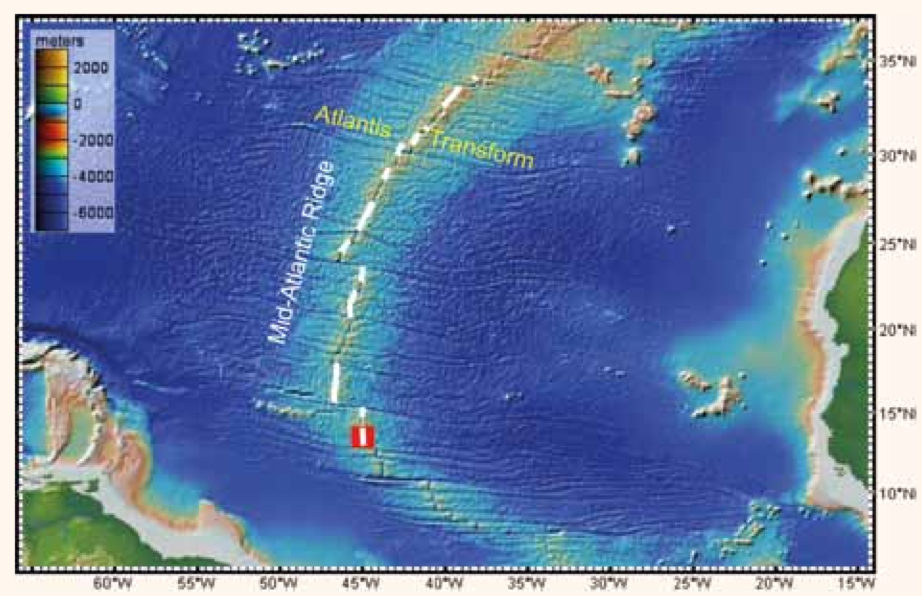
Research and outreach at the Mid-Atlantic Ridge

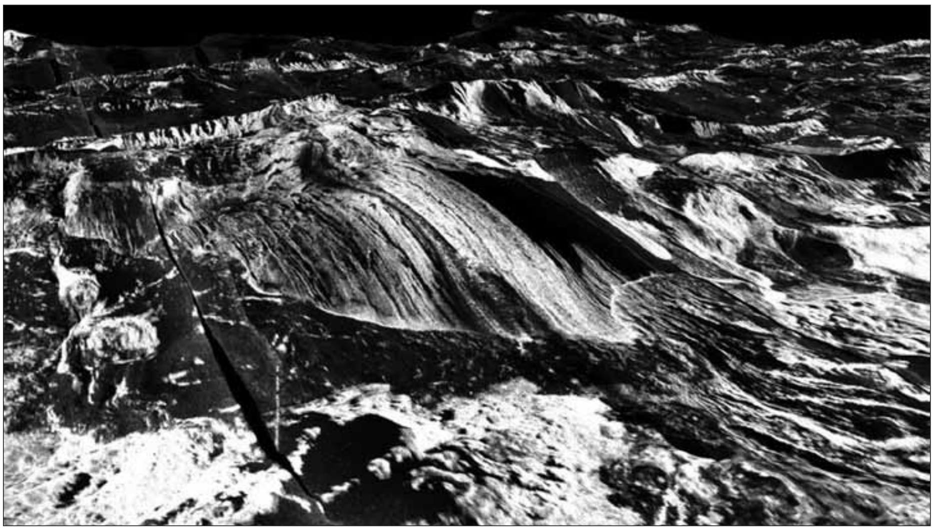
Roger Searle, **Christine Peirce** and **Angela Bentley** look at research on oceanic core complexes and detachments at the Mid-Atlantic Ridge, combined with innovative geophysics outreach.



1 Bathymetry of the North Atlantic showing the Mid-Atlantic Ridge. Sections interpreted as undergoing asymmetric accretion are indicated by white lines, after Escartin *et al.* (2008). Red box indicates the study area. (Figure made using GeoMapApp, Ryan *et al.* 2009)

In 1997, Joe Cann and others described a "corrugated slip surface" at Atlantis Massif on the Mid-Atlantic Ridge (MAR) (Cann *et al.* 1997). Over the next decade many such features were described, including a large cluster near the MAR around 13° (Smith *et al.* 2006); the area is shown in figure 1. They are called oceanic core complexes (OCCs; Escartin & Canales 2011).

