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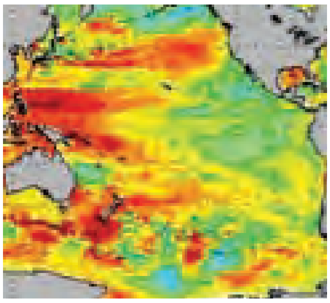

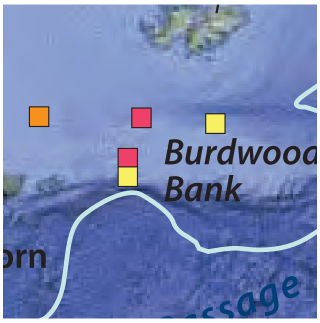

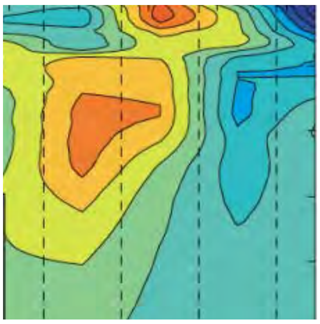

Most of the maps and diagrams were drawn by The ArtWorks.

Cover and heading graphics designed by Ann Aldred.

Cover photograph © Alex Mustard

Message from the Editor

Research vessels (and their space equivalent, ocean-observing satellites) feature prominently in this issue. At the time of writing, RRS *Discovery* is docking after her last research cruise (no. 282) and we have four articles in which oceanographers recall the hard work (and fun) they shared on *Discovery* over the years. Any oceanographer looking forward to working on a new, more convenient RRS *Discovery* (expected to be delivered in spring 2013; p.10) will no doubt feel sympathy for the scientists and seamean who worked on HMS *Challenger*, a model of which may now be seen at the National Oceanography Centre, Southampton (see opposite).

This issue also contains a feature article about ocean interaction with the Greenland Ice Sheet, by Helen Johnson, and another on using deep-sea corals to explore the history of the oceans, by Laura Robinson. There is the usual mix of shorter pieces including two interviews with successful marine scientists who have not followed the conventional academic career path in a university or research institution. There is also a report on the conference to celebrate the career of Harry Bryden, whose many contributions to the oceanographic community include his term as Challenger Society President, which ended in September.

Angela Colling

News from Challenger 2012

The 2012 Challenger Society conference, held at UEA in September, was greatly enjoyed by seasoned oceanographers and students alike – for more about this event, see the report by Raffaella Nobili on p.5. As usual, one of the highlights was the presentation of prizes and awards. Charlotte Williams, a NOC/University of Liverpool Ph.D student, won the Norman Heaps prize for the best oral presentation by a non-established researcher, for her talk on 'Wind-driven nutrient fluxes in shelf seas'. The Cath Allen prize was won by Benjamin Webber, UEA, for his poster 'Ocean dynamics can trigger the Madden–Julian Oscillation'.

Challenger fellowships are awarded to early-career scientists for their achievement or promise in a branch of marine science. At the conference, fellowships were awarded as follows: Jenny Brown, NOC Liverpool (marine physics); Kate Hendry, Cardiff University (marine geology); Daniel Mayor, The James Hutton Institute, Aberdeen (marine chemistry); and Abigail McQuatters-Gollop, SAHFOS (marine biology).

The Challenger Medal is awarded to a UK marine scientist who has made a significant contribution to the development of marine science. Unfortunately, Harry Elderfield, being honoured for his work in palaeoceanography and ocean chemistry, was unable to be present. Harry will give his Challenger talk at the AMBIO meeting next September.

The winner of the President's Photographic Competition (subject: 'Marine science in stormy weather') was Damien Guihen of the British Antarctic Survey. Damien's photo shows a wave breaking over the bow of the RRS *James Clark Ross* in the rough seas for which the Southern Ocean is famous. The photo was taken in January 2012 near the Polar Front, during the transit from South Georgia to the Falkland Islands after BAS's Western Core Box Survey of pelagic marine biodiversity.

At the Society's AGM, held during the Conference, Hilary Kennedy took over from Harry Bryden as President. Newly elected to Council were Karen Heywood (UK SCOR representative), Abigail McQuatters-Gollop (Communications portfolio), John Allen (Editorship of *Challenger Wave)* and Hugh Venables (Education and Outreach portfolio). Retiring members were thanked for their voluntary hard work for the Society.

HMS Challenger *docks at Southampton*

HMS *Challenger* can now be seen in the National Oceanographic Centre, Southampton (NOCS), in the form of a fine scale model which has been given to the Centre by Geoff Harvey of Sidmouth. Geoff has been making model sailing ships for the last 30 years, and each model takes about two years to complete. His models include coastal vessels, square-rigged trading ships and Royal Navy ships. Buiding a model of the *Beagle* gave Geoff an interest in RN ships involved in scientific exploration, including *Challenger*. He obtained copies of the original drawings from the National Marititme Museum and built the model at a scale of 1 : 96.

HMS *Challenger* was a steam-assisted Royal Navy Pearl-class corvette – essentially a sailing ship. The steam engine would be used for manoeuvring in harbours and when collecting data or dredging.

Challenger had an ignominious end. Her final role was as a 'receiving hulk' (a moored ship used to house newly recruited sailors before they are assigned to a crew); she was broken up for her copper bottom in 1921. All that remains is her figurehead, now in the foyer at NOCS. However, the model (now displayed in the NOCS Library) is a permanent reminder of the pioneering oceanographic work done during the *Challenger* Expedition, between 1872 and 1876.

Above *The model in the NOCS Library. At 200 ft long, the original vessel was able to house 243 officers, scientists and crew during the 1872–86 expedition.*

Left *Close-up of the vessel's stern, showing the hatch over the screw well, used when raising the propeller to reduce drag when under sail.*

Below left *The vessel's amidships, showing the funnel and dredging bridge. When the vessel was under sail, the funnel would be 'telescoped' down.*

Below right *The bow, complete with figurehead.* ***Right*** Challenger*'s actual figurehead (recently repainted), which stands in the NOCS foyer.*

(Photos courtesy of Barry Marsh, Ocean and Earth Science, University of Southampton)

Trans-Atlantic Oceanography

A meeting to celebrate the career of Professor Harry Bryden

Friday 30 September 2012 marked the formal retirement from the University of Southampton of Professor Harry Bryden. Harry joined the Institute of Oceanographic Sciences in 1993 and has worked at the National Oceanography Centre since it opened as the Southampton Oceanography Centre (SOC) in 1995.

Harry's distinguished career as an oceanographer includes many achievements, not least leading the Centre's Graduate School through an exciting period of development and growth between 2007 and 2011, the authorship and co-authorship of approximately 90 refereed scientific publications, and being awarded the 2009 Prince Albert I Medal by the International Association for the Physical Sciences of the Ocean. On 30 April and 1 May more than 70 of Harry's friends and colleagues from the UK, Spain, Germany and the USA gathered at NOCS for 'Trans-Atlantic Oceanography: a meeting to celebrate the career of Prof. Harry L. Bryden FRS'. Here, speakers presented recent advances in their own research, which owe a considerable debt to Harry's innovative work over the last four decades.

The title of the meeting was chosen to reflect the fact that Harry spent half of his career in North America, followed by almost 20 years in Southampton, and it was also a reference to Harry's seminal work on the Atlantic Meridional Overturning Circulation (MOC), which served as inspiration for the Rapid Climate Change programme. Following an introduction by Prof. Tim Minshull, Head of the School of Ocean and Earth Science, Raymond Pollard gave a review of Harry's professional trajectory and his publications. Displaying Harry's papers on a map of the world, Raymond made the case that Global Oceanography would have been a more apt title for the meeting!

Harry's pioneering work on ocean transports and the MOC has been an inspiration to several of the speakers. Stuart Cunningham spoke about the measurement of the MOC and oceanic heat flux at 26° N generated by the RAPID–MOC and RAPID–WATCH programmes. Now in the 9th year of observations led by Stuart, the RAPID MOC time-series has had a large impact on our understanding of ocean circulation and climate. After the talk there was much discussion about the possible reasons for the reduction of the MOC observed in 2009–2010.

The discussion continued the following day when Jochem Marotzke spoke on the 'Predictability and prediction of Atlantic circulation and climate'. Jochem highlighted the importance of the initialisation of coupled models and the difficulty of validation. A prediction was made that the reduction in the MOC observed in 2009–2010 would not be sustained over the coming years.

Ocean transports were also a theme of Lisa Beal's presentation 'To the Agulhas and back, and back again'. Lisa spoke about her research in the Indian Ocean, starting with the discovery of the Agulhas western boundary undercurrent during her Ph.D, which was supervised by Harry. Lisa has returned several times to make further measurements of the Agulhas system and is now embarking on a study to investigate the impact of changes in Southern Ocean westerlies on the Agulhas Current, and the leakage of Indian Ocean waters into the South Atlantic.

In a talk entitled 'Starting in the northern lights and finishing in the Mediterranean Sea', Marta Alvarez explained how she was guided by Harry in her early career. She went on to describe her work on the measurement of transports of tracers and analysis of the uptake of CO_2 by the oceans. Gregorio Parrilla then reminisced on his collaborations with Harry on the study of flow through the Straits of Gibraltar and the WOCE A5 section in the Atlantic, as well as on Harry's important influence in the emergence of physical oceanography in Spain.

Harry Bryden is renowned as a physical oceanographer but the last speaker, Eelco Rohling, impressed on the audience that Harry has had a great impact on palaeoceanography too. Eelco has been inspired by Harry's work on the flow through the Straits of Gibraltar and has applied this in two areas of his own research. In the first of these, analysis of core data from the Red Sea has resulted in a valuable record of global sea-level going back 500 000 years. The second study used the palaeo record of outflow from the Mediterranean to estimate the changes in stratification of the North Atlantic.

The audience also appreciated presentations from John Toole ('Two advisee projects: A talk in recognition of Harry's seemingly endless supply of research problems for his students and postdocs'); Carl Wunsch ('Sea-level change – the physical oceanography of everything'); John Shepherd ('Why modelling mixing is messy: a cautionary tale'); and Andy Watson ('DIMES: fun and games in the Southern Ocean').

A recurring theme of the meeting was the inspiration and encouragement that Harry has given students and colleagues. During an after-dinner speech, Lisa Beal reflected on advice she has received from Harry over the years. Some of this advice is encapsulated in 'Brydenisms', quotes known to many of Harry's students and colleagues – including 'Read a paper a day!' Most speakers and several other meeting participants emphasised two of Harry's most admirable qualities: his generosity in mentoring early-career scientists and his seemingly endless supply of great ideas and advice for junior colleagues.

Fortunately, despite this official retirement, Harry intends to carry on working, though in a less formal capacity, for many years to come.

David Smeed and **Alberto Garabato**, NOCS

Photo courtesy of Steve Hall

Fond memories of the Challenger Conference 2012

A UEA helper's perspective

Raffaella Nobili

If you made it to the Challenger 2012 Conference, hosted by UEA, you may already hold the memory of the week dear to your heart. If you didn't make it, I feel sorry for you, but you can still join us in Plymouth in 2014!

Because of its greyness, UEA doesn't strike many as a particularly attractive campus, but we are surrounded by immense parkland and nature conservation areas with our very own lake (a.k.a a 'broad' here in Norfolk). And who doesn't remember the UEA bunny rabbits fondly? They even starred on the BBC One Show. Norwich itself is a user-friendly city full of historic charm, with great examples of mediaeval architecture and quirky little shops.

In my opinion there are certain criteria defining a memory as 'dear', such as:

1 Filled with momentous events

2 Filled with great people

This year, Challenger was all of that and more. I was one of the student helpers for the week, one of those tealy-green T-shirt wearers. Our fun started before everyone else arrived. A few of us are not English native speakers, so first things first: get to grips with the various acronyms. It is true that UEA stands for University of East Anglia but in reality it is also known as the University of Extraordinary Acronyms. I have been at UEA for three years now but I must admit I didn't know that LCR stands for Lower Common Room! Our tasks in the role as helpers weren't difficult: holding the microphones and occasionally trying to do the equivalent of 'herding cats' between events or, since some of us didn't get the meaning, the equivalnt of 'herding plankton'. I like the idea of all of us scientists and aspiring scientists as plankton. They are remarkable organisms whose strength is in their number and in the various abilities they offer to our planet. I think we are just that, a group of great people that together can make a difference. Each of us brings something unique to the table: pieces of the puzzle that make up the bigger picture, understanding and caring for our planet.

Challenger is a very friendly event, enjoyed by scientists at all levels. It gives us a chance to get together to strengthen our bonds, make progress towards our goals and help keep our focus. What I experienced during the week was a group of people passionate about marine sciences wanting to catch up with old friends and make new ones. I was very impressed with the turnout for the 'evening pub walk', demonstrating how pleasant and sociable Challenger can be. Organised by Moritz Heinle and myself, it featured a walk around the alleys of Norwich, and opportunities to sample the local ales and ciders. I loved seeing such a large number of people of all ages mixing informally, enjoying a giggle or two and contributing to the local economy.

Another momentous event of the conference was the dinner. This year, it took place at the 'Top of the Terrace' at Norwich City Football Club and Delia Smith was our hostess (she wasn't actually there, but she runs the catering company). We were treated to some lovely food and an amazing location overlooking a very green football pitch We even had our very own welcome message flashing out on the outdoor scoreboard! And I cannot help but smile when I recall some amazing and unexpected performances on the dance floor. As they say, appearances can be deceiving.

On a more scientific note, this year's debate showcased 'Offshore wind power'. A panel of four experts engaged the attendees in a Q & A session. Overall, the idea was to stimulate public awareness and promote a range of options for the future while trying to engage with the NIMBY (not in my back-yard) approach.

The poster session was a lively one and promoted further networking and exchange of ideas between the participants. I particularly enjoyed the posters embracing interdisciplinary approaches. These combined elements from a variety of disciplines and highlighted the incredible effort that some scientists put into their work.

I enjoyed all the keynote speakers' presentations. David Righton's (CEFAS) performance was particularly humorous with 'Fish behaving madly: how integrating oceanography and behaviour can help us think like a fish'. I was particularly interested in his description of how new advances in technology can make such a huge difference to data-collection compared to a few years ago. Electronic chips have become so incredibly small that tagging a fish is now achievable, allowing for an incredible amount of behavioural and environmental information to be collected.

Important figures in the field of biogeochemistry, such as Jorge Sarmiento and Ken Buesseler, were there as well, sharing their amazing knowledge with us younger scientists in training. I think that the passing of information and feedback from one generation to the next is very important since it's what pushes science forward.

Thank you for a great conference Challenger Society!

Raffaella Nobili is currently finishing her Ph.D at UEA and aims to continue working in the field of zooplankton physiology.
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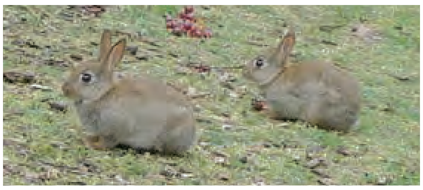


Left *Raffaella at work in the lab at UEA*
Rght *UEA's rabbits, fondly remembered by many conference delegates over the years*

An interview with the Chairman of OSIL

Paul Ridout describes the pros and cons of working in the marine commercial sector

If you are a practising oceanographer, there is a very good chance that you routinely rely on one or more products made by Ocean Scientific International Ltd – the brainchild of its Chairman, Paul Ridout. OSIL's most widely used products are IAPSO Standard Seawater for Practical Salinity, and other seawater standards for nutrients. A large part of OSIL's business is involved in the production of systems for marine environmental monitoring. This includes integrated instrument platforms for measuring currents, waves and water quality, sediment corers, CTD/sound-velocity probes and laboratory salinometers. Here Paul briefly descibes his career, and provides an insight into the pleasures and challenges of working in commercial marine science.

Why did you decide to go into marine science?

I grew up in Newport, South Wales, where trips to the docks to look at the ships were a regular weekend experience during my early childhood. As a student, I found the beaches of Porthcawl, the Gower Peninsula and Pembrokeshire a big draw, and enjoyed surfing (very badly) and fishing. I still find exploring rock pools as exciting now as I did then.

My first proper job was with Imperial College studying pollution on British motorways – not very marine, although I was analysing soils and vegetation for their salt content. It was these skills in chemical analysis which in 1977 landed me a job with the chemistry group at the Institute of Oceanographic Sciences Deacon Laboratory (IOSDL) in Wormley. I was employed to work with Fred Culkin on the preparation and calibration of IAPSO Standard Seawater which is the internationally recognised standard for seawater salinity. In addition, I was fortunate enough to work on a number of research projects, including studies of pigments in deep ocean sediments and trace metals in marine organisms, resulting in the publication of over 35 peer-reviewed papers.

What aspect(s) of your job do you enjoy most?

In one word – freedom. That has allowed me to try out a wide range of ideas in the development of my company. Not all were successful but they all contributed something to the learning experience. The overall result has been quite successful and that is incredibly rewarding, but it's the individual challenges which still excite me. In a small company like OSIL every member of staff has influence and can contribute to and be rewarded by successes.

Left *Close-up of an early ampoule of Standard Seawater calibrated in chlorinity.*

Right *A bottle of IAPSO Standard Seawater, calibrated in conductivity ratio (K_{15}) and salinity. This is the only internationally recognised standard for Practical Salinity.*

For more about the development of Standard Seawater see 'The IAPSO Standard Seawater Service' by Fred Culkin and Paul Ridout in Ocean Challenge*, Vol.2, No.2, Summer/Autumn 1991.*

More recently I have handed day-to-day control of OSIL to the Managing Director, Richard Williams, which releases me to plan the wider company strategy and network through various committee positions which I enjoy. I have served as a Council member for the Challenger Society, and as a trustee for the Marine Conservation Society. Currently, I am a Council member for the Association of Marine Scientific Industries (AMSI) and honorary Vice President of the Parliamentary and Scientific Committee. These voluntary positions allow me to network at a higher level and use my experience to present the world of commercial marine science to a wider audience. AMSI has become highly influential as a collective voice for the industry and the parliamentary committee provides an opportunity for scientists to engage with politicians. Important topics covered have included climate change, fisheries, nuclear power and offshore oil.

What part of your job is the most problematic?

Bureaucracy is the bane of many small business operators. Many of OSIL's customers around the world are government departments where bureaucratic processes are obligatory. One advantage of having worked in the public sector is that at least I have an understanding of the difficulties which many public-funded scientists face when procuring equipment and services. Nowadays, too many of the rules and regulations imposed on small UK companies are disproportionate *to their level of business. Small companies make up the backbone of British business; they are significant employers and vital to the UK economy. Some of the legislation which is relevant to large corporates needs to be tempered more appropriately to suit small companies.*

How did you get into commercial marine science?

During the late 1980s the Conservative government, under Margaret Thatcher, was imposing severe cuts on an oversized civil service (sound familiar?). As a result I volunteered for redundancy from IOSDL with a plan to 'privatise' the Standard Seawater Service. This was quite radical at the time as the Service had been under institutional control since its formation in 1902 by the Danish physicist, Martin Knudsen. Thanks particularly, to support from Fred Culkin and Henry Charnock, Ocean Scientific International Ltd (OSIL) was formed in April 1989 to take over production of Standard Seawater. I literally went home on the Friday night as a civil servant and returned the following Monday as my own boss. We rented premises at the IOSDL site until 1995 when the Southampton Oceanography Centre was opened and OSIL moved to Petersfield, and then moved again, in 2007, to our current units near Havant. During that time OSIL has grown from a one-product company (making Standard Seawater) to an organisation offering over three hundred products and services for marine scientists and technologists worldwide.

What would you change to help business prosper?

Employment law is stifling small businesses in the UK and needs to be changed in order to encourage entrepreneurs to start companies and employ people. This does not mean that all employers will become unscrupulous sweatshop owners exploiting a downtrodden workforce (this can happen under the current system anyway). We need to encourage business owners to experiment with ideas, which may mean taking people on to create and develop those new ideas. This is the principle in the USA where many of the Silicon Valley companies take staff on in a speculative way which, despite the lack of individual job security, stimulates overall growth and creates an exciting atmosphere.

OSIL staff on board the RV **Bill Conway** *testing field probes in the Solent. Personnel (from left): Stuart Holland (Systems Development), Richard Williams (MD), Adam Joliffe (Sales), Becky Childs (Marketing), Nigel Higgs (Seawater Chemist), Gareth Gerard (Systems) and Steve Greenaway (Service Manager).*

How do you see the future of UK Marine Science?

The House of Lords Science and Technology Committee in the 1980s concluded that UK marine science was poorly coordinated, fragmented and underfunded. Some might argue that it isn't much different now but there are some positive signs. At the present time, marine science and technology probably enjoys its highest political profile for several decades. In 2007 the House of Commons Select Committee produced the report 'Investigating the Oceans' *and the Government responded with a recommendation to form a new committee, the Marine Science Co-ordinating Committee (MSCC). The MSCC has now produced a* Strategy for Marine Science in the UK *which aims to deliver the right marine science to meet current and future policy needs.*

*Of course, UK marine science is not restricted to work in the UK. Our capabilities, technology and expertise provide us with a strong position to compete for projects worldwide and it is this global market which has allowed the private sector to flourish during these recent recessionary times. Last year's report on commercial UK marine science and technology (*AMSI Business Report 2011*) has shown considerable growth in turnover (+76%) and employment (+63%) in the past 12 months. In my opinion the trends are generally positive, but we live in difficult economic times, and cuts in public expenditure could have a negative impact on both the private and public sectors if marine science research is not adequately funded by the Government. This year's report on commercial UK marine science and technology (AMSI Business Report 2012) has shown that the market size for the sector has more than doubled in the past two years.*

What advice would you give someone thinking about a career in marine science?

There are good opportunities for marine scientists both in the public and private sectors at present. Offshore oil, climate change studies, coastal defences, renewable energy, port development, fisheries and water quality are all drivers for research, development and business. There are opportunities in the private sector, particularly for systems engineers, data processors, mathematical modellers, instrument technicians, field survey personnel, programmers and communications specialists. Hands-on practical skills are crucial for many of these roles so any practical experience gained during education will be hugely advantageous.

For more about OSIL see http://www.osil.co.uk

The satisfaction of being a catalyst for science

An interview with Phil Williamson

Phil is based at the University of East Anglia, where he works for the Natural Environment Research Council as a Science Coordinator. Currently, his time is divided between programmes on ocean acidification and shelf-sea biogeochemistry, and developing initial ideas for a geoengineering research initiative. He was awarded honorary life membership of the Challenger Society in 2009.

What attracted you to a career in marine science?

Rock pools in Brittany, a visit to the Port Erin marine laboratory at an impressionable age, and – ten years later – gap-year work at the Stazione Zoologica, Naples, all played a part. Yet serendipity was also an important factor: my Ph.D was in terrestrial ecology, with full-time marine research limited to a few years at Robin Hood's Bay, on an (over-)ambitious project to quantify the drivers of annual recruitment variability for rocky shore invertebrates, covering south-west England, Wales and Scotland as well as the Yorkshire coast. That study was NERC-funded, and led to 'administrative' work with the Aquatic Life Sciences grants panel at Swindon. Whilst I am still on NERC's payroll more than 30 years later, my locations have included Plymouth and Stockholm, as well as Norwich and Swindon, carrying out a diversity of national and international activities that can be broadly be described as project management.

What is your basic aim, when managing a large scientific project?

Essentially, it's to add value – to enable research for a purpose. For NERC, it means working with a national team, competitively selected on their scientific strengths, to focus on a specific strategic science problem for a few years, thereby contributing to a stepwise advance in knowledge through enhanced collaborative effort. At the end of one of the earliest programmes that I was involved with, the Biogeochemical Ocean Flux Study (BOFS), researchers were asked how much they thought that the managed programmatic framework had increased their productivity (if at all): the answer was around 20%. NERC's emphasis now is on impact and knowledge exchange, i.e. whether research has wider societal benefits. And whilst those are not so easy to quantify, the impact of a programme that's multi-institutional and interdisciplinary can be expected to be very much higher than would be the case if the component projects had been separately funded and carried out in isolation. Particularly if government departments are partners in programme funding; for example, Defra and the Department of Energy and Climate Change (DECC) have strong interests in the results emerging from the UK Ocean Acidification research programme and the implications they might have for policy.

Can you describe your job and the skills you need to do it?

When formally set out, the job description for science coordination posts can be a bit daunting. Indeed, many of the demands seem contradictory: attention to detail and an appreciation of the big picture; adherence to NERC policy structures and responsive judgement/flexibility; the need for confidentiality and for openness; what you know about topic area X and who you know. Organisation and creative chaos. In addition, an 'honest broker' role involving the trust of the community is vital. In that regard, I have been fortunate enough to work with many of the UK's leading marine scientists, in universities and research centres, as well as to work with their international colleagues in those cases where the NERC programmes have contributed to global or European efforts. The benefits of such linkages become cumulative over the years. For example (and with apology for the acronyms) BOFS/JGOFS, MarProd/GLOBEC, UK SOLAS/international SOLAS, and UKOA/EPOCA.

What would you say to a young marine scientist thinking of going into science management/administration?

There can be very high job satisfaction, since the tasks are challenging and varied, and tangible outputs and outcomes are produced. But there can also be anxious moments to synchronise the completion of full- or part-time work on one programme with the start of another. There is also some bridge-burning: depending on the science/administration/policy balance of project management posts, it may not be that easy to return to full-time research, nor obtain a more conventional academic appointment, nor reach the higher echelons of scientific leadership.

Overall, the satisfaction comes from achieving effectiveness through influence rather than direct control: the research itself is carried out by the community, and the big decisions on project spend and content are made by others.

What do you see as the top priority for marine/ environmental research?

It has to be the processes involved in global change, primarily climate change and its impacts on ecosystem services, both marine and terrestrial. The past twenty years have seen much impressive science in these areas, as synthesised by the Intergovernmental Panel on Climate Change. But neither the natural systems themselves nor global energy policies have changed that much. Unless we are extremely lucky, the next twenty years will not be so benign; the anthropogenic signal will become much greater than natural variability for many drivers, and we may well then realise that the opportunity to avoid 'dangerous' climate change has been missed. It's hardly novel to point out that improved knowledge and understanding of ocean physics, biogeochemistry, ecology and related socio-economics are all crucial to reliable climate prediction and appropriate societal actions; furthermore, the acquisition of such knowledge requires not only maintained support for directed research programmes, but also sustained national capability in marine observations, modelling and technology development, and a strong research base in fundamental science.

You've been working on geoengineering with the Convention on Biological Diversity (CBD) as well as with NERC. Where does that fit in?

The UK Surface Ocean – Lower Atmosphere Study (SOLAS) (2005–2010) *did not involve any ocean fertilisation experiments* per se. *Nevertheless, it did address the atmospheric delivery of micronutrients to the ocean via dust inputs, and my role in that programme resulted in my participation in a* London Convention/ London Protocol *meeting on the regulation of ocean fertilisation research, also my co-authorship of a* Scientific Summary for Policy-makers *document on that topic for the Intergovernmental Oceanographic Commission. In turn, that led to my inclusion in a CBD expert group to assess the impacts of geoengineering on biodiversity – and subsequent lead authorship of the group's report.* The CBD's expectation was that all such impacts would all negative; however, the situation is not so straightforward, and a strong case can be made for further scientific study of the feasibility and implications of different potential techniques. NERC is itself considering a future research programme in this area, with a decision to be made in early 2013 whether to commit funding for such studies.*

Do you miss not being able to spend time in the field or at sea, or your own research?

Professional fulfilment for an environmental scientist does not exclusively depend on directly extracting data from the field: involvement in the subsequent transitions of results to information and knowledge, and the application of that understanding, can be just as satisfying. Whilst I greatly admire those who develop specialist expertise in focussed topic areas, there can be many more dead-ends than breakthroughs in science. Furthermore, career flexibility is easier when working at the level that benefits from everyone else's brilliance, rather than having to continually deliver novel findings of your own.

Oceanography has become much more interdisciplinary over recent decades. Do you think even more interdisciplinarity is needed?

The short answer is 'Yes!' And for even wider links – when justified by the problem being tackled. That doesn't mean that ocean physicists need a second degree in social sciences or economics, but they ought to know someone who does, as well as having close working contacts with chemists, biologists and geologists. In many departments and research organisations, those linkages are in-built; nevertheless, further broadening of horizons will be crucial for the future development of marine science, for the mutual benefit of all involved.

*CBD Technical Series No. 66 (2012) *Geoengineering in Relation to the Convention on Biological Diversity: Technical and Regulatory Matters. Part 1. Impacts of Climate-Related Geoengineering on Biological Diversity*.

Science coordinators don't spend all their time in Swindon. *There is, however, a dilemma in overseas travel – since Phil's own carbon footprint has undoubtedly contributed to the problem of climate change that he is also trying to solve.*

The future RRS Discovery

Edward B. Cooper

The Natural Environment Research Council (NERC) owns and operates two 'blue-ocean' research vessels which are used to support multidisciplinary marine science – a domain in which the UK is a world leader. The first of these vessels, the RRS *Discovery,* built in 1962, has now reached the end of her operational life and completed her service in support of UK research initiatives. The second vessel, the RRS *James Cook,* was delivered direct from build in August 2006.

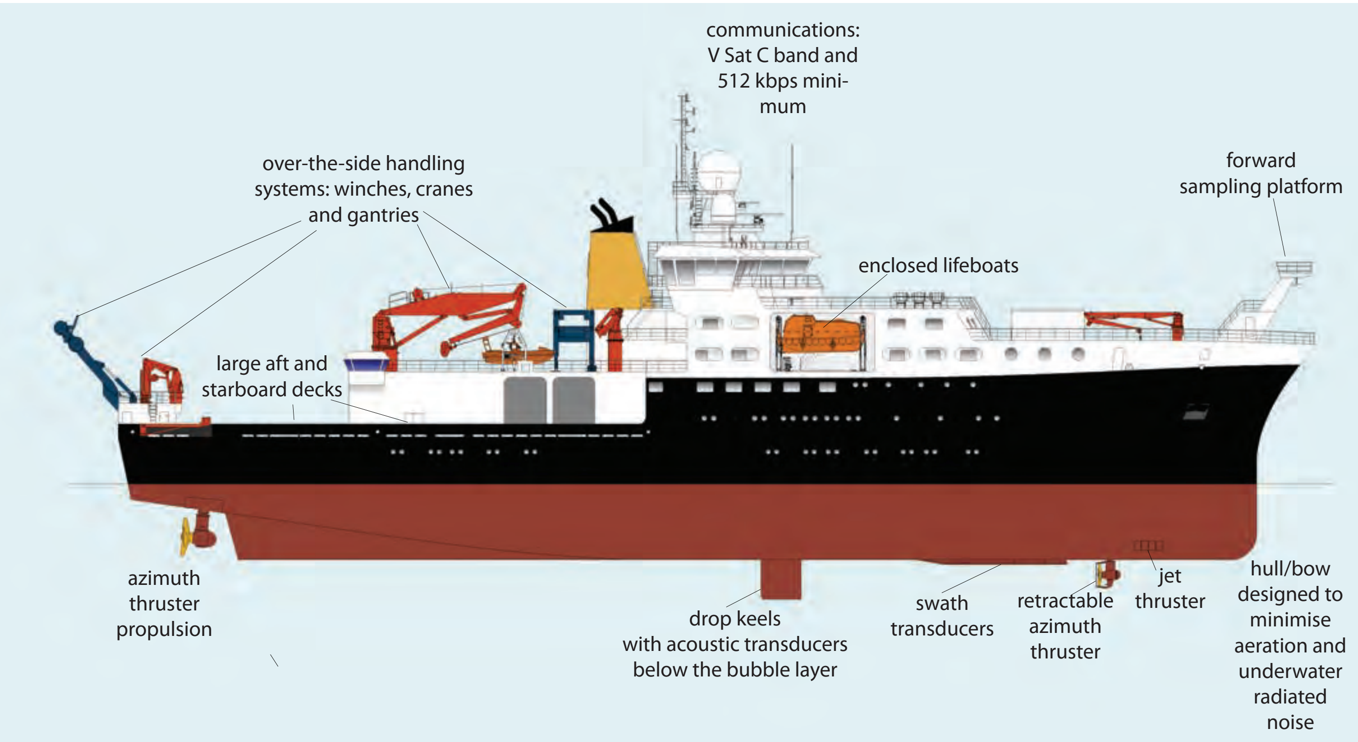
To maintain and extend the infrastructure available to the UK marine science community, a project to replace the RRS *Discovery* was established by NERC in June 2007; this followed preliminary work undertaken in preceding years to justify the need for a new vessel and make the case for priority of investment.

