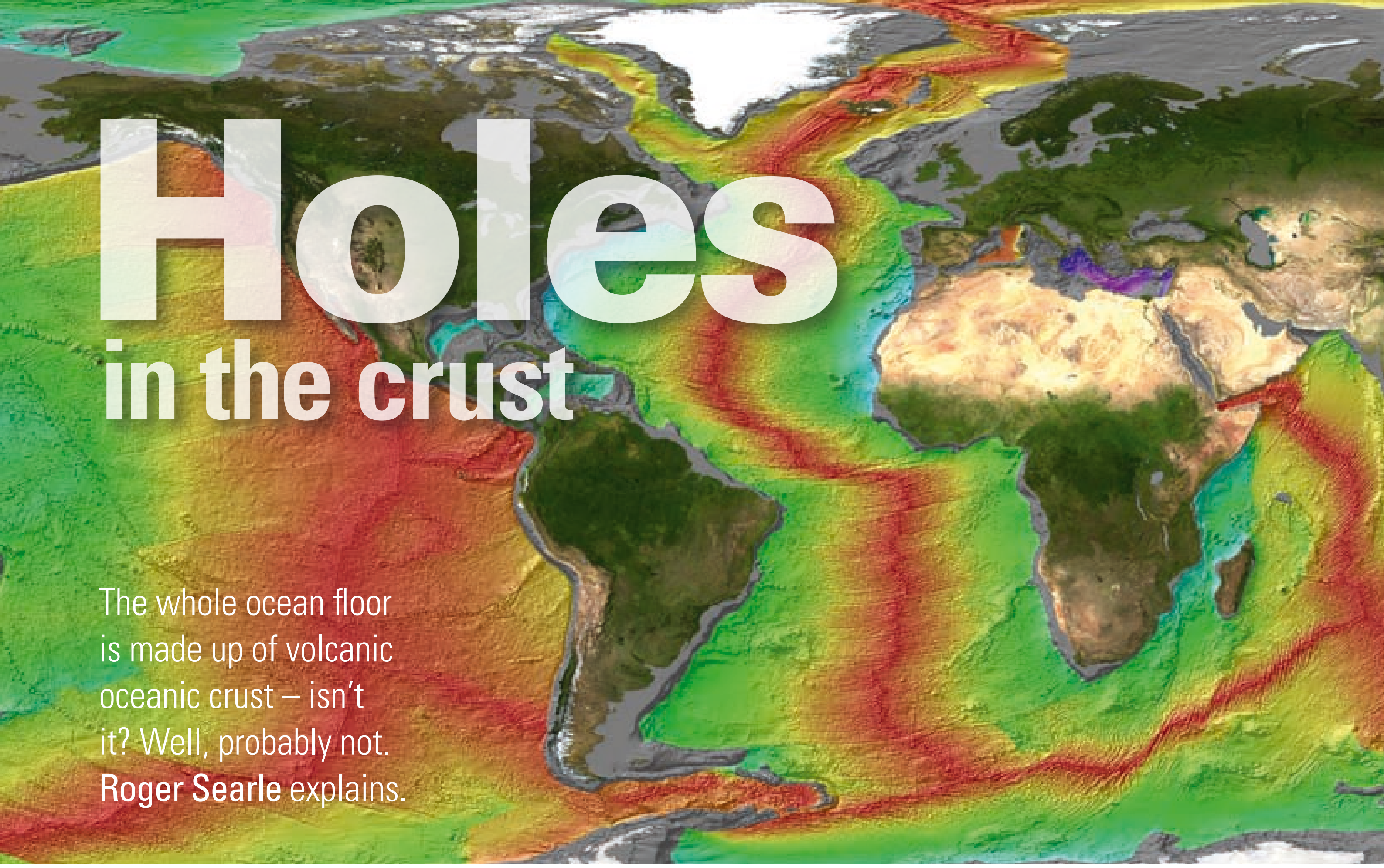


Holes
in the crust

The whole ocean floor is made up of volcanic oceanic crust – isn't it? Well, probably not. **Roger Searle** explains.

Elliot Lim/NOAA/NDGC

The Earth's central core is surrounded by a mantle made of peridotite rock, with a thin surface crust. The 6km thick oceanic crust covers 60 per cent of the Earth's solid surface.

For many years, most marine geologists thought the ocean's crust was just made of volcanic rocks like basalt and gabbro (which forms when basalt slowly crystallises in volcanoes' magma chambers). These rocks are produced as the rising mantle melts at the boundaries between tectonic plates at mid-ocean ridges, and account for between 80 and 90 per cent of seafloor spreading. As the plates separate they are stretched and faulted, producing the remaining 10-20 per cent of spreading.