OCCs are so named by analogy with continental core complexes, where deep-seated cores of metamorphic rocks are exhumed and exposed in the footwalls of normal faults with large offsets. The corrugated surfaces of OCCs generally top otherwise smooth domes up to tens of kilometres across and kilometres high (figure 2), and are interpreted as the outcrops of "detachment faults" that cut right through the lithosphere; they are effectively the boundary between separating tectonic plates. Unlike the "classical" model of seafloor spreading, in which both plates grow symmetrically by injection of magma at the ridge axis, this new mechanism is asymmetric; one plate accretes as ductile mantle is exhumed and cools, while the other plate either does not accrete at all, or perhaps grows by a different, though presumably igneous mechanism. A paper by Javier Escartin and colleagues showed that such asymmetric spreading has been involved in the formation of some 50% of recent North Atlantic sea floor (Escartin *et al.* 2008).



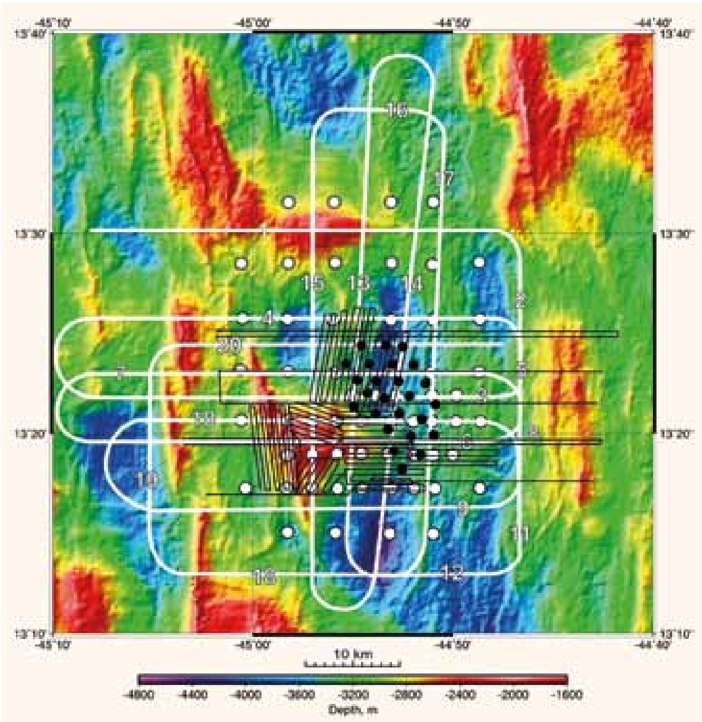
2 Oceanic core complex (OCC) at 13°20'N on the Mid-Atlantic Ridge, viewed as a sidescan sonar image draped over topography. View is to NW looking across ridge axis. Bright, "hummocky" terrain in foreground is recent volcanic sea floor originating from the spreading axis. The striated dome of the OCC is approximately 7 km across. Smaller, partly eroded, normal fault scarps are visible in the distance.

OCC model

In 2007, Chris MacLeod (Cardiff University), Bramley Murton (National Oceanography Centre) and I carried out detailed studies of three OCCs during the inaugural scientific cruise of the UK's research vessel RRS *James Cook*. We proposed a model for the "birth, development and death" of OCCs (MacLeod *et al.* 2009).

However, there remain fundamental questions about OCCs and detachments. One concerns the geometry of detachments: do these faults, which are concave downwards at the sea floor, continue to steepen subseafloor, or do they flatten out? Another is the linkage between neighbouring OCCs: one school of thought sees each as an isolated structure (MacLeod *et al.* 2009), while an opposing view has them linked along both the ridge axis (Reston & Ranero 2011) and the spreading direction (Smith *et al.* 2008), with undulating detachments. The nature of the rocks beneath OCC domes is also uncertain: simple considerations suggest they should be

3 Autosub 6000 being launched during expedition JC132.



4 Positions of planned experiments for JC132. OCC1320 is the red massif just south of centre of image. Adjacent OCC1330 is just north of centre. White lines: multichannel seismic lines; white circles: active (wide-angle refraction) OBSs; black dots: passive (micro-earthquake) OBSs; black lines: Autosub tracks.

predominantly peridotite (mantle rock), yet large amounts of gabbro (a product of partially melted peridotite) are often sampled.

