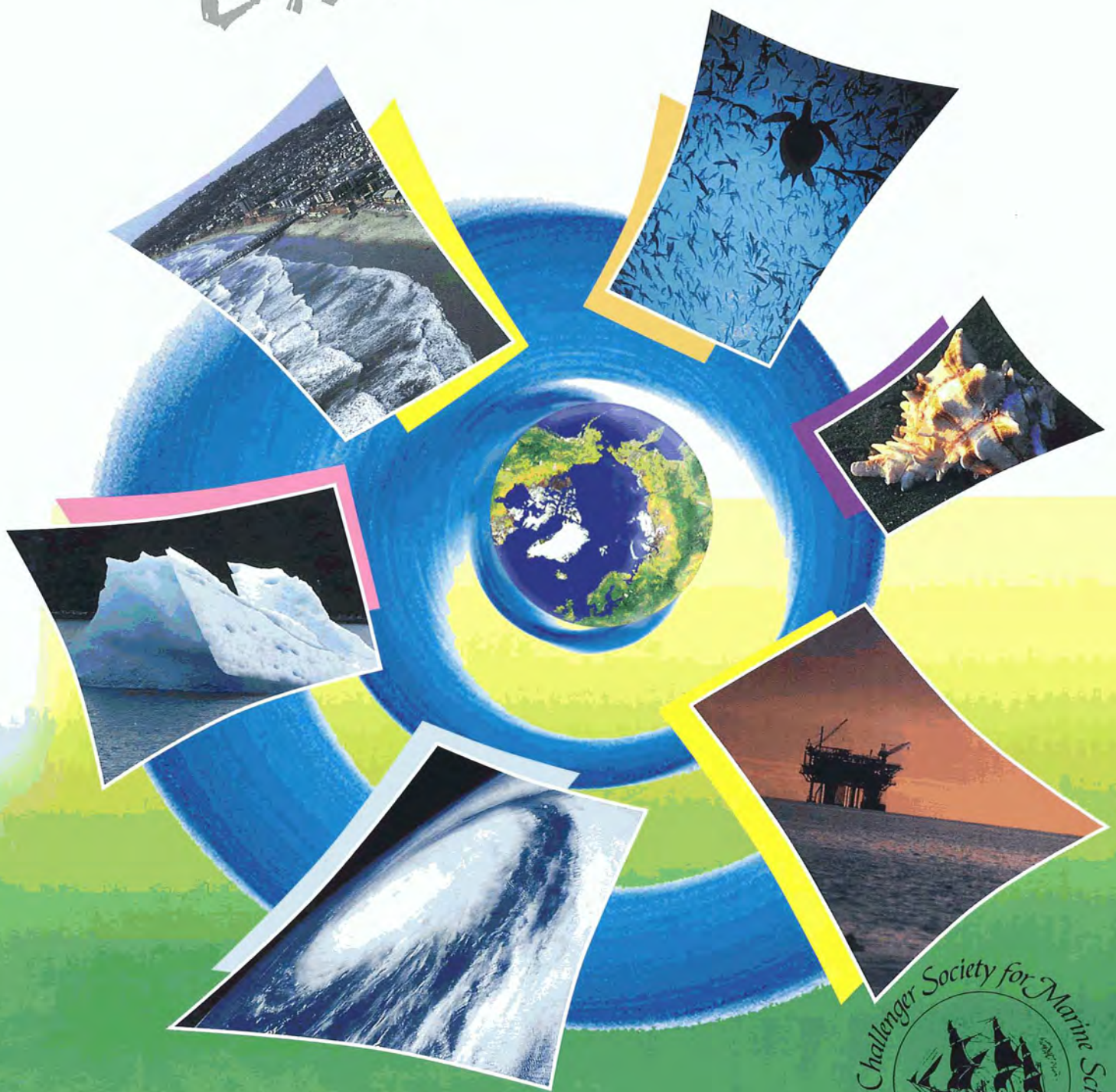
OCEAN Challenge



The Challenger Society for Marine Science

Volume 10, No. 3, 2000

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OCEAN Challenge

The Magazine of the Challenger Society for Marine Science

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SCOPE AND AIMS

Ocean Challenge aims to keep its readers up to date with what is happening in oceanography in the UK and the rest of Europe. By covering the whole range of marine-related sciences in an accessible style it should be valuable both to specialist oceanographers who wish to broaden their knowledge of marine sciences, and to informed lay persons who are concerned about the oceanic environment.

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CONTENTS

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LETTER FROM THE EDITORIAL BOARD CHAIR AND EDITOR

Dear Reader

Welcome to the final issue of Vol.10 of *Ocean Challenge*. At the end of a decade it's amazing to realize how far we've come. This progress is the result of the support of many members of the Challenger Society, and of friends and supporters outside the Society, who have contributed material, and organizational and artistic skills. We thank you all.

Over the next few years, we hope that *Ocean Challenge* will continue to develop. We hope to reach a wider audience throughout the European Federation of Marine Science and Technology Societies and to offset production costs with advertising revenues. These developments depend on the active support of all our readers, so do please continue to send us contributions – letters, news items and articles, short and long.

Tim Jickells
(Editorial Board Chair)

Angela Colling
(Editor)

On behalf of the Council,
Conference Organizing Committees and Members of the
Challenger Society for Marine Science
we would like to thank sincerely the following sponsors of the
UK MARINE SCIENCE 2000 CONFERENCE
for helping to make it such a resounding success

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Thank you!

Remembering UK Marine Science 2000

It's now some time since UK Marine Science 2000, but we begin this issue with a few pages recalling happy memories of Norwich. A summary of the prize-winners is followed (overleaf) by two personal accounts.

There were two winners of the Norman Heaps Prize for the best presentation by a young scientist. Ekaterina Popova (Southampton Oceanography Centre) gave a detailed account of ecosystem modelling and data assimilation in the north-east Atlantic. Ekaterina's presentation was highly visual, and used Powerpoint to great advantage, bringing together the different disciplines of her topic. The work presented by Andy Ridgewell (School of Environmental Sciences, University of East Anglia) was notable for its innovative use of data in models, which simulated the influence on atmospheric CO_2 of glacial–interglacial variability in dust deposition to the Southern Ocean.

The Cath Allen Poster Prize was won by Melanie Witt, with her poster on 'The complexation of metals in rainwater' (see above). The judging panel agreed that should Melanie ever tire of science she could have a career in advertising, with her flair for presenting complex material in an accessible and attractive format.

Melanie Witt with her winning poster

The winner of the President's Photographic Prize was Clare Postlethwaite (Southampton Oceanography Centre). Her photo (below) vividly conveys the harsher side of working in marine research.

The Wednesday afternoon coach excursion to Happisburgh, achieved in spite of the fuel blockade, was a great success. About a third of the party visited the beautiful and unusual East Rushton Gardens, while the rest went for a walk along the beach with Chris Vincent, to observe the effects of coastal erosion and view the artificial offshore islands, built as sea defences. The massive storm surge and flooding of 1953 are still a vivid memory along this part of East Anglia's coastline.

On Thursday evening, in the grand setting of Norwich City Hall, in the presence of the Chancellor of the University of East Anglia, Sir Geoffrey Allen, and the Lord Mayor and his wife, the Challenger Society awards were presented (for details of the awards, see Vol. 10, No. 1, p. 8). The Challenger Prize for the best student of the Open University's Oceanography course was awarded to Marion Rickard. Finally, Professor Peter Liss was presented with the Challenger Medal for his work in the field of air–sea gas exchange and other key aspects of marine science, including aerosol formation, iron fertilization and climate change.

The presentations were made by retiring Challenger Society President, Professor Harry Elderfield, who shortly afterwards passed the historic Challenger gavel to Professor John Shepherd, the incoming President.

'Searching for a previously marked sea-ice sampling station on Saromako, a frozen sea-lagoon on the Okhotsk Sea coast of Japan'
taken by Clare Postlethwaite

Periods of rain, with brighter spells ...

Carol Janzen

Moving to a foreign country is probably the farthest thing from the mind of a student writing up a doctoral dissertation, but I was pleasantly surprised to find such an opportunity while attending the Ocean Sciences 2000 Meeting in San Antonio, Texas. I backed into two young oceanographers from the UK who were enjoying pre-dinner cocktails at an honorary party for Dr Richard Garvine. Little did I know that striking up a conversation with them would prove to be a life-changing experience. A month after completing my dissertation, I found myself storing most of my personal possessions and moving from the University of Delaware to work at the University of Wales School of Ocean Sciences, Bangor. The title of this piece alludes to the weather forecasts that so amused me when I first arrived – all apparently variations on the same watery theme!

My first experience on the job, besides the endless paper trail of bureaucracy, was to attend the UK Marine Science 2000 Meeting in Norwich, which was my formal introduction to the UK oceanography community. While walking in the East Rushton Old Vicarage Garden during the afternoon of social events, my comrades and I met a woman with whom we candidly discussed the merits of the meeting over a pot of tea and some thigh-enhancing cake. Our companion turned out to be the Editor of *Ocean Challenge*, and in light of our discussion, she asked if I would summarize my thoughts on the meeting for an upcoming issue of *Ocean Challenge*, providing an American point of view. Here, I do my best at summarizing the key points I reflect on when I think about the meeting and my first week in the UK.

First, I extend my compliments to the organizers for working around locality issues and unexpected (and successful) fuel embargos. The catered lunches and dinner were very good as well as convenient. Going off-site to eat would have posed a difficulty in terms of both distances and lack of transportation (or, rather, lack of fuel for transportation). The mid-week afternoon of social events, a time set aside to relieve the 'brain strain', was a good feature of the conference format. It was nice to be able to take a break to digest the first half of the meeting without feeling guilty about skipping an afternoon of talks. The most notable event at the meeting was the reception and dinner at St Andrew's Hall in the historic centre of Norwich. The location was very posh and the food excellent. The live music and dancing, in particular, were different from my usual conference experience. This event clearly was a positive way for people to unwind as well as get to know each other outside the more constrained atmosphere of the conference.

I enjoyed the daily programme, where each day kicked off with a keynote speaker in a befitting discipline. Keynote presentations such as 'The Tracer Gauntlet' (Bill Jenkins) gave a nice synopsis of where we've been and where we are going in oceanographic research, whereas others, such as 'Plankton Organisms and Biogeochemical Cycles' (Victor Smetacek), illustrated the voids in our understanding of some widely studied oceanographic processes.

I was impressed with the breadth of work presented at the meeting, and in particular, with the transition to multidisciplinary research the oceanography community is making here. When the title promised multidisciplinarity I found that, generally, the promise was fulfilled. Some examples that come to mind include the number of biophysical coupling presentations, including 'Phytoplankton survival in the shelf-sea thermocline' (Jonathan Sharples *et al.*) and 'Modelling studies of krill survival during transport across the Scotia Sea' (Bettina Fach *et al.*). What we can learn from many of the presentations given in Norwich is that the continuation of coupled, interdisciplinary observational and modelling studies is necessary – for example, you cannot do it with models alone.

In concert with Victor Smetacek's keynote address, Michael Steinke, Gill Malin and Peter Liss presented a story about the use of infochemicals by phytoplankton as indirect defences in aquatic foodwebs. This presentation should have really excited the 'up and comings' in marine biology if it excited a physical oceanographer like me.

I have to admit that I was surprised at the number of 'ocean processes' talks compared with the number on shelf seas, given the extensive coastal environment of the UK. It would have been nice to have had more of the coastal seas presentations given in talks, rather than placed in the poster session.

During the presentations, I noticed how polite presenters and audiences were to each other. Members of the audience decorously posed their questions, often crediting the merits of the presentation before raising the the question. I find this different from our approach in the US, where we tend to be less gracious and more direct in our questioning – a style which appears somewhat aggressive to my peers here.

As with every conference, there were things that could have been improved upon. I kept hearing that one purpose of this event is to give students an opportunity to present to their peers, yet I found that many of the student presentations were put into the poster session. The quality of the posters at this meeting was amongst the finest I have seen, and I commend all those who took the time to make their stories clear, legible and colourful. However, making oral presentations is invaluable experience for learning how to present and defend the key elements of one's research to a larger audience. Therefore, more emphasis should be placed on students giving oral presentations at this meeting in the future. I think this could be accommodated easily by shortening the presentations to 15 minutes.

As for the Tuesday night discussion on 'What Marine Science is For?', it wasn't until the following morning, in Professor Margaret Leinen's talk, 'Ocean Science: Catching the Coming Wave,' that any real answer to this question was given. One important aspect I felt was missing from the discussion was how to bridge the gap between policy and science effectively.