In March 2010, the Department for Business, Innovation and Skills decided to commit funding from the Large Facilities Capital Fund (LFCF) to support the replacement of the RRS *Discovery* with a new state-of-the-art vessel. Following a worldwide tendering exercise, for which there was a very strong response, the contract for the design and build of the new *Discovery* was awarded to CNP Freire, S.A. in Vigo, Spain.

Today the vessel lies alongside an outfitting berth with the hull substantially complete and the installation of the internal fabric of the vessel well advanced. In many areas such as the engine room and switchboard room all the machinery and plant has been mounted, with the associated piping systems for cooling installed and cabling for power control and distribution in place. The initial starting of the main generators took place in September 2012 – the prelude to the commissioning of further equipment suites through the vessel, including the galley, wheelhouse and the oceanographic winch system. All the accommodation and laboratory

Right Discovery*'s bow and stern prior to the launch on 6 April 2012. Strengthening of the forward region, and the specifications of the propulsion, give the vessel ice-edge capability. Note the two stern azimuth thrusters.*

Below Discovery*'s main features. Her performance will suit surveying and slow operations, but her transit speed will be 12 kts and her maximum speed 15 kts. A total of 24 crew members and 28 scientists can be accommodated onboard. Container laboratories (not visible) can be 'plugged in' as necessary on the port side or aft deck. Recreation facilities include a common mess, galley, bar / lounge, conference room / library, video room, fitness centre, hospital and laundries. The vesssel will meet high environmental standards with regard to its exhaust gases, particulate emissions, ballast-water treatment, bilge-water treatment and garbage disposal.*



Discovery ***on the Ria Vigo on launch day***

spaces are now easily recognisable with the vessel some two months from initial sea-trials.

The build began in November 2010 with the cutting of the first steel plates for the hull; the next event of significance was a keel-laying ceremony which took place in February 2011 with a 70-tonne unit (the lowest mid-section of the hull) being placed on the build slipway. From then onwards there was a steady flow of fabricated units assembled on the slipway and joined together to make the full hull, which was completed in March 2012 with the installation of the wheelhouse. This had been subcontracted to a local specialist in aluminium fabrication and then floated across the Ria Vigo to the shipyard on a barge.

While *Discovery* was still on the build slipway, all the hull coatings were applied, the main generators lifted and positioned on board, and the four thrusters for propulsion installed. The two main propulsion units are termed azimuth thrusters and are positioned at the stern in place of the more conventional shaft, propeller and rudder arrangement. The two other thrusters are towards the bow: one is a pump jet similar to, but larger than, the bow thruster on the existing *Discovery* – this is mainly for manoeuvring within harbours. The second forward thruster is another azimuth unit which can be extended for operation or retracted into the hull when not required. The new vessel will have 4400 kW of propulsive power, compared with 1500 kW for the existing vessel since the 1992 refit. The decision about what propulsion systems to use was initially influenced by cost, both at the time of build and throughout *Discovery*'s life, but a further influence was the desire not to have a tunnel thruster forward, as this would have increased the potential for bubble sweep-down, which makes acquiring and interpreting results from hull-mounted acoustic instrumentation more difficult.

The need to mitigate the effects of air bubbles across and under the hull has received particular attention, and the influence of the form of the hull has been studied using both physical models and computational fluid dynamic simulations. These modelling exercises confirmed the benefit of having a deep draft draft (6.5 m) and the need for a fine extended bow with a vertical stem.

After a brief ceremony, *Discovery* was successfully launched from the build slipway on 6 April 2012 and was berthed alongside the outfitting quay. Outfitting is anticipated to last until February 2013, when the vessel will be substantially complete and able to undergo sea trials.

Discovery ***alongside the outfitting quay in October 2012***

After the sea trials, the vessel will sail to a dry dock facility for the installation of the acoustic transducers required to complete the systems used to measure currents (ADCPs), map the ocean bed and substrata (multibeams) and image the water column (multifrequency echo-sounders).

The next activities will be further sea-trials and acceptance-testing leading to the vessel being handed over to the NERC in early June 2013. There will then be a period for the staff of NMF-SS (National Marine Facilities Sea Systems) to acquaint themselves with the vessel, particularly in the engineering and navigation/manoeuvring disciplines. The vessel will probably then sail to deep water west of Iberia for trials of the oceanographic winch system, after which she will return to the UK for 'noise ranging' (to determine the noise she produces) and a naming ceremony. Further technical trials involving key scientists will then be undertaken prior to the vessel being deployed in a science programme in late 2013.

As part of the project, three 20-foot laboratory containers (a radionuclide lab, clean chemistry lab and constant-environment lab) have been fabricated in the UK and included within the NMF–SS-managed National Marine Equipment Pool at NOCS, where they are already being used in support of projects on board the existing RRS *Discovery* and RRS *James Cook*. For cruises on the new *Discovery*, the labs installed will be those appopiate to the planned science.

For further information, including a photographic update and webcam footage, please refer to: http://www.noc.soton.ac.uk/nmf/discovery_replacement_project/d4rpintroduction.html or http://noc.ac.uk/research-at-sea/ships/rrs-discovery-replacement

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The End of the Envisat Era

Samantha Lavender

The colour of the ocean was recorded as early as the 1600s: Hudson (1608), whilst looking for a North-East Passage to China and Japan, noted in his ship's log that a sea 'pestered with ice' had 'a black-blue colour'. The interpretation of imagery obtained by instruments in space began in the second half of the 1960s with cameras on manned space missions and the launch of the first US weather satellite, *Nimbus-2*. Szekielda and Mitchell (1972) transformed black-and-white oceanographic imagery into a 12-colour palette which revealed temperature gradients with differences of as little as 2 °C; now, satellite-borne thermal instruments can detect differences of fractions of a degree. In 1978 *Nimbus-7* carried the Coastal Zone Color Scanner – the first ocean colour instrument – into orbit; the first radar mission, *Seasat,* was also launched in the 1970s.

A consistent ocean colour time-series began in the 1990s with the launch of the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) that collected imagery from September 1997 to December 2010 – a time-series of over 13 years from a mission that had a planned 5-year lifetime. In the late 1990s it was joined by the Moderate Resolution Imaging Spectrometer (MODIS) sensors, launched by NASA, onboard the *Terra* and *Aqua* satellites, in December 1999 and May 2002 respectively.

The European Space Agency (ESA) launched the Medium Resolution Imaging Spectrometer (MERIS) onboard the *Envisat* satellite in March 2002. *Envisat* was much more than an Ocean Colour mission as it carried nine instruments for marine, terrestrial and atmospheric applications. The nine instruments were as follows (further details can be found at http://envisat.esa.int/instruments):

- Advanced Synthetic Aperture Radar (ASAR): C-band SAR that's been used for marine applications such as oil-slick detection and routing around sea-ice.
- Advanced Along-Track Scanning Radiometer (AATSR): land and marine thermal applications including sea-surface temperature (SST).
- Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS): a microwave tracking system which was used to determine the precise location of *Envisat*.
- GOMOS: determining atmospheric constituents by spectral analysis.
- MERIS: land and ocean colour applications.
- Microwave radiometer (MWR): measurement of the integrated atmospheric water vapour column and cloud liquid water content, to be used as correction terms for the radar altimeter signal.
- Michelson Interferometer for Passive Atmospheric Sounding (MIPAS): a Fourier transform spectrometer for the high-resolution measurement of gaseous emission spectra at the Earth's limb (the edge of the Earth, viewed slant-wise through the atmosphere).
- Radar Altimeter 2 (RA-2): two-way delay of the radar echo from the Earth's surface to a very high precision, which provides measurements of sea-surface height.
- SCIAMACHY: imaging spectrometer for global measurements of trace gases in the troposphere and in the stratosphere.

MERIS had narrow and potentially selectable wavebands (although the standard bandset was used for almost all acquisitions to keep consistency), a full spatial resolution of 300 m for coastal areas and a reduced resolution of approximately 1 km with global coverage every 2–3 days; the full-resolution data were available over the whole of Europe (because of the *Artemis* relay satellite) and, where there are receiving stations, worldwide. Initially, the data were primarily used by European investigators, but in later years an increasing number of receiving stations were established, e.g. a MERIS full-resolution data service for imagery acquired over North America was established in collaboration with the Canadian Space Agency in 2008, providing 300 m near-real-time (NRT) data access to a wider geographical coverage.

SST is often used together with ocean colour data for oceanographic applications; for example, increased chlorophyll-*a* levels and variations in SST are frequently found along frontal zones, within upwelling regions and physical features such as eddies, where zooplankton and fish populations are known to accumulate for spawning, early-life development, and feeding. It's also routinely assimilated into numerical modelling, and aids in the accuracy of weather predictions both around the UK and globally; e.g. see https://www.metoffice.gov.uk/research/areas/ocean-forecasting/data-assimilation. As a contribution to the activities of the Group for High Resolution Sea Surface Temperature (GHRSST), because of its stability and quality of calibration the AATSR was also used as an in-orbit calibration source for other satellite SST sensors; see https://www.ghrsst.org/.

Envisat sent its last data to Earth on 8 April 2012 after an onboard anomaly. One of the last images transitted was the MERIS image shown below. Images taken from the ground and from *Pleiades* satellite show it probably tried to enter safe mode, which would have been the first time, but failed to do so. The end of data-collection was unexpected, but not unsurprising, as the satellite had significantly exceeded its design life. However, it will continue to be useful, as it leaves behind a 10-year archive that will continue to be worked on.

One of the last images obtained by MERIS onboard* Envisat*, on 28 March 2012
The lighter coloured water round the UK has high concentrations of suspended particulate matter. These areas will show up more clearly after the application of an atmospheric correction and a mathematical algorithm. (MERIS data from ESA)

What are the follow-on ocean colour and SST instruments?

Visible Infrared Imaging Radiometer Suite (VIIRS), a multispectral scanning radiometer with 22 wavebands between 0.4 μm and 12 μm, was launched onboard the *Suomi National Polar-orbiting Partnership (NPP)* satellite, developed by NASA for the US National Oceanic and Atmospheric Administration (NOAA). It acquired its first measurements on 21 Nov 2011, and the image shown opposite was assembled by the NASA Ocean Biology Processing Group (OBPG). VIIRS is one of five science instruments onboard the *Suomi NPP* satellite. The others are:

- Clouds and the Earth's Radiant Energy System (CERES) measures both the short-wave solar energy reflected by the Earth and long-wave radiation (heat) it emits.

• Cross-track Infrared Sounder (CrIS) and the Advanced Technology Microwave Sounder (ATMS) work together, providing global high-resolution profiles of temperature and moisture.

• Advanced Technology Microwave Sounder (ATMS) works in both clear and cloudy conditions to provide high-spatial-resolution microwave measurements of temperature and moisture.

• Ozone Mapping and Profiler Suite (OMPS) measure the ozone layer.

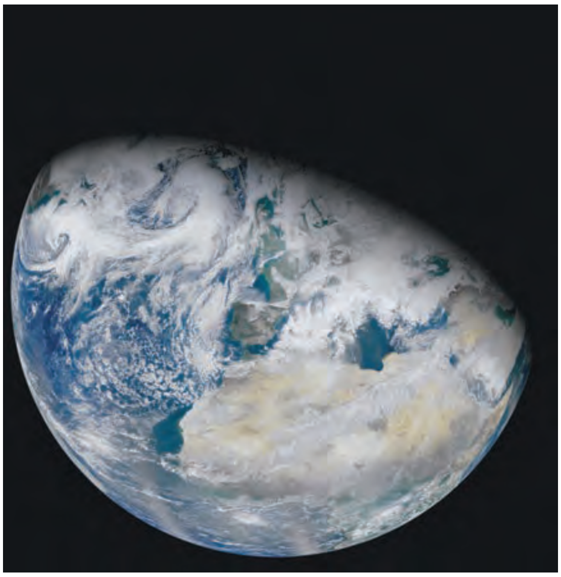
(The above information was taken from http://www. nasa.gov/pdf/596329main_NPP_Brochure ForWeb.pdf)

The European Commission and ESA are developing the future Global Monitoring for Environment and Security (GMES) missions assuming ongoing budgetary discussions are resolved; see http://multimedia.esa.int/Videos/2012/05/GMES-status-update. *Sentinel-1* is a SAR instrument, to be launched late 2013, and *Sentinel-2* (planned for 2014) will be carrying a multispectral instrument (MSI) with 13 spectral channels in the visible/near infrared and short-wave infrared spectral range (spatial resolution will vary between 10, 20 and 60 m).

The first *Sentinel-3* satellite is planned for launch in 2014 with follow-up launches to meet observational requirements, such as improved global coverage and robust / continuous data provision. The Ocean and Land Colour Instrument (OLCI) and Sea and Land Surface Temperature Radiometer (SLSTR) will be launched on the *Sentinel-3* missions alongside a dual-frequency advanced Synthetic Aperture Radar Altimeter (SRAL) supported by a microwave radiometer for atmospheric correction and a DORIS receiver for orbit positioning; see http://www.esa.int/esaLP/SEMTST4KXMF_LPgmes_0.html. OLCI is of a similar design and specification to MERIS with an additional channel at 1.02 μm to enhance the existing MERIS atmospheric and aerosol correction capabilities. SLSTR extends the (A)ATSR time-series of instruments, which started with ATSR-1 in 1991, but has fundamentally different design elements that allow for additional channels, a higher spatial resolution in some channels and a wider swath.

Further missions under development include the Second Generation Global Imager (SGLI) on the *Global Change Observation Mission – Climate* (*GCOM-C*) scheduled for launch by JAXA (Japan) in 2014 and the German *EnMAP* (*Environmental Mapping and Analysis Program*) hyperspectral satellite mission scheduled for 2015. For a full list of ocean colour sensors see: http://www.ioccg.org/sensors/scheduled.html.

VIIRS composite image showing the Earth as if seen from one Earth diameter above south-western Europe on 3 February 2012. The image is composed of imagery from six orbits.



(Image by Norman Kuring, NASA GSFC, using data from the VIIRS instrument aboard Suomi NPP*)*

Making greater use of ocean colour

The opportunities provided by ocean colour and SST satellite missions during the past decade have resulted in major advances in our ability to derive biogeochemical properties of seawater and its constituents which are linked to key oceanic ecosystem processes, as well as improvements in our ability to understand the physics of both the ocean and atmosphere. Historically, the focus has primarily been on science in service of societal needs. However, SST is now used operationally by the meteorological forecasting community, and use of ocean colour is maturing to a level where operational communities are starting to use the data directly e.g. by assimilating biogeochemical properties into ocean models to understand the 'living ocean'.

Commercial operators also realise the value of satellite-derived information, and its utilisation amongst private sector customers is expected to increase significantly over the coming years due to a greater demand for information about the marine environment and high sensitivity to the cost-effectiveness of the different data-gathering approaches. For example, the UK has recently started to form a Satellite Applications Catapult Centre based on the belief that satellite services (including broadband and navigation as well as Earth observation) are an important growth area for the UK economy. This follows the recommendations of the UK Space Innovation and Growth Strategy that stated the UK should aim to grow its global market share of the space sector from 6% to 10% by 2030, and create 100 000 new high-value jobs (for further details see http://www.bis.gov.uk/ukspaceagency/what-we-do/space-and-the-growth-agenda/uk-capabilities-for-overseas-markets/the-space-innovation-and-growth-strategy). However, there still needs to be a link to the research that will improve our understanding of oceanic processes and climate, e.g. determining the Essential Climate Variables (ECVs), used to support the work of the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC).

Further Reading

Brasseur, P., N. Gruber, R. Barciela, K. Brander, M. Doron, A. El Moussaoui, A.J. Hobday, M. Huret, A.-S. Kremeur, P. Lehodey, and others (2009) Integrating biogeochemistry and ecology into ocean data assimilation systems. *Oceanography* **22** (3), 206–15.

Hudson, H. (1608) A second voyage of Henry Hudson for finding a passage to the East Indies, by the north-east. *Collections of the New-York Historical Society, for the Year 1809*, Vol. I. New-York: Riley, pp. 81–102.

IOCCG (2008) Why Ocean Colour? The Societal Benefits of Ocean-Colour Technology. In Platt, T., N. Hoepffner, V. Stuart and C. Brown (eds), *Reports of the International Ocean-Colour Coordinating Group*, No.7: IOCCG.

Rast, M., J.L. Bezy and S. Bruzzi (1999) The ESA Medium Resolution Imaging Spectrometer MERIS – a review of the instrument and its mission. *International Journal of Remote Sensing*, **20** (9), 1679–80.

Szekielda, K.H. and W.F. Mitchell (1972) Oceanographic Applications of Color-enhanced Satellite Imageries, *Remote Sensing of Environment* **2**, 71–6.

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NCOF – strength in partnership

Kelvin Boot

The National Centre for Ocean Forecasting (NCOF) came to life in 2005 when four of the UK's leading marine research institutes – the National Oceanography Centre (NOC Southampton), Plymouth Marine Laboratory (PML), Proudman Oceanographic Laboratory (POL, now embraced within NOC), and the Environmental Systems Science Centre (ESSC of NERC/University of Reading) – formed a partnership with the Met Office to assess and improve the quality and scope of marine forecasts. NCOF's brief encompasses predictions of surface waves, storm surges, sea-ice, temperature, salinity, currents, nutrients, sediments and plankton, for both deep ocean and waters over continental shelves. Apart from the scientific sense of combining resources to avoid duplication, another aim of the partnership will be to make information more widely available by providing forecasts to government agencies and commercial companies to assist with, for example, search and rescue, military operations, management of water quality, fisheries and ecosystems, offshore energy farms and oil exploration, shipping safety and coastal flood-risk management.

Whilst the intent seems simple, the reality was a little more complex. The idea of bringing together a range of specific computer models that had been developed to address particular aspects of the ocean and atmosphere is an obvious, but complex, step. Getting people who had been working on their own projects to give up some of their cherished methods could have been challenging. Recognising the potential problems from the start ensured they could be overcome, and at a very early stage a team of managers who would be collaborating on a day-to-day basis was identified, and workshops of working-level scientists were held to develop early buy-in to the NCOF vision. In turn, a strategy was developed to provide a direction that could be monitored on an annual basis, and working-level groups of scientists established. Of course, there were already very good working relationships and joint projects between combinations of the NCOF partners, but by formalising the consortium, duplications in outputs and capabilities can be avoided, with end products being generated more efficiently. Most importantly, each partner is able to 'pull through' techniques that others have developed, and embrace results that have been obtained, ensuring that relevant comparisons can be made across individual research areas. In short, the whole is now greater than the sum of its parts! A major catalyst in ensuring the success of NCOF was the 'MONSooN super-computer', which is a shared resource of the Met Office and NERC.

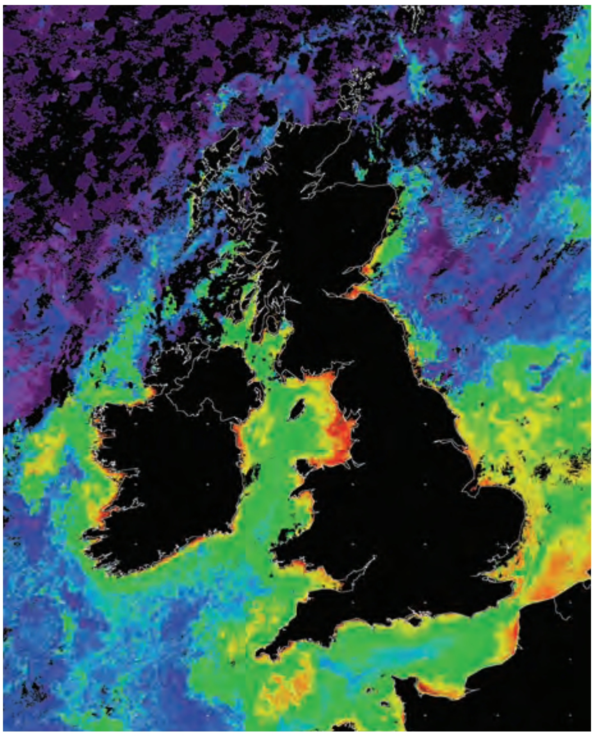


Figure 1 *Chlorophyll-*a *from the* Aqua *MODIS sensor. This 7-day composite for late Sept 2008 shows an autumn algal bloom south of Cornwall as seasonal stratification starts to break down in the Western Channel. A chlorophyll-*a *algorithm tuned to turbid shelf seas was used to minimise errors due to suspended sediment, and this has successfully indicated a further algal bloom in the turbid Liverpool Bay. (In images produced by previous sensors, chlorophyll was often masked by, or indistinguishable from, suspended sediment.) Due to the warm and calm conditions there were also increased algal concentrations off western Ireland and around the Scottish coast.*

Expertise in different aspects of ocean/atmosphere modelling is only one part of the NCOF collaboration. The ability to assess models and validate predictions through real-time measurements from Argo floats, tethered buoys and shipboard sampling, brings an observational dimension to ocean forecasting and fully utilises the range of experience and skills within the partnership, so giving a more concerted, systematic and joined-up approach of mutual benefit. The logic is impeccable: share resources, combine expertise, address the same issues from a number of directions, ensure the data are comparable and encourage scientists to work to mutual advantage. Externally this has to be a good thing too, demonstrating that the assets are being 'sweated' and providing excellent value for money in a joined-up approach that establishes ocean forecasting as part of national infrastructure. But has it worked?

Successes

Early warning of harmful algae

Operational forecasting of marine ecosystems is at the cutting edge of marine science, exactly where the NCOF partnership aspires to be. Providing a nationwide early warning system of potential nuisance algal blooms has obvious benefits to fisheries, shellfish and aquaculture industries as well as relevance for bathing water standards of interest to the Environment Agency (a funding supporter), local authorities and the wider public. AlgaRisk was designed as a pilot project to bring together modelling data generated through the POLCOMS–ERSEM model (developed by POL and PML and maintained at the Met Office) with near-real-time satellite observation data provided by the Earth-Observations group at PML. By combining the ERSEM biological model with the operational Medium Range Continental Shelf (MRCS) model, modelled parameters of nutrients, chlorophyll, plankton, sea-surface temperature, stratification and daily mean currents are available for combining with Numerical Weather Prediction variables to create a set of indicators for anticipating algal blooms. This combination of predictive modelling and actual observation resulted in a sophisticated water quality and algal bloom prediction tool, ideal for the Environment Agency's needs (cf. Figure 1).

Buoys and barnacles

At a more fundamental level, opportunistic sharing of capabilities can also prove of mutual benefit. The Porcupine Abyssal Plain (PAP) Observatory, 300 nautical miles from shore, was first established by NOC in the 1980s but the addition of a Met Office Ocean Data Acquisition System (ODAS) Buoy in 2010 greatly enhanced its usefulness through the real-time transmission of a range of meteorological and oceanographic information back to land, for assimilation into forecasting models. However, while the ODAS buoy is fairly self-sufficient it does require routine maintenance from time to time so, last year, the NERC-run RRS *James Cook* was used to recover, clean and repair the buoy whilst on a mission to the PAP. Once recovered, in the face of challenging weather conditions, the buoy was found to be festooned with goose-barnacles which needed to be removed. Sensors, batteries and communication systems were also replaced and a new keel and frame support were added – work that may be thought of as routine but which had never been carried out at sea before. Further detailed repairs to, and replacement of, the satellite transmission system were also carried out with the help of direct instructions from shore-based Met Office staff – a truly successful outcome with mutual benefit for the NCOF partners. In a further NCOF collaboration another ODAS meteorological buoy is to be installed at the Western Channel Observatory (WCO) monitoring site, E1, with additional oceanographic sensors added by PML to maintain and enhance the long-term dataset that has already been collected by WCO partners.

Model partnerships

It is the modelling aspects of NCOF that could have been the greatest challenge but have become its greatest triumph. Not least is the success in bringing together partners to use a single system – the Nucleus for Modelling of the Ocean (NEMO) code. In order for this to happen, partners had to relinquish some of their existing modelling in favour of a combined NEMO approach. Originally developed by French scientists as an open ocean system, and now maintained by a broader consortium including NERC and the Met Office, NEMO has been modified for the shelf – a dynamic environment with waters less than 200 m deep and strong tides – by the inclusion of improved parametrisations of bottom friction and turbulence and improved representations of horizontal pressure gradients, advection and diffusion. Putting the modified NEMO code into practice has shown that when assessing the location of tidal mixing fronts where the difference between the temperatures at the water surface and the bottom is 0.5 °C, the NEMO system is an improvement on its predecessor, the POLCOMS (POL Coastal Ocean Model System) model (Figure 3(a)). In addition, when applied to the main tidal constituents measured by tide gauges, the margin of error is less for NEMO than for POLCOMS. The results show that such collaborations can work, and that giving ground for a better working

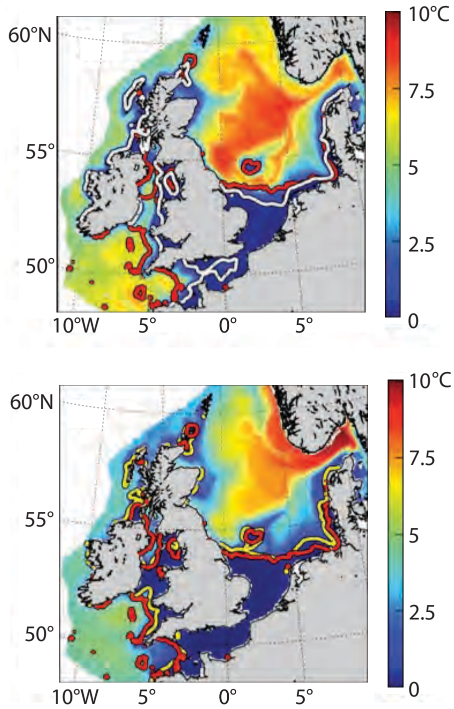


Figure 3 *Mean surface-to-bed temperature difference for summer (June, July, August) 2008 in **(a)** POLCOMS and **(b)** NEMO–FOAM. The lines show the location of the tidal mixing fronts according to the ICES climatology (red), POLCOMS (white) and NEMO–FOAM (yellow).*

method enables the NCOF partnership to engage at an international level. Indeed, other partners from Italy and Germany are contributing to NEMO, the NCOF partners are strongly engaged in the MyOcean* consortium, and some other countries are looking closely at NCOF with the aim of emulating the way that it is working.

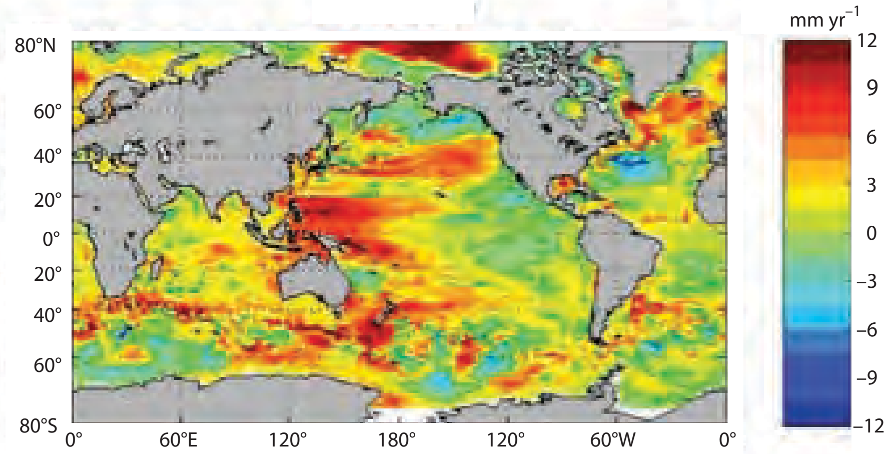
The NEMO collaboration has opened up other modelling opportunities including the Joint Ocean Modelling Programme (JOMP) which was initiated in response to the need to combine efforts to maintain the UK at the forefront of development and application of global ocean modelling. The first major output from this was a ‘reference’ ORCA025 configuration of

Figure 2 *The barnacle-encrusted ODAS buoy, which was recovered by RRS* James Clark Ross *for cleaning and maintenance.*

*MyOcean is a series of projects granted by the European Commission within the GMES Programme (7th Framework Programme), whose objective is to define and to set up a concerted and integrated pan-European capacity for ocean monitoring and forecasting.

NEMO that can be used by the UK community as a whole. The first version has been released and is in use at NOC, the Met Office, ESSC and University of East Anglia (UEA). The same NCOF partners have also carried out a 21-year global ocean ¼° reanalysis covering the period 1989–2010, which includes diagnostics of the Meridional Overturning Circulation, and ocean heat and freshwater transports. The results have obvious applications in climate change studies (see Figure 4 and Box) and are already being used in several NERC projects.

Biogeochemistry also lends itself to the NCOF approach of blending the various expertises of its partners. The ERSEM model, which was developed by PML to simulate the pelagic and benthic cycling of nutrients and plankton in European continental shelf waters has been running in the Met Office's operational suite since 2007 as part of the POLCOMS Medium Resolution Continental Shelf (MRCS) system.