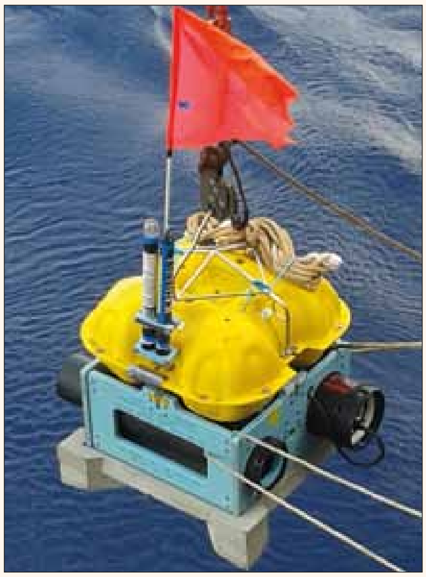
We decided to return to the site of our 2007 studies, with a radically new approach, new tools and new methods. We teamed up with seismologists Christine Peirce (Durham University) and Tim Reston (Birmingham). Christine would lead the wide-angle seismic refraction work "shooting" sound to ocean-bottom seismographs (OBSs, figure 5) to infer crustal and subcrustal seismic velocities and thus structure, while Tim would lead multichannel seismic reflection studies, using reflected low-frequency sound to image vertical sections of the crust. Chris MacLeod and I would use NERC's autonomous underwater vehicle (AUV) Autosub 6000 (figure 3) to obtain high-resolution magnetic field and bathymetry data. We also involved Rob Sohn (WHOI), who would infer the detachment geometry from OBS recordings of microearthquakes, and Javier Escartin (University of Paris), who had independently conducted near-bottom observations with a French AUV.

Three trips

Our proposal was funded in 2012, and we then joined a queue for ship time. We had requested two one-month legs, allowing the passive seismograph network to be separately deployed or recovered later to provide several months of recording. In the end we had three legs: the passive seismographs were deployed on RRS *James Cook* cruise JC102 in April 2014 and recovered on JC109 in October–November 2014, and the other experiments were all carried out on JC132 in January–February 2016.

Modern marine geophysics requires intense and detailed planning lasting many years. Not only did we have to mesh with

The bottom line: sea-floor geophysics



5 An ocean-bottom seismograph (OBS) being launched on JC132. The yellow section contains spherical glass floats; the sensors and data logger are in the box below. The concrete anchor is released on command from the ship to return the instrument to the surface.

By Christine Peirce (Durham University)

Social media makes it much easier to share the experience of marine geophysical exploration, as we found with our blog explaining the day-to-day activities associated with ocean-bottom seismometry as the JC132 research expedition progressed.

JC132 used up to 58 ocean-bottom seismographs at once. Each instrument is dropped overboard and sinks for about an hour before reaching the seabed. After the experiment, which can last between days and many weeks, each OBS is released and slowly resurfaces. Back on deck, the data are downloaded, copied and stored. Deploying, recovering and setting up the OBSs requires 24/7 shift working, sometimes for weeks.

While the OBSs were on the sea floor, the ship sailed in a grid pattern, creating artificial seismic waves with airguns. These signals were recorded both by the OBSs on the seabed and by an array of hydrophones towed on a 3 km long cable behind the ship. Such seismic surveys can take many days, with thousands of airgun array shots fired at intervals of between 20 s and 60 s in this case.

The goal is a 3D seismic survey of the subsurface. It's a computing challenge similar to medical tomography, except over a much bigger area, with a distant target under 3 km of water. Additionally, the instruments have to withstand harsh conditions – not to mention damage from sea creatures with sharp teeth, puncturing and scraping cables.

http://obsatsea.wordpress.com

NERC's wider ship programme, we also had to ship the OBSs back and forth and allow their refurbishment between cruises. And on JC132, we had to interleave OBS deployment and recovery, seismic shooting and Autosub deployments and recovery, all the while taking account of staff working-time and variable weather.

An important part of our outreach project was the Teacher at Sea initiative, in which a teacher joined us on the JC132 cruise, along the lines of an "artist in residence". We were lucky to obtain the services of Angela Bentley for this project (see box "Teacher at Sea: outreach from the Mid-Atlantic Ridge"). She took a full part in the expedition, engaging schoolchildren and others via electronic media from the ship, and will use the experience to develop new teaching and outreach materials.