Overall, I was pleased to have the opportunity to attend this meeting as my first experience in the UK oceanography community, and look forward to future meetings with my new friends and acquaintances.

Carol Janzen is working on the EU Project on 'Oceanographic applications to Eutrophication in regions of restricted exchange' at the School of Ocean Sciences, Bangor.

Can the curmudgeon have mellowed?

John Wright

Everyone agreed it was a brilliant conference, and Tim Jickells and his team fully deserved the applause they got. It was wonderful that all the Key-note presentations were in plenary sessions, also that there were no more than two parallel sessions, which were literally on top of one another (in lecture rooms on adjacent floors). That made moving between them really easy – especially as nearly all the session chairs followed the time-table very well. Another excellent feature was the greater proportion of papers and posters in biological oceanography, a sure sign that marine science is becoming more multidisciplinary. The days are long gone when life in the oceans was regarded as a passenger rather than an active participant in the system.

I do hope too that the evening panel sessions on topical issues will continue. The subject at MS2000 was 'What is Marine Science For?' and the large attendance demonstrated that marine science is alive and well. Apparently, the objectives of 'sustainable development and responding to the challenge of climate change' form part of a policy document from the Office of Science and Technology, but this aspect wasn't really addressed during the wide-ranging discussions, which provided almost as many answers to the question as there were marine scientists present.

The daytime sessions were enlivened by some whizzy presentations, with Powerpoint much to the fore – I wonder if anyone will be using slides or overhead projectors at MS2002? The new developments in presentation reflect advances in measurement techniques: thus, a strategically placed video camera and sophisticated image processing can record environmental changes (e.g. in beach morphology) that would be impossible using conventional survey methods. Measurements are being made nowadays that were considered unachievable barely ten years ago, and rates of data-acquisition are increasing almost daily. The trouble is that 90% of these data go straight into storage, because new information comes in so fast that there is no time to do anything meaningful with most of it. This excess of data is almost bound to increase, as ever more sophisticated and versatile (and inter-communicating) instruments become available to explore the oceans in progressively finer detail. Few can seriously doubt that in future the oceans will be monitored more, not less, especially now that anthropogenic global warming is well and truly with us.

A couple of years ago, I was properly taken to task for being critical of those who use improved techniques and better technology to advance scientific knowledge and understanding. It is inevitable that science nowadays is largely a matter of crossing t's and dotting i's – but so what? It may not lead to great new discoveries, but at least it can help refine and strengthen existing paradigms. To be sure, there is a dearth of recognizably new paradigms that can match the sea-floor spreading/plate tectonics 'revolution' and the recognition that the deep sea is neither azoic or uniformly tranquil. On the other hand, I felt that there could be some paradigm shifts in the offing. For instance: Is Broecker's Thermohaline Conveyor a reliable simplification of ocean current systems? (Rainer Zahn); Could evolution's 'survival of the fittest' be more a matter of building better defences against predation and disease than of developing efficient feeding or mating strategies? (Victor Smetacek). For me, though, the most exciting new development came from Axel Miller's research into the imbalance between carbon sequestered in primary production and what ends up on the sea-bed. There is a missing sink in the global carbon cycle that seems to involve neither the oceans, nor the northern temperate forests (e.g. *Nature*, **398**,106–7). Axel's results suggests that the sink may be oceanic after all: as much as a fifth of the particulate organic carbon in the oceans may be converted to dissolved inorganic carbon (DOC) that remains unrecorded and thus escapes inclusion in the carbon budget.

A great number of other items caught my fancy. They make an eclectic collection and reflect my peculiarly idosyncratic interests in the marine sciences, so they are bound to be quite different from anybody else's selection. In the You-Learn-Something-New-Every-Day category I placed the incidental intelligence that renewal of deep water in sea-lochs occurs more readily in dry weather, when river flow is low and there is less resistance to high spring tides slopping water over the sill (Tim Brand). In the same category, though more substantial, is the potential for measuring properties from space that are normally determined from surface vessels. Thus (1) the inverse correlation between salinity and the concentration of yellow substances (Gelbstoff) means that surface colour could be used to estimate estuarine salinities; and (2) turbidity (and hence Secchi depths) could be determined by measuring reflectance, which is proportional to suspended sediment concentrations (Dave Bowers) – though in this case it might be cheaper to get in a boat with a Secchi disk! Among the Points-to-Ponder is the proposition that low $\delta^{13}C$ values, commonly taken to indicate high rates of biological production, could as well indicate upwelling of ^{12}C-rich water, i.e. a recycling of 'old' light carbon rather than drawing down a lot of 'new' carbon (Simon Holgate). Under Awkward-Side-Effects I would classify the proposition that if natural halocarbons have adverse effects on the ozone layer (as CFCs do) then fertilizing the oceans to increase primary production – and pull more CO_2 out of the atmosphere – might also generate more halocarbons and destroy more ozone (Duncan Purdie). Apparently, halocarbons are also produced by rice paddy fields, which are on the increase worldwide. In my Mixed-Blessing category were *Autosub* data showing that the decline in fish stocks is real, that the numbers aren't going down because the fish are avoiding the survey vessels used to count them (Andrew Brierley, see also *Nature*, **404**, 35–6).

A couple of presentations made me wonder if there is a (probably undesirable) trend towards the 'screen-oceanography' mentioned in the panel discussion, viz it's cheaper and quicker to do marine science on a screen than to spend time and money on a research ship. But that is a minor quibble. The standard of presentations at MS2000 was better than ever, and speakers' timing was almost uniformly excellent too – I have vivid recollections of conferences where people over-ran by several minutes and were still only halfway through their presentation (with heaps of overheads to go) when cut off by the session chair. That hardly happens at all now – and a good thing too.

We hope that several of the presentations made at UEA will appear as articles or short features in future issues of *Ocean Challenge*.

Marine sample collections: use them and care for them – or lose them!

Guy Rothwell and Gordon Paterson

As a result of a meeting at the Natural History Museum, London, on 3 April last year, a series of recommendations was recently formally presented for publication by the Inter-Agency Committee on Marine Science and Technology (IACMST, UK). Some of the more important of these recommendations are set out overleaf.

Marine sample collections – cores, dredges, biological specimens – often provide unique time-series of samples from an era before widespread human impact. Collecting such samples has been costly for the tax-payer, and continues to be so, but most collections have a continued value long after the initial research has finished. Improved awareness of existing collections would enable scientists to identify research priorities, and save time and money by encouraging secondary use, resulting in more efficient use of public funds. The best way to ensure long-term support for sample-based collections of physical objects is their continued use in research that addresses contemporary issues.

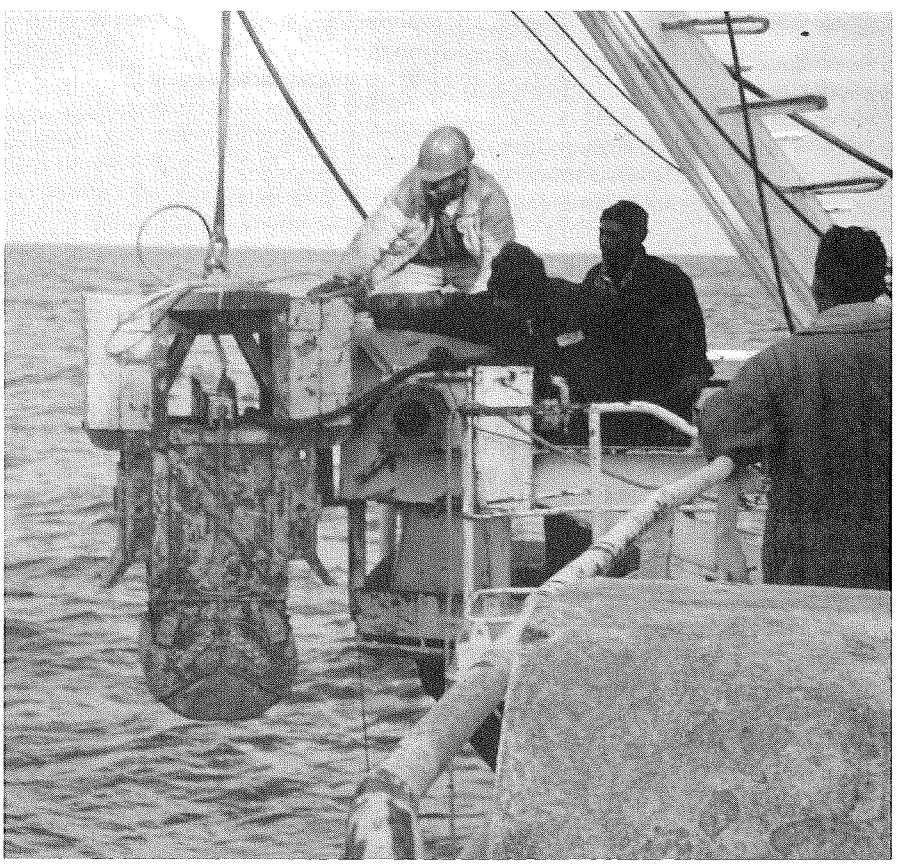
Securing support for facilities for collections of samples/physical objects is, and probably always will be, difficult. The recent spate of transfer of custody of important collections, by organizations such as the Institute of Oceanographic Sciences and the Marine Biological Association, due to store and site closures, raises a number of resource issues which need to be addressed to ensure the long-term preservation of collections which are often of national, and even international, importance. Sudden acquisition of material during transfer of custody often results in a need for additional resources (such as storage space, access and databasing) by the new host institution.

In recent years, many sample collections have been put together during the course of environmental impact assessments and monitoring programmes. Commercial companies have undertaken many of these collections, either for governments or for other companies. Such collections can be important beyond the purpose for which they were originally taken. In areas such as the North Sea they represent a time-series, recording anthropogenic impact since the beginning of oil exploration and extraction. Until recently there was no agreement as to what should happen to this material, and inevitably some of it has been lost.

In April 2000, forty-one researchers and specialists in collection-management, from as far afield as Greece, Madeira and Tasmania, met at the Natural History Museum to discuss current issues associated with collections of oceanographic samples and their associated data. The meeting originated from a suggestion by the Marine Environmental Data Advisory Group of the UK's Inter-Agency Committee for Marine Science and Technology (IACMST) that it would be timely to organize a meeting of the oceanographic community to review modern and potential usage of marine sample collections. The meeting also provided an opportunity to discuss common problems relating to provision of wider access and adequate funding of these important data resources.

A series of talks and posters was presented covering a range of topics involving sea-floor sample collections, both biological and geological, and included reports of modern innovative research using existing collections. Phil Rainbow (Natural History Museum, London) reviewed the diversity of marine samples held by the Natural History Museum and its vital role in identification, description and taxonomy, that underpinned studies in phylogenetics, biogeography, biodiversity and conservation. Parts of the Museum's holdings preserve unique and hard-won records which provide potential benchmarks for models of community change over time. Susan Chambers (National Museums of Scotland) described

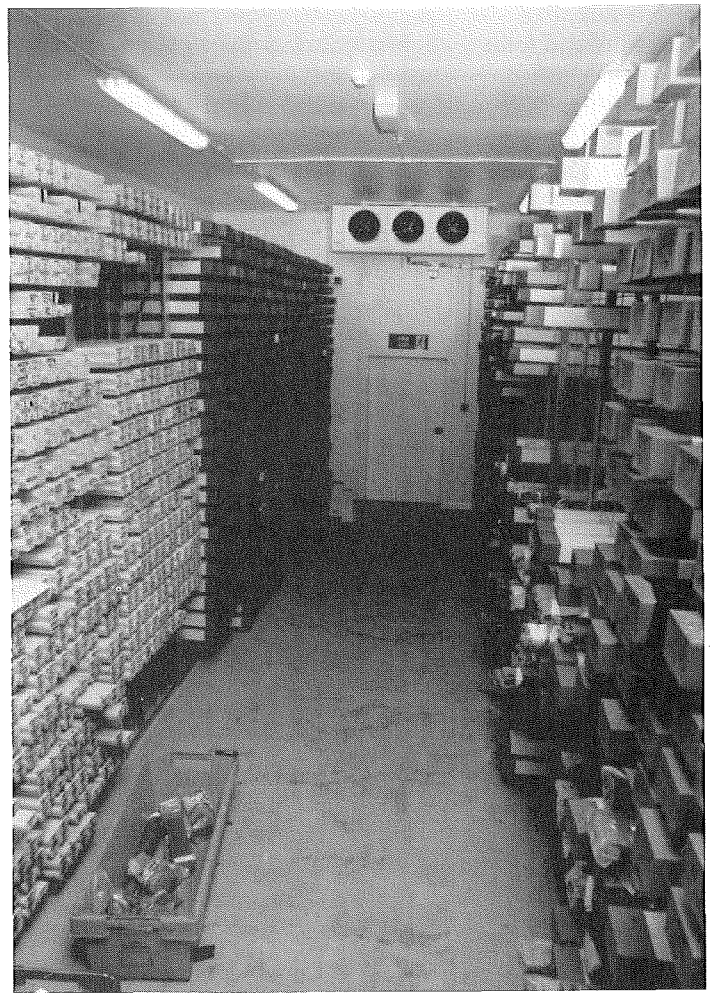
Collecting samples is often expensive and arduous



how Scotland's national museums have arranged for the long-term care and maintenance of marine invertebrate samples collected by the Atlantic Frontier Environmental Network (AFEN) during surveys undertaken to the west of Shetland in 1996 and 1998, as part of the environmental programme relating to exploration and production on the Atlantic margin. This scheme provides an excellent example of how museums can develop partnerships with the commercial sector to preserve and make available to the wider scientific community samples they have collected. Geoff Boxshall (Natural History Museum, London) described the Ocean Biogeographic Information System (OBIS) and the Census of Marine Life (CoML) – international initiatives promoting and funding research to assess and explain the diversity and distribution of species in the world's ocean. Ian Tittley (Natural History Museum, London) described the extensive collection of benthic marine macro-algae held by the Natural History Museum, a collection which extends back 350 years. Collections of algal material over long time periods record deterioration in water quality in some coastal areas, while variation in warm-water and cold-water forms may relate to climatic variation. Museum voucher collections of such species (i.e. specimens that authenticate their cited taxonomic records) will be important in assessing future climate change.