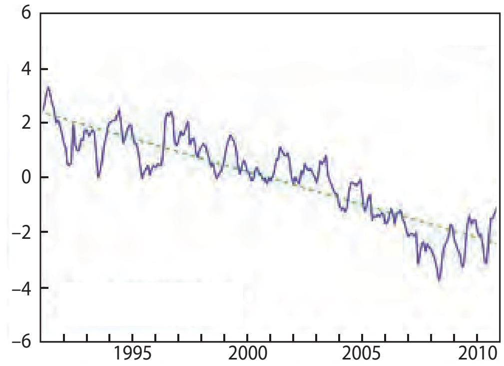
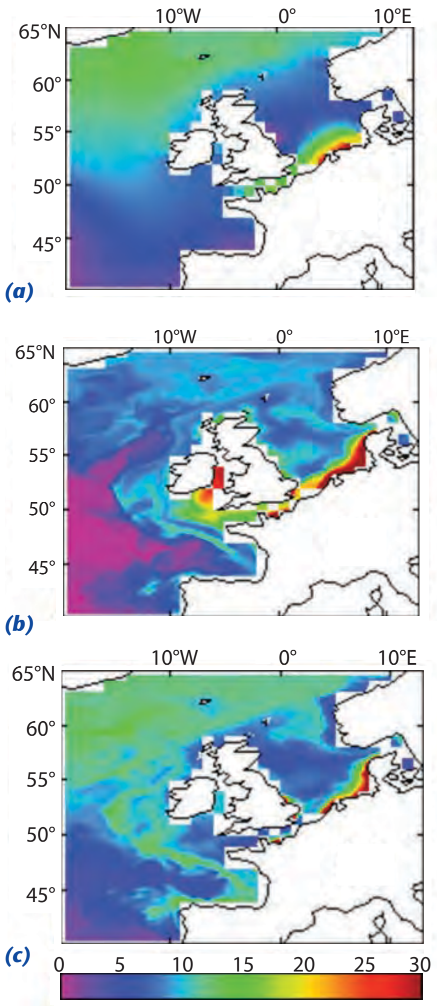


Figure 4 *Results from the new global ocean high-resolution reanalysis (see yellow Box below)* ***Above*** *Sea-surface-height trends from the UR025.4 ¼° ocean reanalysis, which indicate that sea-level is rising fastest in the Arctic (although there are fewer data to constrain the results in this area).* ***Right*** *Arctic basin sea-ice volume anomalies and trends from 1991 to 2010. The dashed line corresponds to a mean decline in ice volume of 2000 km³ per decade.*

A new global ocean high-resolution reanalysis

A 21-year 1989–2010 global ocean ¼° reanalysis (UR025.4) forced with ERAInterim meteorology has been produced through a collaboration between ESSC University of Reading, the MetOffice and NOC. This involved using the UK common reference NEMO configuration v3.2 with 75 levels as set up by NOC on the MONSooN shared computer, along with an improved Met Office FOAM data-assimilation system which was ported to MONSooN by the FOAM team. Assimilation datasets include the version 3 Ensembles database (EN3) profile data with XBT bias corrections, along with a new Collecte Localisation Satellites (a French company) geoid, satellite altimeter sea-level anomaly data, and SST and sea-ice concentration data as used in the Operational Sea-surface Temperature and sea-Ice Analysis (OSTIA) product. The run was carried out from Reading University with diagnostics being developed to look at the Meridional Overturning Circulation and ocean heat and freshwater transports as well as assimilation diagnostics. This run is available for joint analysis on the MONSooN computer and will also be provided as the UK GMES ocean reanalysis for the EU Marine Core Services. The results are already being used in several NERC projects, e.g. Rapid-Watch studies of the Atlantic thermohaline circulation, and studies of variability in the Arctic circulation and budgets.

Figure 5 ***(a)*** *Monthly average surface nitrate values (mmol m^{-3}) from the AMM7-NE model with WOA09 boundary conditions,* ***(b)*** *the same with zero-flux boundary conditions, and* ***(c)*** *climatological values. (Model fields are from December 2008)*



More recently it has been implemented in the NEMO Atlantic Margin Model (AMM) system (Figure 5). The new implementation outperforms the original and in particular provides a realistic representation of the seasonal cycle for nitrate and phosphate (Figure 6) and more realistic simulations of silicates and chlorophyll. Figure 5 shows that some substantial improvements were due to changes in the boundary conditions.

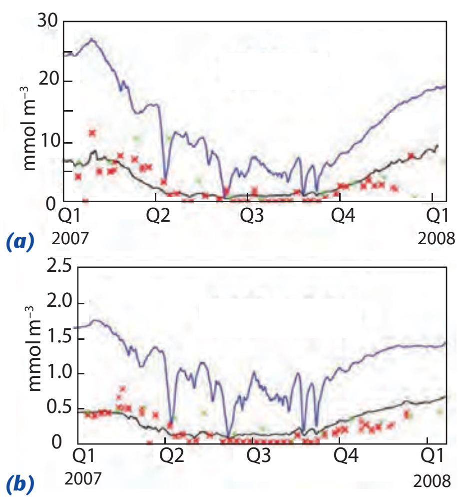


Figure 6 *The simulation of* ***(a)*** *nitrates and* ***(b)*** *phosphates at the L4 monitoring site near Plymouth in 2007. Crosses are* in situ *measurements. The blue line is the original simulation, and the black line the new simulation using the ERSEM model in the NEMO Atlantic Margin Model (AMM). Q1–Q4 indicate the four quarters of the year.*

This was another good example of a productive closer working relationship between the Met Office and PML.

The future

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Written by Kelvin Boot from interviews, materials and suggestions provided by NCOF partners (Met Office: Mike Bell and Keith Haines; PML: Tim Smyth).

Kelvin Boot is a Science Communicator working on a number of marine science programmes for range of organisations.
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Sharks on the lawn

The reality of rising sea-level on Indian Ocean islands

Charles Sheppard

Everyone knows that climate is changing and sea-levels are rising; corals get killed periodically from warming episodes, and coral islands can suffer from erosion as a result. But sea-level rise on coral islands is not like many people imagine – it is not a slow but steady attritium of the land. And it is not even average sea-level rise that causes problems, but rather the high tides, especially high spring tides. The situation is complicated by the fact that many coral islands are roughly concave, with raised rims around interiors which are close to sea-level. High tides gradually erode away the soft limestone of these rims, so we see no change for year upon year until, one day, high tide broaches the rim, and the sea floods in, covering part of the land.

Lemon sharks swimming over grass on Diego Garcia in March this year

This point has now been reached in several parts of the Chagos islands in the Indian Ocean. Here, in the atoll Diego Garcia, this happened in several places in March 2012. Within a few minutes of the broach, water had flooded the roadside grass to more than knee deep. It was fascinating to see coral-reef fishes swimming over the grass and around the poles carrying electrical power to the south of the island. A group of small lemon sharks joined in, swimming over the unfamiliar grass on their eternal quest for food, and inspecting my own wetsuit boots. This is not sea grass, but land grass. 'Croquet spoilers', someone called them, or 'Lawn Sharks' (you have to say that one aloud to get it).

Lemon sharks swim alongside a flooded road, where poles support power cables

But really, it isn't amusing. This area and several others on Diego Garcia were flooded repeatedly on several consecutive high tides, then neap tides came and the water went for a month at least. But the salty water left behind percolates down to fresh water tables, and even salt-resistant shoreline grass and other resistant plants can't take that for too long. Diego Gargia supports an expensive military facility, and so here it is possible to fortify the land against water incursions (though it is costing millions), but it is a different matter for the many coastal settlements in the rest of the tropical ocean.

Charles Sheppard has conducted research in all atolls of the Chagos Archipelago for many years.
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WHERE THE ICE MEETS THE OCEAN

Ocean interaction with the Greenland Ice Sheet in Petermann Fjord

Helen Johnson

The increasing rate of sea-level rise is one of the major pressing concerns associated with climate change. It has potentially severe consequences for over 200 million people who live on coastal flood plains around the world, as well as for the trillion dollars' worth of assets lying less than one metre above current sea level. Reliable predictions of sea-level rise are essential for adaptation and mitigation; the largest uncertainty in these predictions currently comes from our lack of understanding of likely future change in the Greenland and Antarctic ice sheets.

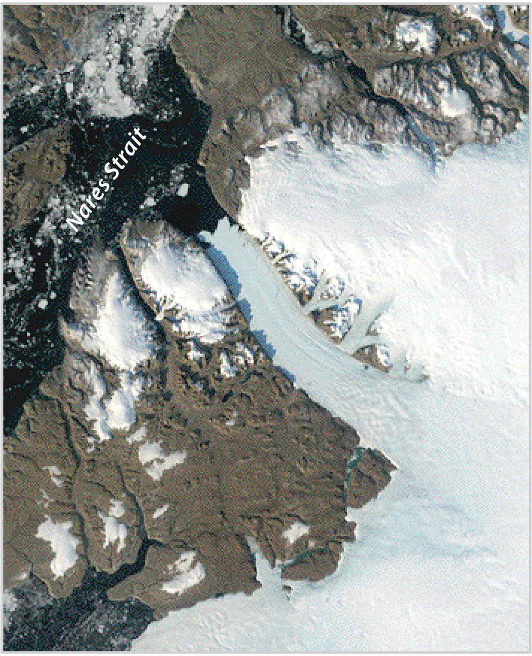
The shrinking Greenland ice Sheet

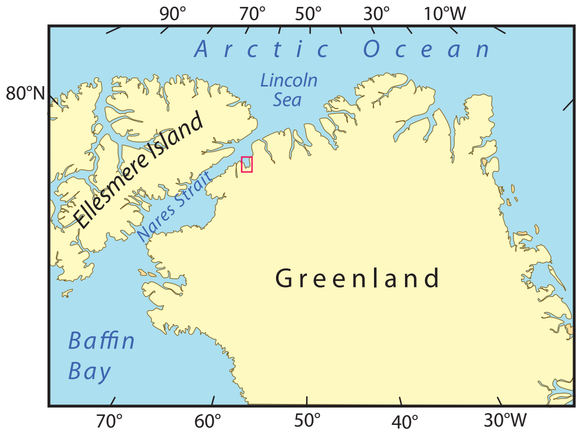
The Greenland Ice Sheet presently accounts for about a quarter (0.5 mm yr^{-1}) of global mean sea-level rise each year, and its contribution has more than doubled in the past decade. Much of this change has been due to increased ice discharge associated with the acceleration of outlet glaciers flowing into fjords in western and south-eastern Greenland. Higher ocean temperatures are thought to have played a role. However, the circulation within Greenland's fjords is not well known, and the interaction between glacial ice and the ocean is poorly understood; the role of the ocean in the ice sheet mass budget is largely unquantified.

There is clearly an urgent need to understand the changing mass balance of the Greenland Ice Sheet and its interaction with other components of the climate system. While this has largely been the domain of glaciologists until now, the realisation that the ocean is implicated in the acceleration of Greenland's melting demands that oceanographers get involved!

Unlike Antarctica, Greenland is not surrounded by extensive floating ice shelves. In the majority of cases, its outlet glaciers interact with the ocean exclusively at their calving fronts. Only four major outlet glaciers have grounding lines significantly below sea level, and only two of these (Petermann Glacier and 79°N Glacier) now flow out over the water in the fjord to form a substantial floating tongue or shelf of ice. A third such glacier (Jakobshavn Isbræ) has recently lost its ice shelf, rapidly retreating back to its grounding line over the past decade. This is thought to have been due to an increase in ocean temperatures beneath the floating portion of the glacier, and has resulted in a significant speeding up of the glacial ice flux over land. This in turn has caused concern over the vulnerability of Greenland's remaining ice shelves.

Petermann Glacier in north-west Greenland drains about 6% of the Greenland Ice Sheet. It terminates in a floating tongue of ice 20 km wide and 50 km long. It made international news in August 2010 when an ice island four times the size of Manhattan calved off its ice shelf. However, its most interesting feature from a Greenland mass-budget point of view is not that it periodically calves but that, in fact, 80% of its mass is lost through unseen basal melting of the floating ice shelf by the ocean beneath, even before the ice has reached its calving front. Here I report some





Prior to August 2010, Petermann Glacier had a floating ice-shelf 70 km long

Figure 1 ***Left*** *MODIS satellite image of Petermann Glacier and Fjord, taken on 10 September 2003. The fjord is ~ 20 km wide and, at this time, Petermann Glacier's floating ice shelf was about 70 km long.* ***Above*** *Petermann Fjord opens out into Nares Strait, which connects the Arctic Ocean to the north with Baffin Bay to the south.*

results from a series of opportunistic ocean surveys conducted in Petermann Fjord prior to the major 2010 calving, and on what they can tell us about the ice–ocean interaction in that area.

Petermann Fjord

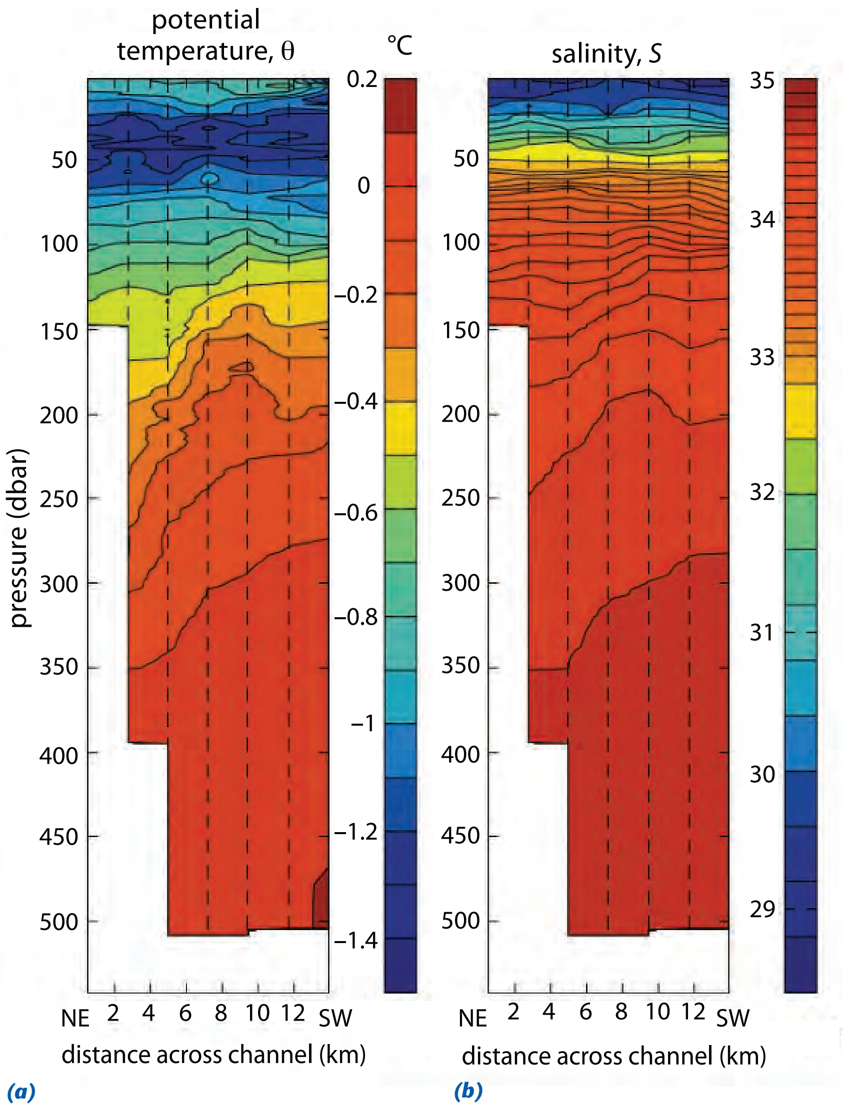
Steep-walled Petermann Fjord (Figures 1 and 2) lies at approximately 81° N and 61° W. It opens out into Nares Strait, which connects the Arctic Ocean to the north with Baffin Bay to the south. Petermann Glacier flows into the fjord at a rate of about 1 km yr^{-1}. Its ice shelf, about 70 km long when our measurements were made, thins from 600 m at the grounding line to about 60 m at its front. Glaciologists have estimated that only a small fraction of this thinning (5–10%) is due to surface melting, indicating that most of the ice loss is due to melting by the ocean beneath.

Very few ocean measurements have ever been made in Petermann Fjord. The fjord mouth and neighbouring Nares Strait are covered with sea-ice for most of the year, much of it thick multi-year ice, and often land-fast. Access by ice-breaker is only normally possible during a brief window in late summer. The ocean measurements described here were made during one-day surveys from the US Coast Guard Cutter *Healy* (in 2003) and the Canadian Coast Guard Ship *Henry Larsen* (in 2007 and 2009) while the ships were engaged in other oceanographic research in the area.

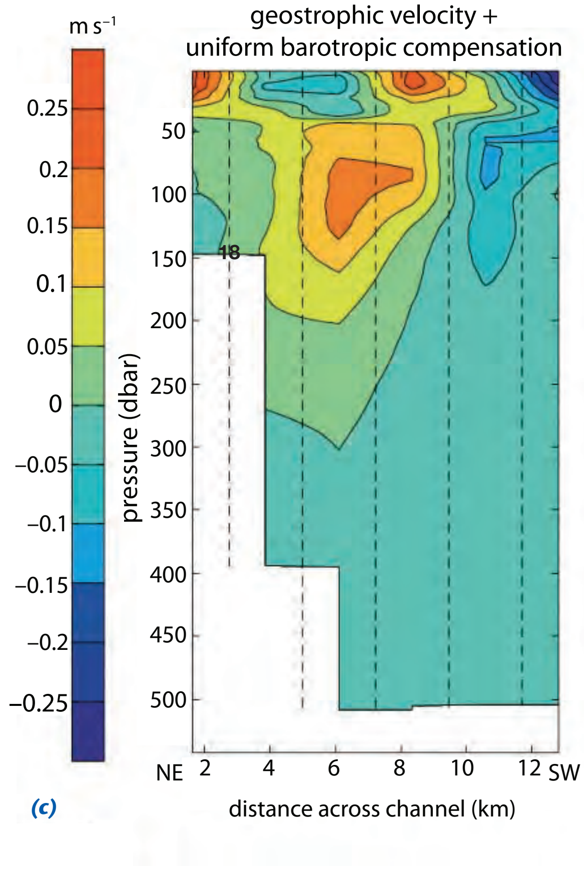
Figure 2 *Collecting hydrographic data near the ice front of Petermann Glacier's floating tongue on 20 August 2009. The ice shelf has a thickness of about 60 m near its front, and hence a surface elevation of just 6–7 m. The fjord is bordered by near-vertical cliffs which reach a height of 900 m and which deliver subsidiary glaciers as well as surface run-off to the fjord.*

(Photo by courtesy of David Spear, Institute of Ocean Sciences, BC, Canada)

Due to basal melting, Petermann Glacier's ice shelf thins dramatically – prior to August 2010 it had a thickness of ~60 m at its front, with 6–7 m above sea-level



Relatively warm water of Atlantic origin flows into Petermann Fjord over its ~400 m sill, supplying more than enough heat to effect the observed basal melting of the glacier



Prior to these surveys, even the depth of Petermann Fjord and the bathymetry at its mouth were unknown. From a combination of ship-track echo-sounder data and hydrographic constraints, we now know that the fjord reaches depths greater than 1100 m, and is separated from Nares Strait by a sill 350–450 m deep. The water mass properties in the fjord close to the ice front (Figure 3) are typical of Arctic regions; a cold fresh layer in the upper 50–100 m overlies a warmer, saltier layer of water that has come, originally, from the Atlantic. It has reached Petermann Fjord via Nares Strait after circulating around parts of the Arctic. *En route* it has cooled significantly, but at 0.2 °C it is still warm enough to melt ice (especially if that ice is below sea-level, as the melting point goes down with increasing pressure).

Below sill depth the properties of the water in the fjord are fairly homogeneous and similar to those at a depth of 400 m in the strait outside; the deep part of the fjord is filled up with Atlantic-origin water that periodically spills over the sill. How often the water is ventilated like this isn't clear; there is some variability in the temperature and salinity of the deep water between years, which suggests frequent renewal events.

From our measurements of temperature and salinity as a function of depth along a line across the fjord we can estimate the velocity in the along-fjord direction. This geostrophic velocity (calculated from the density field) suggests that above sill depth there is outflow on the north-east side of the fjord with currents reaching a maximum of 0.2 m s^{-1}, and weaker inflow on the south-west side. While we don't expect this geostrophic estimate of the flow to be very good near the surface or the side walls due to friction, the general circulation pattern is consistent with the surface circulation inferred from satellite imagery, which shows a cyclonic gyre in the mouth of

Figure 3 *Cross-sections of* ***(a)*** *potential temperature (°C),* ***(b)*** *salinity and* ***(c)*** *geostrophic velocity (m s^{-1}) across Petermann Fjord close to the ice front in August 2009. The data are plotted looking into the fjord, with the north-east wall of the fjord on the left (at 0 km) and the south-west wall of the fjord to the right (at ~16 km). The temperature and salinity data have been interpolated onto a regular grid (indicated by the vertical dashed lines) and projected onto a plane perpendicular to the axis of the fjord before plotting. The geostrophic velocity is calculated from the density field. Positive velocities are directed out of the fjord. The velocities shown have been obtained by adding a uniform compensating velocity (− 0.032 m s^{-1}) over the cross-sectional area spanned by the data, to ensure zero net flux.*

the fjord. Tidal currents in the fjord have a similar magnitude to the geostrophic flow. The circulation in the fjord is clearly not a simple estuarine flow, but is fundamentally three-dimensional.

Heat and freshwater fluxes

Since Petermann Glacier's ice shelf is about 16.6 km wide at its terminus, thins by 550 m over its length, and advances by about 1130 m per year, the net freshwater flux out of the fjord due to glacial melting must be approximately 327 $m^3 s^{-1}$. To melt this much ice would require a heat flux from the ocean of 1011 watts. A calculation of the heat flux into the fjord based on our measurements of temperature close to the ice front and our geostrophic velocity field suggests that three times this amount of heat is supplied to the fjord by the ocean. While our measurements represent only a summer snapshot, there is evidence from year-round moorings in Nares Strait that the temperature at sill depth does not change much throughout the year. There seems, therefore, to be ample heat available to cause the basal melting that is observed at Petermann Glacier.

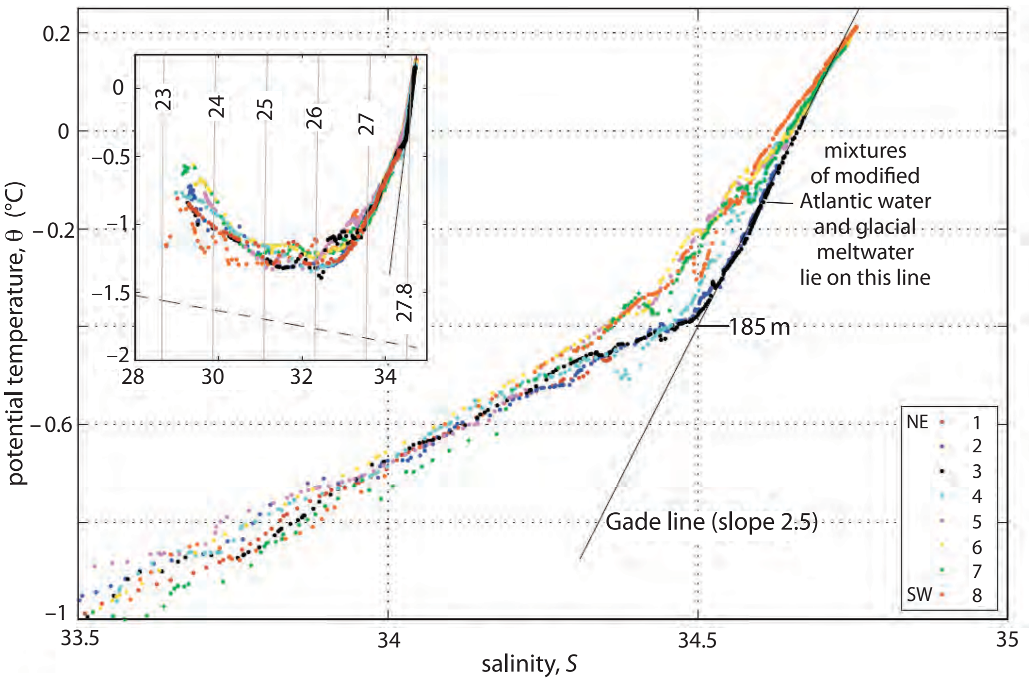
The freshwater flux out of the fjord is much harder to interpret. A similar calculation based on our measurements of salinity across the fjord close to the ice, together with our geostrophic velocity estimates, results in a freshwater flux of 2600 $m^3 s^{-1}$ – an order of magnitude bigger than that expected due to glacial melt! This is in fact not surprising given the many other sources of fresh water in the region, such as run-off from the land and sea-ice melt. Very fresh (salinity 15) surface plumes were observed during our 2009 survey, thought to be surface melt that has drained off (or through) the ice and subsequently been dammed by under-ice topography or behind loose pieces of ice. In the case of fresh water we expect variability in space and time to be important. We expect, for example, that there will be co-varying changes in flow and salinity associated with tides and with wind events that might lead to episodic release of fresh water. A longer-term mooring programme would be required to fully understand the fjord's freshwater budget.

Under-ice water-mass structure

But can we see evidence of the glacial meltwater anywhere in our measurements? To spot this we have to look at a plot of potential temperature versus salinity (Figure 4). When glacial ice melts from below, the latent heat of melting must be extracted from the seawater. A consideration of the heat and salt budgets during this melting process tells us that one might expect a mixture of seawater and glacial ice melt to lie along a Gade line* with a slope of approximately 2.5 °C per salinity unit. This is what we see on the north-east side of the fjord below about 185 m in all three of our ocean surveys (2003, 2007 and 2009). So the glacial meltwater seems to be mixing with the Atlantic water and exiting the fjord on the north-east side, well below the surface.

*A Gade line is a type of mixing line used where ice is melting from below. It takes account of the removal of latent heat from seawater when there is melting.

Figure 4 *Potential temperature–salinity (θ–S) diagram showing all the data collected along a section across Petermann Fjord in August 2009. Bottom right: The locations at which the CTD data were collected are numbered from the north-east side of the fjord. The inset panel shows the full range of the data, with the freezing line at zero pressure (dashed) and contours of density anomaly (σ_t in kg m^{-3}) added. Note that the data on the north-east side of the fjord at depths greater than 185 m (i.e. temperatures higher than about −0.4 °C) fall on a straight Gade line* with a slope of 2.5 °C per salinity unit, indicating that this water is a mixture of the warm modified Atlantic water flowing under the ice shelf and glacial meltwater.*



Glacial melt water mixed with modified Atlantic water exits the fjord on the north-east side below 185 m

Why doesn't the water above 185 m contain any glacial melt? This is still an open question, but we believe there are clues in ocean data collected by glaciologists in 2002 through a hole drilled in the floating ice tongue close to its grounding line far upstream. These data were collected in the crest of one of a number of channels running along the length of the underside of the ice shelf. They show that down to a depth of about 135 m the temperature and salinity of the water are very similar to the surface mixed layer formed by convective mixing under growing sea-ice during winter in nearby Nares Strait. Because the ice shelf is only about 60 m thick at its front, this cold fresh water in the upper 100–130 m can intrude far beneath the shelf, and persist there year-round (Figure 5).

This intruding winter mixed layer is too cold to melt the glacial ice. And because this layer has a low density, it blocks the rising plume of meltwater (mixed with warm Atlantic water), forcing it to separate from the underside of the ice. This has two important consequences. First, it implies that basal melting is limited to the inland portion (20 km) of Petermann's floating ice tongue, before its bottom rises above the base of the winter mixed layer formed in Nares Strait (at a depth of 100–130 m). So what, then, governs the melt over the outer portion of the ice-shelf? And what determines the position of the glacier's calving front? Does the ice thin through ocean melting by as much as it possibly can, and yet still remain too thick to calve?

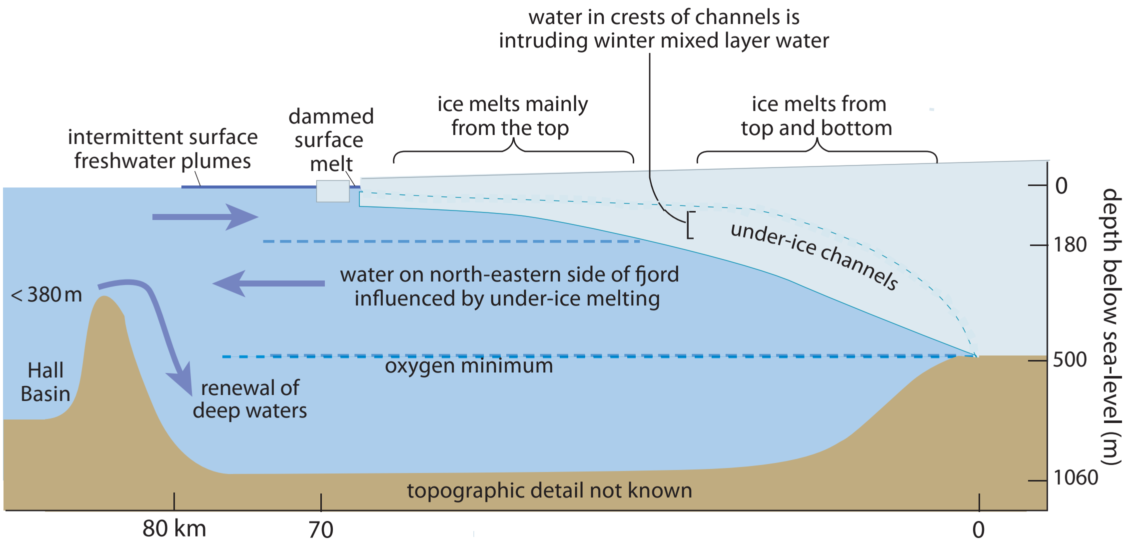
Secondly, insulation of the ice shelf by intruding winter mixed layer water implies that the mass balance of Petermann Glacier depends in part on sea-ice conditions in Nares Strait (and perhaps the Lincoln Sea; cf. Figure 1 map). In the past, the amount of convective mixing, and hence the depth of the winter mixed layer, has been limited by the fact that Nares Strait becomes completely covered in land-fast ice in early winter. However, there are indications that persistent drift-ice conditions, more typically seen in summer, may become common in the area year round. Could this result in more net sea-ice formation, deepening the winter mixed layer and reducing the oceanic influence on the floating ice shelf? Our ocean observations have certainly highlighted the links between Petermann Glacier's mass balance and broader, regional-scale processes. And have raised more questions than they have answered!

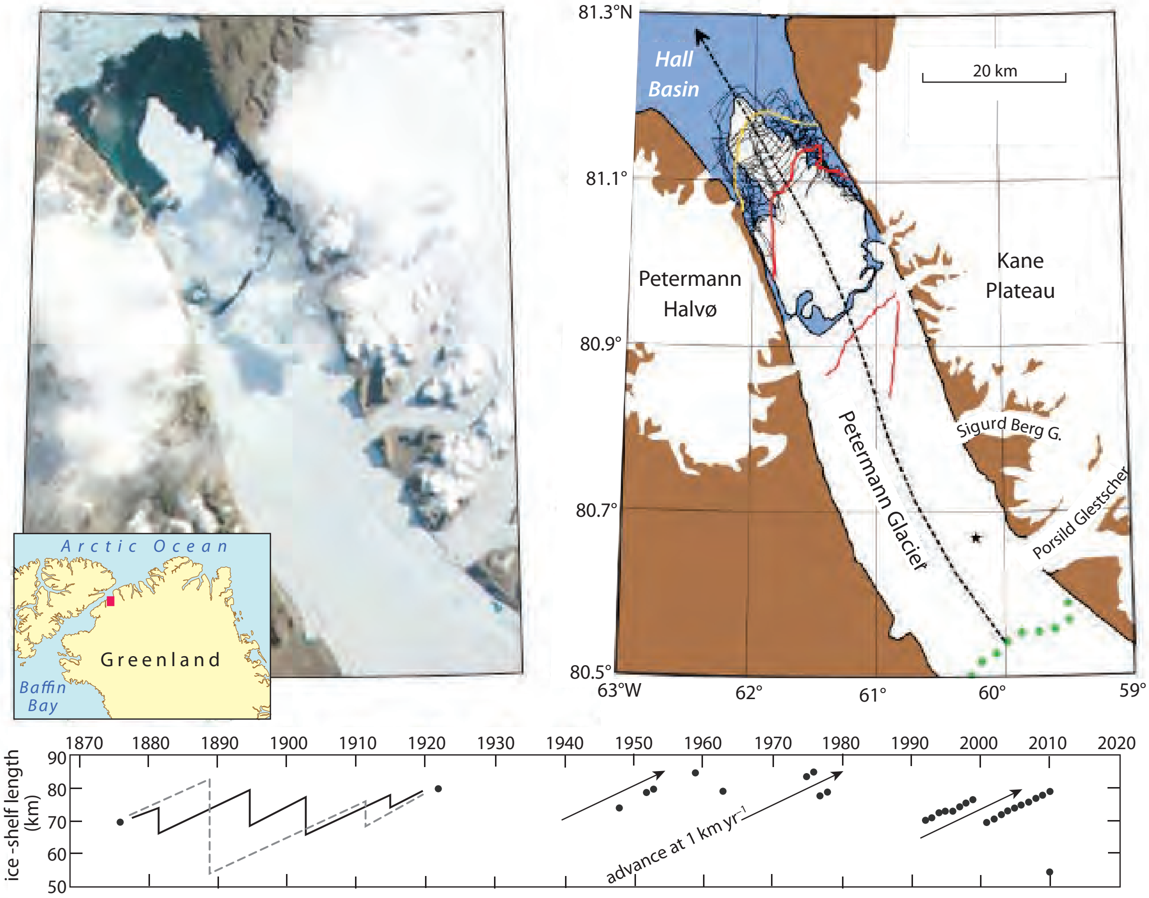
The 2010 calving event

On 4 August 2010 a huge chunk of Petermann Glacier's floating ice shelf (with an area of 253 ±17 km^2) broke loose and, after fracturing into several pieces, made its way southward towards Baffin Bay. This calving event captured the attention of the media, public and politicians, all worried about the implications for shipping and offshore operations, as well as the possible connection to global warming. But did this event signal a change in the glacier's dynamics, or was it simply a result of natural variability of the system? A look back at previous calving events, and the position of Petermann Glacier's calving front through time, can help us to judge its significance.