But towards the end of the 20th century, more and more places were discovered where it seemed the 'crust' was missing and the mantle itself was exposed on the seafloor. Many of these places contain structures called 'Oceanic Core Complexes' (OCCs). Intensive worldwide study has shown that OCCs consist of broad domes, 10-20km across and 1-2km high. Cores and dredges show they mostly contain peridotite (mantle) or gabbro (crust), but the actual distribution of these rock types was unclear.

Models suggest that OCCs form when the supply of melted rock from the mantle is reduced. Then, as the proportion of plate separation due to the injection of magma falls, the proportion due to faulting increases. This means OCCs are effectively giant, long-lived faults (called 'detachments').

Planning, planning…

Together with colleagues Chris MacLeod from Cardiff University and Bramley Murton from the National Oceanography Centre, Southampton (NOCS), I was recently funded by NERC's UK Integrated Ocean Drilling Program to investigate how mantle rocks manage to reach the seafloor and how OCCs work.

We assembled an international team of geologists and geophysicists, and were privileged to take the first scientific cruise on NERC's new research ship RRS *James Cook*. We sailed from Tenerife in March 2007, four years after first forming our plans.

During the seven days it took us to steam 3400km towards the Mid-Atlantic Ridge we reviewed previous work.
We refined the focus of our study to a region about 1800km east of Barbados. Here, Debbie Smith of Woods Hole Oceanographic Institution had recently mapped many OCCs. This region offered the promise of extensive peridotite with a chance to investigate, for the first time, active core complexes.