Guy Rothwell (Southampton Oceanography Centre) described the new UK national repository for deep-sea cores – BOSCOR, the British Oceanographic Sediment Core Repository – located at the Southampton Oceanography Centre. He also discussed EU-SEASED, a European Union-funded project to set up an internet database of seabed samples held at European institutions, thus promoting access to this previously underexploited raw data resource. Colin Graham (British Geological Survey) described the BGS marine core collection, which covers approximately 32 000 offshore sample sites, at a sample density such that sites are between ~ 5 km and 10 km apart, over the entire UK continental shelf.

Ivor Rees (University of Wales, Bangor) discussed the long-standing problem of archiving sea-floor photographs and videos. He reported on a recent UK Department of Transport and the Regions project, which is producing a photographic archive for the seabed in an area of the Irish Sea. There must be hundreds of thousands of photographs and miles of film and video footage of the sea-floor in institutes and universities around the world. While such collections may be well curated within an organization, locating particular photographs can be difficult. Often there is no catalogue of holdings. It appears that while we can photographically map the planets, we have not collated what is already available for our own oceans and made these records easily accessible to other researchers who might find them of value.



Sediment cores stored under proper conditions can remain in pristine condition for several decades

The British Oceanographic Sediment Core Repository houses over 700 deep-sea cores and exclusive data on 1200 within its data bank. Cores do not always demonstrate their full value within a few years after collection. As new measurement techniques become available and new ideas evolve, existing cores can be re-sampled to add to the knowledge base.

Lawrence Hawkins (Southampton Oceanography Centre) and John Lambshead (Natural History Museum) presented research that showed that glycogen in preserved material may provide a simple retrospective indicator of environmental stress. John Wilson (Royal Holloway, University of London) reviewed advances in geobiology and sedimentology, based on the use of extensive existing sample collections. He described good curatorial practice and emphasized the need for vigilance and care when collections are moved from one location to another. Alex Rogers (Southampton Oceanography Centre) discussed molecular methods for marine biodiversity research and the use of preserved material from museum collections. He demonstrated how new techniques had revealed cryptic species (i.e. species that are morphologically so similar to another that they cannot readily be distinguished from it, except under genetic investigation), fundamental aspects of population structure, and valuable new information on evolution

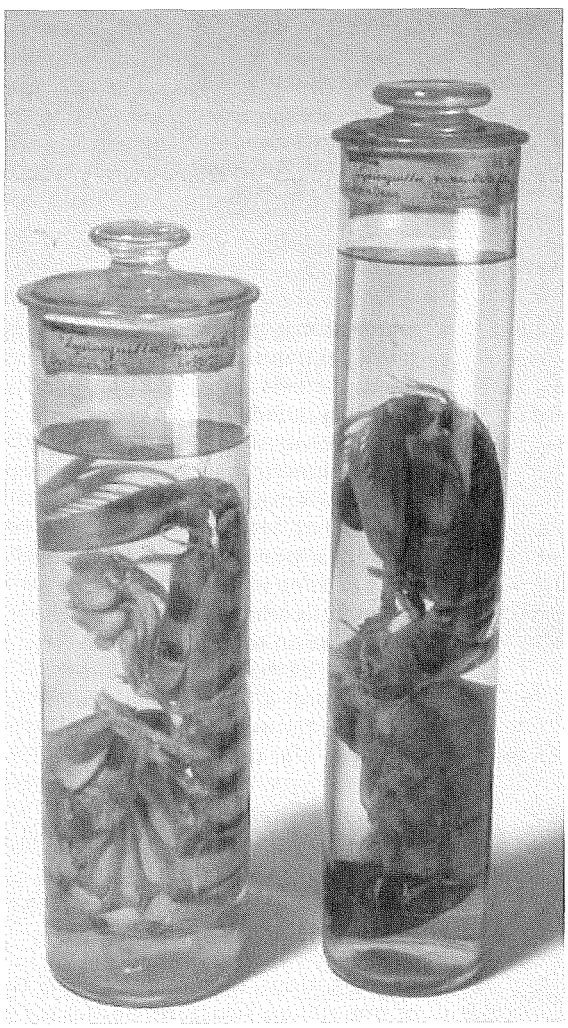
in marine systems. His talk, like that of Lawrence Hawkins and John Lambshead, showed how novel analytical methods can provide important new data from preserved material.

In addition to the oral presentations and posters, a discussion was held on common problems facing curators of sample collections, particularly regarding how to better secure their future through long-term funding and promote their use and accessibility to researchers.

The series of recommendations made by the participants is being formally presented in the Meeting Report published by the Inter-Agency Committee on Marine Science and Technology (IACMST, UK). These aim to raise the profile of marine oceanographic collections and secure the necessary resources for the long term. Recommendations include getting data-management guidelines (both at national and international levels) to include proper curation of physical samples; and to lobby funding agencies to stipulate proper curation of samples collected by research programmes as a condition of granting funding awards. It was recognized that collections will only be used if the scientific community is aware of their existence; so promoting wider knowledge and access is a priority.

Specific recommendations on making samples and associated data more accessible include the following:

- Storage facilities need to establish on-line catalogues of their collections.
- Consortia of collection-holding facilities should be formed to develop proposals to fund such catalogues. Organizations such as IOC and IODE should be approached to gain international support.
- Many institutions have been successful in attracting European Union funding for databasing and promoting accessibilty. Other organizations should investigate this opportunity to gain recognition.



Specimen collections held in museums and other institutions around the globe represent a vast and largely untapped resource for studies of molecular phylogenetics, biodiversity and historical genetic changes in populations

Other recommendations made include :

- The collection facilities community should encourage the commercial sector to properly curate environmental collections that have long-term value, and to enter into collaborative partnerships to achieve this. Collection storage facilities could encourage the forming of partnerships by showing the added value they can bring to companies, for example in terms of publicity for environmental awareness, contributions to biodiversity research, etc.
- Where the government is the client and sponsor of an environmental impact assessment, it should stipulate that collections be properly curated and deposited in a recognized collection facility and make the necessary funding available to allow this.
- Institutions' data-management policies and plans should include provision for photographic and video collections, and for any new types of collections developed through innovative investigative techniques (e.g. molecular biological samples).
- Consortia of institutions holding photographic collections should be formed to develop catalogues of holdings, to enable the research community to gain access to this valuable, but presently under-exploited, data resource.

It is hoped that the meeting has started a debate, both nationally and internationally, on the importance of sample collections, particularly in regard to initiatives needed to promote long-term use and accessibility, and the acquisition of long-term funding to secure these objectives.

The abstracts from the meeting may be viewed on the World Wide Web at http://www.nhm.ac.uk/zoology/taxinf/Ocean/Main.html

For further information, please contact:

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Looking over the Horizon

David Pugh

A small group of leading marine scientists and technologists met recently to brainstorm marine issues which could become important in the future. This highly interactive and democratic process produced surprising agreement, with a few unexpected results.

Conception

Isaac Newton once famously acknowledged that if he had seen a long way in science it was because he had stood on the shoulders of giants. Anticipating the future has always been challenging. The speed of technical and scientific change makes it increasingly difficult, but ever more imperative, that we try to anticipate the potentially most damaging issues which could be just over the horizon.

Governments, even more than scientists, need to show that they are prepared for future shocks. Recent examples of difficult issues include experience with BSE, the ozone layer, climate change and, of immediate marine interest, the disposal of the *Brent Spar*. The *Brent Spar* issue put deep-sea experts alongside other marine scientists, economists, and the petroleum industry in advising governments, who are also trying to understand and respond to public opinion.

An official publication by the UK Office of Science and Technology on 'The Use of Scientific Advice in Policy Making' emphasizes: *'... it is important that there should be mechanisms for early identification of issues, which affect more than one Department/ Agency, or may have an international dimension, and for early provision and exchange of information'*. In response, the Government's Inter-Agency Committee on Marine Science and Technology decided to invite a group of people with long marine experience to anticipate marine issues which could become politically important and affect our lives in the future.

Planning

IACMST asked Mike Cowling (Glasgow University) and me to arrange the details. Fortunately, Mike knew Ottilia Saxl, Director of the Institute of Nanotechnology in Stirling, who had run similar interactive meetings. We invited Ottilia to join us as Facilitator, with the job of driving the whole meeting towards a conclusion. To keep the group together we needed a comfortable but isolated location. Luckily we were able to use the University of Wales' residential centre at Gregynog, Powys, which was comfortable, relatively remote, and extremely welcoming.

Our first difficulty was to decide whom to invite. Surprisingly, even in marine affairs, giants were very hard to find, so we settled for mere mortals with long experience. Our goal was to include around 20 delegates, and in the event 23 people attended (see Box 1), bringing well over 500 years of collective marine experience.

Box 1 Participants

Catherine Coates	John Portmann
Mike Cowling	David Pugh
John d'Ancona	Siân Pullen
John Davies	Howard Roe
Kevin Deeming	Ottilia Saxl
John Griffiths	Graham Shimmield
Paul Leonard	John Simpson
David Lewis	Jane Smallman
Peter Liss	Ian Townend
Paul Mason	Mike Waldock
Iain Orr	Lynda Warren
David Palmer	

Participants represented a balanced range of interests in marine issues and activities: the commercial sector, conservation groups, Government, academia, as well as scientific, legal, and policy specializations.

Gregynog proved to be an ideal venue, set in beautiful grounds. With cool, showery weather, and a bar that did not open until late evening, attendees were more than willing to participate fully in the work of the meeting.

The Process

Mike introduced the meeting and Ottilia set us to work immediately. First we agreed ground rules: not to hog the floor; no criticism; no interruption; and everyone to keep to time and attend all sessions unless there was good reason (one participant was later excused some sessions because of the onset of malaria ... not contracted in Wales). We also agreed on our common purpose: *to identify marine-related issues which could become important.*

We then exercised our collective creativity by filling several flip charts with lists of:

- Why the marine environment is important
- Threats to the marine environment
- Threats from the marine environment.

Some of the more popular, interesting, or just bizarre suggestions are shown in Box 2 (*overleaf*).

So far, so good. Even enjoyable. But the next stage was more difficult. As a group we were asked to discuss, line by line, which of the topics on the long list could become significant. Half an hour later we had covered about five of the 200 points, energetically, but without much agreement.