Figure 5 *Schematic cross-section along the axis of Petermann Fjord, showing interactions between the ocean and the overlying ice shelf. Note that the circulation is in fact three-dimensional, and that following the major calving event in 2010 the distance from the grounding line to the ice front was approximately 55 km. The intrusion of winter ocean mixed layer water under the ice shelf insulates the ice from the warmer Atlantic water and limits basal melting to the inland portion of the shelf.*

Cold low-salinity water originating in the surface mixed layer in winter intrudes far under the ice, protecting it from basal melting





Petermann Glacier's calving front is currently much closer to the grounding line than ever previously observed

Figure 6 ***Left*** *NASA* Aqua *satellite Moderate Resolution Imaging Spectroradiometer (MODIS) true-colour image, taken at 0840 GMT on 5 August 2010, showing calving of Petermann Glacier.* ***Right*** *A map showing 31 known frontal positions of the ice tongue. White is glacial ice. The red line closest to the sea is the ice front in 1876; behind it in red are the locations of large 'fissures' also observed at that time. The yellow line shows the frontal position in 1922; black curves represent frontal positions in 1948, 1952, 1953, 1959, 1963, 1975–1978, 1991–1999, 1999–2010, and July 2010. Green dots represent the grounding line, and the black star is the location of an automatic weather station. The black broken arrow traces the total movement of the glacier from 1922 to 2010.* ***Below*** *Time-series of ice-shelf length as measured along the central axis from the grounding line; decreases in length indicate calving. The two lines connecting the data points for 1876 and 1922 represent two hypothetical scenarios. The arrows represent steady ice advance between calving episodes; the gradients of the arrows (distance over time) indicate velocities of* ~ 1 *km yr*$^{-1}$*.*

(From Falkner et al.*, 2011)*

Petermann Glacier's ice front was first mapped by the British Arctic Expedition in 1876. Between then and the 1990s, when satellite imagery became routine, constraints on its position are few but suggest that the position of the ice front was relatively constant (Figure 6). The glacier appears to advance at a fairly constant rate, and calve at roughly decadal intervals. While calving events of a magnitude comparable to that in 2010 have been observed before (e.g. in 1991), what is unusual is the resulting position of the ice front, much closer to the grounding line than ever previously noted. It may not be unprecedented, however; gaps in the record prevent us from knowing. At current ice-tongue velocities, it will take about two decades for the ice front to return to its 2009 position. To put the calving in the context of the ocean–ice interaction discussed above, an amount of ice equal to that lost in the 2010 calving event is lost through basal melting every two years.

Many factors can influence calving frequency and location. Calving may be limited by the amount of energy available from wind and tide to flex the ice shelf, as well as buttressing by sea-ice. It is possible that even fjord geometry plays a role – the long-term mean position of the ice front (cf. black curves) is close to the narrowest part of the fjord. Could the lateral pressure exerted on the ice by the converging walls make it difficult for ice to escape until the fjord widens again?

But see Stop Press overleaf!

At the time of writing, there is no concrete evidence that the mass balance of Petermann Glacier is changing. However, because Petermann's grounding line and much of its drainage basin lie below sea level, the fjord represents a potential conduit to Greenland's depressed interior bedrock. Petermann Glacier therefore has the potential to retreat rapidly; if the buttressing due to its ice shelf is reduced, any speeding up and thinning would cause the grounding line to move not only inland but also into deeper rather than shallower water, allowing further basal melting and retreat. The consequence of this would likely be accelerated land-ice loss as observed at Jakobshavn Isbrae further south.

The Future

Associated with climate change, we might expect a change in the temperature of the modified Atlantic water reaching the sill of Petermann Fjord. Considerable changes in atmospheric temperature and sea-ice extent are also likely. However, the impact of such changes on glacial melt and calving rate is far from evident. Our ocean measurements have indicated that, because cold, low-salinity water originating in the surface mixed layer in Nares Strait in winter intrudes far under the ice, basal melting is limited to the inland portion of the ice shelf. Sensitivity to seawater temperature will depend on the detailed processes occurring at the ice–ocean boundary layer, which are at present poorly known. The melt rate and long-term stability of Petermann ice shelf may depend on regional sea-ice cover and fjord geometry, in addition to the supply of oceanic heat entering the fjord. A targeted and sustained observational campaign, plus modelling effort, is required to assess the impact of future forcing changes on Petermann Glacier and its floating tongue, and hence quantify the role of the ocean in the mass balance of the Greenland Ice Sheet.

Further Reading

Falkner and 11 others (2011) Context for the recent massive Petermann Glacier calving event. *EOS, Transactions, American Geophysical Union*, **92** (14),117. doi:10.1029/2011EO140001

Holland, D.M., R.H. Thomas, B. de Young, M.H. Ribergaard and B. Lyberth (2008) Acceleration of Jakobshavn Isbræ triggered by warm subsurface ocean water. *Nature Geoscience* **1**, 659–64. doi:10.1038/ngeo316

Johnson, H.L., A. Münchow, K.K. Falkner, and H. Melling (2011) Ocean circulation and properties in Petermann Fjord, Greenland. *J. Geophys. Res. (Oceanographic Research Papers*), **116**, C01003. doi:10.1029/2010JC006519

Rignot, E. and K. Steffen (2008) Channelized bottom melting and stability of floating ice shelves. *Geophysical Research Letters*, **35**, L02503. doi:10.1029/2007GL031765

Shepherd, A. and D. Wingham (2007) Recent sea-level contributions of the Antarctic and Greenland ice sheets. *Science*, **315**, 1529–32.

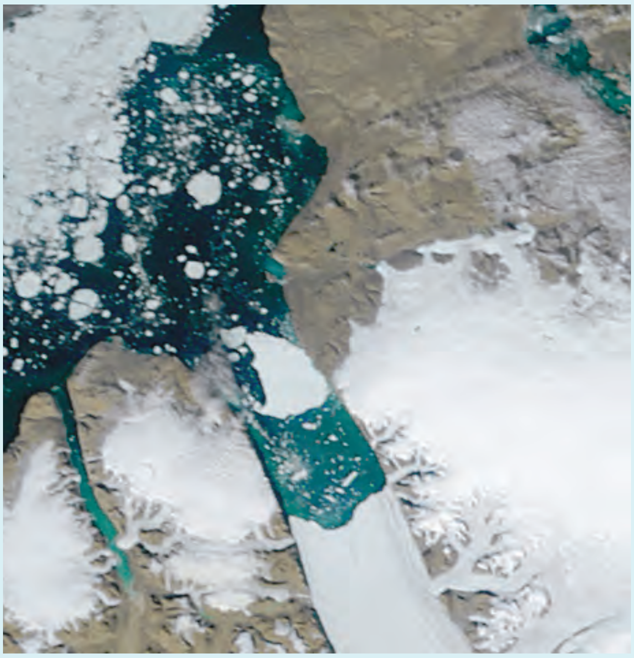
Straneo, F., G.S. Hamilton, D.A. Sutherland, L.A. Stearns, F. Davidson, M.O. Hammill, G.B. Stenson and A. Rosing-Asvid (2010) Rapid circulation of warm subtropical waters in a major glacial fjord in East Greenland. *Nature Geoscience,* **3**,182–6. doi:10.1038/ngeo764

Helen Johnson is a Royal Society University Research Fellow and Lecturer in the Department of Earth Sciences at the University of Oxford. Her research is focussed on understanding the ocean circulation and the role it plays in climate. She uses fluid dynamics theory, numerical models and ocean observations to address a wide range of questions, and became interested in ice–ocean interaction as a result of several research cruises to the Arctic. In 2008, she was awarded a Challenger Society Fellowship.
Helen.Johnson@earth.ox.ac.uk; see also http://www.earth.ox.ac.uk/~helenj/ for some interesting fieldwork blogs.

Stop Press

On 16 July 2012 Petermann Glacier's floating ice shelf underwent another major calving event (http://www.bbc.co.uk/news/world-europe-18896770). The resulting ice island is half the size of that formed in 2010 and leaves the calving front even closer to the grounding line. This NASA MODIS image shows that by 30 July it had travelled 22 km and rotated counterclockwise. The calving event occurred unusually soon after the previous one in 2010, before which calving had happened every ten years or so (cf. Figure 6). However, it was not unexpected – a fracture was first observed 8 years ago.

Helen Johnson is part of an international team conducting further fieldwork in the area to determne the extent to which the mass balance of Petermann Glacier is changing, and the implications this may have for sea level. Together with colleagues at BAS, she also has funding for a proposal to send *Autosub* under what's left of Petermann's ice shelf if/when complementary US proposals to conduct a research cruise are also funded. *Ed.*



Letters to the Editor: the Chagos debate

These letters relate to Charles Sheppard's article 'Protecting the Chagos Archipelago – a last chance for Indian Ocean reefs', which appeared in Ocean Challenge*, Vol.18, critical correspondence that appeared in the same issue, and Prof. Sheppard's response to this in the most recent issue (which itself provoked further critical email correspondence).*

A plea for science that informs policy rather than politicised science

As an interested observer with experience of working in tropical locations and coral reef conservation, I read with some interest the recent debate between well known UK scientists, concerning the best course of action for the Chagos Archipelago, but I was disappointed that the focus of the debate shifted from what would be best for reef conservation to arguments dissecting the differences in individual approaches and beliefs, and past errors. I have not turned a blind eye to the issues raised and I have my own opinion on both the comments made and whether or not it would be right for the UK to establish the world's largest MPA at the expense of possible re-location of the Chagossians. I also note that there is a big difference in our colleagues' beliefs on the drivers behind possible resettlement and the likely outcome of such activity. However, it is not my intention to describe these here. I am writing to ask whether we, as a scientific community of the UK, can perhaps move the argument forward and focus on what we are world renowned for, which is high quality science.

I completely understand the arguments and I sympathise. As conservation biologists our views are unavoidably tempered by the wider social and political context, so we may arrive at conclusions about conservation which may seem at odds to our principles, or we may find ourselves pushing forward conservation recommendations which are constrained by the extent to which we feel they will be supported. In other words, compromise is at the very heart of the world of conservation, and we constantly have to make judgement calls.

However, I feel we must look to the bigger picture, and put our recommendations forward on the science and the science alone. The role of a conservationist often spills over from biology into the socio-political arena which cannot be ignored – policy, after all, is what we want to inform. However, I can also see the real and present danger of politicising science rather than simply using science to inform policy. At the end of the day it will not be scientists who decide whether Chagos becomes a strict no-take area or whether the Chagossians who were 're-located' by our government should be allowed back and subsequently supported, enabling them to become an integral component of the wider Chagossian ecosystem. Our role must surely be to identify, evaluate and debate the conservation value and scientific credentials of the Chagos Archipelago and produce clear, concise information which is not open to misinterpretation and can subsequently be used by policy-makers to make a decision. If we find that the scientific information is simply not available then we must say so or perhaps caveat our recommendations depending on the circumstances. The information we provide is just one piece of the puzzle, and policy-makers and government must put these pieces together in the most effective way possible to produce an action plan that itself can be politically debated.

My real concern here is that the differences in opinion and bad feeling between our academics may cloud the view policy-makers have of the scientific process and validity of our recommendations. We all know that science-informed policy does not always result in sound science-orientated political judgement and this will be all the more likely if the scientific community fails to do what it is supposed to do, which is to provide evidenced scientific information to policy makers so that it can be considered and included in the decision-making progress. I fear for a world where politicians are free to make policy decisions concerning the environment without solid science underpinning these decisions. Airing divergences of opinion is healthy for science, but focussing on scientific disagreement may have severe consequences for general confidence in the results of independent, non-biassed and conscientious scientific research.

By focussing on the similarities rather than dissimilarities within this debate, you cannot fail to conclude that the Chagos is a very special and quite unique place. We all agree that it should be protected and that protection and management need data. I therefore ask, with a great deal of respect, that our colleagues agree to disagree and we as a community, within which disagreement forms a key part of the scientific debate, continue to do our very best to inform policy rather than politicise science.

Prof. David J. Smith *Director of the Coral Reef Research Unit, University of Essex*

Chagos corals – the view from Mauritius

The response by Professor Charles Sheppard in the Spring edition of Ocean Challenge *('Chagos corals – the debate continues') purported to quote a Mauritian government official and asserted that 'Mauritian sovereignty over Chagos could be alarming in terms of potential impacts on Chagos' reefs'. It is surprising that a scientific expert should use arguments of a political nature and make an innuendo of this kind. Whilst it is highly unlikely that a Mauritian official would have made the remark that Prof. Sheppard attributes to him/her, it certainly does not reflect the policy of the Government of Mauritius. The Professor should stick to his area of expertise which clearly does not include Mauritius and its conservation policies.*

It should be recalled that the Chagos Archipelago, including Diego Garcia, forms an integral part of the territory of Mauritius under both international law and Mauritian law. The Government of Mauritius does not recognise the so-called 'British Indian Ocean Territory' which the United Kingdom purported to create by illegally excising the Chagos Archipelago from the territory of Mauritius prior to its accession to independence, in violation of international law and of UN General Assembly Resolutions 1514 (XV) of 14 December 1960, 2066 (XX) of 16 December 1965, 2232 (XXI) of 20 December 1966 and 2357 (XXII) of 19 December 1967.

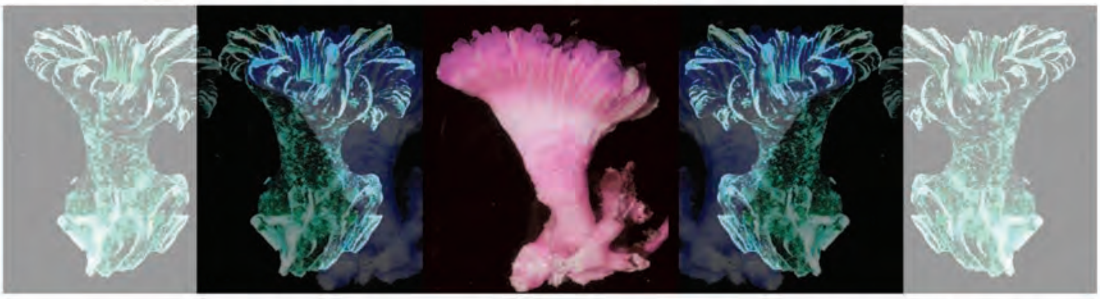
Mauritius takes pride in the way it protects its unique terrestrial and maritime environment, attracting visitors from around the world, and balances tourism with conservation. Unlike in the Chagos Archipelago, it is not just scientists and military personnel who are allowed to enjoy the wonders of our seas. Should Mauritius not have been prevented from effectively exercising its sovereignty over the Chagos Archipelago because of the de facto *control of the UK over the territory, it would have spared no effort to protect the rich biodiversity of the Chagos Archipelago for the long-term benefit of the planet.*

The UK purported to establish a 'marine protected area' (MPA) around the Chagos Archipelago in a manner that was inconsistent with its international obligations, further impeding the exercise by Mauritius of its sovereignty over the Chagos Archipelago as well as the exercise of the right of return of Mauritian citizens who were forcibly removed from the Archipelago by the UK in the late 1960s and early 1970s.

On 20 December 2010, the Government of Mauritius initiated proceedings against the UK Government under Article 287 of, and Annex VII to, the United Nations Convention on the Law of the Sea *to challenge the legality of the 'MPA'.*

Mauritius High Commission, London

Using deep-sea corals to explore the history of the oceans



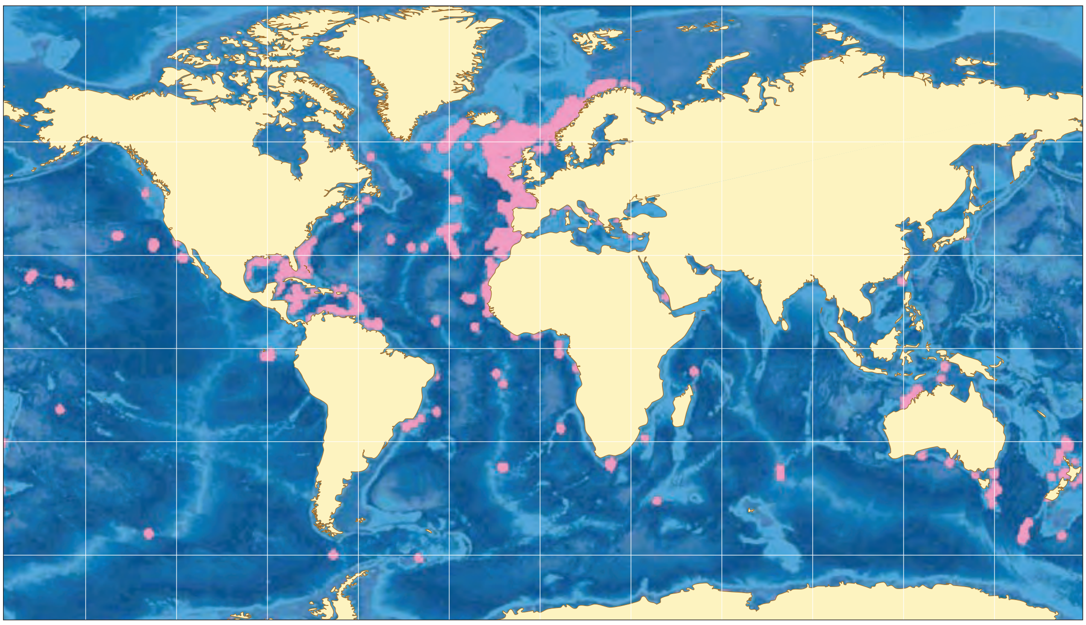
Laura F. Robinson

One of the major challenges when reconstructing past climate is finding archives that record abrupt events on time-scales that are relevant to modern climate-change processes. The carbonate skeletons of corals provide some of the best records of variability within the ocean and there have been many studies on the corals that grow in tropical shallow seas. However, their symbiotic relationship with photosynthetic algae limits these corals to the warm, shallow waters of low latitudes. Luckily some corals do not use algal symbionts and are able to live in cold and/or dark waters, extending their potential habitat range to the deep ocean and high latitudes. There are many species of cold-water corals (also known as deep-sea corals) and they have a wide range of habitats and growth morphologies. Some of these corals form reef-like structures and some are solitary. The growth rates of only a few of the many cold-water coral species have been examined, but it has been shown that some species are extremely long-lived, with life spans of hundreds or even thousands of years.

Despite the unique nature of cold-water corals as climate recorders, their potential has not been fully realised for reconstructions of climate variability, either recent or in the distant past. Compilation maps of the known locations of modern cold-water coral distributions show that they live in all the ocean basins, and at depths as great as 5000 m (Figure 1). However, despite their apparent global distribution, the known coral distribution is patchy, reflecting in large part biased sampling efforts. Although we know rather little about the biology and ecology of

Figure 1 *A summary of the known distributions of framework-forming cold-water corals highlights their global distribution. The true distribution is probably greater, as large tracts of the sea floor have not been surveyed, and many areas support solitary species, which do not form reefs. (After Roberts* et al. *2006)*

Cold-water corals live in all the ocean basins, and at depths as great as 5000 m



these organisms compared with those of their shallow-water counterparts, we do know enough to predict likely habitats and collect fossil samples suited to reconstructing ocean variability over tens of thousands of years.

Collecting cold-water corals in the Southern Ocean

The Southern Ocean plays a crucial role in modulating global climate, and exhibits a sensitive response to perturbations. Today, some of the most obvious symptoms of changing climate, such as ice-shelf melting and ocean temperature rise, are being observed in the Southern Ocean and coastal Antarctica. This sensitivity of the Southern Ocean means that the native fauna are likely to experience large changes in their environments over coming decades. However, we have little understanding of how climate change may affect the distribution and health of cold-water corals and improving this understanding is a pressing concern. One way to understand the major controls on coral populations is to determine the ages of many fossil corals, and to relate changing population sizes to evidence of global climate change in the past. In the spring of 2008, a team led by coral biologist Rhian Waller (University of Maine) and myself sailed south onboard RV *Nathaniel B. Palmer* to map, image and collect cold-water corals from the Drake Passage and the Scotia Sea (Figure 2). In 2011 we followed up with a second cruise to the central and western Drake Passage. The cruises brought together interdisciplinary teams to use deep-water corals and other benthic organisms to reconstruct Southern Ocean conditions during the later stages of the last glacial period (~ 30 000–10 000 years ago), and to investigate their past and present biogeography in the Drake Passage.

During both cruises we used multibeam sonar techniques to map the sea-floor bathymetry of continental slopes, fracture zones and seamounts in order to identify likely areas for cold-water coral habitats. From previous experience and from global compilations, we know that some of the corals that we are interested in – e.g. *Desmophyllum dianthus* (Figure 3) – tend to thrive on hard substrates and in strong currents, so the seamounts in the Drake Passage, which lie in the Antarctic Circumpolar Current, provide ideal coral habitats. Some species also thrive in sedimented areas, as are found up

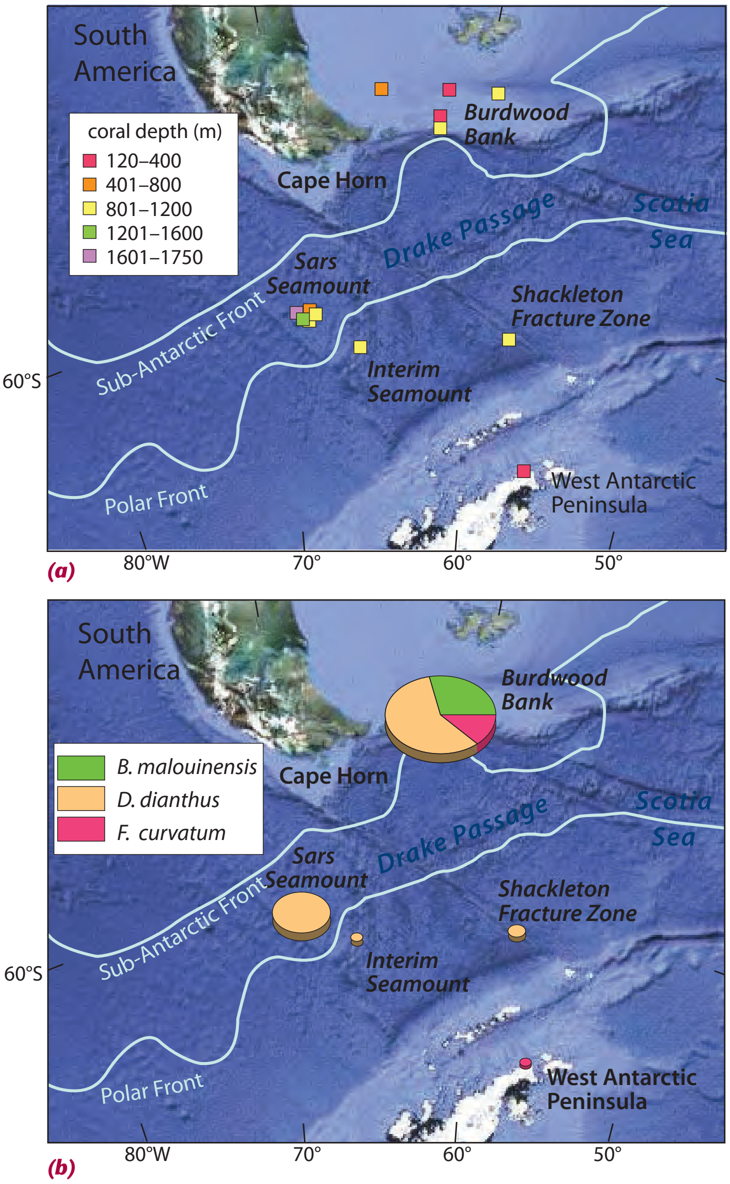


Figure 2 *Cold-water coral data from the 2008* Nathaniel B. Palmer *cruise.* ***(a)*** *Station locations colour-coded by depth.* ***(b)*** *Sites where specimens of* Flabellum curvatum, Desmophyllum dianthus *and* Balanophyllia malouiensis† *have been dated; the size of the pie chart is proportional to the total number of specimens dated at the site (100 corals were dated in total)*. Also shown are two major fronts in the Antarctic Circumpolar Current, of which the Sub-Antarctic Front marks the northern edge.*

(Data after Burke et al.*, 2010; station locations are from the NBP0805 cruise report; bathymetry is from ETOPO2)*

Cold-water corals are found in a wide range of environments in the Southern Ocean, at depths of 300 m to > 2500

*Many more corals have been dated since.

† *D. dianthus, B. malouiensis,* and *F. curvatum* have calcium carbonate skeletons and are known as scleractinian (or 'stony') corals.

Figure 3 *Two specimens of* Desmophyllum dianthus *corals† collected in the Drake Passage ~ 800 m from the Burdwood Bank on leg NBP08-05. The one on the left is fossilised and coated in a ferromanganese coating. The one on the right is alive. Both are ~ 8 cm in length.* D. dianthus *has a life span of ~ 100 years. It can live close to the surface in high-latitude fjords as well as at depths of thousands of metres.*

(Photos by courtesy of Dann Blackwood, USGS)

The TowCam system produces a mosaic of sea-bed photos

Figure 4 *The WHOI TowCam system being deployed from the port A-frame of the RV* Nathaniel B. Palmer. *It is towed behind the ship at about 5 m above the sea floor and takes thousands of overlapping images, which form a mosaic.*

on the continental shelves (cf. Figure 2). Once we had identified areas that were likely coral habitats, we collected long transects of overlapping sea-floor photographs using a deep-towed camera sled (TowCam from the Woods Hole Oceanographic Institution; Figure 4) to provide *in situ* sea-floor images. We also obtained high-resolution images using a camera system that takes photographs closer to the sea floor. The diversity and abundance of corals in seemingly inhospitable locations such as Cape Horn is remarkable (Figure 5).

The sea-bed off Cape Horn appears to be a biodiversity hot spot and may be a key source of larvae of cold-water corals

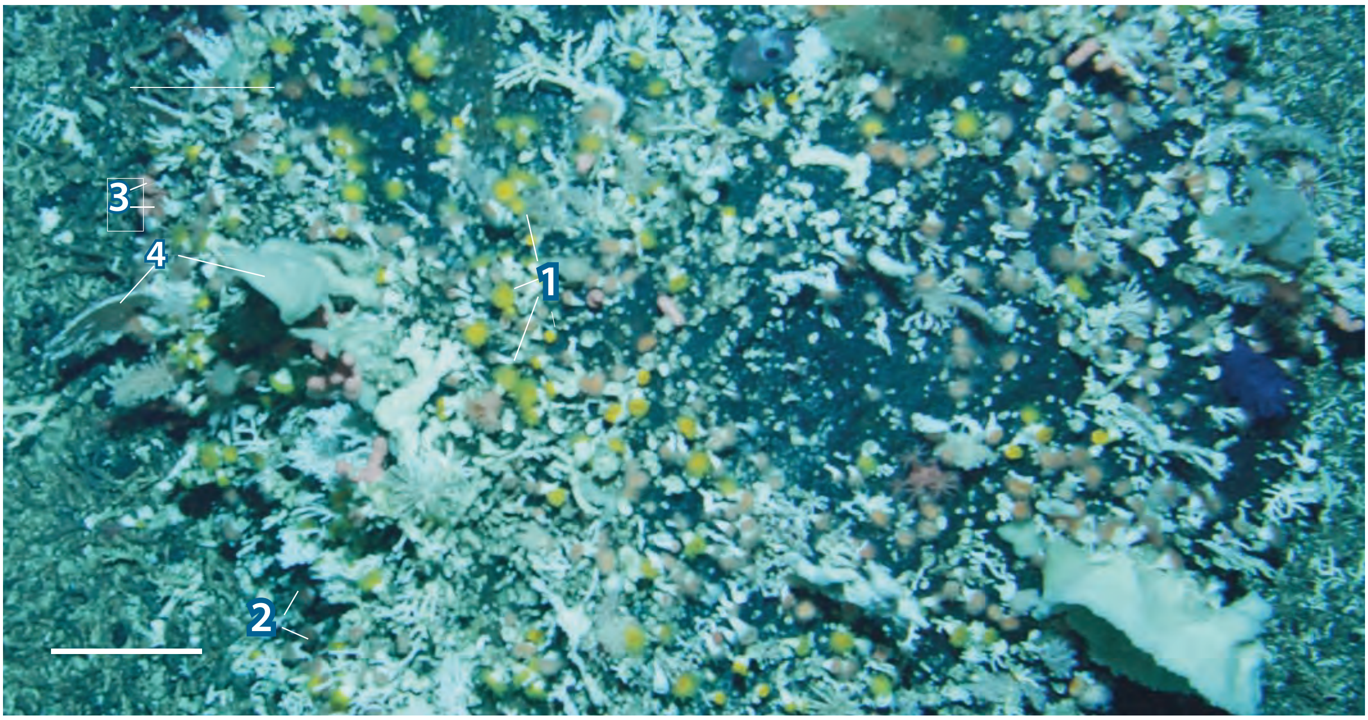
Ideally we would use remotely operated vehicles (ROVs) with cameras and specialised manipulators to collect samples, but such delicate equipment is not well suited to the challenging conditions in the Southern Ocean. Instead, we used small research trawls and dredges to collect samples. Prior to our first cruise we knew of only two solitary fossil corals that had been recovered from the central Drake Passage. They both came from Sars Seamount (Figure 2) and were dated to about 17 000 years old. During our follow-up cruises we have been able to collect thousands more samples of many genera of cold-water corals (cf. Figure 6) from water depths ranging from ~ 300 m to over 2500 m.