Ten dives

Briefly, we conducted the following experiments (figure 4). The passive seismic experiment deployed 25 OBSs around the 13°20′N OCC to detect microseismicity from its actively slipping detachment. Preliminary results indicate that many thousands of events were recorded, which should adequately characterize the fault geometry. Wide-angle seismic refraction lines were shot in the same area, and will be used to build 3D tomographic models of the seismic velocity, and hence infer crustal structure. Parallel sets of multichannel seismic reflection lines were shot over two OCCs, parallel and orthogonal to the ridge, in the expectation of imaging the detachment fault directly. Ten Autosub dives were made, each lasting approximately 24 hours. All these recorded magnetic field, with four long east–west lines being analysed to provide a detailed sea-floor spreading history both over and between OCCs, while the closely gridded data will be used to infer lithological structure. Six of the dives recorded detailed microbathymetry, which has been gridded to ~4 m resolution, and will yield additional information on the volcanic and tectonic structures around and between OCCs. Our rich dataset will engage the team, including several postdocs and PhD students, for some time to come! •

AUTHOR

Roger Searle, emeritus professor of geophysics, Durham University.

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Teacher at Sea: outreach from the Mid-Atlantic Ridge

By Angela Bentley (Aquinas College, Stockport)

The Teacher at Sea concept is simple: a classroom teacher joins an academic team on a research vessel and speaks and writes about the experience. I applied after I saw the role advertised on Twitter and in a *Teaching Earth Sciences* newsletter, but I did not expect to get the position – I was amazed to get an interview. I'm a middle-aged classroom teacher and a mum: surely this sort of thing happens to other people? Cool people?

The specification for the role has been quite open, so that I can make of it what I wish. The blank canvas is both liberating and daunting. Where do you start? What do the scientists, the Natural Environment Research Council (NERC), my blog followers and new contacts need, want or expect? I felt the role was to provide outreach and resources for schools and to inform the wider public about life and science on a research ship.

I started by sorting out the social media: http://teacheratseablog.wordpress.com for the blog, @teacheratseaMAR for Twitter, and "teacheratsea" as a community page on Facebook. I think the best start for outreach is Twitter, reaching a wide and varied audience with relative ease. The blog contains longer articles and they are categorized by suitability for educational key stage or whether they are about day-to-day life on board or about the science. Facebook has also been a successful tool to access the blog and it is useful to be able to post pictures easily. I am also creating a teacher resource pack so that the people most likely to use the resource – teachers – will have easy access to the information.

Survival

I had to undergo a medical and pass a Personal Sea Survival Course (PSS). I was worried about this because I knew I'd have to climb into a lifeboat from the water unaided. Last summer, before getting the post, I had struggled to get back on to a pedalo even with help from a convenient husband and son, neither of whom would be at the PSS course – or in the middle of the Atlantic Ocean! In the end I loved the survival course – and I did manage to haul myself into the life raft by myself.

Christine Peirce invited me down to Southampton to meet some of her team and to have a tour around the RRS *James Cook*. This was a good experience and very reassuring. The ship seemed like the TARDIS: bigger on the inside than the out, a maze of corridors and stairs and surprisingly spacious for the 52 people living and working on the ship.

On the morning of 14 January 2016, we cast off from Cape Verde to begin our expedition; I would not see land again until the last week in February. I joined the scientists on JC132 for one of the data collection phases of their research. One of the main objectives of this expedition is to map the faulting at 13°N at the Mid-Atlantic Ridge in order to gain understanding of the formation of the ocean core complex at this location. OCCs, discovered in 1997 at this location, demonstrate that sea-floor spreading is not always neatly symmetrical.

Collecting data

The goal of this voyage was data collection. My knowledge and understanding of the data collection processes used in ridge science has been greatly enhanced. I've also had to learn a vast amount of terminology! We collected bathymetry data from shipboard sonar, made reflection and refraction seismic surveys with, respectively, airguns and hydrophone streamers towed behind the ship, and an array of ocean-bottom seismographs, deployed and recovered from the ship.

In addition, we used the submersible Autosub to take detailed near-bottom data at 13°N. The resolution compared to that of the sonar swath is amazing and the contrast makes you very aware of just how little information the scientists have to work on – particularly in comparison to land data. Autosub also collects detailed magnetic data.

I learnt a lot as Teacher at Sea, not least the complex planning behind every aspect of the expedition: logistics, research goals, equipment robust enough to descend through 3000 m of water and ascend again, data intact. OCCs are not uncommon and we need to know more about them. Bathymetric maps of the sea floor are beautiful. And scientists are just like everyone else: they are not socially inept nor are they narcissistic villains from a comic strip; we had a BBQ, played table football, watched box sets and played darts. You don't have to be super bright to be a scientist, just enthusiastic and hard-working.

I have thoroughly enjoyed my time as part of the JC132 team and would recommend the Teacher at Sea experience most highly. I am now writing up a detailed pack of resources for teachers. I am also visiting schools and institutions across the country, speaking about the science of JC132 and life on board a research vessel – please email me if you would like me to visit your institution.

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