Ottilia gave up and tried a different approach (I believe that, Canute-like, she wanted us to realize that the task was impossible and that something more drastic was required). We were all asked separately to list five concerns which we thought likely to be important in the future, and then to select from these

Gregynog residential centre – an unlikely hot-bed for debate on marine issues

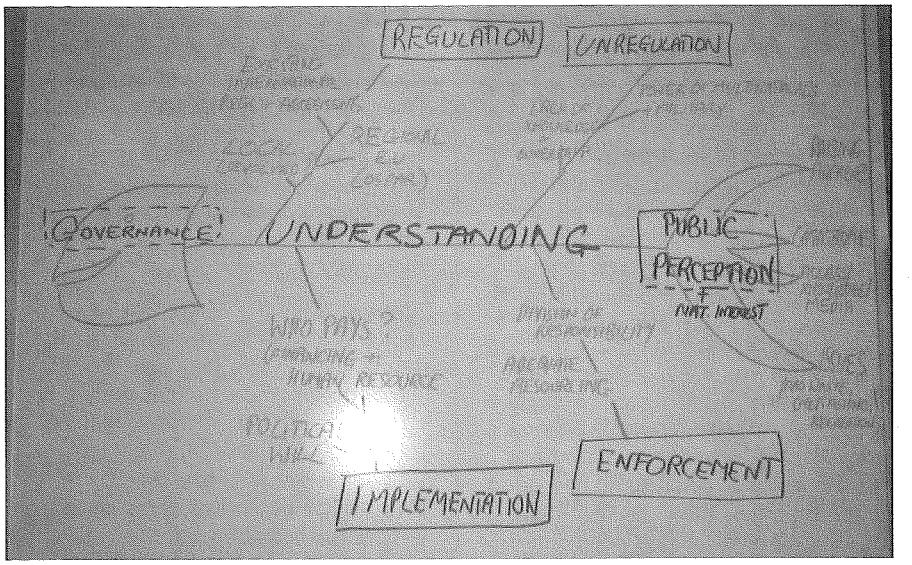
the single most threatening issue. The results, with a fair degree of agreement, were grouped into four main topic headings: *Energy, Climate Change, Ocean Governance,* and *Marine Ecosystems.*

Four sub-groups worked on detailed aspects and contributions of these two issues. We used relationship analysis, structured around fish-bone diagrams (*see right*) which produced much argument and some insight.

Our work was regularly interrupted for meals, tea, cake, and lots of non-linear interaction. John d'Ancona gave a short talk on possible industrial futures, and Siân Pullen told us about marine work in the conservation movements.

By now the group seemed to be working as a team with easy communication and a flow of ideas. As a reward we were given time off on Sunday afternoon to walk around the grounds between rain showers and to decide on our final individual choices. This resulted in 12 high priority topics to be taken forward to the final consideration, grouped under the four general headings.

Finally, after a voting procedure only marginally less complicated than selecting a President for the United States, but one which involved yellow and red lollipops and no chads, we reached a final list of priorities.



A fishbone diagram can stimulate argument and insight

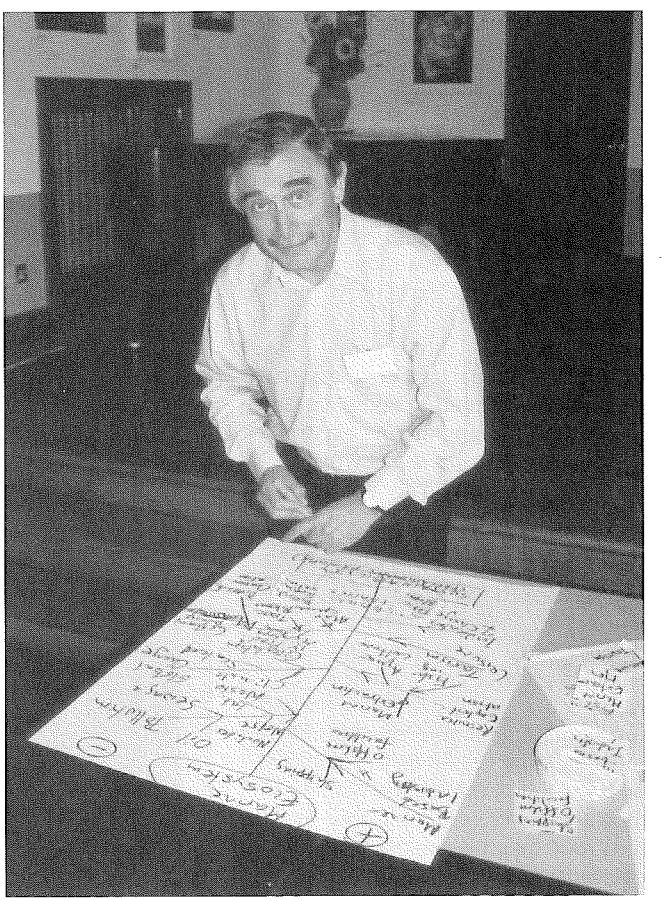
Outcomes

The final results are shown in Box 3. The topics show a significant shift from those selected by participants before they came to Gregynog. People felt that the workshop had had a substantial and positive impact in achieving agreement and priorities amongst the broadly based group.

The possibility of Gulf Stream blocking and the subsequent influence on the UK climate was the most supported topic. However, a number of topics within the overall Ecosystem category were not far behind. Participants recognized that the topics and categories identified are not necessarily independent of each other; there is some overlap and a mixture of 'apples and pears'. For example, some issues of public concern, and regulations for dealing with them, are not independent and can be considered part of the continuing response process.

We agreed that the results should include a warning. All participants recognized that the process of brainstorming and exchanging ideas is not rigorous. Nevertheless, the results of

Peter Liss decides how to vote for the future



Box 2: A selection of suggestions

Why the marine environment is important (selected from 140)	Threats to the marine environment (selected from 41)	Threats from the marine environment (selected from 24)
Stable	Man	Flooding
Nice for amphibians	Low priority	Sharks
Heat storage	Poor regulation	Sea level rise
Difficult to own	Extra-terrestrial thieves	Source of conflict
History and tradition	Tourism	Over-dependency
Links with moon	Over-active scientists	Unpredictable
Fish and chips	Bycatch	Irresistible
Source of stories	Sewage	Bermuda triangle
Storage		Tsunami
Political boundary		
Disasters		
Scale, size		

the process, in terms of areas of concern and some specific items within those areas, were generally agreed. They are the result of a brainstorming session, involving a group of leading, knowledgeable, marine experts. A different approach, or a different group of people, might have produced a different set of results.

Discussion

We wondered what these results would mean to people – politicians and advisers – setting Government policy. John d'Ancona, with long experience of these things, summarized for the whole group.

- We do not know enough about climate change and its potential impacts on marine ecosystems and coastal security.
- Changing demands for energy, particularly renewable energy in a climate context, need attention.
- People are by no means convinced that mechanisms exist for letting Government take coherent cross-Department initiatives in marine issues.

A more general discussion considered the UK need for a Marine Policy Unit to advise Government. This should be cross-Department, and should introduce political realism tests into the advice which might emerge from purely scientific criteria. Such a Unit would need to have international credibility so that ideas could be tested in the widest possible context. This goes beyond the scope of IACMST, but it should be considered.

Box 3: Priority issues identified before and after Gregynog

Voting on top issues for the future (after Gregynog)

Area(s)	High Priority Topics	Scoring*
Climate	Gulf Stream blocking	1023
Ecosystems	Aquaculture impacts	1015
Ecosystems	Circulation/primary productivity	1013
Ecosystems	Quantifying uncertainty	1013
Energy	Incentives/investment	1009
Ecosystems	Resource exploitation	1009
Ecosystems	Ecosystem change	1008
Climate/Ecosystems	Monitoring	1007
Regulations	Political will	1006
Climate/Ecosystems	Global prediction	1004
Energy	Aesthetics	1003
Regulations	Raising awareness	1002

*Recognizing that all of the listed topics were given very high priority, 1000 has been added in each case.

Major current issues identified before Gregynog

- Sustainable fisheries
- Waste management
- Coasts and climate change
- Environment regulation
- Impact of aquaculture
- Data policy and management
- Offshore renewable energy

Actions

The conclusions are listed in Box 4. All of the Government Department members of IACMST are now looking at their research portfolios, and we will be looking at their collective responses to see if there are gaps. The very large recent increase in Government funding for research into sudden climate change, our first priority, is encouraging.

Box 4: Conclusions

- The workshop produced considerable unanimity on a shortlist of marine topics which will achieve a greater degree of importance in the future.
- There was general agreement that the UK was paying insufficient attention to these high priority topics and their likely consequences for the UK in the medium term.
- It was generally agreed that more effort was required to raise general public awareness of the issues highlighted.
- There was a consensus that there is insufficient planning for the impact on UK wealth creation and quality of life, if the predictions for change become a reality.
- A major generic difficulty is the levels of uncertainty included in the modelling of marine systems. A remedy requires substantial investment in additional research.
- The IACMST could be effective in taking these issues forward.

A Personal Reaction

The Gregynog experience was exhausting, stimulating, and fun. Some of the people whom I met for the first time have continued to take an interest in IACMST and help with our work. Without Mike's leadership and Ottilia's shepherding we would not have reached any kind of consensus. Of course, the arguments continue.

There was no argument that the venue and the two local diversions were a great success. One evening a local schoolgirl harpist, Alecs Peate, entertained us; despite our collective persuasion for marine science, she is still determined to pursue a law degree in Aberystwyth. On the other evening, the Controller of the Gregynog Press, Daffydd Vickers explained his work. Gwas Gregynog is internationally famous for its production of high quality limited edition books.

As a final reward for their hard work, Daffydd had prepared for the participants embossed copies of a limited edition booklet containing a poem about the geese at Gregynog. The geese could be taken as a symbol of our attempts to anticipate the future. Every winter they fly away over the horizon. Every spring they return. But maybe, just maybe, next spring ...

David Pugh is Secretary of the Government's Inter-Agency Committee on Marine Science and Technology.

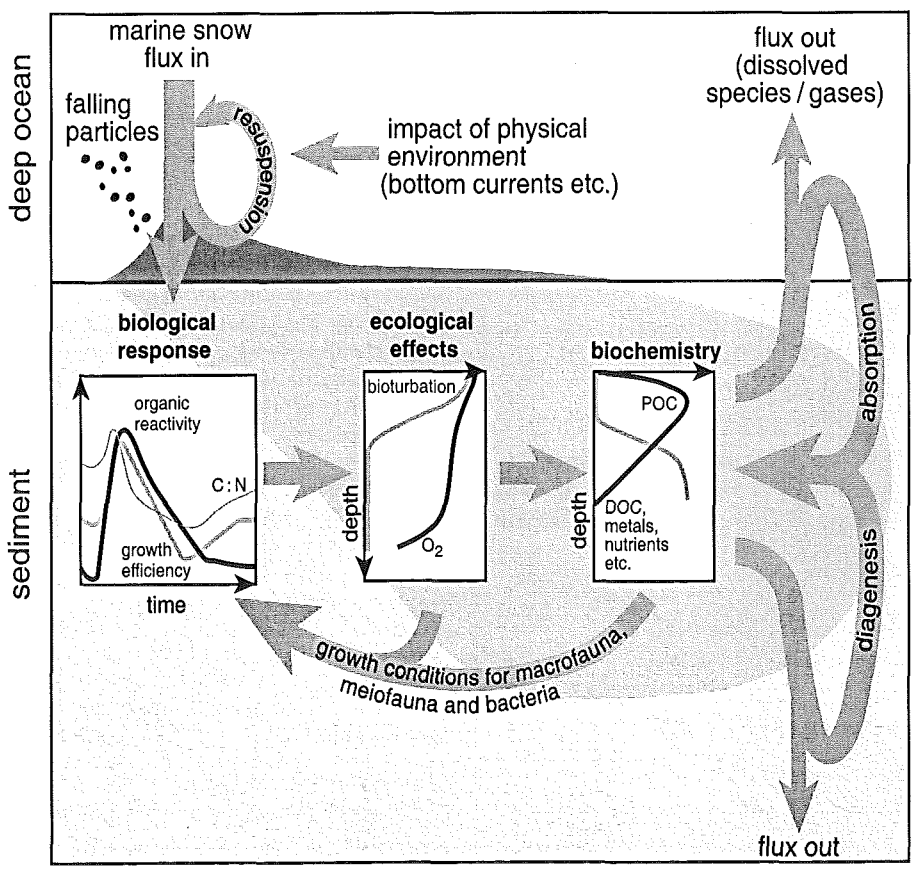
BENBO – The Final Curtain

Biogeochemical processes operating within the deep ocean benthic boundary layer bring about the transition which occurs when material descending through the water column becomes incorporated into the sedimentary record (see diagram below). This transition zone is affected by a variety of mechanisms, both physical (e.g. benthic storms and boundary currents) and biological (e.g. pulses of seasonal phytodetritus from plankton blooms), operating over time-scales ranging from daily to seasonal. Since 1997, scientists involved with the NERC-funded BENBO Thematic Programme have been studying these processes at three contrasting sites in the eastern North Atlantic (see *Ocean Challenge*, Vol. 9, No.1, 1998) in order to quantify the sea-bed response to various forcings, in particular the seasonal sedimentation of marine snow.