Dating deep-sea corals

A particular advantage of using carbonate coral skeletons as archives of climate variability in the past is that they can be dated using the radioactive decay of uranium to thorium. The principles of this method are simple: the coral incorporates uranium into its skeleton, that uranium then decays to thorium and we can measure the ratio of uranium to thorium to calculate the

Figure 5 *High-resolution photograph of cold-water corals living on rocky sea-bed off Cape Horn, at a depth of 1400 m. Here you can see scleratinians, including* Balanophyllia malouliensis *(1) and* Flabellum curvatum *(2), octocorals (which are colonial but do not have calcium carbonate skeletons), including* Paragorgia sp. *(3), and stylasterids (hydrozoan corals) (4). The corals that appear 'fluffy' have their polyps extended and are feeding. Also visible are sponges, brittlestars and anemones. The photograph was taken from ~ 2 m above the sea-bed, and the field of view is 1.35 m across; scale bar: 15 cm.*

(From Waller and Robinson, 2012)



age. Of course, there are complications with this technique, but we have methods that account for any potential biases, and we can also estimate appropriate associated uncertainties. This dating system is robust, precise and works for dates back to about half a million years ago.

However, the analytical load associated with uranium–thorium dating is extremely heavy, and so we have been developing a number of 'reconnaissance' methods based on radiocarbon dating. Both stable and radioactive isotopes of carbon – ^{12}C and radiocarbon, ^{14}C – are incorporated into the coral skeleton as it grows. As with the uranium system, the change in the ratio of these two isotopes of carbon as ^{14}C decays to ^{14}N can be used to calculate an age. Most recently we have used a new gas source adaptation to an accelerator mass spectrometer at the Woods Hole Oceanographic Institution which allows us to date some 40–50 samples a day. Dates obtained using radiocarbon-based techniques are not as accurate as uranium–thorium dates, and are only appropriate for samples less than 40 000 years old. Nevertheless, it is extremely useful to have a 'first pass' approximate age.

Using these dating methods we have now looked at the age distributions of hundreds of corals from the North Atlantic, the Southern Ocean and the tropical Pacific. The ages range from modern, back to over a quarter of a million years ago. A surprising result is that in all cases the coral populations have not been constant, but seem to wax and wane over thousands of years. We suspect that these changes are associated with changes in the coral environment, for example access to food. In order to ascertain why these coral populations change over time we are looking at the history of the locations in which they live. One way to do this is to use geochemical tracers measured in the skeletons themselves, as archives of the local environment.

Using cold-water corals to reconstruct past climate

Corals, like other organisms, manipulate the chemistry of seawater when they precipitate their skeletons. This process means that the chemistry of coral skeletons is not always the same as would be predicted for an inorganic system – a factor that can complicate the interpretation of geochemical data. However, we are actively working on developing new geochemical proxies that do reflect aspects of the ocean environment in the past. For example, one new approach to reconstructing past seawater temperatures is to measure the ratio of two trace metals, magnesium and lithium. Thus far, this method has an uncertainty of about 2 °C, but we hope to improve on this with better calibrations using our new sample sets. (See Further Reading for more information.)

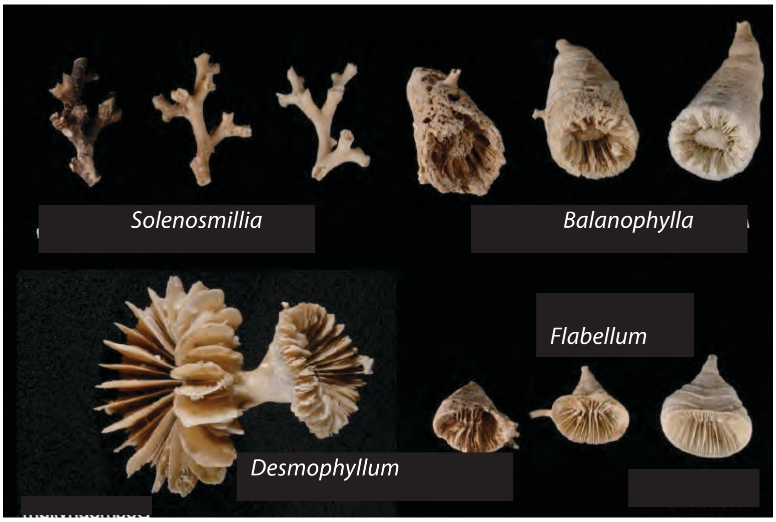


Figure 6 *Specimens of four genera of scleractinian corals collected from the Drake Passage in 2008.* Balanophyllia, Flabellum *and* Desmophyllum *are solitary, and* Solenosmillia *is colonial. Apart from the* Desmophyllum, *three examples of each are shown: one very corroded or coated in ferromanganese crust on the left, one well-preserved 'pristine'-looking on the right, and one in-between in the middle. Such crusts form on sediments and on corals after they die. They are rich in heavy metals, including thorium, and so have to be thoroughly removed by intense physical and chemical cleaning before uranium–thorium dating can take place.*

(Photos by courtesy of Dann Blackwood, USGS)

Ferromanganese crusts have to be removed from corals before uranium–thorium dating if they are not to bias the final ages

Thus far, however, the most successful palaeoclimate studies using cold-water coral skeletons have been reconstructions of the radiocarbon content of seawater. In this case, instead of using radiocarbon to find out the age of the coral skeleton, we use radiocarbon to trace the circulation history of the ocean. Radiocarbon is produced in the upper atmosphere, and enters the ocean through exchange with surface waters. If that surface water then sinks down it becomes isolated from the atmosphere and the radiocarbon decays away, providing the basis for a tracer of the rate of ocean circulation. Results from fossil corals collected in the North Atlantic have shown that the radiocarbon content of the deep ocean exhibited large-amplitude, decadal-timescale variability during the transition from the last glacial period to the modern warm interglacial period (20 000–10 000 years ago). The fact that these changes coincided with major changes in Northern Hemisphere temperature highlights the strong links between ocean circulation and climate. We have also reconstructed the radiocarbon history of the Drake Passage, allowing us to investigate the links between this important part of the ocean and global climate. By comparing our coral-based radiocarbon record with palaeoclimate records from ice cores and other parts of the marine system we have shown that increased mixing in the Southern Ocean probably played an important role in changing atmospheric CO_2 levels.

The future of deep-sea coral research

Deep-sea corals form an exciting area of research, because of their ecology and biogeography, their long lives, and their ability to record ocean conditions in the past. Increasingly, interdisciplinary and multinational efforts are being devoted to systematic surveys of these habitats through dedicated ship time and laboratory analysis. I, for one, look forward to the day when we have enough data to produce maps that reflect the real distribution of deep-sea corals, not one that simply reflects our sampling effort. By that time, we should be in a position to understand how and why these corals live in certain locations, how they should be conserved, and how we can use them to learn more about the history of our planet.

Further Reading

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Burke A. and L.F. Robinson (2012) The Southern Ocean's role in carbon exchange during the last deglaciation *Science,* **335** (6068)*,* 557–61. doi: 10.1126/science.1208163

Case, D.L., L.F. Robinson, M.E. Auro, A. Gagnon (2010) Environmental and biological controls on Mg and Li in deep-sea scleractinian corals. *Earth and Planet. Sci. Letters*, **300**, 215–25.

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Laura.Robinson@bristol.ac.uk

Progress stalled on MPAs around Antarctica

The 31st meeting of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) was held in November 2012. There had been hopes for significant progress regarding marine protected areas (MPAs) as members had previously committed to developing a system of Southern Ocean MPAs by 2012, in line with the global deadline for the MPA target agreed upon at the World Summit on Sustainable Development in 2002. In particular, decisions were expected on proposals for MPAs in the Ross Sea and in East Antarctica. But despite years of preparation and effort, the decisions were postponed. The International Union for Conservation of Nature (IUCN) is seriously concerned that CCAMLR members were not able to reach consensus when significant groundwork had already been put in place.

CCAMLR – one of the few regional management bodies – is balancing the need for resource harvesting with the need to maintain ecological relationships between harvested, dependent and related populations of Antarctic marine living resources, and prevent changes in the marine ecosystem. Consensus of all 25 members is needed for progress, and some countries, including Russia, Ukraine and China, refused to compromise on the proposals. This is especially bad news at a time when pressure on polar regions from climate change and ocean acidification is higher than ever, and there is also growth in human activities such as resource extraction, shipping, and tourism. It is hoped that progress will be made at a special session of the Commission which will meet in Germany in July 2013.

Discussions at the recent meeting also focussed on the idea of 'time-limiting' MPAs – MPAs with a fixed life-span. The IUCN is deeply concerned that MPAs should not become short-term, with temporary management arrangements, because to ensure conservation benefits they need dedicated, long-term management. Any investment in conservation would be wiped out by even short-term suspension of reserve status and the fishing that this would allow.

The very first entirely high-seas MPA is an area of around 94 000 km^3 to the south of the South Orkneys, proposed by the UK delegation in 2009. Within its boundaries there is a ban on all fishing activities, as well as on waste disposal and discharge from fishing vessels. The existence of the reserve also aids the coordination of scientific research activities.

The future of deep-sea coral research

Deep-sea corals form an exciting area of research, because of their ecology and biogeography, their long lives, and their ability to record ocean conditions in the past. Increasingly, interdisciplinary and multinational efforts are being devoted to systematic surveys of these habitats through dedicated ship time and laboratory analysis. I, for one, look forward to the day when we have enough data to produce maps that reflect the real distribution of deep-sea corals, not one that simply reflects our sampling effort. By that time, we should be in a position to understand how and why these corals live in certain locations, how they should be conserved, and how we can use them to learn more about the history of our planet.

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50 years of *Discovery*

from the days of steam to the 21st century

John Gould

The year is 1962: astronaut Scott Carpenter orbits the Earth three times in the *Aurora 7* capsule; *Telstar,* the world's first communication satellite, is launched; the Beatles release their first record, 'Love me do'; Marilyn Monroe dies; the Cuban missile crisis grips the world; and the Ford Cortina is launched at a price of £850. On 3 July that year, in an era very different from the 21st century, the new Royal Research Ship *Discovery* was launched from the Hall Russell shipyard in Aberdeen. The ship was to replace the 33 year-old RRS *Discovery II* as the main research vessel for UK scientists, particularly those at the National Institute of Oceanography (NIO), established a decade earlier at its new home at Wormley in Surrey under the Directorship of Sir George Deacon.

An innovative new research vessel

Discovery II, with her steam reciprocating engines and cramped accommodation, was slow and had proved to be increasingly inadequate for modern global scale science and so, under the leadership of an NIO scientist, Henry Herdman, and the Liverpool-based naval architects, T.R. Little, a new *Discovery* was designed. She was to have many innovative features, including a bow propeller fitted in a tunnel through her hull that would help her to stay on station. Studies of the flow around the bow propeller tunnel had been made in the towing tanks at the National Physical Laboratory in Feltham and they had also helped refine her hull form. (The same basic hull was adopted by the Royal Navy for their

Discovery *was launched by Viscountess Hailsham, wife of the then Minister for Science, on 3 July 1962*

The new vessel in Willoughby's dry dock in Plymouth where her four-bladed propeller was replaced by a five-bladed one

H-Class survey ships *Hecla, Hecate* and *Hydra.*) Her fixed-pitch main propeller, driven by an electric motor, would both give her controllability and make her acoustically quiet. She would have hydraulically operated cranes capable of handling the largest nets used by NIO's biologists, and up forward there would be something akin to a lift shaft (known as the asdic trunk) allowing instruments to be mounted and demounted on the hull without the need for dry-docking. The cost of the finished vessel totalled £850 000 (the equivalent today of £15million).

Following fitting-out and sea trials, *Discovery* arrived at her new home in Millbay Docks, Plymouth, on 21 December. For five days in January 1963 she was on display in London where she was visited by many dignitaries, and in February she sailed on her sea trials. Her departure from the Pool of London was not without incident – Tower Bridge was slow to open and the anchors had to be hurriedly prepared, 'just in case'. Though most aspects of the ship worked well during the trials, serious problems were found with the winches. The spooling gear on the small winches (amazingly still steam-driven) did not work properly and the cheeks on the main trawl winch spread and jammed when the wire was hauled in under tension.

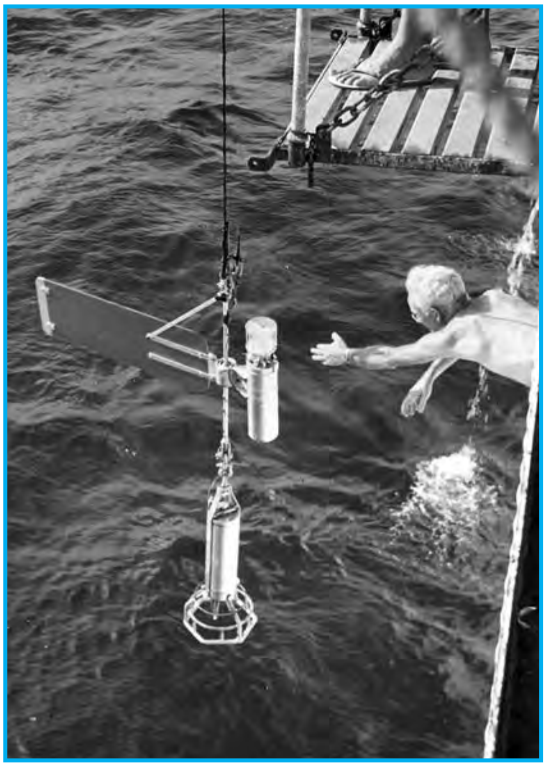
DIscovery *photographed during the IIOE by Bob Munns from WHOI aboard* **RV Atlantis II**

International Indian Ocean Expedition

With these defects corrected, on 1 June 1963 *Discovery*, resplendent in her tropical white-painted hull, and with her complement of 18 scientists and 45 officers and crew, sailed from Plymouth to take part in the multidisciplinary International Indian Ocean Expedition (IIOE). Life on board was, by modern standards, rather formal. The ship was then run by the Royal Fleet Auxiliary, who operate the Royal Navy's supply ships, and so there were many echoes of naval tradition. Jackets and ties were worn for dinner, with officers and scientists waited on by stewards, while the crew ate in separate messes for seamen, petty officers, greasers and boys. The food was not particularly exciting and often led to complaints, although In the bonded store were stone wicker-clad jars of 110% proof 'pusser's rum' that was issued on special occasions. The air-conditioning throughout the ship was a pleasant bonus, particularly to those who had sailed on the *Discovery II*.

Scientists' social life centred round the smoke room (bar) or the cinema that doubled as a library down near the centre of the ship. Bar games included liar dice, Monopoly, bridge, Scrabble, and an American game called Kriegspiel, that required three chessboards, two players and a referee. The officers were keen on Ludo, known as 'Uckers' in naval circles. The films were renewed from time to time by the RN film service. In rough weather, cinema-going was hazardous as the metal chairs and their occupants slid from side to side, crashing into the glass-fronted library cupboards.

At the time of the IIOE many aspects of seagoing science had changed little from pre-war times or even from the 19th century. Though there were 'modern' navigational aids such as Decca and Loran, the coverage was limited and navigation still relied on star sights and dead-reckoning, or radar fixes on temporary buoys. This was still the era of water bottles and reversing thermometers, though yellow plastic NIO bottles had replaced the traditional Nansen bottles. The 10 kHz, wide-beam echo-sounder had a transducer in a towed fish and the depths from the Mufax recorder were written in a log book every 10 minutes by the scientific watchkeeper in the plotting office. The biologists fished their nets, geophysicists detonated charges of Geophex explosive and recorded the signals on sonobuoys, and dredges that were virtually



Far Left *The centre of scientific watchkeeping – the plotting office*

Left *The prototype CTD and recording current meter that were lost on the IIOE (the scientist is Bruce Hamon from CSIRO)*

identical to those used on HMS *Challenger* in the 1870s brought up rock samples. Deploying multiple wires over the side at the same time, particularly in the high shear of the Somali Current, was soon found to be a poor idea when wires were cut through and equipment lost. In a separate incident, prototypes of a CTD and of an internally recording current meter (the forerunner of the Aanderaa RCM4) were lost. These were instruments that would come into routine use in the 1970s.

A time of change

On her return from the IIOE, *Discovery*'s hull was painted black, a more appropriate colour for work in the North Atlantic and easier to keep looking smart. The formal traditions of life on board continued, although they were slowly eroded, particularly when the ship left the Royal Fleet Auxiliary in 1969 and came wholly under the management of NERC and its newly formed Research Ship Management Unit in Plymouth (it moved to the Research Vessel Base in Barry in South Wales in 1969).

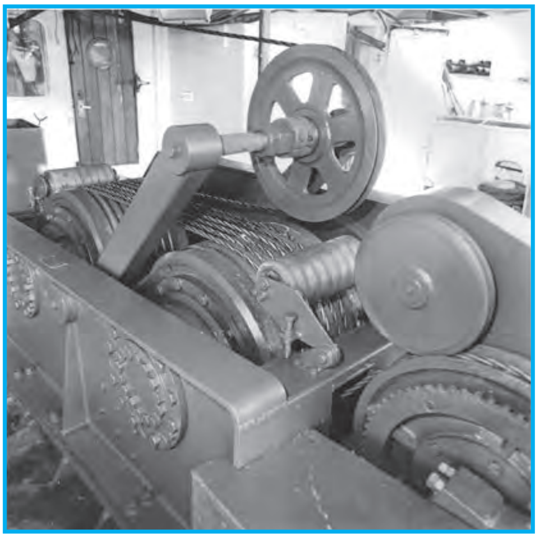
Science was changing rapidly at that time, and during a major refit by her builders between October 1968 and January 1969 significant changes were made. The officers' smoke room (complete with coal-effect electric fire) was sacrificed to provide a new hydrographic lab and, most significantly, space for an IBM 1800 computer – one of the first sea-going computers. A Magnavox Transit satellite receiver was installed – it had serial number 11 and was the first satnav system on a UK ship. The computer was linked to a two-component electromagnetic ship's log capable of measuring the athwartships movement of the vessel. This, with reliable if infrequent satellite fixes, improved navigation and also allowed surface currents to be measured. The new information on surface currents captured the imagination of the then Master, Geoff Howe, who made a pastime of compiling surface current charts. Some, with arrows going in all directions, he described as a good representation of the Battle of Hastings.

In the summer of 1969 a further refit equipped *Discovery* to handle the new *GLORIA* towed sonar vehicle designed and built at NIO. As

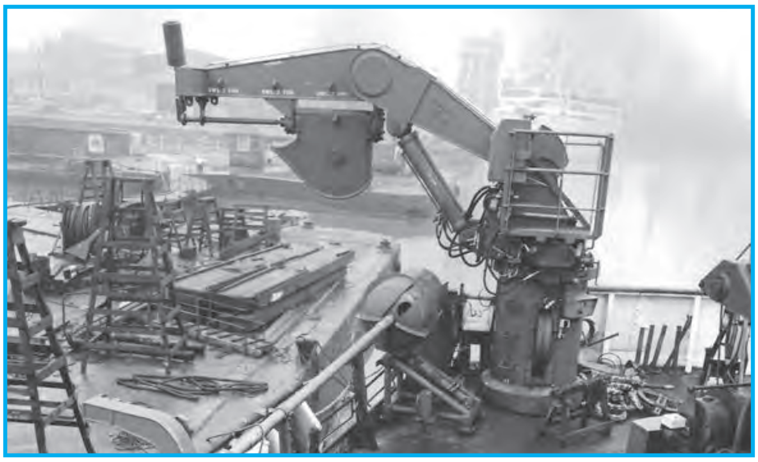
Below *The IBM 1800 computer in what was once the officers' smoke room*

Below Discovery *fitted with the* GLORIA Mark I *vehicle in Empress Dock Southampton in 1969*

Above *Jim Crease inspecting the trawl winch in 1972. This is the same winch that caused such trouble before the IIOE*



The new winch fitted in 1981
Right *The traction unit and the storage drum.*
Below *The Schatt davit*



well as needing substantial power supplies and electronics it required the removal of one of the ship's lifeboats and its replacement by a purpose-built davit. Deploying and recovering *GLORIA* was a complex operation involving the use of divers and a cat's-cradle of cables and accumulator springs across the after deck. In 1977 a new, easier-to-handle *GLORIA Mark II* version, which could be deployed from a gantry on the aft deck, came into service.

These developments were symptomatic of a new era during which the world of marine science was to change greatly. Ocean-observing satellites started with the brief life of *SeaSat* in 1978. This coincided fortuitously with the JASIN air–sea interaction experiment in the Rockall Trough that provided ground truth, including data from *Discovery*. CTDs replaced water bottles and, together with the sample bottles, required ever bigger packages to be handled. Nets became bigger and more complex and the deployment and recovery of moored instruments and bottom-mounted packages (tide gauges, benthic landers, seismographs) was commonplace. *Discovery* with her 1970s layout virtually unaltered did sterling service into the 1980s and '90s.

Another major refit in Immingham between October and December 1981 saw the installation of a traction winch carrying 15 000 m of tapered warp to replace the old trawl winch. Together with a 15 tonne Schatt davit on the starboard quarter and a larger aft crane, these could handle a 50 ft Driscoll corer and allow biological and geological sampling at the 5500 m-deep Great Meteor East site. A new, more powerful White–Gill bow thruster aided station-keeping. These changes equipped *Discovery* to carry out commissioned research into the feasibility of the disposal of high-level radioactive waste – a £6m contract at 1985 prices (£20m today).

A refit for the 21st century

By the end of the 1980s further changes were afoot. The plans for a new generation of Earth-observing satellites carrying altimeters, scatterometers and ocean colour sensors brought the exciting prospect of studying the oceans on a truly global scale. To complement these measurements, international, ship-based projects were planned, most notably the World Ocean Circulation Experiment (WOCE) and the Joint Global Ocean Flux Study (JGOFS).

Since *Discovery* had neither the endurance nor the laboratory space and accommodation for the large scientific parties needed for such work, the then NERC Director of Marine Science, John Woods, made the case to the Thatcher government for funding for a major refit that would fit *Discovery* for this new era. Over 20 months starting in October 1990 *Discovery* was transformed in a shipyard in Vianna do Castello in

The 1990s refit
Left *The funnel and superstructure are removed*
Right *The bare hull ready to be lengthened and refitted*

northern Portugal into a ship fit for the 21st century. The transformation was total – the hull was lengthened by 11 m, she was given new engines, a new large after deck with an A-frame, a midships gantry to handle CTDs, a hanger for submersibles and totally new accommodation and laboratories, including space for labs in shipping containers. All that remained easily recognisable of the ship launched in 1962 was her bow and the iconic foremast – a bit like the broom that has seen long years of service but with three new handles and four new heads. It is that ship that serves the community in 2012, and it is precisely this ability to reinvent herself every few years that has enabled her to cope with technological changes and serve the oceanographic community so well. Along with her new look the ship had a new home in Southampton alongside the newly opened Southampton Oceanography Centre.

Despite her new look, *Discovery* maintained a direct link with her illustrious predecessors, not just though the name but also through the series of *Discovery* station numbers. These had been started during the *Discovery* Investigations of the Southern Ocean between the two World Wars and continued to be used until, in the 1990s, they were increasingly disregarded by Principal Scientists who preferred their own numbering system. The last recorded use was *Discovery* Station 16 667 on Cruise 341 in 2009.

And so *Discovery* still serves the UK's science community in a working world that would have seemed like science fiction in the 1960s. She deploys and recovers autonomous vehicles, and assists in monitoring the heat transport of the North Atlantic; thanks to GPS she always knows her position to within a few metres, she has sufficient computing power to process almost all data on board and is connected to the internet. She has sailed between 1 and 1.5 million nautical miles during her life and will have worked in all the major oceans on a total of 362 separate science cruises. (It should be noted that in recent years, cruise numbers have been allocated to trials cruises and passage

Discovery *in Empress Dock, alongside the National Oceanography Centre, Southampton*

Incarnations of Discovery compared

Discovery	1962	Post-refit	New
Main propulsion (kW)	1491	1500	4400
Bow thruster (kW)	261	550	2925
Length overall (m)	79	90.2	99.7
Beam (m)	14	14	18
Draft (m)	4.7	5.3	6.5
Gross registered tonnage	2707	3008	5941
Operating speed (knots)	10.5	10	12
Operational endurance (days)	28	45	50
No. of officers and crew	45	22	24
No. of scientists	18	28	28

legs on which no science has been carried out. Her last numbered cruise will be number 383 – a passage leg to Southampton.)

Cruises have been led by 135 individual scientists; 10 of them have been women, the first being Penny Barton from Cambridge University in 1988. The ship has been commanded by 24 Masters, and among these, Roger Chamberlain started his sea-going on *Discovery* as a 16 year-old galley boy in 1972 and rose to the rank of *Discovery*'s captain in 2003. Ashore, the ship's work has been supported by a dedicated band of people, in Wormley, Plymouth, Barry and Southampton, who endured the discomforts of cold winter-time refits, supervised loading and unloading and the shipping of vital last-minute spares to far-flung corners of the world. And finally we must not forget the friends and families left behind, and all the birthdays, wedding anniversaries and other notable events missed by those at sea.

Discovery has contributed to major scientific discoveries, and has endured the ocean's roughest seas; in February 2000 (Cruise 245) she recorded the largest wave ever measured by a ship – 29.01 m. She has also survived fires – the most serious in November 1975 resulted in the tragic death of a greaser, William Jones. Following the fire, an engineless *Discovery* was towed

The ship's company during the IIOE, with the officers in tropical rig

into Teneriffe at an unprecedented 15 kts by the tug *Friesland* which was later contracted to go much more profitably to Iceland to assist in the third Cod War which had just broken out.

Valued officers and seamen

Throughout the ship's life, scientists have been unstintingly assisted in their work by the officers and seamen, but two individuals from the early days merit special mention: bosun Harry Moreton (who for a consideration would do your laundry and return it neatly ironed) and netman Dick Burt. Working on *Discovery* from 1963 until his retirement in 1980, Dick had years of expertise in rigging and deploying equipment. The netman's store adjacent to the after deck was an Aladdin's cave of shackles, wire stoppers and tools and had an aroma of tarred hemp and oil redolent of the days of sail. Dick's notebooks are now kept in the archives of the National Oceanographic Library in Southampton. Both were awarded the British Empire Medal, Harry in 1969 and Dick in 1970.

Happy Birthday Discovery!

To celebrate a half-century of service to marine science, over 150 people associated with *Discovery* gathered on 2 July 2012 to bid her 'Happy Birthday' and to look forward to her successor due to come into service in 2013. The talks by Gwyn Griffiths, David Billett, Roger Searle, John Gould and Peter Burkill described *Discovery*'s contributions to science and technology, and those by Howard Roe and former Master Mike Harding (who gave 'A view from the bridge') described the ship's history and aspects of life on board. Edward Cooper then described the new *Discovery* presently being built in Spain (see pp.10–11).

Talks by Howard Roe and Tony Rice highlighted the way in which *Discovery* had contributed to the building of national and international scientific communities. In summing up, Tony suggested that *Discovery*'s longevity is unique, but that seems not to be true since the US RV *Flip* celebrated 50 years of service this year and Canada's *Hudson* will do so next year. However, *Discovery* has certainly proved the most adaptable of ships and one that has proudly held her place in an illustrious line of ships of that name.

In autumn 2012, she will end her scientific service under NERC ownership and will sail to pastures new (and as yet unknown). A proud history and memories will remain: the preparations for the 50th birthday party resulted in a treasure trove of photographs, memorabilia and stories coming to light, and those will find a place in the NOC archives at Southampton. Perhaps her iconic foremast could be preserved in Southampton as a permanent memorial to all who served on her.

At Discovery's 50th Birthday Party, a gathering of scientists who took part in the IIEO. Front left to right: Peter Herring, Jim Crease, Martin Angel and Bob Belderson; Back left to right: Bob Whitmarsh, Arthur Fisher, John Moorey and John Jones.

References and websites

Laughton, A.S., M.J. Tucker, J. Gould and H. Roe (2009) *Of Seas and Ships and Scientists – the remarkable history of the UK's National Institute of Oceanography,1949–1973*. Lutterworth Press, 350pp. ISBN: 978-0--1889230-2

The Aberdeen Ships Project (photographs of *Discovery* during her build and sea trials). http://www.aberdeenships.com/

Booklet on *Discovery*'s life and a flip-book of descriptions of many of her cruises are at http://noc.ac.uk/news/fifty-years-discovery-ocean-exploration-0

Dick Burt's notebooks may be found at http://eprints.soton.ac.uk/id/eprint/14367

John Gould first sailed on *Discovery* in spring 1966 (Cruise 10 led by John Swallow) and subsequently joined the NIO at Wormley where he worked on the measurement of ocean currents. He sailed on 35 cruises, including 15 on *Discovery*, on eight of which he was principal scientist. He helped to plan the *Discovery*'s 50th Birthday celebrations and compiles a twice-yearly Newsletter, *Oceans Wormley,* distributed to those interested in the work carried out in the NIO/IOS/IOSDL labs in Surrey between their formation and the move to Southampton in 1994.
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RRS *Discovery* and the IIOE cruises

when oceanography came of age

Peter J. Herring

The replacement of the ageing *Discovery II* with the new purpose-built research vessel RRS *Discovery* was expedited by the impending International Indian Ocean Expedition (IIOE), but it was a fine-run thing and late delivery in December 1962 thwarted the intention of a first IIOE cruise that year. After brief trial cruises in 1963 (in which there were problems with all the winches) *Discovery* sailed from Plymouth on 1 June for three Indian Ocean cruises that would continue until her return in September 1964 (interrupted only by a brief and originally unscheduled return to the UK for essential refit over Christmas 1963). *Discovery*'s hurried introduction to the IIOE inevitably led to some later mechanical and electrical problems during the cruises, an experience she shared with the new German vessel *Meteor* and the refurbished presidential yacht *Anton Bruun*.* I was lucky enough to be involved in the whole IIOE experience, although at the time I perhaps did not appreciate the full significance of the opportunity!

Planning 'a combined assault on the largest unkown area on Earth'

Oceanography had played a limited part in the International Geophysical Year (IGY) (1957–58) but before it was over the International Council of Scientific Unions had set up a Special (later Scientific) Committee on Oceanic Research (SCOR) to address its future direction. George Deacon (later Sir George), who had been appointed founder Director of the National Institute of Oceanography (NIO) at Wormley in 1949, was a key member. At its first meeting in Woods Hole in 1957 SCOR determined that, after an initial period of encouragement of international links and standardisation in deep ocean measurement procedures, it should make 'a combined assault on the largest unknown area on Earth, the deep waters and seabed of the Indian Ocean'.

Thus was born the International Indian Ocean Expedition (IIOE). How it was to be structured caused considerable argument. The IGY had been based on a predetermined grid of stations and George Wüst proposed a similar grid survey in the Indian Ocean from 30° S to the Antarctic, with more intensive coverage in the more northerly monsoon-affected regions and the Somali Current. This plan was included in SCOR's 1960 prospectus, but many oceanographers were reluctant to submit to a surveying role that would limit their individual scope for addressing particular scientific problems. George Deacon was one of those who opposed a coordinated grid study, although in a letter to *Nature* he later defended SCOR's original prospectus against Henry Stommel's criticisms.

In July and August 1960, Deacon, Roger Revelle and Anton Bruun succeeded in the immense task of synthesising the Indian Ocean working group's proposals into a coherent programme that both accommodated conflicting interests and involved the developing countries bordering the region. At the same time, Deacon was Chairman of the British National Committee for Oceanic Research, and a member of all five of its working groups which were drawing up the UK scientific programmes for the IIOE (published by the Royal Society in 1962).

It was decided that the proposed IIOE grid sections and reference stations should be encouraged but were not mandatory. Basic hydrographic and meteorological data were to be routinely collected. All ships were asked to keep their echo-sounders running and make their records available to others. All biological participants were urged to take zooplankton hauls from 200 m to the surface using the Indian Ocean Standard Net. These samples were to be preserved in hexamine-neutralised formaldehyde

*The *Anton Brunn*'s surprising history is described on p.45, after this article.

and archived and analysed in a new centre at Cochin, India. (Unfortunately the heat and the hexamine combined to produce excess acidity that decalcified many of the samples to the point where they could not be used.)