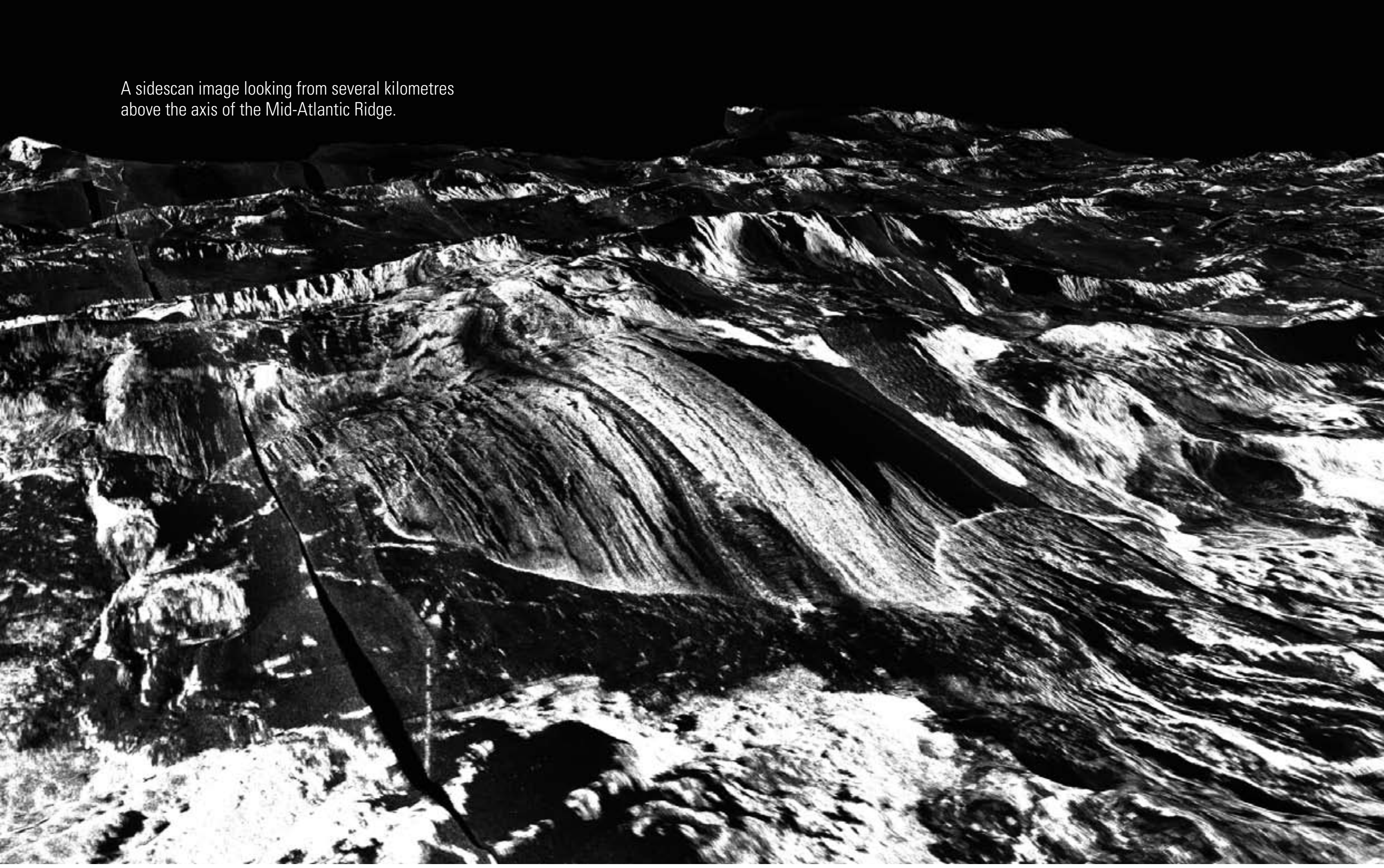
Tools of the trade

First, we carried out a detailed geophysical survey using the NOCS underwater vehicle TOBI, equipped with high-resolution sidescan sonar and other instruments.

As TOBI was towed at a slow walking pace above the seabed, *James Cook*'s multibeam echo-sounder mapped the depth of the seafloor. Seawater quickly blocks light, so any large-scale seafloor imaging uses sound. Echo-sounders estimate depth by sending sonar pulses downwards and timing their return. A multibeam echo-sounder uses a fan of over 100 narrow beams to map a swathe of depths several kilometres wide.

Data from many tracks are combined in a grid to make a digital terrain model. This can be displayed in a variety of ways, including oblique 3-D views with shading to suggest illumination. The shapes revealed are powerful indicators of geological structures like volcanoes and fault scarps.

In contrast, sidescan sonars project sideways and plot the varying 'backscatter' against range. This produces images similar to satellite photographs and reveals seafloor texture. TOBI's images are 6km wide with a resolution of just a few metres. A powerful way of viewing these data is to 'drape' the sidescan image over a 3-D view of the topography, and use special software to 'fly' around the resulting image.



A sidescan image looking from several kilometres above the axis of the Mid-Atlantic Ridge.

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The mantle revealed?

When we combined our data in this way, we had unprecedented views of active OCCs. These images tell us much about the structure of OCCs and how they work.

The sidescan image shown above is viewed as though from several kilometres above the axis of the Mid-Atlantic Ridge, looking away from the plate boundary. It shows an actively forming OCC, with a smooth dome whose striated surface is emerging from older seafloor at its foot. We interpret the smooth dome as the surface of an actively slipping detachment fault. The fine, bright, curved line at the foot of the dome is thus the current tectonic plate boundary.

Beyond the smooth dome is a higher, blockier region that we think is the volcanically-formed crust. There is a sharp boundary between these two regions. Based on our sampling and the sonar imagery, we interpret this as the boundary between a thinned crust and the mantle, with the smooth dome being exposed mantle.

In the foreground is a bright, highly backscattering ridge, indicating very young volcanism and therefore marking the place where new volcanic crust is forming. One of our most important findings is that this very young seafloor is largely absent opposite the core complexes. This nicely confirms the numerical models that predict a reduction in melt supply at OCCs.

A new view of seafloor spreading

We have now put together a comprehensive model explaining how core complexes are born and die. We believe they begin when sea water circulating in faults in the crust encounters peridotite rock at depth.

This is most likely in areas where the supply of magma from below is reduced, making a thinner volcanic crust. Peridotite reacts easily with water to produce the extremely weak minerals talc and serpentine, which lubricate and weaken the fault and allow it to keep slipping for millions of years, becoming a ‘detachment’.

Now, most of the separation of the plates is happening as rocks slip across the detachment, and little or no new volcanic crust is being made. One plate grows by continuously pulling hot, malleable rock out of the mantle, while growth on the other plate is stalled because no melted rock is added to it.

One tectonic plate is now growing much faster than the other, and this pattern of growth is unstable. The detachment fault starts to move back towards its original position on the mid-ocean ridge. Eventually, magma starts to be injected into the fault again, re-establishing vigorous volcanism at the ridge axis and stopping the fault from slipping any further.

This is a very different mode of seafloor spreading from the classically accepted one, but it is now becoming recognised on many parts of the ocean floor. ❖

MORE INFORMATION

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C. J. MacLeod, R.C. Searle, B.J. Murton, et al., Life cycle and internal structure of OCCs, *Earth and Planetary Science Letters*, in press, 2009.