The curtain has been slowly coming down on BENBO, and it officially ended at Christmas. So it was pleasing to see such a strong representation by BENBO scientists in the Benthic Environment section of the UK Marine Sciences Meeting at the University of East Anglia. On behalf of the BENBO fraternity, as BENBO Programme Manager I would like to thank the organizers for arranging the special session; also to thank Professor Nick McCave from Cambridge University, who acted as Session Chair and has been at the helm of the BENBO Scientific Steering Committee.

Altogether, eight BENBO talks and several posters were presented at the meeting. Andy Gooday (Southampton Oceanography Centre), a world expert on benthic and pelagic foraminiferans, described temporal changes in foram assemblages from BENBO site C (water depth 1900 m, on the flank of the Feni Drift) and from a deeper site (4850 m) on the Porcupine Abyssal Plain. From past studies, changes are known to follow fall-out of marine snow – food for the beasts! Knowledge of such changes is of great value for resolving problems in palaeoceanography, using fossil foraminiferans. Gooday found that a large proportion of the assemblages at the two sites were delicate agglutinated forms (i.e. with tests consisting of organic coatings to which are attached organic and inorganic particles) which have little preservation potential. However, remains of very small calcareous species (e.g. *Eilohedra nipponica*), which have a high preservation potential, were found after the bloom at BENBO site C, and increased in abundance quite dramatically relative to agglutinated species in both the fluff and the underlying sediment. Because of its high preservation potential, *E. nipponica* in particular may be useful for research into deposition of organic matter to sea-floor environments in times gone by.

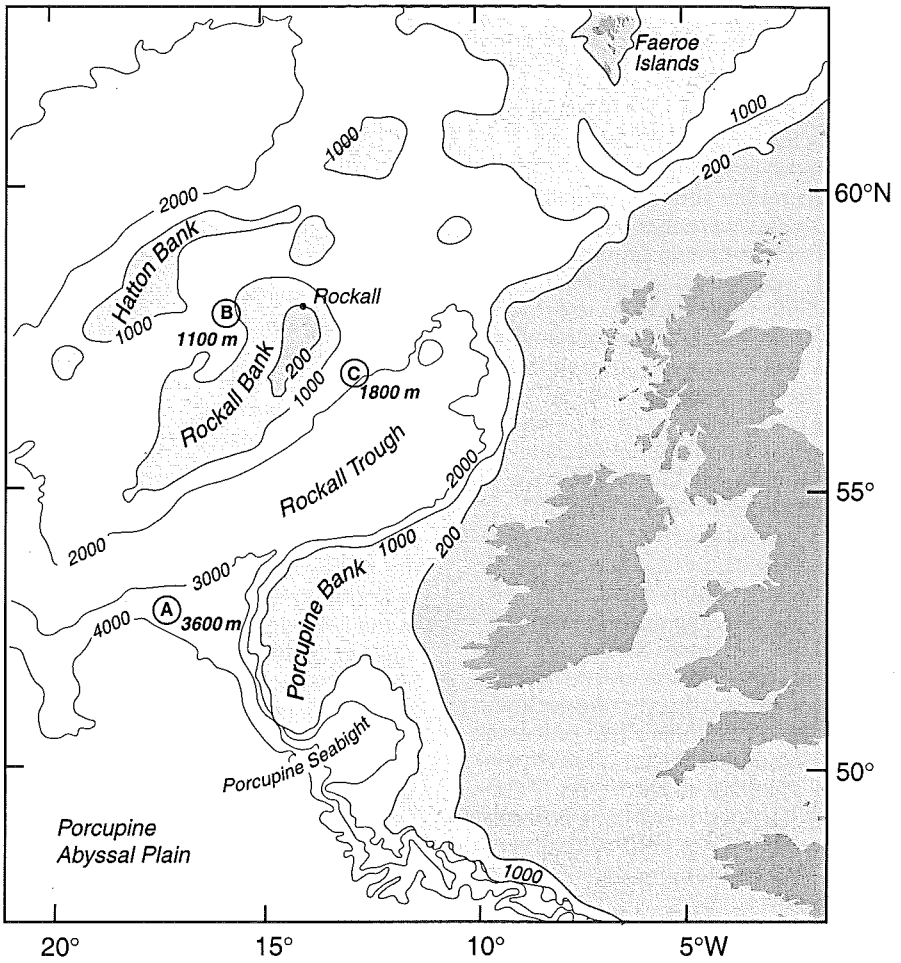
The biological theme was continued by Carol Turley and Joanna Dixon, (Plymouth Marine Laboratory), who presented results on the factors which mediate bacterial production at each of the BENBO sites. The three sites selected by the BENBO Scientific Steering Committee for investigation are subjected to contrasting hydrodynamic regimes, with differing water depths and marine snow input. Turley and Dixon's data indicate that natural bacterial populations are adapted for growth at the low temperatures and high pressures found in the deep sea, and confirm a broad decrease in bacterial biomass with increasing depth. The relationship between



Major physical and biogeochemical pathways at the deep ocean sediment–water interface. The diagram illustrates the links between the biological response to sedimented phytodetritus, the ecological repercussions for bottom-dwelling organisms, and the biogeochemical consequences (e.g. solute fluxes, carbon preservation).

(In the diagram, C : N is the carbon : nitrogen ratio in particles, and POC and DOC are, respectively, particulate and dissolved organic carbon.)

(Courtesy of G. Ruddy)



The setting of the BENBO study area in the 'Atlantic frontier' to the west of Ireland and Scotland. Sites A, B and C (see text) are on the flanks of the Rockall Trough and in the eastern north Atlantic.

(Courtesy of Richard Lampitt)

bacterial production (i.e. cell division rate) and depth is not so clear, however: bacterial production was found to have an exponential relationship with the C:N ratio. Production was much lower in the deeper site, presumably due to the far lower C:N ratio of the marine snow. These results effectively separate physical from biochemical factors and show directly that the key determinant affecting bacterial growth in the deep Atlantic is the availability of food, rather than specific environmental conditions.

Bacteria form an important trophic link in the deep ocean food chain, as they transform particulate organic carbon (POC) to dissolved inorganic carbon (DIC) via the intermediate dissolved phase (DOC). A group from the University of Wales, Bangor, headed by Hilary Kennedy and Dave Thomas, reported on the distribution of DOC in surficial sediment layers at the BENBO sites, and showed a net accumulation of DOC near the oxygen-rich sediment surface and in the anoxic layer (when present) in the sediments. However, at the two shallower sites (B and C) the calculated DOC flux across the sediment–water interface was a minor component of the carbon budget when compared with the calculated DIC flux. At the deepest site (A), below the surficial enrichment the pore water DOC declines to concentrations close to oceanic bottom water. Sorption onto mineral surfaces, the most likely controlling mechanism for DOC in the pore waters at this site, has been investigated during laboratory experiments that have been designed to assess the extent to which this process is reversibile.

The Kennedy group also reported work based upon isotopic signatures of oceanic carbon. Biological productivity in the euphotic zone results in two isotopically distinct carbon pools, particulate organic and inorganic carbon. A small proportion of this primary production is exported to the sea-floor and accumulates in the sediments. In isotopic terms, the decomposition of sedimentary organic matter releases to the pore waters CO_2 containing carbon with strongly negative $\delta^{13}C$, while the dissolution of $CaCO_3$ adds CO_2 that contains carbon with a slightly positive $\delta^{13}C$ value. The isotopic composition of the pore water therefore reflects modification of bottom waters by these two processes and provides a way to study benthic carbon cycling. The group also described specific experiments that were designed to track carbon isotopic changes during sediment decomposition under fully oxic conditions at realistic *in situ* temperatures and pressures. The collaboration between Kennedy's and Turley's groups has substantially improved understanding of bacterial metabolism and rates of biogeochemical transformation of carbon at the deep ocean bed, and these efforts are scheduled to continue well beyond the life-time of the BENBO programme, using samples collected during the cruises.

Emily Good and Greg Cowie (Department of Geology and Geophysics at the University of Edinburgh), returned to the theme of the particulate carbon phase. It is now widely accepted that most marine sedimentary organic matter is intimately associated with mineral surfaces. This association results in narrowly defined loadings, in the range 0.5–1.0 mg of organic carbon per m^2 of available sediment surface area in continental margin sediments, whilst in deep-sea sediments the loading is substantially less. A longer exposure to oxygen has always been suggested as the likely cause. The BENBO work confirmed a lower ratio of organic carbon:surface area for each of the sites, which indicates that the transition to loadings more typical of the deep sea occurs at relatively shallow depths in the Rockall region. The organic carbon:surface area relationship was found to decrease with increasing oxygen exposure time, in a similar fashion to that observed at other deep marine sites such as the north-east Pacific (Washington margin), suggesting that oxygen exposure time is indeed a first-order control on the remineralization of organic material. The potential for 'sorptive preservation' of bound organic matter depends upon the nature of the organics (i.e. labile versus refractory) and the reaction rates of sediment bacteria.

The thematic mode of funding, in particular, permits studies like this to be undertaken in conjunction with those of Turley and Kennedy, provid-

ing a far greater insight into the many processes involved in bacterial breakdown of marine organic material.

Organic material isn't the only stuff that attaches itself to mineral grains. Mark Williams and Graham Shimmield from the BENBO host laboratory (Dunstaffnage Marine Laboratory) showed how the eventual 'crash' of a surface phytoplankton bloom can remove a variety of dissolved metals from the water column as the phytodetritus sinks to the sea-bed. The relatively rapid deposition of fluff following the surface ocean crash provides a mechanism whereby metals can be rapidly concentrated in the benthic waters and on the sea-bed. The implications of this for the transfer of pollutants to the deep sea are obvious. There are those who might think of this as a good thing – 'out of sight, out of mind' – but I prefer to think of it as pollution of an otherwise pristine environment. Bill Davison (University of Lancaster Aquatic Chemistry Research Group) presented an interesting follow-on talk about the fate of metals in the sediments following particle deposition. His research group have been instrumental in developing novel technologies (gel probes termed DGT and DET) which can be used to measure trace metals (and also dissolved sulphide) in pore-waters at mm and sub-mm spatial resolution in one and two dimensions.

Their DGT data, based upon both *in situ* and retrieved samples, reveal biogeochemical processes such as remobilization in newly arrived material (fluff) in the top centimetre of sediment, and sub-oxic remobilization of redox sensitive metals lower down the sediment column. Additionally, however, they showed a detailed fine structure on mm and sub-mm scales in both the horizontal and vertical dimension. Correspondence of small-scale profile features suggested that metal remobilization can be governed by a variety of mechanisms operating very close to one another, which may be understood by viewing the sediment as an array of random, reactive microniches. Such features cannot be explained by the traditional view of steady-state pore-water concentrations, and it was interesting to listen to audience discussion of the implications of this work for conventional (steady-state) models of pore-water processes, as well speculation on the origin and nature of sediment microniches.

The majority of studies funded by the BENBO Steering Committee (ten altogether) were process-type studies focussed on the surface sediments. Three studies were funded, however, (a) to assess sediment processes (namely accumulation and mixing) on longer time-scales, and (b) to provide an inventory and biomass of benthic macro- and megafauna at each of the sites. The accumulation/mixing studies were jointly headed by John Thomson at Southampton Oceanography Centre and Gus Mackenzie and Gordon Cook at the Scottish Universities Research and Reactor Centre (SURRC) in Glasgow. Radionuclide activity profiles can be used to quantify the accumulation and mixing processes that act on sediments after deposition. A variety of natural and artificial radionuclides were used to examine these processes on thousand-year (^{14}C), hundred-year ($^{210}Pb_{excess}$) and decadal (^{241}Am, ^{137}Cs) time-scales using metre-long cores retrieved using a circular NIOZ box-core.

The Holocene accumulation rates determined by the radiocarbon method are 4.4 and 6.5 cm yr^{-1} at sites B and C, respectively. Accumulation at site A, situated between Feni Drift and Porcupine Bank, was interrupted by an erosional event in the mid-Holocene, which removed c. 0.25 m or more of the uppermost sediment present at that time. The estimated accumulation rate since that event is 2.1 cm kyr^{-1}. Different estimates of surficial bioturbation mixing depths at site B are returned by the $^{210}Pb_{excess}$ and ^{14}C methods, with the former indicating <10 cm and the latter an unusually deep value of 17 cm. At site C, $^{210}Pb_{excess}$ and the fallout radionuclides, ^{137}Cs and ^{241}Am, are present in two distinctly separated depth zones, with the deepest mixing down to ~15 cm, similar to the ^{14}C mixed-layer depth. This is ascribed to deep burrowing by sipunculid or echiuran worms at site C, while at site B similar deep mixing is thought to be necessary to produce the differences in mixed layer depths derived from the longer- and shorter-lived radionuclide profiles, although deep burrowing episodes must be rare (< 1 event per 10^2 years). The greater accumulation rate at site C compared with site B is produced by an enhanced flux of clay- and silt-sized material, brought in by bottom currents. This fine material dilutes the $CaCO_3$ content of the site C sediment and is responsible for it having a higher C_{org} content than site B. Unlike the sediments from sites B and C, which are fine-grained, the coarse 63–125 μm size fraction is the most abundant size class in the late Holocene sediments at site A, suggesting that the sediments at this location have been winnowed. (The inference about sediment winnowing is substantiated by some shipboard erosion experiments I have conducted using a benthic chamber.)