Cruise 1 and the novices

Discovery's scientific complement for Cruise 1, under the direction of Ron Currie and John Swallow, was drawn largely from their colleagues at the NIO but also included scientists from Canada, India, the MAFF and DAFS fisheries laboratories and the Marine Biological Association, as well as Lt Cdr Bob Nesbitt from the Hydrographic Office. The NIO contingent included the first woman to go to sea on a British research vessel – bacteriologist Betty Kirtley. Alongside these experts were five scientific novices: Royal Society John Murray postgraduate students, who were to serve the whole 16-month period. Peter Brewer and Graham Topping were chemists from Liverpool University, Roger Bailey was an ornithologist from Oxford, while Martin Angel and I were zoologists from Bristol and Cambridge, respectively (somehow we were omitted from the personnel list in the cruise report ...). My only seagoing experience was a week in the Sargasso Sea with the Woods Hole Oceanographic Institution the year before, and none of us knew what to expect – or what was to hit us.

En route

We set off from Plymouth on 1 June 1963 and after a thankfully gentle crossing of the Bay of Biscay progressed calmly through the Mediterranean and the Suez Canal. In the Red Sea, a brief interlude was provided by an emergency call to the ship's doctor to aid an injured lighthouse keeper (said to have been fallen on by a donkey). This became pure farce when it transpired he'd been bandaged so tightly that he couldn't breathe! Brown boobies flew aboard while we were hove to awaiting the casualty, presenting our bird man, Roger, with his first sampling problem. His attempts to wrestle with them and get them to vomit up their previous meal provided great entertainment and scope for several (unhelpful) suggestions.

The science begins

The novelty of sea-going rapidly morphed into serious science when we reached the Gulf of Aden. *Discovery* had become our home; camaraderie took over from family, while duty-free bar prices compensated for some of the catering deficits. Once off the Arabian coast in the South-West Monsoon, we embarked on a sampling programme (devised by Ron Currie) that was both a contribution to the IIOE and a stand-alone survey comparable to the earlier Benguela Current one by *Discovery II*. Life got serious, and the seas rough. Five lines of stations, at 10- and 30-mile intervals running out from the coast, were intensively sampled with vertical nets, water bottles and current meters, usually simultaneously. The ability of the bridge to keep three wires vertical – each with gear at different depths of up to 3500 m – from a vessel with a length of <100 m, seemed near miraculous. Rare tangles only emphasised the skills of the deck officers. Bathythermographs, bottom grabs, neuston* nets and a few midwater trawls added to the variety.

***Four of the five IIOE 'novices'** (the fifth appears overleaf)*
***Left** Peter Brewer and Martin Angel relax at an end-of-cruise party*
***Below** Roger Bailey on Hasikaya island with two blue-footed boobies*
***Bottom** Graham Topping attaches an open water bottle to the hydrographic wire*

*Neuston is the collective term for the organisms that float on or in the surface layer of the ocean.

The author washing down the NF70V plankton net

A key interest was the possibility of commercially exploitable fish stocks in the region. Echo-sounder watches kept an 'acoustic eye' not only on the bottom but also on the scattering layers of midwater animals. The chemists received what seemed like a continuous stream of water samples for oxygen, nutrient and salinity determinations, which backed up like motorway traffic if there was any pause in the analyses to allow the chemists to sleep! We biologists had to deal with our samples at once, but when they were preserved we could breathe a brief sigh of relief – until the next station. Most systems broke down at some point: the for'ard steam winch failed during one hydrographic cast leaving 3.5 km of wire and bottles to be wound in by hand during the 4–8 watch!

Off Oman, fogs, dense blooms of algae and high zooplankton volumes were dramatic markers of cold upwelled water which was even more clearly delimited by its nutrient values. One night we encountered an amazing display of surface bioluminescence. A neuston net was launched and collected 7 litres of plankton instead of the usual few ml! We had encountered a dense swarm of luminous ostracods, so numerous that they came out glowing on the wings of emerging flyingfishes. The experience triggered a lifelong enthusiasm for ostracods in Martin Angel, and for bioluminescence in me.

The seas were often so rough that the accumulator on the aft net winch could not keep the wire from going slack as the vessel pitched, preventing the brass messenger from operating the net. A 'human accumulator' was added, with one of the watch continuously maintaining the tension by hand, hauling on a rope attached to a pulley through which the wire ran. An 8-hour-on, 8-hour-off watch system was death to our biological clocks, but breakfast at the end of the 12–8 night watch was nirvana. As students, we worked alongside the leaders in their fields, but perhaps only really appreciated our good fortune later. It was an eye-opener to discover that one very eminent fisheries biologist didn't delete the expletives from his field notes!

A brief mid-cruise port call at Karachi gave us a taste of life quite beyond our previous social experiences, and included *Discovery*'s impromptu cricket XI being routed by a team of Pakinstani naval cadets! A personal highlight was a night-time camel ride to watch turtles coming ashore to lay their eggs. Back at sea we could easily have believed ourselves to be alone in our endeavours (apart from the alarming appearance of implacable oil tankers) but radio discussions with *Atlantis II* emphasised that *Discovery* was one of many participating vessels.

A change of direction for Cruise 2

On our return to Aden, the science proposed for Cruise 2, run by Maurice Hill of Cambridge University, moved from what would now be called biogeochemistry to geophysics. Martin Angel and I left for a shore station in Zanzibar, but the other three John Murray students remained with the ship, which worked in tandem with HMS *Owen* for parts of the cruise. The emphasis was on the Carlsberg Ridge, which had been surveyed previously by HMS *Owen*, but two island visits were also made for studies of their birds.

Tony (later Sir Anthony) Laughton of NIO was Hill's deputy and was responsible for all the sea-floor photography, sometimes discovering fields of manganese nodules. *Owen* was the firing ship for the longer seismic refraction lines, using naval depth charges. On one occasion the *Discovery* scientists heard a colossal bang over the radio, just after the 'Charge away!' call. The charge had gone off prematurely, deluging and shaking *Owen*, but luckily no damage was done. At the end of this cruise *Discovery* returned for refit to the UK (instead of to Durban as originally intended), coming out again to Aden on 3 March 1964 for Cruise 3, a series of biological and physical studies in the western Indian Ocean.

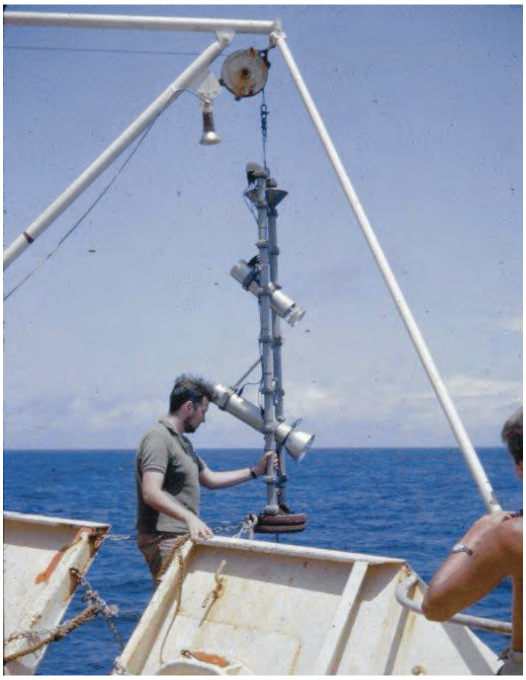
Martin Angel and I rejoined our fellow students but not without some unexpected events in between. In Zanzibar we had worked at the Fisheries laboratory. *Atlantis II* had called in and I was offered the chance to join her programme under Arthur 'Rocky' Miller, who said later that the IIOE witnessed the evolution of 'old-time oceanography into new-time oceanography'. We sailed to the Seychelles, Mauritius, and finally Cape

Town, and in December I returned from there to Zanzibar, where independence celebrations and a bloody revolution followed in rapid succession. Going 'home' to *Discovery* would be quite a relief! After brief escapes to East African game parks, Martin Angel and I returned to Aden and joined the others (who had been refreshed by Christmas at home).

Cruise 3: in for the long haul

Discovery's Cruise 3 lasted more than 7 months, from 15 February to 28 September 1964, with 344 stations. There were port calls at Aden, Mauritius, Cochin (two calls were made to this port, one scheduled and one unscheduled following the breakdown of the ship's electric motor soon after we left port), Seychelles, Mauritius again, Mombasa, and twice more to Aden, before returning home. During the second call at Mauritius, *Discovery*'s sporting capacity was again tested to the limit by a challenge rugby match. Fifteen volunteers were found, eleven of whom knew some of the rules, and we survived an honourable defeat!

John Swallow was the principal scientist for seven of the legs, and Ron Currie for the other two. Much of the physical programme was designed to investigate the equatorial current system and the Somali Current, while biology involved repeat sections off the Arabian coast and comparative work in the central regions both north and south of the Equator. More mid-water trawls were fished, reflecting the particular interests of Peter Foxton (shrimps) and Malcolm Clarke (squid), both of whom were actively involved in designing better ways of capturing midwater animals. By now we were more prepared for the fray, and appreciated the fact that the intervals between some stations were generally much longer than on Cruise 1. Nevertheless the emphasis on hydrography and chemistry again caused the water samples to accumulate and it was a relief to have additional help in dealing with these. *Discovery*'s hydrographic contribution was enhanced by the presence of three Australian oceanographers (Dave Rochford, Bruce Hamon and Fred Davies) who brought with them not only a prototype CTD (then known as a TSD) that was hung beneath the midships current meter, but also chemical expertise that allowed an invaluable intercalibration of UK and Australian analytical techniques (a key part of the original IIOE philosophy). The pressures experienced by the shipboard chemists were a major incentive for Peter Brewer to develop automated methods not long afterwards!



Preparing to investigate the sea-bed
Far left *Dick Burt (netman) and John Cleverley stand by to launch the explosives for seismic refraction on Cruise 2*
Left *John Jopling guides the sea-floor camera over the side*
Below *Alastair McIntyre deploys a grab to collect sea-floor samples on Cruise 1*

Somali Current stations

The international element of the IIOE was further emphasised by our collaborative operations in the Somali Current with the US ship *Argo*, though we sighted her only once. The current speeds made life very difficult. There could be up to 5 kt of shear between the surface and 200 m, and with two wires out at different depths, one could be streaming forward and the other aft while the ship struggled to maintain station against a surface current of up to 7 kt! The precious TSD left onboard by Bruce Hamon, and a Bergen current meter, were lost on one of the occasions when the two wires crossed. The drag on the hydrographic wire increased the wire angle and slowed the messengers to a degree that prevented some bottles operating effectively. 'Vertical' nets presented particular manoeuvring difficulties, with the ship's screw lying in wait for any errant gear. In the end, sampling had to be restricted to a single wire at a time, greatly slowing the progress of the stations.

IIOE Cruise 3 tracks: in detail, for 12 June–7 September 1964 (red track with stations) and, more generalised, for 7 March–8 May 1964 (pink) and for 12 May–8 June 1964 (mauve). The blue arrow is a generalised representation of the (seasonally varying) Somali Current.

Cruise 3 activities ***Above*** *John Swallow recovers an NIO water bottle brought up from depth.*
Left middle *Launching the Isaacs–Kidd midwater trawl, with (from left) Malcolm Clarke, Martin Angel, Harry Moreton (Bosun), Peter Foxton and two deck crew.* ***Below*** *John Cox (centre, Met Office), Arthur Fisher (left) and Graham Topping preparing a helium-filled Met balloon for the daily flight.*

Extraordinary fronts, marked by sudden surface temperature changes of up to 7 °C (and long lines of dead pufferfish, killed by 13 °C water at the surface), demonstrated the intensity of the upwelling events that we encountered. Oceanic regions had a more muted dynamism, and biological sampling elsewhere included night fishing for squid, where even the poorest of anglers had a reasonable chance of success. A shore party visited the island of Hasikaya (one of the Kuria Murias, off the Arabian coast) to study the seabirds. The dinghy's outboard broke down *en route*, resulting in Bob Nesbitt (by now a Commander) having to row half the way; the same happened on the return to the ship, and a rowlock broke too, so we returned on one oar! Six blue-footed boobies were collected, but only when we returned did we realise the shotgun had been left behind. Such visits were always a break from routine, and a treat for the biologists, but plans for others were mere Will o' the Wisps. The Cargados shoals, Agalega, the Farquhars, Astove and Aldabra all came and went during the Mauritius–Mombasa leg, because poor weather prevented any landings.

Frustrations with weather and with breakdowns on that leg generated a keen student anticipation for the Mombasa port call, though it was an enthusiasm that John Swallow, whose science programme had been disrupted, did not share. By the time we reached Mombasa, rust stains had caused *Discovery*'s tropical white to look pretty drab, but a rapid paint job on the hull by port labourers on pontoons almost restored her pristine state – until it peeled off again not long after in the Somali Current.

A glimpse of the future

Chemistry and hydrography combined in spectacular fashion in the Red Sea on the return home. In 1958 *Atlantis* had found suspiciously warm water near the bottom at about 2000 m and in 1963 both *Discovery* and *Atlantis II* had noted something similar. John Swallow set a deep hydrocast over a sea-floor depression of about 200 m (later named Discovery Deep) in a bottom depth of ~2000 m. The bottles came back with the most extraordinary samples: those nearest the bottom contained hot brine (44 °C), so saline (>270‰) that it crystallised when it dripped on deck! The hot, dense, brine pools even produced an odd acoustic layering visible in the echo-sounder records. They provided a tantalising glimpse of the existence of undreamt-of sea-floor phenomena, namely hydrothermal vents and brine seeps, which were not recognised until 13 years later. It was a fitting finale to a spectacular voyage.

The legacy of the IIOE

The IIOE ran from 1959 to 1965 and involved some 40 research vessels and scientists from 33 countries. Its flexible structure led to rather disjointed collaborations, but the core data were incorporated in three massive atlases summarising the physical, biological and geological/geophysical achievements. *Discovery*'s new design and her consequent capability for servicing all the scientific disciplines underpinned the UK's contribution.

What did NIO gain from the IIOE? The three *Discovery* cruise reports present the station data and a basic narrative. Yet the legacy was much, much, more than the science. The undertaking vindicated all the effort that George Deacon had invested in its genesis: it tested the capabilities of the new ship to the full; it gave a real feel of international seagoing collaboration with NIO in the vanguard; it cemented relationships between individuals and disciplines as no other activity could have done; and it stimulated a whole range of new interests and techniques that kept NIO at the forefront of oceanography for years to come.

Finally, five postgraduates had the times and experiences of their lives and couldn't wait to sign on for the longer term! Graham Topping went first to Strathclyde University and then to the DAFS (now CEFAS) laboratory at Aberdeen, where he joined Roger Bailey who had gone there straight from Oxford. Roger went on to become Fisheries Secretary for ICES, but sadly died in his late fifties. Peter Brewer went to Woods Hole Oceanographic Institution where he stayed for 24 years before joining the Monterey Bay Aquarium Research Institute (MBARI), becoming its President and CEO from 1991 until 1996. Martin Angel and I rejoined our shipmates at NIO, later IOS, and undertook many more *Discovery* cruises (34 in my case), which simply reinforced our affection for the vessel and all her quirks.

The first three *Discovery* cruises took 16 months, but in the subsequent 49 years there have been almost 380 more. Along the way, the pace of cruises has changed and so has the ship – of the original vessel, only the hull and foredeck remain. But for novices on their first cruise the excitement and anticipation has always been the same, and *Discovery* has been the nursery for many distinguished oceanographic careers.

Further Reading

Behrman, D. (1981) Assault on the largest unknown. *The International Indian Ocean Expedition 1959–65*. The Unesco Press, 96pp.

Currie, R.I. (1966) Some reflections on the International Indian Ocean Expedition. *Oceanography and Marine Biology Annual Review*, **4**, 69–78.

Deacon G.E.R. (1964) The International Indian Ocean Expedition. *Nature*, **201**, 561–2.

Deacon, G.E.R. (1961). The International Scientific Expedition to the Indian Ocean. *The Geographical Magazine* **34**, 284–93.

Foxton, P. (1965) A mass fish mortality on the Somali coast. *Deep-Sea Research*, **12**, 17–19.

Laughton, A.S. (2003) IIOE: recollections of the International Indian Ocean Expedition. *Ocean Challenge* **13**, No.1, 18-24.

Swallow, J.C. (1965) The Somali Current: some observations made aboard RRS "Discovery" during August 1964. *The Marine Observer*, **35**, 125–30.

Swallow, J.C. (1964) The equatorial undercurrent in the western Indian Ocean. *Nature*, **204**, 436–7.

Swallow J.C. and J. Crease (1965) Hot salty water at the bottom of the Red Sea. *Nature*, **205**, 165–6.

Wooster, W.S. (1984) International Studies of the Indian Ocean, 1959-1965. *Deep-Sea Research*, **31A**, 589–96.

Peter Herring joined NIO in 1966, having taken part in the SOND cruise in 1965. He has spent several years of his life on *Discovery*, concluding with cruise 243 in 1999. He studied bioluminescence, colour and vision in deep-sea animals and his nine cruises as PSO introduced many international colleagues with similar interests to the capabilities of *Discovery* and the sampling skills of the IOS biologists. He retired in 2000, continuing part-time at NOC until 2008. His interests now extend to trees and fungi. pjherring1@tiscali.co.uk

Photos provided by the author and Graham Topping

A tribute to Anton Brunn

An inspirational leader and gifted scientist

Torben Wolff

On 13 December 1961, the day before his 60th birthday, Dr Anton Bruun died suddenly in the middle of a meeting where we were discussing the defence of the first doctoral thesis arising from the *Galathea* Expedition (1950–1952). On several occasions he had told me that he wanted a quick death. He certainly got what he wanted, but unhappily it took place when rich working years should still have lain ahead of him, and when cooperative oceanographic investigations, then at the planning stage, would have benefited from his undoubted talent for working with people.

Born in Denmark in 1901, Bruun was the son of a farmer, and was probably destined to follow a life in agriculture. However, as a child he contracted polio and instead embarked on an academic career – one that turned out to be remarkably active and adventurous, not the quiet life that a polio sufferer might have sought.

Bruun became a student in zoology in 1920 and a Master of Science in zoology six years later. Meanwhile, he was also attached to the Danish Fishery Research Institute and went on cruises in Danish and North Atlantic waters. Of great significance for Bruun's development was his participation in the 1928–30 circumnavigation of the *Dana,* where he and the Expedition leader, Professor Johannes Schmidt, were the only zoologists. His work during this expedition laid the foundations for his insight into oceanographic techniques, and his knowledge of animal life of the sea and oceanography in general, all of which later allowed him to be an excellent leader of expeditions.

In the following years Bruun worked intensely on the *Dana* collections. In 1938 he was appointed assistant curator at the Zoological Museum of the University of Copenhagen, and in the same year led his own research cruise, this time to study the bottom fauna off the coast of Tunisia. During the 1930s and the early 1940s he published a number of weighty treatises, of which the first and foremost was his 1935 doctoral thesis on the flying fishes of the Atlantic Ocean. However, his interests extended far beyond flying fishes, and around that time he published on a wide range of subjects, including fisheries biology, leeches, cephalopods, bivalves and gastropods.

Immediately after the end of the war, Bruun was assigned the leadership of a nine-month cruise to the coast of tropical West Africa. This was on board a large privately owned yacht, the *Atlantide*; working on such a vessel (even with the owner taking part in the expedition, as in this case) places heavy demands on the leader. However, Bruun´s diplomatic abilities and his open manner contributed to making this expedition an unqualified success.

Although the *Galathea* Expedition began in 1950, it was originally conceived nearly ten years earlier. There was a lot of support for the idea, but conditions in Denmark after the war meant that it was a challenging enterprise. It was primarily Bruun´s project and without his endeavour would never have been carried through. It was he who saw the scientific possibilities in continuing the intensive work of the *Dana* in the water column of the open ocean, through an expedition primarily focussed on an investigation of the animal life of the deep ocean, including the trenches, having ascertained that life did indeed exist there.

In addition to his experience as expedition leader, his personal qualities were also ideal for this kind of responsibility. From the first day of a cruise he was by virtue of his even temper and personal charm the unifying force onboard and an essential contributor to the good spirit which predominated on the *Galathea*. He was also an excellent representative of the expedition to the outside world, whether it be the highest authorities, university teachers or students, or Danes living abroad. In harbour after harbour, the goodwill that surrounded the visiting ship was largely due to his capacity for gaining friends wherever he went.

It is easy to see why, after the *Galathea* Expedition, Bruun recieved offers from all directions. In 1958, he was elected Secretary General of the International Union of Biological Sciences but had to resign from the post because of ill health. Nevertheless, he continued to be active in international oceanographic matters, becoming deeply involved in the planning of the International Indian Ocean Expedition, inspired partly by the International Geophysical Year in 1957–58.

(Photo by courtesy of the Natural History Museum, University of Copenhagen)

His last decade was marked by much travelling, and by participation in a succession of international congresses and meetings in institutions of marine research. His knowledge of languages, great experience and commonsense made him a splendid negotiator and intermediary at these meetings, and he was an indefatigable spokesman for marine biological research off Denmark and elsewhere. He was involved in the creation of SCOR (Scientific Committee on Oceanic Research), and a short time before his death he was honoured by being chosen as the first President of the newly established Intergovernmental Oceanographic Commission.

In these later years he produced a succession of treatises. In spite of their modest size most of them have been amongst the most frequently cited papers in the continuing discussion about the origin and spread of the fauna of the deep sea.

Anton Bruun´s enormous circle of friends in Denmark and abroad were shocked by his sudden and untimely death. He was widely missed, both because of his qualities as a human being and because he was an inspiring and perceptive person and an extraordinarily multifaceted naturalist.

Further Reading

Wolff, T. (1967) *Danish Expeditions on the Seven Seas.* Rhodos International Science and Art Publications, Copenhagen, 325pp.

Torben Wolff was the Executive Leader of the *Galathea* Expedition.

The ship renamed in honour of Anton Bruun

Tony Rice

The vessel known to oceanographers as the *Anton Brunn* (cf. Peter Herring's article, p.38) was 30 years old by the time she acquired this name, and had already had quite a colourful career. She began life as the luxury yacht *Aras,* built and launched from the Bath Iron Works in Maine in 1931 for the wood-pulp magnate Hugh J. Chisholm. She was steel-hulled, around 244 feet long and with a 36-foot beam, powered by two Winton diesel engines driving her at a speed of 13.5 knots.

After a decade of catering for the foibles of the American wealthy (but possibly not so great or good), she came down to earth with a bit of a bump in 1941 when she was purchased by the US Navy and refitted in Brooklyn, New York, to re-emerge as the gunboat USS *Williamsburg*. After fitting out at the Norfolk naval yard, Virginia, the *Williamsburg* arrived at Halifax, Nova Scotia, on 6 December 1941, the day before the Japanese attack on Pearl Harbour. After the declaration of war by the USA against the Axis powers later the same month, the *Williamsburg* was sent to Iceland and spent the whole of 1942 in the northern Atlantic.

1943 and 1944 were also spent mainly in the northern Atlantic, but mostly off the east coast of the US, based in the Hampton Roads–Chesapeake Bay region. Plans to convert her into a specialised amphibious force flagship (for employment in the Pacific) at the Norfolk navy yard in the summer of 1945 were curtailed after the Japanese surrender in August. Instead, she was converted back into her original role as a luxury vessel and replaced the USS *Potomac* as the presidential yacht in November. She remained in this role throughout the remaining tenure of President Harry S. Trueman and briefly into that of President Dwight D. Eisenhower, until he directed that she should be taken out of commission in May 1953. For the next eight years or so the *Williamsburg* was more-or-less mothballed, first at the Washington navy yard and then at Newport, Rhode Island, until she was finally removed from the US navy list in April 1962.

But this was the springboard for her brief, but significant, scientific career. Transferred to the ownership of the National Science Foundation in August 1962, she had all her presidential trappings removed and replaced by the much more basic paraphernalia of a 1960s oceanographic vessel, including winches and a crane for handling over-the-side gear. Her first two years as a research vessel were spent almost entirely in the Indian Ocean as part of the United States' contribution to the International Indian Ocean Expedition (IIOE) and it seemed therefore totally appropriate to name her in honour of Anton Bruun whose contribution had been so vital, but who had died only months earlier, in December 1961.

The rules for commemorating a person in the name of a vessel are normally pretty similar to the rules for being canonised. The person being honoured has to have been able to perform miracles – in the sphere of oceanography, mostly scientific or political ones. Then they generally have to have been dead for a long time, presumably so that all their enemies are no longer about to rubbish their reputation.* However, Anton Bruun's personality and achievements were such that naming a vessel after him within months of his death was viewed as wholly fitting.

During 1963 and 1964 the *Anton Bruun* undertook ten cruises during which her international scientific complement gathered vast amounts of data as well as biological collections. Eventually, after the conclusion of the IIOE, she returned to the USA in February 1965 and continued her oceanographic career with a series of cruises, particularly in the Pacific.

In 1968 it was decided that ownership of the *Anton Bruun* should be transferred to the Indian government so that she could continue to contribute to the understanding of the Indian Ocean as she had done during the IIOE. Sadly, and somewhat ironically, during work in a floating dry-dock in preparation for this transfer the dry-dock itself sank and the resulting damage to the *Anton Bruun* made her restoration as a research vessel uneconomical. Her glory days were now well and truly over and the *Anton Bruun* story began a downward spiral.

*Classic British examples are the vessels *Charles Darwin*, *James Clark Ross* and *John Murray* and the slightly more precipitate *Frederick Russell* and *Alister Hardy*.

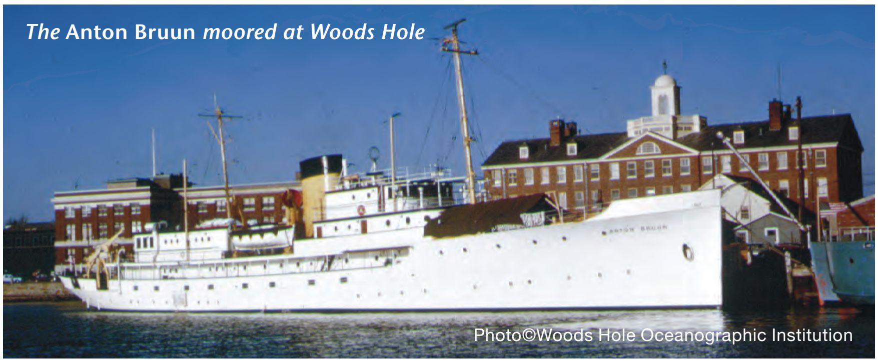
Offered for sale by the US Maritime Administration she was purchased by a commercial organisation and was installed in a berth on the Salem River at Pennsville, New Jersey, where she became for several years a floating (actually grounded) hotel restaurant. Naturally, the name 'Anton Bruun' would have meant little to her new clientele and accordingly her owners reverted to the *Williamsburg*, her name when the presidential yacht.

Finally, in 1993 the old ship, now 62 years old, was sold once more and taken to Genoa in Italy, apparently to be converted yet again into a luxury yacht. Perhaps not surprisingly, this conversion was never undertaken and the poor old lady is now languishing at a navy wharf at Rapallo, Italy, where she is offered for sale for a mere 8.8 million euros, with an estimated cost of 33 million euros to restore her to her former splendour (see www.yactworld.com/boats/1930/USS-Williamsburg-Custom-1603111/Rapallo/Italy). If no takers are found, her ultimate survival seems to hang by a thread, dependent upon the success or otherwise of her preservation society based in the US, which has the aim of bringing her home. Interestingly, her dedicated supporters belong to the 'USS *Williamsburg* Preservation Society', who seem to be unaware of her short-lived but glorious career as a research vessel.

Further Reading

Nelson, S.B. (1971) *Oceanographic ships fore and aft.* Office of the Oceanographer of the Navy, 240pp.

Tony Rice is a deep-sea biologist, formerly of the National Oceanography Centre, Southampton.



The Anton Bruun *moored at Woods Hole*

Photo©Woods Hole Oceanographic Institution

Recollections of *Discovery*

Malcolm Clarke

In 1962 the National Institute of Oceanography (NIO) accepted a sparkling new ship – 100 m long and 2665 tons in displacement, *Discovery* was able to carry 40 crew and 21 scientists. Here was a ship which was built to allow us to do all the things we couldn't do on *Discovery II*. I first saw her the year before she was launched when I ventured through Aberdeen to examine a Ph.D student. I introduced myself at the shipyard and was duly issued with white managerial overalls and allowed to nose around the part-built ship to see for myself what progress was being made and, more to the point, how the design would match up to a biologist's dreams. (It was no surprise that on my return to Wormley, Henry Herdman took only an hour to seek me out and admonish me for my nosiness.)

Discovery was painted white in preparation for her first expedition, which would be to the Indian Ocean. Her lines were smooth and she had a crane on her poop deck to handle large trawls over the stern. She had a large opening in her bottom through which we could look into the sea and lower instruments – although we biologists never did. She had a bow propeller which helped to keep the ship 'hove to'. There was luxurious lab space which we quickly filled up, and wonderful cabin accommodation, lined on all sides with smooth plastic panelling and – best of all – air conditioning. The original design of the ship had been revised so that the vessel was shortened by cutting off the stern, and the ship transferred the waves' energy into a pitching motion which only transformed into rolls in very rough seas. When this happened, all unattached furniture was flung hither and thither in dangerous fashion and no-one was what you might call remotely comfortable below.

The main gripe of the biologists was that *Discovery*'s deck was much further above the water than in the old ship, and to fish for squid, or land the catch of long lines, we needed to suspend a platform from the ship's side. This sometimes seemed a bit exposed, especially when large sharks came around, and a hasty retreat up the rope ladder sometimes led to unseemly competition between friends. Also, on the old ship, the ship's rail was a little lower which led to Ron Currie (who was short) cracking a rib as he helped to lower one of my pop-up nets over the side: his planned improvement in the new ship brought it to *my* chest level with the same result for me when I lowered my first net over the side. Clearly he had the foresight of a promising leader!

Although the new ship lacked the soul of the old one, had no coziness and was clad like a kitchen, we adapted to it and it grew on us. Its bar became more friendly, and its food and water became much better. We found that we could eat our meals off a table in the normal manner, rather than having to hold our plates in one hand while using a spoon with the other. We could also do more science from the ship, and with less danger than previously, but it was still not a good platform for my own hobby of launching large trawls.

Shakedown

During the 'shakedown' cruise all the ship's gear was tested and all manner of exciting problems arose involving considerable scientific effort. To start with, all the wires on the winches were covered in thick tallow. As the wires were paid out and the tallow was squeezed out of them, it had to be scraped off by as many as seven people using twists of cloth and pieces of wood as the wire was pulled inboard. The small vertical winches broke down when the wire was fully out and on one strenuous morning John Swallow and I wound the 5000 m of wire in by hand with a car-starter type of handle. The warp on the main trawl winch had to be paid out to stretch the wire before it could be used for trawling. However, after a few thousand metres were out it was noticed that the end flanges had been buckled by the weight of the wire and could not be used again. Then the wire on the large coring winch on the foredeck was paid out and would not come back in. We waited and scratched our heads until suddenly, without warning, it slowly started coming in. It turned out that the electrician working in the hold had accidentally touched his screwdriver across two terminals and started up the winch again. Other things worked splendidly and the labs, constant-temperature room and scientific accommodation were vastly superior to the old ship.