Altogether some 30 papers will be produced by BENBO scientists in the literature, enhancing our knowledge of the important processes operating in the benthic boundary zone. Significant advances in experimental methodology and technologies have also arisen directly from work within the programme, and valuable training opportunities have been provided for young scientists.

The deep ocean is the last great unspoilt frontier on Earth. It is the most extensive ecosystem, covering some 300 million square kilometres, and forms the largest repository of carbon, in the form of fine-grained ooze and marl sediments. Human beings are venturing into this remote and cold environment in search of the hydrocarbon reserves of the future, and increasingly the deep sea is viewed as an area of communication development (e.g. sub-sea telecommunications) and as a region for the disposal of waste. The BENBO programme is perhaps a timely initiative to describe and quantify processes occurring in this remote and inhospitable environment, and thereby increase our understanding of it. Most certainly the data collected (to be banked with BODC) are a valuable resource in providing an environmental *status quo* prior to the inevitable pollution and disturbance by future prospecting for hydrocarbons in the deep ocean.

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New Tyndall Centre to encourage Integrated Climate Research

Mike Hulme and Simon Torok

The interdisciplinary Tyndall Centre for Climate Change Research, opened recently at the University of East Anglia by Environment Minister Michael Meacher (*see photo*), has announced its first round of research projects aimed at providing sustainable responses to global warming.

Based in Norwich, and with partners distributed across the UK (see box), the Tyndall Centre encourages climate scientists, social scientists, engineers and economists to collaborate in studying the causes and consequences of climate change – and help the Government, business leaders and policy-makers to develop sustainable responses. The real challenge for climate-change science in the end is not merely to be able to predict future climate – it is to give society the options to choose its own climate future.

Research at the Tyndall Centre is organized into six main interconnected programmes that collectively contribute to all aspects of the climate change issue. All programmes address a clear problem posed to society by climate change, and will generate results to guide the development of climate change mitigation and adaptation strategies at national and global scales. Although marine science is not singled out as a distinct activity within the Tyndall Centre, contributions from the marine science community are relevant to three of the six Tyndall programmes.

Tyndall Centre Partners

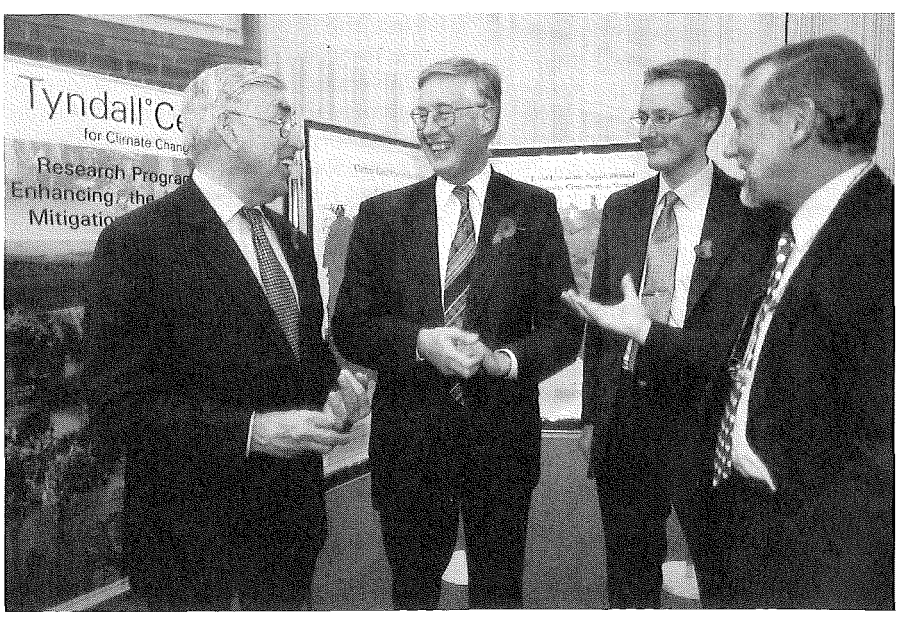
- School of Environmental Sciences, University of East Anglia, Norwich (Headquarters)
- UMIST (Regional Office, Tyndall Centre North)
- University of Southampton (Regional Office, Tyndall Centre South)
- University of Cambridge
- Complex Systems Management Centre, Cranfield University
- Science and Technology Policy Research (SPRU), University of Sussex
- Institute of Transport Studies, University of Leeds
- Energy Research Unit (CLRC–Rutherford Appleton Laboratory)
- NERC's Centre for Ecology and Hydrology (Edinburgh and Wallingford)

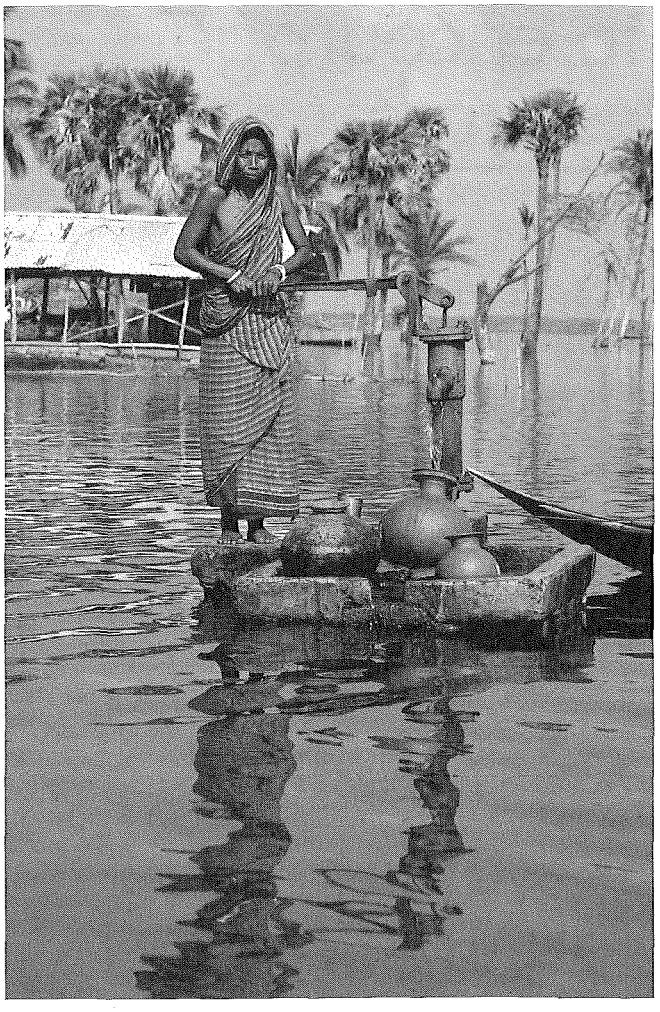
The programme concerned with Managing Coastal Zones, led by Professor Andrew Watkinson at the University of East Anglia's Schools of Environmental and Biological Sciences, will find better ways to manage the extremely vulnerable, dynamic and socially valuable coastal systems. For example, one project will use tide-gauges and satellite measurements to asses the contributions of climate change and the North Atlantic Oscillation (NAO) to sea-level change and wave height. The project will also investigate the impacts of these on the British coastal environment now and in the future. Another project will use computer simulations to explore the sensitivity of marine and coastal biodiversity to changes in sea temperature and the coastal environment. The programme will also investigate the impact of climate change on small island states.

The programme on Extreme Events and Rapid Climate Change, led by Professor Nigel Arnell at the University of Southampton, will assess the risks of encountering dangerous climate variability and rapid rates of change, compared with gradual change in average conditions. The accuracy of extreme temperature simulation in General Circulation Models and higher resolution models will be analyzed to assess the implications for comfort, energy use and carbon emissions from buildings in the UK. The impacts of events such as strong winds and storms on the insurance and forestry industries will also be examined.

The programme on Carbon Management and Reduction, led by Dr Simon Shackley at UMIST's Manchester School of Management, will explore and evaluate ways of reducing net emissions of greenhouse gases from fossil fuels. One project in this programme will assess the costs, political acceptability, engineering performance and environmental impacts of carbon reduction options –

At the launch of the Tyndall Centre, Environment Minister Michael Meacher (second from left), discusses climate change issues with (from left), Sir Anthony Cleaver (Chairman of AEA Technology), Dr Mike Hulme (Executive Director of the Tyndall Centre) and Professor John Lawton (Chief Executive of NERC).





Marine science relating to climate change is relevant to three of the six programmes at the new Tyndall Centre

such as carbon sequestration by newly planted forests, and the removal and disposal of carbon dioxide from flue gases. Another carbon-related project will assess the implications of Clean Development Mechanisms (CDMs) in developing countries, providing guidance for UK government agencies and private sector investors in CDM projects. The effect of architecture and urban planning on greenhouse gas emissions, and conversely the effect of climate change on buildings and cities, will be another important aspect of the programme.

The Renewable and New Energy Technologies programme, led by Professor Nick Jenkins at UMIST's Department of Electrical Engineering and Electronics, will identify and develop new and renewable low-carbon energy sources in ways that allow integration into existing energy systems. Projects will examine the long-term role of hydrogen energy in the transport sector to reduce greenhouse gases; identify niche applications of fuel cells to provide heat and power in the urban environment; investigate the efficiency of small generators integrated in buildings (microgrids); and consider the technical and regulatory changes required to integrate renewable and Combined Heat and Power sources into the UK electricity system.

Enhancing the Options for Mitigation and Adaptation is led by Dr Neil Adger at the University of East Anglia's Centre for Social and Economic Research on the Global Environment (CSERGE). The programme will investigate strategies for identifying and overcoming the barriers to long-term mitigation and adaptation to climate change. The vulnerability of populations in different countries will be linked to their capacity to adapt to climate change, for all countries where economic, social and other data are available. Researchers in this programme will also develop and assess pathways that transport and other sectors can follow, to make significant long-term reductions in carbon emissions.

These five programmes will feed into the Integrated Assessment research programme, led by Professor John Schellnhuber, the Tyndall Centre's Visiting Research Director. This programme will develop Integrated Assessment Models (IAMs) to explore future climate and its consequences for the world, the UK and local communities. For example, one project aims to develop a computer simulation of social perceptions, responses and policy negotiation, that takes into account changing views in response to future events. Technological change and its effects on the economy will also feature in the IAMs. A key activity of this programme will be the trial of a component of an IAM that represents changes in climate due to human activities. One of the challenges of this task is to be able to emulate the behaviour of more complex coupled ocean–atmosphere climate models. This will allow the effect of key sensitivities and uncertainties to be explored using large numbers of ensemble simulations.

The Tyndall Centre is named after the 19th century British scientist John Tyndall, who was the first to prove the Earth's natural greenhouse effect and suggested that slight changes in atmospheric composition could bring about climate variations. In addition, he was committed to improving the quality of science education and knowledge, often speaking and writing about difficult concepts to make them understandable and entertaining to different audiences. The Centre's headquarters are at the University of East Anglia, with regional offices at the University of Science and Technology in Manchester and the University of Southampton. The full Tyndall Consortium includes the University of Cambridge, NERC's Centre for Ecology and Hydrology, the University of Sussex's Science and Technology Research Unit, the University of Leeds Institute for Transport Studies, Cranfield University's Complex Systems Management Centre, and the CLRC–Rutherford Appleton Laboratory's Energy Research Unit. The Centre is funded by three research councils – the Natural Environment Research Council (NERC), the Engineering and Physical Sciences Research Council (EPSRC) and the Economic and Social Research Council (ESRC) – with support from the Department of Trade and Industry.

For more information, visit the Tyndall Centre website: www.tyndall.uea.ac.uk or call Simon Torok on (01603)-593-906; Fax: (01603)-593-901 or Email: s.torok@uea.ac.uk

The Science of Decommissioning

Report on a joint conference of SUT and SAMS

Eric Breuer and Martin Sayer

Exploration and production of oil and gas reserves in the North Sea over the last 30 years have left a legacy of more than 1000 structures, several million tonnes of drill cuttings material and thousands of miles of pipelines and cables on the sea-floor. While continuing extraction is expected into the near future, the operational lifetime of numerous platforms is coming to an end, with decommissioning of these structures expected to take place between 2005 and 2020 in accordance with the Oslo/Paris (OSPAR) Commission directive 98/3. This directive effectively excludes oil and gas platforms and associated peripheral structures from being left in place after decommissioning.

Decommissioning is an emotive subject (as demonstrated by *Brent Spar*) and presents a dilemma with respect to environmental and economic considerations. Numerous conflicts and controversies surround the subject of whether platforms and associated paraphernalia should be removed or retained. Contentious issues include: costs to the taxpayer; possible total removal on grounds of safety and fishing access versus retention to protect and promote threatened fish stocks; the environmental impact of the drill cuttings piles, and arguments for the removal of the piles versus blanketing them or not disturbing them at all. Along with the environmental implications, many of these issues involve the health and safety of salvage personnel and fishermen, as well as the moral obligations of large multinational companies.

At a meeting entitled 'Man-made objects on the sea floor' (Society of Underwater Technology, May 2000) a resolution was drafted and accepted that the OSPAR directive 98/3 had been made without reference to any underpinning scientific rationale. It was also noted at this meeting that there had not yet been a conference to examine the scientific pros and cons associated with North Sea Decommissioning. The Scottish Association for Marine Science (SAMS) agreed to host such a meeting at its main site at Dunstaffnage, near Oban. The event was supported through financial donations from the UK Offshore Operators Association, the Argyll and the Islands Enterprise, and the Argyll and Bute Council. The objectives of this conference were to discuss many of the issues pertaining to decommissioning within a rigorous scientific and technological context.

The conference, held on 12–13 October 2000, focussed on three areas of decommissioning: (1) drill cuttings – scientific and technological developments; (2) ecological impacts associated with decommissioning; and (3) legalities, practicalities and cost evaluation. The first day was devoted to issues relating to drill cuttings (the collective name for drilling mud, speciality chemicals, and fragments of reservoir rock resulting from the exploration and production of oil and gas reservoirs) deposited onto the sea-bed of the North Sea. In the North Sea, there are an estimated 7 million m^3 of drill cuttings on the sea-bed around oil platforms in the North Sea, with pile heights ranging from 2 to 20 m.

There were some very interesting and informative talks on pioneering scientific and technological ideas developed through work on North Sea drill cuttings piles. Professor Graham Shimmield (SAMS) started the conference with a talk on diagenetic processes in accumulations of drill cuttings in the central and northern North Sea. He noted the different decommissioning options, ranging from minimal removal to complete relocation of both cuttings pile and main structure. He pointed out that the highest metal concentrations, most rapid biogeochemical reactions and largest fluxes take place near the tops of the cuttings piles.

Jon Rees (CEFAS laboratory, Lowestoft) presented physical and chemical observations from the *Fulmar Alpha* cuttings pile in the central North Sea, obtained through the use of CEFAS's flexible, non-intrusive sea-bed lander. He showed the dynamic nature of the cuttings pile, with evidence of highly episodic, transitory and dynamic fluidized beds, whose behaviour is controlled by the tidal direction. Jon noted that moderate waves can penetrate to the sea-bed (77 m) and modify the tidal sediment transport, and that the platform legs and the cuttings pile significantly alter the tidal current ellipse by causing both 'shadows' and enhanced tidal currents.

Kevin Black (Dunstaffnage Marine Laboratory, DML) presented data from a laboratory flume study on the erosion of sediments in cuttings piles. Whilst there is an increasing amount of literature on the geochemical characteristics of cuttings piles, comparatively little is known regarding transport of drill spoil sediments by tidal currents and waves. In this case, laboratory flume experiments conducted to ascertain the entrainment threshold of such sediments from two locations on the *NW Hutton* platform, indicated that the sediments were unlikely to be moved by the prevailing tidal currents.

Eric Breuer (DML) presented diffusive oxygen fluxes and depth distributions of oxygen consumption rates within North Sea drill cuttings piles. He had used *in situ* measurements of fine-scale oxygen and sulphide distributions, and concluded that a rapid rate of organic matter decomposition and oxygen consumption occurred within the pile itself but decreased with distance, indicating a change in organic matter content and lability. Additionally, the reactive zone between the rapid consumption of oxygen and the production of sulphide allowed dissolution of metal oxides and subsequent remobilization of metals within the pile, and fluxes of metals out into the surrounding water.

Rebecca Artz (University of Aberdeen) gave a talk on methods for detecting *in situ* degradation of drill cuttings and their impact on the microbial sediment community. Rebecca discussed new methods developed for (I) the assessment of the effect of pollution by drill cuttings on the indigenous microbial sediment community, and (2) the quantification of *in situ* hydrocarbon degradation rates. Rebecca and her colleagues have developed a reliable test to quantify anaerobic degradation rates. This system allows quantification of the activity of different bacterial groups (e.g. sulphate-reducing bacteria, methanogens etc.) and their relative roles in degradation of the pollutant.

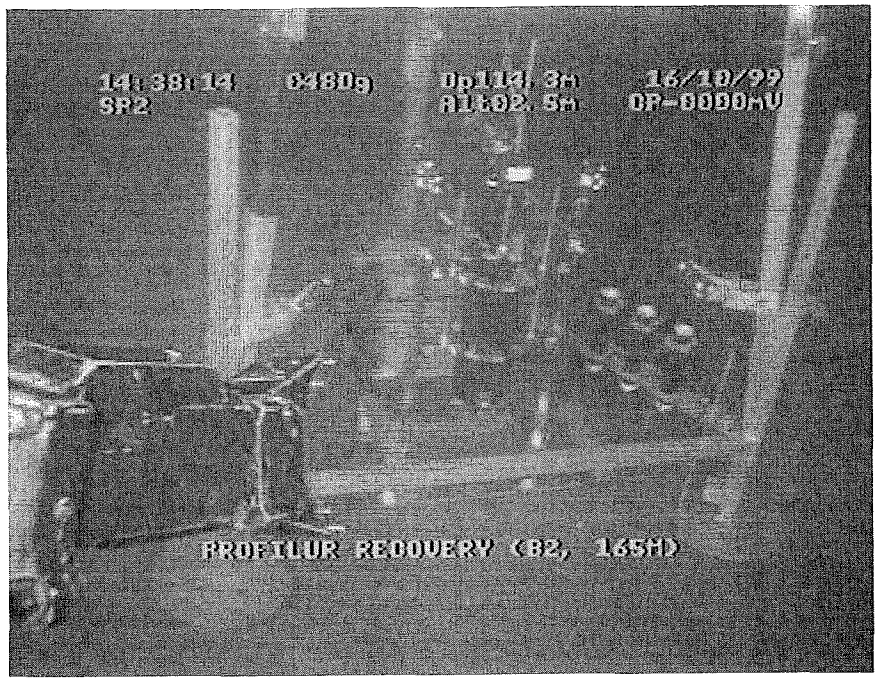
Gerrard Douglas (University of Aberdeen) described analytical procedures to improve scientific understanding and analysis of drill cuttings piles. Gerrard talked about

the analysis of drill cuttings using X-ray fluorescence (XRF) spectrometry and noted past difficulties in comparing results obtained by different analytical techniques. He proposed that the XRF could provide a standardized approach which would allow reliable comparison to be made.

Ally Skinner (British Geological Survey) gave a talk on the technical challenge of measuring and sampling drill cuttings in the North Sea. In many respects, cuttings do not behave like sediments, so traditional survey and sampling technologies need adaptation if they are to meet the challenges posed by the composition of cuttings. Also, their very location means that *in situ* measurement and sampling methodologies often have to be innovative. Furthermore, procedures for handling samples have to conform with health and safety considerations in addition to those normally applied to marine sampling. Novel measurement techniques are needed to analyze the material in both the field and the laboratory. Ally presented evidence from older traditional methods along with new developments in these fields.

Graham Collie (FMC Corporation) gave a presentation on eliminating the problem of cuttings disposal at source, by re-injection while drilling. FMC recently designed and installed a Drill Cuttings Re-injection system for Statoil, to be used on their Aasgard and Gulfax fields. He concluded that re-injection of drill cuttings offers a cost-effective alternative to back-loading the drilling debris. It eliminates the environmental impact of dumping cuttings, either on the sea-bed or in a land site. It also removes the requirement to retrieve, clean and dispose of sea-bed cuttings at a later date.

Oli Peppe (DML) gave a presentation on a new approach to the study of biogeochemical processes occurring in drill cuttings piles, through the use of autonomous benthic lander technology. New technology enables measurements to be made *in situ*, providing valuable measurements and data that were previously unattainable. In a study of a cuttings pile at the *Beryl Alpha* platform, DML recently deployed two of their landers using an autonomous vehicle. Because of the complications associated with deploying equipment so close to oil platforms, the landers were adapted for deployment by ROV from an industry survey vessel. The two landers were positioned on the



Video image showing how, after 12 hrs of sampling, the Dunstaffnage Benthic Profiler is recovered using the ship's remotely operated vehicle.

cuttings pile by the ROV, enabling them to gather data simultaneously within a few metres of each other, providing real-time visual feedback of their operations on the sea-bed for the first time. Oli concluded with a discussion of the value of lander systems as efficient and versatile tools for studying the environmental impact of drill cuttings piles.

Peter Robertson (Robert Gordon University, Aberdeen) gave a presentation on a sensor for detecting and measuring hydrocarbons, synthetic-based fluids and heavy metals, designed to be used for environmental monitoring during removal of drill cuttings piles. Peter reported the development and application of such 'multicapability' optical sensors for real-time *in situ* monitoring of concentrations of three key marine environmental materials: hydrocarbons, synthetic-based fluids and heavy metals. These sensors will be crucially important tools for real-time *in situ* environmental monitoring during decommissioning of offshore structures. The multicapability sensors will also provide information on the dispersion of contaminants from drill cuttings piles, either while they are *in situ* or during their removal.

Concluding day one, Andrew Tyler of British Marine Technology brought the day's themes together with a paper on modelling the behaviour and environmental impact of cuttings piles during decommissioning. As part of a major research programme, funded by the oil industry, to study the options for decommissioning offshore facilities, a new model has been developed to simulate the physical dispersion and biogeochemical behaviour of cuttings piles during removal/intervention operations, and under naturally dispersive conditions. The talk described the development of the modelling system, demonstrated typical outputs from the simulation, and outlined the ongoing work to further improve process-representation within the model, and to validate the model with data from full-scale field trials.

The second day began with a series of talks concentrating on the ecological impacts of decommissioning. The first presentation was given by Jans Peter Aabel of Alliance Technology, Stavager, on the ecological impacts of 5 000 km of oil and gas pipelines in the Norwegian sector of the North Sea. As a result of the corrosiveness of the marine environment, it has been standard practice to shield all sub-sea pipelines against external corrosion by means of protective coatings and cathodic protection. The rates of leaching of the heavy metals associated with corrosion protection vary considerably, but estimates for the next 100 years indicate that if the anodes are not removed, leaching of heavy metals from them will contribute between 0.001 and 1% of the total metal input to the North Sea. However, although the concentrations of heavy metals in the central and northern parts of the North Sea could become elevated, the concentrations should remain

relatively low, and models suggested that no acute negative effects should be expected. The effects of long exposure, however, are not as yet fully understood. The paper concluded with a brief overview of the potential conflict between the commercial fishing industry and pipelines on the sea-bed.

Murray Roberts (SAMS) gave a presentation about the discovery of growths of the deep-water coral *Lophelia pertusa* on North Sea oil rigs. Prior to 1999 the only verified locations of *Lophelia pertusa* in the North Sea were two sites where trawls had recovered dead coral. It is now becoming clear that structures around several oil platforms in the northern North Sea have been colonized by *L. pertusa*. The size of the colonies suggests that pioneer organisms may have arrived shortly after the structures were put in place. The colonies are restricted to depths below 60 m where there is year-round presence of cool Atlantic water. It seems likely that coral planulae (i.e. larvae) have been transported into the North Sea from the Atlantic margin via the East Shetland Atlantic Inflow Current. The floor of the North Sea is predominantly muddy, so the presence of hard substrate in the form of steel and concrete platforms has provided attachment sites for a variety of suspension feeders, including soft corals, anemones and hydroids. The talk included a detailed description of the distribution of *L. pertusa* and other conspicuous epifauna on two single point moorings in the *Beryl Alpha* field.