Two years in the Indian Ocean

Then for two years *Discovery* participated in the International Indian Ocean Expedition, which involved 43 ships of as many nationalities. I planned to join the ship at Bombay (Mumbai) and, on the way, Roy Bowers and I took a little leave to call at Athens, Istanbul, Baghdad, Tehran and Bombay. Our boarding the plane at Istanbul was delayed a little and at first we were placed in seats well apart. Roy had a quiet word with the stewardess and she obligingly placed us on some vacant front seats, which they had planned to keep empty. After the trip I asked Roy what he had said to get us our new seating. 'Oh' he said, 'I just said you were mad and unreliable and I was your nurse.' Leaving Baghdad for Tehran, a massive barrier of mountains rose in front of us. The pilots (who were visible to us through the cabin door) placed newspapers across the windscreen to blot out the morning sun and then read books until we neared Tehran.

Our trip from Tehran to Bombay was at night. We were told that all alcohol would be confiscated at Bombay so we decided to tackle our bottle of brandy; this caused our air hostesses a little concern, particularly when I reached up to adjust the overhead light and somehow brought down 15 feet of the cabin ceiling onto our heads revealing a mass of coloured wiring.

We arrived at Bombay airport in a glorious dawn and took a long taxi drive past many miles of a slum with apparently one roof, and long queues, each for a single water tap. We booked into a hotel opposite the main gates to the harbour. Our hotel served meals to an accompaniment of Victorian-style music produced by a band decked out in white uniforms with red sashes and turbans. After we had settled in and had breakfast, we entered the port confident that we would easily find *Discovery*. During the morning we were propelled to the front of several long queues by excessively kind officials. We finally

The author with a deep-sea ray caught on a drop line

found out, from a charming powerhouse of a woman answering three phones at once, barking at several acolytes and obviously in command of numerous situations, that the *Discovery* was 1000 km away in Cochin, southern India. We returned to our hotel for the heat of the afternoon and spent some time booking a flight to Cochin.

We were amazed to see that at night first the traffic islands and then the footpaths and roads filled with sleeping people. Next day we thoroughly enjoyed our unscheduled sightseeing air trip down the west coast of India in a pocket-sized aircraft. We finally stood within sight of the ship with relief in our hearts and just one rupee between us. We persuaded one of the boatmen to take us across the gap – he agreed on the understanding that we rowed. And so we joined the ship, tired and penniless but grateful at finding her.

We left Cochin on 19 May 1964. The routine hauls I had to do involved vertical nets known as NF70Vs (see p.40). An NF70V had a flow meter in the mouth to enable us to calculate the volume of water fished, a depth gauge on the end to show us the depth at which the net had started and finished fishing, and a throttle which would stop it fishing when it was closed by a brass messenger running down the wire. By knowing the rate of fall of the messenger we could calculate the depth it would meet the rising net, so we could close the net at any depth we chose. The full series had nets open 5000–4000 m, 3000–2000 m, 2000–1000 m, 1000–900 m, 900–800 m, 800–700 m, 700–600 m, 600–500 m, 500–400 m, 400–300 m, 300–200 m, 200–100 m, 100–50 m, and 50–0 m. While nets were being fished open the ship's officers had to keep the ship as still as possible relative to the water or the samples would be collected obliquely rather than vertically. That was a very skilled operation, and not infrequently impossible if there were currents below the sea-surface, although the bow propeller was a considerable help.

Biologists of the NIO had a great tradition, stretching back to between the Wars, that gear should never be lost at sea. The first net I tried to put out was thrown into the air by a wave – the wire hitched over a groove already worn in the pulley supporting it, which cut it straight through. I watched open-mouthed as one precious net and its equipment sank out of sight. I then worked ever so carefully on a grid south of Arabia until we moved to the Equator.

Here, the physical oceanographers had recently discovered an Equatorial Undercurrent flowing eastward below the wind-driven westward surface current. In the core of the current, about 100 m down, flow speeds reached 2 kts or so. We deployed nets to 1000 m, water bottles to 5000 m and current meters to 500 m across the current system – all at the same time! Not surprisingly, we tangled the three lots of gear several times. The first time, the rope throttle of our net was cut through as a result of the impatience of a water catcher who brought his bottles up full pelt although he knew there were tangles between his wire and our net. We biologists then hid a wire inside the vulnerable rope throttle on our net and we did not lose another net until a month or so later when we were approaching the port of Mombasa where I was due to leave for England. I was very shy of meeting Ron Currie who was relieving me at Mombasa. He was not at all amused at my loss of depth gauges and flow meters and three nets. However, by the time he returned to England three months later he was much more understanding – not only had he seen the conditions we had been working in, but he had himself lost a net on his first launch into turbulent water off Mombasa.

Adventures in the Seychelles

We called in at the Seychelles at a time when visitors were strictly limited. Most of the men over 18 years of age had gone to Africa to work and venereal disease among the rest of the population was very widespread. Sex seemed to be a major topic of conversation for everyone from diplomats to servants. As if reflecting this preoccupation, the unusually formed Seychelles double coconut, the coco de mer, looks uncommonly like the middle of a woman, and uncommonly like the middle of a man when it germinates (the nuts were sold specially cut to emphasise these features). The coco de mer only grows in the Seychelles, and for hundreds of years was only known of through being cast ashore around the Indian Ocean.

While in the Seychelles, I broke a toe. My arms had just been loaded up with a number of large pineapples by Roy Bowers. We were in the market and I turned to step down off the half-metre-high concrete ramp. What I could not see was a half oil drum with its near side directly under my foot. I trod on the near side, did a forward roll and the other side came hard under my other foot across the toe. My graceful loop through the air in my beautifully pressed colonial white shorts, the shower of pineapples and my pedalling bare legs caused a general howl of amusement from the large crowd, which changed to cries of sympathy as soon as they saw the blood. Helpful hands bore me aloft to the fountain and my wound was bathed with copious amounts of water, and dressed. Later I learned those soothing waters were full of hookworms and *Schistosoma*, the flukes that carrry Bilharzia, and should not be even touched, let alone used to clean a wound. However, I came to no harm from our visit to the market, except from a violent allergic reaction to a surfeit of pineapple juice.

In search of Aristotle's Nautilus

A visit to Mauritius has less bizarre memories. The town square had a statue of 'Victoria, our much regretted Queen'. Seeing a pearly nautilus shell in a shop window, I thought I had discovered the first from the western Indian Ocean. I nearly bought it for a pound but then asked where it came from. 'The Philippines' was not the answer I expected or wanted. However, I learnt from a shell collector I met at a party that the pearly nautilus lived on a reef to the north of the island but all the available shells had been given to a scientist on a recent visiting American oceanographic ship! When I told Anna Bidder, my 'cephalopod mentor' at the time, she exclaimed, 'Aristotle was right!' He had referred to 'Nautilus' and everyone thought he must mean the paper nautilus, *Argonauta*, because the Greeks never reached the Pacific. But the Greeks *did* reach the Indian Ocean.

While in Mauritius we were delayed because the ship's log (which records the speed of the ship though the water), protruding as it did from the ship's bottom, had been bent over by a whale and we had to wait for a hard-top diver to straighten and then cut it off and rivet a plate across in its stead. His diving seemed to require innumerable cups of coffee and much sitting in the sun, while his burly assistants leant on the large hand wheel of the compressor pump smoking and, we imagined, deciding how to spend the vast amounts of money our visit had afforded them.

Mauritius was a pleasant stop with interesting strolls through tea plantations, glorious silver beaches and wonderful swims on undamaged reefs. However, my ignorance of the animal kingdom meant that I had quite a shock on first encountering metre-long sea cucumbers, those soft snake-like echinoderms with nothing but sticky threads to entangle prey. Fresh in my mind was discovery of a sea snake in the laboratory one morning – a colleague had thoughtfully placed it in a dustbin after netting it over the side. There are about 60 species of sea-snake; most of them are extremely venomous, even lethal, and choosing the correct antidote depends on identifying the species. That was why, when confronted by several snake-like cucumbers, I made a rapid exit from the water. But I soon learnt better and, when I did encounter sea-snakes in the sea, I mistook them for cucumbers.

While I waited, I arranged to go round a Japanese tuna factory ship. I learnt that the factory ship had a fleet of 12 tuna vessels, each of which shot and retrieved 100 km of line each day. The fleet followed the tuna between latitudes 5° S and 5° N in a line across the equatorial Indian Ocean. A vessel spent a month at sea before returning to the factory ship to disgorge the catch. The factory ship returned to Japan each year to be replaced by another. When we were in Mauritius, the catch averaged 2 tonnes of fish per haul but when the Japanese first came to the Indian Ocean only four years before the catch had been 20 tonnes per haul. This was at a time when the efficiency of the Japanese tuna fisheries had not been generally recognised.

Discovery in the North-East Atlantic

After the Indian Ocean cruises we settled into regular annual biological cruises on *Discovery* in the north-east Atlantic. In November and December of 1965 I went on the SOND cruise, which spent most of the time to the south-east of Fuerteventura in the Canary Islands. We used a large range of nets, including the Engels mid-water trawl (EMT), which was my special responsibility. This enormous net had a mouth some 20 m high by 35 m wide. The otter boards weighed 750 kg each and the net had 100 aluminium floats on its headline. Between hauls, launching and retrieving the net was difficult, dangerous and time-consuming. To make it possible to fish three hauls in a night, I developed a method, when the net lay astern, of pulling the cod end in over the top of the net, emptying it and then paying it out over the net so that the full net was not brought in board until three hauls had been completed. To keep within as small an area as possible I fished the net in a triangle and took in the cod end after each leg. I later adopted the same method with the RMT90,* the easier and far less dangerous replacement for the EMT. Within an area 25 miles in diameter I reckon we towed nets for 1000 miles.

My other interests were to develop and calibrate the rate of rise of a small pop-up net, the use of deep-sea cameras to photograph deep-sea squids on the continental slope, and the use of bottom lines to catch larger fish. Although my main aim was to catch squids, among many fish I only caught one cephalopod, a deep-sea octopod. We made continuous records with echo-sounders at 10, 26, 36, 54 and 68 kHz to try to correlate catches of midwater animals with particular frequencies shown on the echo-sounder traces. This led to a group of publications detailing many aspects of the effects of daylight and moonlight on the depth of animals.

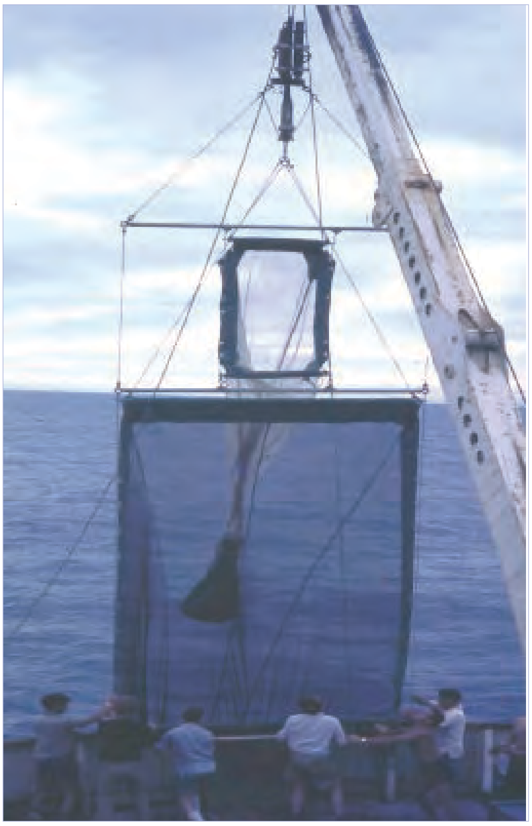
The Engels mid-water trawl floats astern after launch

On all the oceanographic ships it was obligatory for anyone having a birthday to organise a party in the wardroom with a range of small eats and free drinks, finishing off with liar dice or other rough games appropriate to the ship. During the *Discovery* cruises 'letting ones hair down' usually involved singing songs (latterly with the aid of computer printouts of a songbook), accompanied by Julian Badcock on the guitar and Bob Aldred on his banjo. Bob never believed that he got his job as my assistant mainly because he played the banjo and spent his vacations as a student lifting heavy furniture, and not primarily because of his degree in zoology. (He was also good at cutting hair!)

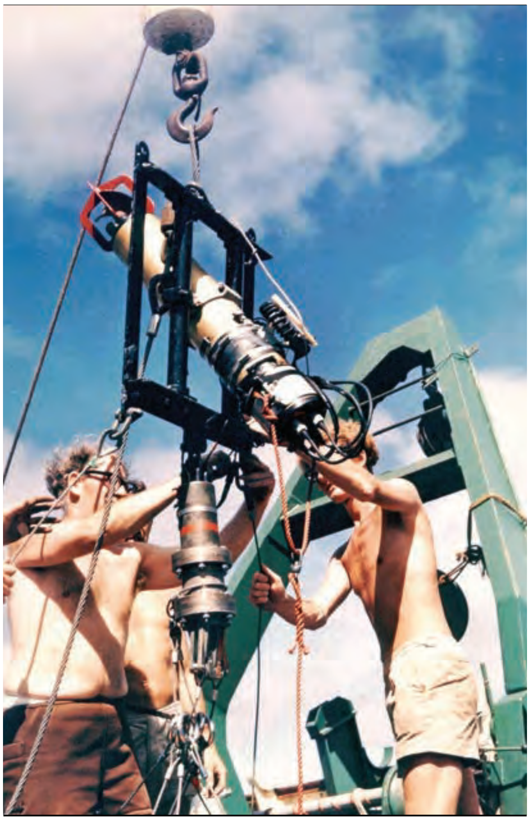
On long cruises certain non-scientific skills were much appreciated: here Bob Aldred gives the author a trim

*The RMT90 was a rectangular mid-water trawl with a sampling area of 90 m^2.

In October and November 1966, I led another cruise to the Fuerteventura position to collect observations to compare with those from the previous year and also with results of sampling done earlier on cruises off Madeira, the Azores and Morocco. I had a good run of Engels trawls and pop-up nets. This cruise was marked by a potential rebellion. All the scientists wrote a formal letter to me, as Chief Scientist, to complain about the food which was generally considered totally tasteless. I then had the job of giving the good news to our ex-marine, ex-boxer, Chief Steward. He was not amused, but things did improve.



Launching the opening/closing rectangular midwater trawl (RMT1+8)



Howard Roe (right) and the author deploying the first monitor for the opening/closing net, designed and built by Derrick Bishop, Roy Bowers, Dicky Dobson and Malcolm Harris

Life on board *Discovery* was particularly comfortable as Chief Scientist as my cabin had its own shower room and state-room for entertaining and planning. It was designed as a replica of the Captain's cabin and lay directly below his. The planning of cruises, which came with the job of Chief Scientist, was always pleasurable for me. My own obsession with developing sampling gear, with the overall aim of catching more and larger animals with better information on their depth of capture, supported my own and colleagues' interest in ecology as well as providing numerous animals for physiological, taxonomic and anatomical research. In the interests of economy, I was able to fill the scientific complement with very talented biologists from all the universities and Institutes who wanted information on a diverse range of animals. It gave me a wonderful opportunity to enjoy their company for three months and make lasting friendships.

In July to August 1967 I was Chief Scientist overseeing 'Physiology and biological gear trials'. A three-month cruise during 1969 was mainly spent between the Canary Is and the Cape Verde Is. We used the first RMT combination net, RMT1+8 (with fishing mouth areas of both 1 m^2 and 8 m^2) and a new RMT90 which was much easier to use off *Discovery* than the Engels trawl; the RMT90 caught much larger animals and all were in better condition than those caught with nets of other sizes and designs. We completed a day and night vertical series of RMT1+8s at 18° N, 25° W. Working with us were the eminent physiologist Prof. Eric Denton and his team who made many discoveries on buoyancy, eyes and bioluminescence of deep-sea fish and cephalopods.

From January to April 1968 I took part in the cruise down the West African shelf and then an intensive study of the vertical distribution of animals at 11° N, 20° W and again off Fuerteventura. This was when the physical oceanographers kindly lent us their first TSD (temperature, salinity, depth instrument). I was lowering the instrument, which John Swallow had valued as the same as a new Rolls Royce, when Dick Burt came to my side to pass the time of day. 'When will this be in?' he asked. 'Quite soon' I answered. 'I'm only putting it down to 2500 m.' 'Is there that much wire on the winch?' he wondered. We both looked over the top of the housing and there we saw the clean central barrel of the winch appearing as the last turns of wire unwound. I stopped the winch with unseemly haste and thanked my lucky stars. On this cruise we discovered that the deep water to the north of the shelf rolled onto the shelf and then southwards along it in boluses until it sheared away into deep water near Dakar. Here the life died, making our nets slimy and green.

In 1970 a vertical series with the RMT1+8 was done at 40° N, 20° W. Bad weather during the cruise meant that we had to shelter behind the islands of the Azores. For eight days we lay in the lee of the island of Pico and although the wind was more than 30 kts the swell was low enough to allow us to work a new RMT25 opening/closing net and long lines to depths of as much as 1253 m. The stomach contents of the sharks we caught included a piece of thin condom-like rubber, several deep sea cephalopods, a piece of whale blubber and adults of a tapeworm whose larval stage is found in the blubber of whales; all very intriguing.

From large to small, from basic to smart

My final cruise on *Discovery* was in 1976 as a guest. As the nets were relatively small we caught no cephalopods of interest and I found the regular echo-sounding watches a bore. It left me thinking that we collected too much information 'in case we needed it'. I had been at the forefront of all this collecting of sea states and currents, and weather and salinities, and temperatures and water depths, and net depths and ship speeds, and winch speeds and net speeds, and positions and directions etc. etc. and I have to admit that much of it was never used. In my subsequent work on *Challenger, Frederick Russell* and *Sarsia* I reduced such paperwork to the minimum and things seemed to work just as well.

Further Reading

Clarke, M.R. (1969) A new midwater trawl for sampling discrete depth horizons. *Journal of the Marine Biological Association of the United Kingdom*, **49**, 945–60.

Clarke, M.R. (2003) Searching for deep sea squids. In *Coleoid cephalopods through time. Neontological approaches to their palaeobiology in the light of the fossil record*. Berliner palaeontologische abhandlungen.

Baker, A. de C., M.R. Clarke and M.J. Harris (1973) The N.I.O. combination net (RMT1+8) and further developments of rectangular midwater trawls. *Journal of the Marine Biological Association of the United Kingdom*, **53**, 167–84.

Clarke, M.R. (1977) A brief review of sampling techniques and tools of marine biology. p.439 in *A Voyage of Discovery*. Suppl. to *Deep Sea Research*, ed. M. Angel. Pergamon Press.

Clarke, M.R. (2006) Oceanic cephalopod distribution and species diversity in the Eastern North Atlantic. *Aquipelago. Life and marine sciences*, **23**A, 27–46.

Malcolm Clarke began his association with the NIO by serving as an NIO-backed Whaling Inspector during his Ph.D. He was at the NIO from 1958 to 1972 and then continued to work on squids and their predators, as well as developing nets with lights, at the Marine Biological Association of the UK, in Plymouth. He semi-retired in 1987 and now lives on the island of Pico in the Azores, where he continues his research and, with his wife Dorothy, has founded a 'Sperm whales and squids' museum. mac@clarkes.co

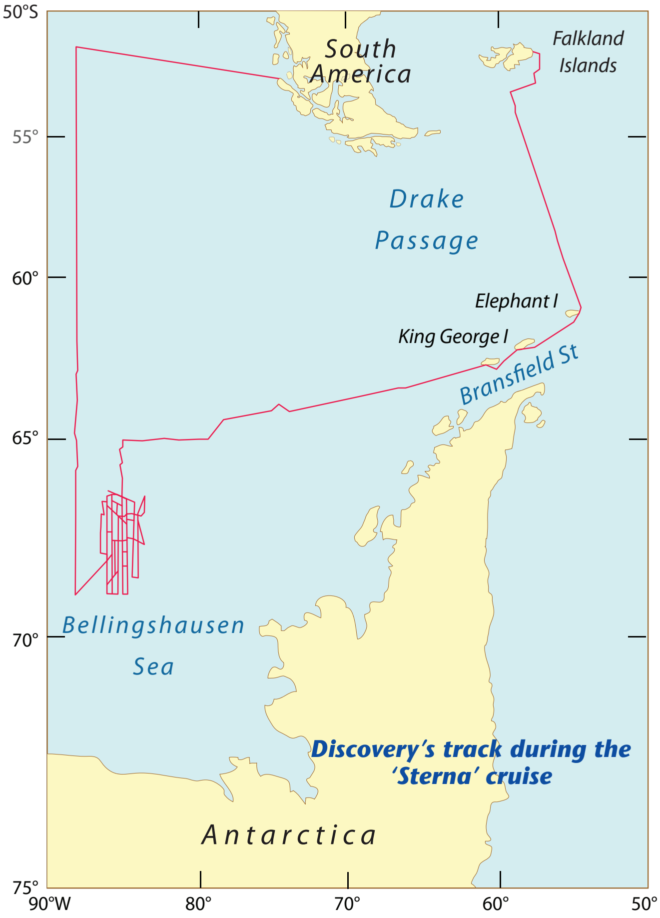
Photos provided by Howard Roe and Peter Herring

Discovery's 'Sterna' cruise

As described elsewhere in this issue, during 1991 *Discovery* was completely gutted, lengthened and rebuilt. This was done to increase her endurance and to provide a better platform for future international multidisciplinary research programmes. Brief trials took place in the Atlantic before her first season of research cruises, to be undertaken in the Southern Ocean. The first cruise (number 198) was planned by the Plymouth Marine Laboratory and the British Antarctic Survey, under the auspices of BOFS (the Biogeochemical Ocean Flux Study) and was called 'Sterna'. It was to be multidisciplinary and mult-project, with two ships surveying the ice edge in the Bellingshausen Sea. The primary objectives were to investigate the importance of the region as a sink or source of climatically significant gases and to evaluate the magnitude and variability of the biogeochemical fluxes associated with the spring phytoplankton bloom.

The cruise also included two sections for WOCE (the World Ocean Circulation Experiment) and hydrographic surveys for the IOS Deacon Laboratory research project 'Physical processes determining the structure of the upper ocean'. The plan was for *DIscovery* to survey the open water north of the ice edge, following the ice as it retreated, while the BAS ship, RRS *James Clark Ross*, investigated the water beneath the solid pack ice.

DIscovery sailed from the Falkland Islands on 11 November 1992 for her six-week cruise. Jane Read's account (*starting overleaf*) conveys what it was like to be on *Discovery* during that cruise.



Discovery's track during the 'Sterna' cruise

Letter from Discovery

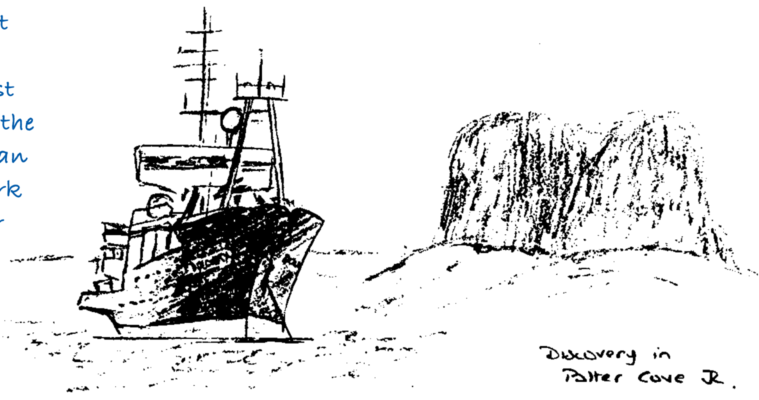
Jane Read

Nov. – Dec. 1992

Some things never change – the Discovery used to roll, and she still does, even in the slightest of swells. It's a long slow roll that never seems to end – not even when you, and your chair, are flung across the lab. I lost my first mug as soon as we sailed out of Berkeley Sound (leaving the Falkland Islands). Fortunately we had good weather as we headed south across Drake Passage. It was foggy at times, restricting our work, but this, one of the roughest areas of the world's oceans, let us off quite lightly. We had a superb passage between Clarence Island and Elephant Island – glorious sunshine, crystal clear skies, spectacular scenery, all shapes and sizes of icebergs. Penguins, petrels, albatrosses and even a tern. Surely an Arctic Tern, *Sterna paradisaea*, must be a good omen for this, the 'Sterna' cruise.

Our next excitement came in Potter Cove at King Edward Island. Anchored for twenty-four hours while we calibrated an acoustic 'fish' device, we were given permission to go ashore to visit the Argentinian base. Sadly, rough and worsening conditions meant that only a few people made it, the chief engineer deciding that it was too rough to try to land anyone else. The rest of us had to make do with boat trips. But even that was fun – exhilarating, spectacular and wet.

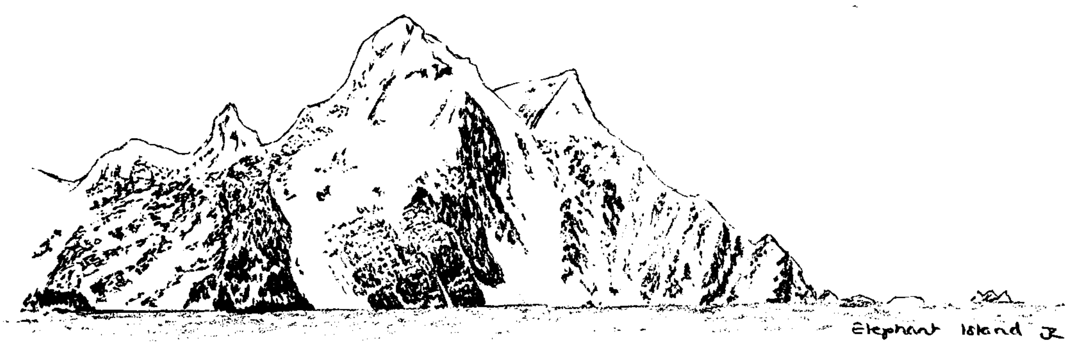
From Bransfield Strait we headed due west into the Bellingshausen Sea, stopping occasionally for a station on the way – just to keep our hand in. But before we reached the survey area we learnt that we were to have an early rendezvous with the RRS James Clark Ross. Our chef was very ill and the Master wanted to consult the doctor on the British Antarctic Survey ship.



Discovery in Potter Cove JR.

I would recommend a diet before joining ship. Not only was the food good, it was imaginative and very appetising. Some of us carnivores even explored the culinary delights prepared for the vegetarians on board. A far cry from the legendary days of hard tack and bully beef. The new 'cafeteria' system worked well, and the 'two-sitting system' almost vanished as the cruise progressed and people came and went as they pleased. Meals became a lot more sociable than they used to be. So that it was with great concern that we learned that our chef was sick.

It was an anxious afternoon – rumours and counter-rumours abounded as we waited for the doctor's diagnosis, and the Master's decision, and then a decision from the Research Vessel Service base and another from the British Antarctic Survey.

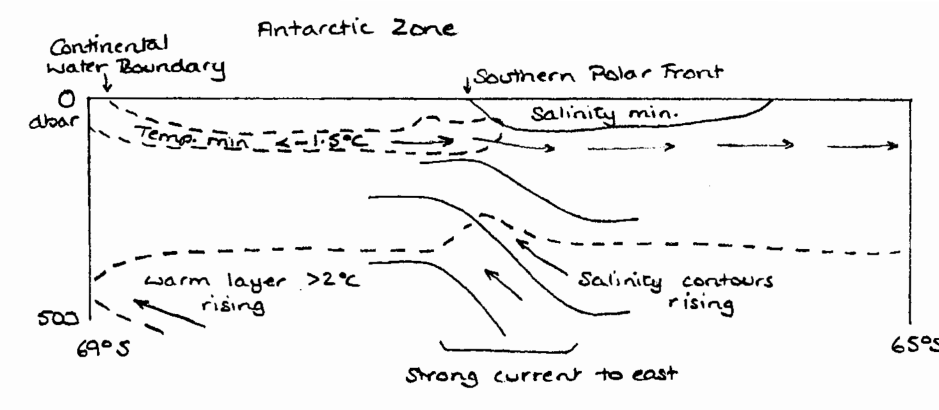


We worked on our intercalibration exercise, drawing off water samples and exchanging them with our opposite numbers on the James Clark Ross, but we still found time to linger – had anyone heard anything? Eventually our waiting was over. Despite the bad conditions, our invalid was to be transferred to the James Clark Ross and they would evacuate him to the hospital on the Falkland Islands.

We tried to keep out of the way but were reluctant to leave the rails as one of the small boats was hoisted on board and the sick man – so pale that he was barely recognisable – climbed into the boat with the doctor, to be let down as gently as possible into the stormy sea. We waved good-bye as they sped back to the James Clark Ross, and she made off, full speed into the deteriorating weather. We waited to hear our own fate: an overnight break, then on with the survey! (During the remainder of the cruise we were kept up-to-date with bulletins of the chef's condition and were pleased and relieved to hear that he made a good recovery. Meanwhile, the remaining catering staff took on the extra work of the chef and did an excellent job of keeping us fed.)

After delays from the bad weather we were eventually able to start our ice-edge survey, and made our way down to the starting point. From the bridge, we could see a long line of white marking the horizon. Bright sunshine caused it to sparkle, and as we drew closer we could distinguish the massive icebergs and thin brash ice in between. Time for us to turn back, as we were not ice-strengthened, but there were plenty of other icebergs around to see. We had to detour several times to go round them. For the next few days we surveyed backwards and forwards, approaching the ice in the day, heading away from it in the 'dusk' that passed for night. We saw little of the ice edge itelf – most days it was shrouded in fog.

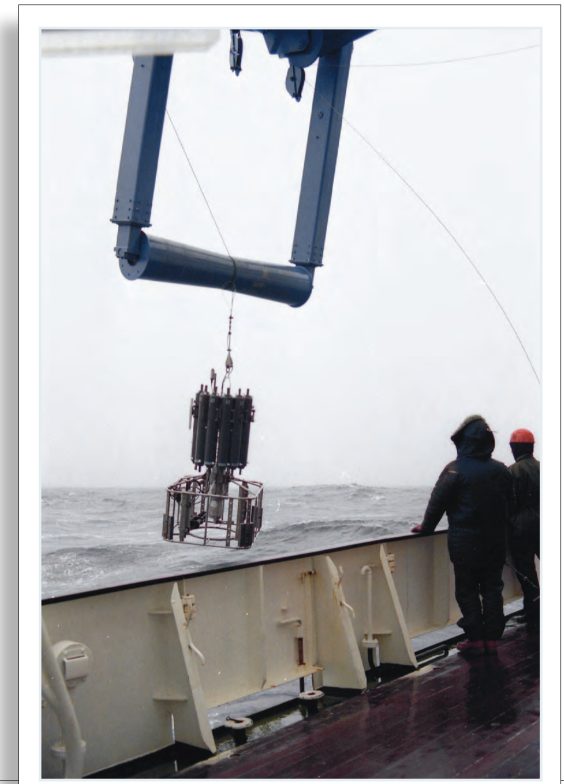
Our task was to map the temperature, salinity, chlorophyll and currents of the upper ocean, together with a wide variety of surface measurements including CO_2, light, various inorganic nutrients, biogases and phytoplankton production. Sampling the water was a chilly business – the highest temperatures reached only 2°C, while the lowest were well below zero. The surface layers were the worst, having been cooled to less than −1.5°C by the winter weather, although now it was spring, the surface was warming up, leaving a subsurface temperature minimum – a characteristic feature of the Antarctic Zone.



South to north section at 85°W, showing some of the hydrographic features of the top 500 m of the Antarctic Zone

We found that we were surveying a front, which we called the Southern Polar Front, where a tongue of fresh surface water lay almost due east–west and beneath which there was a strong salinity gradient. The gradient wasn't so noticeable in temperature, which showed steeper gradients further to the south, at the Continental Water Boundary. But the currents were most pronounced at the Southern Polar Front and showed a jet of water flowing to the east at speeds of up to 1.5 knots.

Upper: Bringing the water-bottle rosette onboard in less than ideal conditions. Lower: Taking seawater samples from the water bottles. On the right you can see the temporary wooden barricade that was erected when the lab door was smashed in by a wave.



Running alternately due north and south brought us almost beam-on to the swell and the Discovery's roll became more and more exaggerated. The galley lost a great variety of plates, bowls, dishes and glasses, and I lost my second mug. Just when we thought there would be nothing left to eat from, the Master called a halt to the scientific programme. Only to discover that we couldn't retrieve our gear. During the rough weather some bolts on the overhead gantry on the stern had sheared off and the massive roller arm was held in place only by a hydraulic ram. It was too rough to repair, but too risky to work underneath to recover our equipment. With 500 m of wire hanging over the stern we couldn't heave to, because of the risk of fouling the stern propeller. All we could do was steam slowly into the wind and sea and hope that at some stage the wind would drop enough for recovery. Some of us had visions of sailing on for ever and ever, unable to get out of our predicament. In fact, once again we were lucky. Next morning the weather had moderated and soon there were men swarming all over the gantry frame. It didn't take them long to repair things and they soon recovered our gear.

This was not the only problem we had. There were plenty of teething problems to be sorted out: the air conditioning couldn't be fixed until refit and despite sub-zero temperatures outside, the labs and cabins were hot and stuffy. On our passage west we took a heavy wave over the side which smashed the side door into the deck lab. We had to spend most of the day hove-to as the engineers welded a protective barricade in place. It looked like Fort Knox by the time they had finished, but it seemed that Discovery was vulnerable to waves. On the extremely stormy passage preceding our cruise one of the portholes had been stove-in, and this could have caused serious injury if anyone had been near.

So we had to have all the deadlights bolted down over the portholes in case it happened again and I thought the worst thing was the claustrophobic feeling this engendered. And it meant that we missed out on all that was happening outside when we were working in the labs. One scientist called the bridge at 4.30 a.m. to ask for deck lights to be turned on so that he could work outside. The mate wanted to know why he wanted lights because it was broad daylight! Well, we were not accustomed to nearly 24 hours of daylight.

After a break from our first survey it was time to start the second, a repeat of the first but further south to follow the retreating ice edge. But after only two days it ended even more ignominiously than the previous one – our equipment dropped off the end of the cable. It took some time for this news to sink in as we wandered around with dazed looks on our faces. This was definitely not planned. Later the same day we had another rendezvous with the James Clark Ross to borrow some of their equipment, and a technician to run it. It wasn't the same, but at least we were able to measure something. Still, it was with some relief that we gave equipment and technician back to the James Clark Ross a couple of days later and started on the last leg back to South America. For some this was the signal to visit the bar, to celebrate? drown their sorrows?

The bar was popular in all weather and at all times. Compared with the old bar, the room was so vast that the spare barrels of beer had to be kept in the library because it was closer than the other end of the bar. Both rooms, bar and library, were useful for meetings, large groups and small groups respectively. The saloon was also used but suffered the severe drawback of being directly above the stabiliser control valve. This debatably useless piece of equipment clanged and echoed like an old train in a tunnel. Normal conversation was made very difficult.

At last we came to the end of our final section. All the equipment was stripped down and packed into its boxes, and customs forms were prepared for docking. For some it was a time to relax, spend some more time in the bar or wander round the deck looking for the first sight of land. For others there was the more serious task of archiving all the data, so laboriously collected, that were to be analysed back at home.

Land!! Most people spent the best part of the day out on deck watching the scenery go by as we made our way through the Magellan Straits. We were no longer surrounded by sea but by bleak hills with snow-capped mountains beyond, and once, in some remote valley, the glimpse of a glacier. The pilot boat brought the pilot to us, to direct the ship on the very last part of its voyage, and eventually we docked at about 1 o'clock in the morning in Punta Arenas, Chile. All of us, of course, stayed around on deck to watch the momentous occasion. Later in the morning we began the interminable waiting that signifies the end of a cruise: waiting to sign off, waiting for dockside equipment, waiting for customs clearance, waiting for 'subs' (foreign money that is essential to our survival in a foreign country), waiting for transport, waiting to go! Eventually we made it. Ashore at last, and so begins the adaptation to 'normal' life. Waiting for the bed to stop swaying when you lie down. Listening to the ringing in the

A photomosaic of Elelphant Island, taken from the Discovery at ~61°S

ears – you become so accustomed to the continuous throb of the ship's engines which penetrates all but the most remote parts of the ship that you still hear them long after reaching home.

And how do people react to being ashore? Hugging a tree – or business as usual in the bar. Walking to stretch legs cramped by six weeks on board. Setting off to explore as much as possible of this strange new place chance had landed us in. Or slipping away to be alone for a little while, maybe make a quick phone call home ... or post that letter which has been six weeks in the writing.

This article was first published in *Ocean Challenge*, Vol. 4, No. 3, pp.33–6.

Jane Read is now a visiting scientist at the National Oceanography Centre, Southampton, where she has worked since it opened in 1995. Fieldwork has taken her to many parts of the world's oceans and her research interests include ocean circulation and the interaction between physical processes, biological distributions and biogeochemical processes.

Book Reviews

More than just swimming and adventure

The Oxford Handbook of Maritime Archaeology by Alex Catsambis, Ben Ford and Donny L. Hamilton (2011) Oxford University Press, 1203pp. £95 (hard cover, ISBN 13: 978-0-19-537517-6).

It's always a proud moment seeing a loved one grow to maturity and take their first tentative steps towards a life of relative independence. Pushing out on their own, out from under the shadow of previously restricting influences, and blossoming into a fully rounded individual, to be taken seriously in their own right. OK, enough of the melodrama, but this is the journey that Maritime Archaeology has taken over the last forty years or so. Whilst studying maritime archaeology I was mocked by some of my peers who described it as 'a degree in swimming and adventure' (a good enough reason to study it as any, I thought!). Times have changed now however, and much of the work presented here represents a burgeoning discipline that reaches far beyond the simple notion of 'shipwreck as a time capsule' that was used to encapsulate maritime archaeology for so long. Much more emphasis is placed on the study of maritime culture as a whole, and far more than simply shipwrecks are now studied to build our knowledge of the important role that the sea played in the lives of numerous communities around the globe. With the publication of this book, and several similar ones in recent years, it can now be demonstrated with some confidence that Maritime Archaeology has 'grown up'.

The book is split into seven distinct sections, with the first being an introduction from the godfather of maritime archaeology, George Bass. He starts with a potted history of the discipline and then outlines a few of the more important issues potentially affecting its progress, including the shortfall in publication of investigated sites, the treasure-hunting debate, and the problems with technology and funding affecting deep-water archaeology.

Part II is The Process, which over fifteen chapters describes various approaches which are applied to maritime archaeological projects. These include geophysical survey techniques, ship reconstruction both physical and virtual, various post-excavation techniques, and the storage of archaeological data. Chris Underwood writes an excellent account of the excavation planning and logistics of the HMS *Swift* project in Argentina. He outlines problems encountered on the site and their subsequent solutions, and then continues to describe each phase of the excavation and post-excavation work and even the outreach work to keep the local population informed. It's a brilliant explanation of all aspects of the work needed for a site from start to finish. These chapters give a good indication of the breadth of the discipline, but really only act as an introduction to each technique rather than a comprehensive guide. However, the extensive references at the end of each chapter give the reader plenty of scope for further research.

Part III, Ships and Shipwrecks, opens with five chapters describing the development of ship design around the Mediterranean and up into north-west Europe. The chapters then take on a more international flavour, encompassing southern Africa, the Red Sea, India, China, Australia and the Pacific, and then move on to American shores for chapters on the Caribbean, the Gulf of Mexico, South America, and also North American steamships. This section finishes with a chapter on 'Underwater archaeology of the world wars', highlighting the growing interest in 20th century war wrecks as archaeological sites, and looks at issues of conservation, wrecks as war graves and as environmental hazards (pollution and unexpended munitions), and the problems that may arise when archaeologists begin to investigate the wrecks.

An example of the content of these chapters is Lucy Blue's 'The Red Sea' in which she highlights the rich nature of this area historically and archaeologically as a major trade link and pathway between Europe and Asia. She also emphasises how work in this area is still very much in its infancy and would have so much more to offer if the resources were available.

Part IV is entitled Maritime Culture and Life Ashore and demonstrates how maritime archaeology now encompasses far more than just the study of shipwrecks. Christer Westerdahl opens the section with 'The maritime cultural landscape' which outlines the importance of looking at associated terrestrial and marine sites as part of a wider landscape geographically (or physically), culturally, politically, environmentally and technologically. The other chapters cover 'Coastal archaeology', 'Submerged prehistory in the North Sea', 'Ancient harbours in the Mediterranean', 'Shipyard archaeology' and 'Ship abandonment'.

Finally, there is an excellent chapter on 'Maritime communities and traditions' by Jesse Ransley, which stresses, by reference to her research in India, the importance of studying the communities themselves as well as the material culture; it also emphasises how ethnographic studies into ship-building technology can be vital where historical data are lacking.

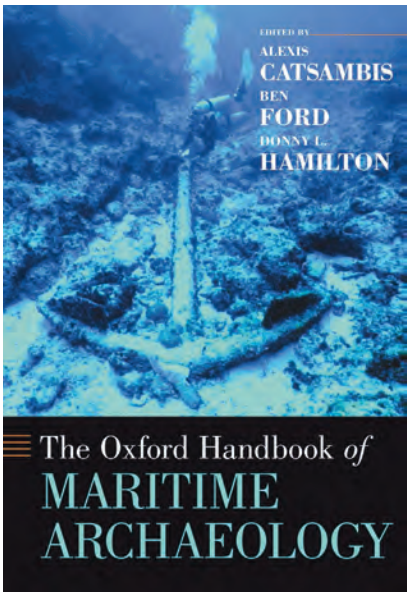
Part V, Beyond the Site, has an assortment of chapters that deal with various topical debates existing within the discipline today and in the near future. Ethics and law, resource management, tourism and presentation of maritime archaeology in museums are all included as well as a fascinating chapter on 'Maritime archaeology and industry' by Fredrik Søreide. He describes some of the conflicts between the archaeological community and industry, but also goes on to describe a case study where the two sides have come together to carry out outstanding work on the Ormen Lange gas field, located in the Norwegian Sea. A collaboration between the Norwegian University of Science and Technology and Norsk Hydro, a Norwegian energy firm with interests in oil and gas, allowed a deep-water survey and excavation to be carried out on a wreck site discovered during a survey for a proposed pipeline.The result was academically sound, professional archaeology, but with an industry budget provided by a commercial firm. It will be very interesting to see how this relationship between industry and maritime archaeology develops.

Peter D. Fix's chapter 'From sky to sea: the case for aeronautical archaeology' is another interesting one in that it argues, in much the same way that maritime archaeologists did several decades ago, that underwater aircraft archaeology should 'become an integral speciality within the theoretical framework of mainstream archaeology'. The section where he discusses terminology – whether it should be aircraft archaeology or aviation archaeology – is particularly reminiscent of the debates over the relative merits of 'underwater archaeology', 'nautical archaeology' and 'maritime archaeology' (amongst others). The chapter focusses on the large number of aircraft wrecks around the globe and some of the archaeology associated with them. These sorts of wrecks have rarely warranted much more then photo-spreads in *National Geographic* and tourist guide books, mainly due to their recent historical context and the fact that nearly all of these aircraft will be well documented. However, the argument is that, in the same way as has been proved with shipwreck archaeology since the times of extensive documentation of ship design, it can help understand 'historical perspectives, technological advancements, and period construction practices' missing from the documented history. It remains to be seen whether this subject will develop into anything more than a slightly specialised branch of the wider maritime discipline.

Part VI is a concluding chapter drawing together many of the subjects described in the book and outlining what the future may or should hold for the discipline. Part VII contains two appendices that should not be overlooked. The first is an extensive and very useful illustrated glossary of ship and boat terms by J. Richard Steffy. The second is a table of techniques for scientific analysis and dating, used for different materials.

One area in which this book excels is the number of different case studies that are present throughout the chapters. They range from the previously well documented like those in Colin Martin's chapter and the 'Pepper wreck' mentioned in Donald Sanders 'Virtual reconstruction of maritime sites and artifacts', to much more obscure ones like the aforementioned Ormen Lange site, HMS *Wager* off of southern Chile, or the shipwreck off Oranjemund, Namibia. Even if some of these sites are only briefly mentioned, their inclusion gives the reader the opportunity to find out more about them through the references provided. This goes to prove one of the key points made several times throughout the book – the importance of publishing survey and excavation reports. Leaving a site unpublished denies the rest of the academic community the knowledge gained and does nothing to further our understanding of maritime history.

The content is not as globally satisfying as it could have been: over half of the authors appear to be from North America, and so there tends to be a bias towards case studies in the Americas which, considering the abundance of material worldwide, is a little disappointing. There is very little mention of either the Baltic Sea or the Black Sea, which verges on the criminal, considering the former's rich heritage and the latter's future potential. The cold brackish water of the Baltic has provided hundreds of well-preserved wrecks that help chart the development of ship technology and trade routes in north-west Europe, whilst the anoxic nature of much of the Black Sea has already led to the discovery of several wrecks including *Sinop D* (referenced briefly in Chapter 9, Shelley Wachsmann's 'Deep-submergence archaeology'), and has the potential to yield scores of fascinating wrecks from periods, technologies and civilisations that have been poorly preserved elsewhere. However, these areas get scarcely more than a passing mention throughout the book.



In a subject as visually stimulating as this, it is a disappointment that there are so few images included. Granted black-and-white photographs and diagrams are liberally scattered throughout the book, and they are all very well presented, but with such a wealth of quality colour underwater photography available today it seems a shame that more advantage hasn't been taken of this material to bring some of these chapters to life. I acknowledge, however, that this volume is intended as an academic resource rather than as a pictorial account of the discipline, and that further photographs might have made the size (and price!) unmanageable.

The term 'handbook' tends to bring to mind a pocket-sized manual, useful as a basic introduction to a subject or as a handy reference guide to have to hand in the field. Well, this book certainly doesn't fit that perception. At 1203 pages long, it's a weighty tome that is unlikely to fit into the kitbag of any field operative, but may well take pride of place on a (slightly bowing) shelf by the computer, possibly alongside Muckelroy's *Maritime Archaeology* and Steffy's *Wooden Ship Building and the Interpretation of Shipwrecks.* It is by no means a complete guide to maritime archaeology, but it is a good overview of the work being carried out today and an indication of the directions in which the discipline is headed. It is not a book for beginners tackling the subject for the first time, but with an excellent balance between methodology, current archaeological theory and case studies, it is a valuable research tool for the experienced and enthusiastic maritime archaeologist.

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Into the blue

Beyond the Blue Horizon. How the earliest mariners unlocked the secrets of the oceans by Brian Fagan (2012) Bloomsbury, 313pp. £20 (hard cover, ISBN 13: 978-1-4088-2506-8; E-book ISBN 13: 978-14088-3350-6).

In 1851 Matthew Fontaine Maury, director of the US Naval Observatory, published the first edition of his *Physical Geography of the Sea*, followed by a whole series of updated editions over the next 20 years or so. Although often considered the first truly global oceanographic text, *Physical Geography* was based on rather little of what we would now consider to be firm oceanographic data. Instead, it grew out of the wind and current charts that Maury had been publishing in the 1840s to help sailing-ship masters to find better and more efficient sea routes. In turn, these charts had been based on wind and current observations meticulously extracted from ship's logs deposited in the observatory, supplemented by new information collected on special forms issued by Maury to naval and merchant vessels rents. In *Physical Geography* Maury extrapolated from these observations to try to describe and explain the oceanography of the world ocean. Though he came to many unjustified and incorrect conclusions, Maury's work represented a major advance at the time and provided a first synoptic view of winds and surface currents.

In *Beyond the Blue Horizon* Brian Fagan has tried to do a 'Maury' in reverse, using a wide range of archaeological information to deduce what our ancient seagoing ancestors must have known about oceanography to enable them to undertake the often remarkable voyages that they did. The basic question is: How on Earth did ancient mariners dare to venture out of sight of land with any realistic expectation of surviving, and especially of successfully returning home to where they started from? The author is well qualified to tackle this question, based on a professional life as an archaeologist and anthropologist and a lifetime's interest in small-boat sailing throughout the world's oceans.

Starting about 55 000 years ago in south-east Asia (modern Vietnam and Malaysia), he attempts to explain how our ancestors were able to spread slowly, but seemingly inexorably, south and east through what we now call Indonesia, by raft or canoe, with the minimum of technology. After about 25 000 years they had reached the region of the Solomon Islands, about half way across Melanesia. There is, apparently, plenty of evidence of travel and trade back along the chain of islands already passed, but the eastward progress seems to have more or less stopped for several thousands of years. About 3500 years ago another phase of eastward colonisation began, finally reaching Fiji, Tonga and Samoa by about 800 BC. So far, says Fagan, the migrations had been made largely by coastal sailing and island-hopping, with relatively short passages totally out of sight of land. Even these voyages required intimate knowledge of winds and weather, tides and currents, and an ability to 'read' the approach of land in such things as wave forms, floating debris and bird sightings. But about 1000 AD a new phase of colonisation began, involving sailing huge distances in fairly simple canoes across unknown waters almost entirely 'beyond the blue horizon'. Such journeys both depended upon and resulted in a much more detailed knowledge of changes in the weather and current patterns over vast areas of the Pacific, what we now explain by Hadley cells, El Niño and the rest. Modern radiocarbon dating techniques suggest that progress across the Pacific was rapid, reaching the Society Islands by about 1100 and New Zealand, Hawaii and Rapa Nui by about 1250, and the Marquesas not much later. Some Polynesian sailors, says Fagan, may even have reached South America some hundreds of years before Europe 'discovered' the Pacific.

Having 'done' the Pacific, where there are very few written historical records, Fagan deals in a similar way with the much better documented voyages in the Mediterranean, North Atlantic and Indian Oceans, again teasing out what the different seafarers must have known in order to undertake their journeys and why they did so in such different types of vessels. The sweep is enormous, from the Egyptians and Phoenicians, Greeks and Romans to the Vikings and medieval Chinese. And the range of written sources used alongside the archaeological evidence is equally broad, from Homer and the Viking sagas to sailing directions in mediaeval European rutters and portolans – and all points in between.

It is all fascinating stuff, but the sections I particularly liked were those dealing with what Fagan calls the Monsoon World, essentially the Indian Ocean. Unlike the Pacific, the early sea journeys here were for trading between shorelines already linked by overland routes, albeit long and difficult ones, rather than to colonise newly discovered lands. And the crucial key to the seafaring was an understanding of the regular alternation between the steady, and almost always gentle, north-east winds of the winter monsoon and the much more turbulent and less predictable south-west winds of the summer monsoon. For hundreds, possibly thousands of years Indian Ocean seafaring, at least in the Arabian Sea region, was entirely what is referred to as cabotage, i.e. coastal sailing with frequent trading port calls and using knowledge based on countless generations of experience. Then, about 100 BC a Greek navigator, Hippalus, learned to sail the direct route from Arabia to India using the south-westerly monsoon. Within a couple of hundred years, such open water sailing in the Indian Ocean became commonplace. So common, in fact, that some time during the first century AD a seafarer of the day produced the *Periplus of the Erythraean Sea*, one of the earliest known pilots or sailing directions for mariners, including descriptions of many parts of the Indian Ocean coastlines.

All this was almost 1500 years before Vasco da Gama's expedition sailed round the Cape of Good Hope in 1497 in tiny 30-metre long caravels to open up the Indian Ocean to western Europe. This was, of course, a tremendous achievement. But if he had made the voyage 70-odd years earlier he might have encountered one of the seven even more amazing Chinese exploratory and trading voyages across the Indian Ocean in the opposite direction, led by the military command administrator Zheng He between 1405 and 1433. The statistics of these voyages, given by Fagan, are awesome: tens of thousands of men in hundreds of vessels supporting treasure ships of up to 134 m in length and 55 m wide, some of the largest wooden ships ever built. The story of these remarkable voyages is still not widely known in the west; hopefully, *Beyond the Blue Horizon* will help to correct this.

So over all, what did I think of the book? I am no expert in this area and therefore have to take the interpretations and coverage more or less on trust. As far as I am aware, the treatment is pretty even and comprehensive, though I was a bit surprised that the single vaguely relevant topic that I have any knowledge of, the famous *Carta Marina* of Olaus Magnus, isn't mentioned. Published in 1539, *Carta Marina* is a map of the waters between north-western Europe and Iceland, incorporating all the contemporary knowledge about the area that Olaus could gather together. A recent reassessment by Thomas Rossby and Peter Miller (*Oceanography*, **16** (4): 2003) suggests that strange whorl patterns shown in the area north of the Faroes actually indicate what is now known as the Iceland–Faroes front, a region of great temperature, current and wind variability, apparently well known to the northern Atlantic seafarers of the time. This seems to me to be a superb example of what *Beyond the Blue Horizon* is all about, so why isn't it there?

But this omission apart, I found the book pacey, well written, very readable and full of fascinating information about topics that would interest many *Ocean Challenge* readers. My main grouse is not about the subject of the book *per se*, but rather a moan about the quality of production that I have noticed in many similar books in recent years. How is it that in an age when glossy brochures and catalogues advertising anything from wine to holidays, given away free in their hundreds of thousands, can be full of superbly reproduced colour photos, while the potentially informative illustrations in a book like this one, costing £20 or more, are in black-and-white only and are reproduced so badly that they might just as well not be there? But don't let my curmudgeonly moan put you off reading the book; despite the poor pictures it's well worth it.

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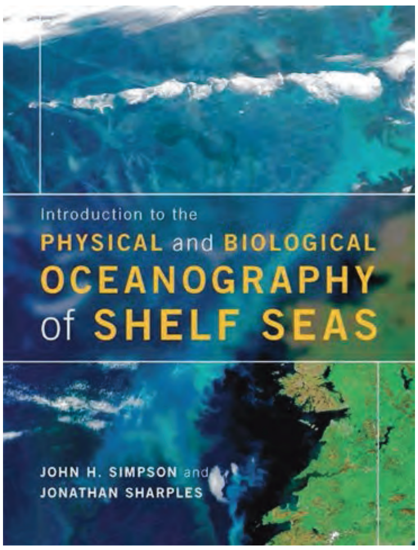
with an interest in the history of
oceanography

Interdisciplinary shelf-sea science

Introduction to the Physical and Biological Oceanography of Shelf Seas by J.H. Simpson and J. Sharples (2012) Cambridge University Press, 424 pp., £65 (hard cover, ISBN 13: 978-0-521-87762-6) or £35 (paperback, ISBN 13: 978-0-521-70148-8).

A few years ago I was preparing a module for fourth-year undergraduates who were studying at SAMS for the degree in Marine Science at the University of the Highlands and Islands. The module was on 'Coastal and Shelf Sea Dynamics' and I needed a text book that students could buy to accompany it. Unfortunately Bowden's classic *Physical Oceanography of Shelf Seas* was out of print and there was nothing else that really did the job for me. If only *Introduction to the Physical and Biological Oceanography of Shelf Seas* had been around then.

This book, in fact, would also have served other modules because it combines the physicists' understanding of the dynamical processes of shelf seas with an insightful and erudite description of the response to those processes by the phyto- and zooplankton ecology. The authors are well placed to write it. For many years John Simpson has been a world leader in research of the dynamics of shelf seas; and Jonathan Sharples has made an international name for himself by researching the borderland between small-scale physical processes and biological activity on the shelf. Both have taught their subjects to undergraduates. Their stated aim is to make this book 'accessible to a wide range of students from different disciplinary backgrounds' but I think that it goes beyond that because it will also help established researchers with either a physical or a biological background, to gain understanding of the other discipline, in what has become a very interdisciplinary field.



The authors successfully lead the reader through two very different but inter-related disciplines by first establishing the basic theory of the geophysical fluid dynamic regime of shelf seas (forced by the solar heating cycle, freshwater inputs, wind stress and tides), and how we measure it. These chapters are followed by one that is dedicated to the fundamental biological building blocks and cycles of the sea. This chapter includes a section with the fascinating title 'Finding prey in a viscous environment' which discusses the unexpected problem for small zooplankton which exist in a low Reynolds number fluid environment that makes the ocean seem viscous to them. (To find out how turbulence helps them find their prey, and how much time they need to grab hold of it you'll have to read the book.) Having introduced the basics of both disciplines, the text now becomes truly interdisciplinary and subsequent chapters commence with a description of a specific fluid process or system, which is then summarised before a final section that describes the biological response. This structure thus allows the authors to produce a well rounded book in which the two disciplines are neatly dovetailed. There is also a nice attention to detail and a very useful glossary; the book is well referenced and has a full index; and each chapter contains a set of exercises.

It's probably inevitable with a natural system as complicated and diverse as this that the authors should focus on the topics with which they are most familiar and have previously taught. So although they try to be global in outlook (for example the description of the Kelvin wave propagation is distinctly antipodean with the boundary on the left) the reader should be aware that there is a focus on the processes that dominate wide temperate shelves, and specifically the European shelf. The impression I get is that the authors are more comfortable talking about the processes on the shelf than those at the shelf edge, but to some extent there is good reason for this as exchange at the European shelf edge is still not well understood.

However, none of this detracts from the authors' outstanding overall achievement. Introduction to the *Physical and Biological Oceanography of Shelf Seas* ends with a plea for more interdisciplinary research given the increasing pressures that modern demands are placing on shelf seas. It is well placed to help students of oceanography respond to that plea.

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Revolutions that made the Earth by Tim Lenton and Andrew Watson (2011) Oxford University Press, 423pp.£29.95 (hard cover, ISBN-10: 0-19-958704-3, ISBN-13: 978-0-19-958704-9).

I found this book both an interesting and a somewhat unsatisfying read. Essentially, the book is based around two models for the development of intelligent life on Earth: the 'critical steps' model due to Brandon Carter (1983, developed further by Watson in 2008) and the Gaia model due to James Lovelock. The heritage is clear, as Watson was Lovelock's Ph.D student and, in turn, Lenton was Watson's Ph.D student. The authors designate the critical steps in the Earth's history as 'revolutions' and identify four in the history of the Earth (summarised in their Figure 20.1): the inception of life, the development of oxygenic photosynthesis, the development of complex life (evolution of eukaryotes – cells with nuclei) and finally the appearance of human beings, with language being the key factor for the last revolution. Each revolution is followed by the emergence of a new stable Earth, though the outcome of the final revolution, with regard to stability, is in doubt. That doubt arises from the uncertainty surrounding humanity's response to the changes that are occurring in the environment as a result of its own actions.

While their 'revolutionary' thesis is appealing, the evidence that is presented in the book is far from conclusive regarding the timing of these revolutions, which theoretically should be roughly equally spaced in time over the life of the Earth to date. The authors detail the scientific uncertainties associated with when life first developed, and when organisms first appeared that could carry out oxygenic photosynthesis. There is also the question of whether life developed once or more than once, the so-called 'second Genesis' possibility, that is not addressed by the authors. I was left somewhat unsatisfied in reading the book in that, while the revolutions thesis is interesting, the supporting evidence presented does not convince. Simon Conway Morris' book *Life's Solution* covers similar ground in a much more convincing way.

Many of the arguments advanced to support the authors' revolutions thesis are based on geochemistry and assume a degree of knowledge of that topic that goes well beyond that of even a scholarly reader, unless they have some background in the subject. The difficulty of following some of the arguments is compounded by the fact that quite a few of the diagrams are poorly explained, with undefined symbols, and some are too small to read easily (possibly a function of my ageing eyes). At least one figure is incorrectly captioned: Figure 19.6 is not the global temperature record but the global temperature anomaly.

The book ends with the authors' prescription for how the revolution involving humanity might achieve a stable outcome. Given humanity's impact on the Earth (one example being our use of fossil fuels, leading to increasing atmospheric carbon dioxide concentrations and so to global warming), it is not clear that a stable Earth will result from the latest revolution. The three options for possible futures are considered: apocalypse, retreat and revolution, with the way forward being revolution. To be successful, the required revolution has to be based on what we have learned about, and from, the previous three revolutions.

As this review is for an oceanographic journal it is worth saying that this is not an oceanographic book. Furthermore, it would probably not be the first choice if you looking for a detailed exposition of the Earth's history, whether geological, biological, chemical or physical. Finally, I am not sure that it achieves the authors' stated aim of writing 'scholarly popular science' (p.ix) as the arguments and science presented seem too detailed at points. Despite this, it is interesting and provocative read.

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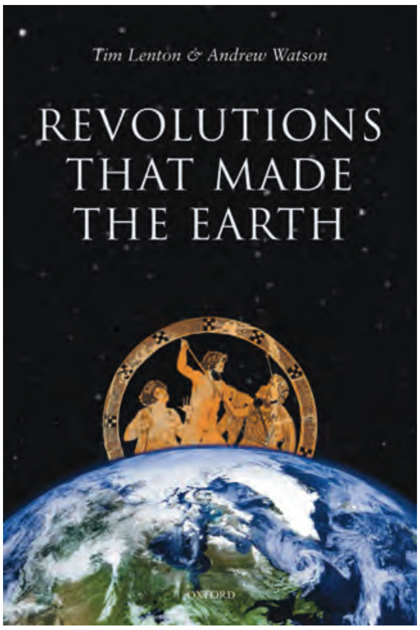
*Carter, B. and W.H. McCrea (1983) The anthropic principle and its implications for biological evolution, *Phil. Trans. R. Soc. Lond. Series A*, **310**, 347–63; Watson, A. (2008) Implications of an anthropic model for the evolution of complex life and intelligence, *Astrobiology*, **8**, 175–85.



Ocean acidification edited by Jean-Pierre Gattuso and Lina Hansson (2011) 352 pp. £37.50 (flexicover, ISBN 13: 978-0-19-959109-1).

The effects of ocean acidification on the biological, ecological and biogeochemical health of the world's oceans is a cause for concern, and may have serious implications for humanity. This book is a synthesis of the findings of recent national and international research efforts, including those of EPOCA (European Project on Ocean Acidification), set in a broader global context. It reviews our current knowledge of the chemical, biological, biogeochemical and societal implications of ocean acidification, with a particular emphasis on its impact on marine organisms and ecosystems. There is also an assesment of the uncertainties, risks and thresholds related to ocean acidification at molecular, cellular, organism, local and global scales.

This research-level text is the first to synthesise the very latest understanding of the consequences of ocean acidification, with the intention of informing both future research agendas and marine management policy. A prestigious list of authors has been assembled, among them the coordinators of major national and international projects on ocean acidification.

The book is intended for graduate-level students as well as professional researchers in oceanography and marine biology. It will also be of relevance and use to a more general audience of marine scientists and managers interested in the effects and potential impacts of ocean acidification.

For more about ocean acidification, see Ocean Challenge*, Winter 2011. There will be a lot more on the subject in forthcoming issues.*

The Challenger Society for Marine Science