Martin Sayer of DML presented a critical evaluation of the potential for developing artificial reefs from decommissioned North Sea platforms. Because of their existing locations, and/or opposition to relocation in coastal waters, it is unlikely that artifical reefs will ever be adopted for near-shore leisure use. In addition, there are almost insurmountable regulatory and liability frameworks to comply with, and a lack of support from the petroleum industry. Arguments are sometimes presented for creating extensive artificial marine reef 'parks' in order to protect and/or enhance commercial fisheries. Certainly, fish aggregations are common around platforms. However, a comparison of the existing area 'protected' by platforms in the UK, and the estimated area thought likely to have any marked effect on commercial stocks, indicates that 'rigs to reefs' as a concept for fisheries management in the North Sea should be rejected. The conclusion, therefore, was that partial toppling associated with retention of exclusion zones could not be dismissed as a viable strategy beneficial to fisheries management, but the lengthy and costly business of cleaning and relocating rigs as reefs must be.

The final session of the meeting included the legal and practical aspects of decommissioning, and economic evaluations of certain practices. The session started with Mike Curtis of the Scottish Environment Protection Agency (SEPA) giving a thorough and detailed overview of the regulatory framework in which offshore decommissioning activities for oilfield infrastructure have to operate in the UK. Regulations pertaining to the national and international guidelines for full or partial removal were reviewed in detail, and included all Health and Safety laws as well as environmental protection legislation. Mike concluded his talk with an introduction to the SEPA guide to the regulation of decommissioning activities.

The actual practicalities of large-scale decommissioning projects and relevant pre-existing experience in the marine salvage industry were examined in a joint presentation by John Noble of British Maritime Technology Ltd, and Moya Crawford of Deep Tek Ltd. The presentation gave an account of important salvage-related issues relevant to decommissioning. These were summarized as: the preservation of human life, the preservation of the environment, and the analysis of risk and cost versus benefit. These criteria, combined with the broadening of emphasis beyond hydrocarbons, indicate that decommissioning strategies should be underpinned by chemical and biological research. The presenters concluded that high-quality scientific knowledge is essential to aid discrimination and support decision-making, both during salvage and any subsequent recovery operation. In relation to both the costs and benefits of removal and retention of obsolete oil and gas installations and drill cuttings piles, experience from the salvage industry was drawn on to discuss: the environmental benefits of leaving certain man-made objects *in situ*; the proven techniques for working in confined, hazardous spaces and clearing the debris field; innovative technology to move and handle drill cuttings with a minimum of mixing with the water column; and endocrine suppressors and diesel-based muds as potentially harmful contaminants.

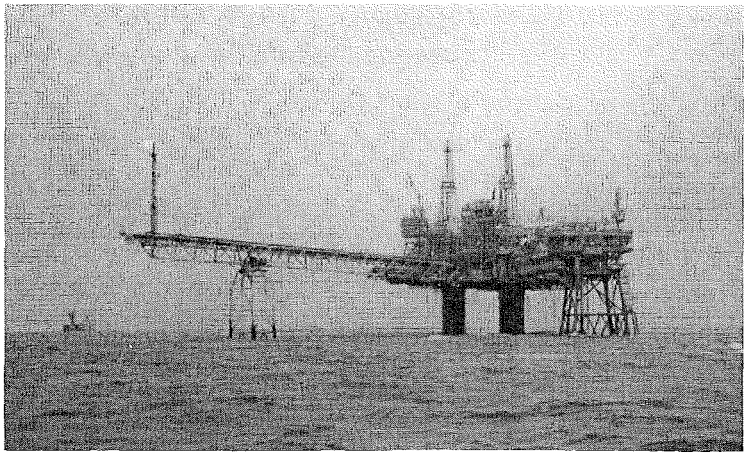
Roger Stave of AGR Services, Norway, assessed the process of removing drill cuttings from the sea-bed.

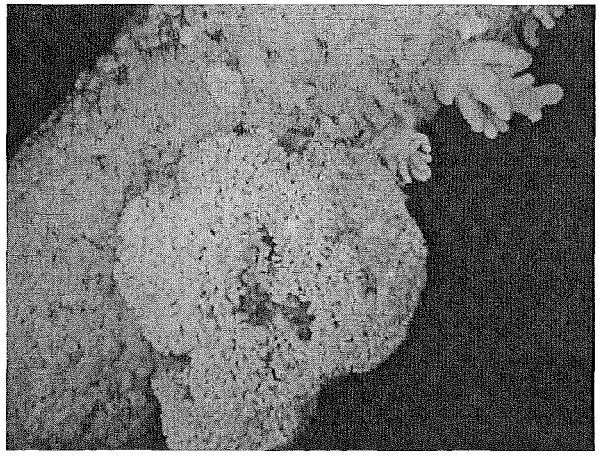
Left *The* Beryl Alpha *platform in the northern North Sea showing the flare and its supporting tower*

(Photo J.M. Roberts)

Right *A single colony of* Lophelia pertusa *growing on this flare support tower at a water depth of 72 m. The colony is approximately 30 cm in diameter and 20 cm in height and is surrounded by sea anemones (probably* Metridium senile*); several colonies of soft coral (*Alcyonium digitatum*) are visible above.*

(Photo: Mobil North Sea Ltd)





Left undisturbed, drill cuttings may not represent a big environmental threat. However, when the platform structure is removed, the actual process of removal and/or later fishing activities may result in disturbance and dispersal of material with pollution potential. It was argued that removal of cuttings could be the best alternative for the environment providing that they could be removed with a minimum of resuspension. Roger then outlined a Cuttings Transport System (CTS) recently developed by AGR Services. This sub-sea system is used to pump up and remove drill cuttings during top-hole drilling. The following talk was by Ron Duguid of JP Kenny Caledonia Ltd, Aberdeen, who detailed a comprehensive and representative assessment of the companies and technology available to provide the services considered necessary to excavate mounds of drill cuttings. By assigning score percentages to a series of measurable criteria or categories associated with cuttings removal, the assessment procedure provided the project team with a set of raw data that could be processed to give an overall 'Fitness for Purpose' for each scheme proposed.

Ian Eames (University College London) considered the economics of covering drill cuttings piles versus removal options, given that there are about 1 million tonnes of drill cuttings on the floor of the North Sea. The presentation outlined a series of laboratory-scale experiments designed to examine how the pile radius varied as a function of the particle-size distribution, particle volume flux, volume deposited and water depth. A model of drill-cutting pile formation has been developed and there is satisfactory agreement between experimental measurements and model predictions, which were applied to interpret available field data. Ian then demonstrated how the newly validated mathematical model is being applied to assess the economics of pile-treatment by either covering or removing part of the pile.

Pipeline decommissioning was the subject of the last two papers. John Anderson, of Boreas Consultants Ltd, Aberdeen, considered three aspects of pipeline decommissioning: the legal framework for decommissioning, the process of decommissioning, and the technical options for pipeline decommissioning. The cost evaluations for the removal of decommissioned oil and gas pipelines in the Norwegian sector of the North Sea were considered in the final presentation, from Jans Peter Aabel of Alliance Technology, Stavanger. It was concluded that from a technical point of view all decommissioned pipelines could be removed. Through a series of projects, the Norwegian Ministry of Oil and Energy has addressed various aspects of decommissioning pipelines, including one study on the costs involved for the different options.

The second day concluded with another lively discussion period, chaired by Andy Tyler, and attempted to place the science firmly into context within the general issues relating to decommissioning. The feeling of the meeting was that although scientific research was contributing to the debate it was overshadowed by largely unsubstantiated emotive argument. The UKOOA drill cuttings initiative was held up as a prime example of a well co-ordinated strategic science-led programme of research, but it was felt that more holistic strategy-led science programmes were required, there being some urgency for science to play a more central role in deciding decommissioning strategy. In particular it was noted that future decisions should be based on sound scientific reasoning.

The meeting closed with a call for full scientific papers to be submitted for publication in a forthcoming issue of *Underwater Technology*.

Both SUT and SAMS recognized the enormous contribution made by Dr Liz Cook of SAMS in organizing the conference. For a complete view of conference abstracts, visit the Dunstaffnage website at: http://www.sams.ac.uk/dml/events

Eric Breuer and **Martin Sayer** are both at Dunstaffnage Marine Laboratory, Oban, Argyll, PA34 4RA, Scotland, UK.

The greening of a Southern Ocean eddy

Weekly reports from the Chief Scientist on the EisenEx Cruise

Victor Smetacek

Week 1 (30 October–6 November)

RV *Polarstern* left Cape Town on 25 October with 58 scientific and technical personnel and 44 crew members on board. We scientists are a motley lot, representing 15 countries and several major disciplines of physics, chemistry and biology, and on the way south we busied ourselves unpacking and setting up the instruments in preparation for the hard work ahead.

Because the oceans contain far more CO_2 than the atmosphere, the balance of carbon at the ocean surface is critical in setting the atmospheric concentration, and this is influenced by the phytoplankton that grow suspended in the sunlit surface layer. By taking up and converting dissolved CO_2 into organic material, the algae create a CO_2 deficit in the surface layer which is compensated for by drawdown of CO_2 from the atmosphere. The bigger the algal biomass, the more CO_2 enters the ocean. What is crucial for the CO_2 budget is that if the phytoplankton biomass is broken down in the surface layer by bacteria and zooplankton, no net removal of CO_2 occurs. However, if organic matter sinks out of the surface layer, the equivalent amount of CO_2 is removed from the atmosphere for tens to hundreds of years.

Phytoplankton growth is dependent on light supply and the availability of dissolved nutrients, of which nitrate is the most important. However, in three vast regions of the ocean – the equatorial and sub-Arctic Pacific and the entire Southern Ocean – phytoplankton production is low despite favourable light climate and high nitrate concentrations. This enigma has been solved over the course of the past decade: several experiments have shown that iron is the limiting nutrient in these regions.

There is considerable evidence that the main source of iron in the open ocean is continental dust (which is rich in iron) settling on the sea-surface from the atmosphere. Analysis of ocean sediments and ice cores shows that much more dust was deposited on the oceans during cold (glacial) periods than during warm (interglacial) periods. If the Southern Ocean were as productive during glacial periods as the North Atlantic is today (thanks partly to Saharan dust) then this could account for a significant proportion of the difference between the 0.018% and 0.028% of CO_2 in the atmosphere during cold and warm periods respectively. The main aim of our cruise is to test this hypothesis. We intend to simulate a 'dusting' episode by fertilizing a patch of ocean with iron sulphate solution and then studying the response of the plankton.

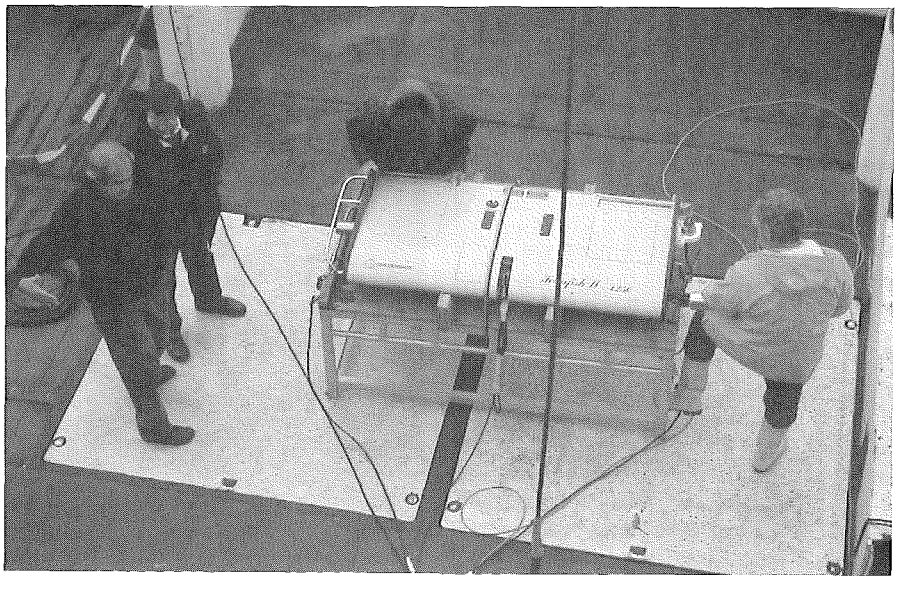
But first we need to select an appropriate site which fulfills the necessary criteria: low iron concentrations, and a stable water mass that will maintain its integrity over the course of the experiment. We need to be able to follow the fertilized patch and be sure it will not be ripped apart by the strong currents typical of this region, i.e. the site must be away from the tracks of the frontal jets that stretch across the Southern Ocean. We gained an overview of the position of the fronts by towing an undulating instrument package called *ScanFish* (see photograph below) for 750 km along the 20° E meridian from 45° to 52° S. *ScanFish* records temperature, salinity and chlorophyll fluorescence in the upper 250 m, and preliminary results indicated low iron and low phytoplankton concentrations throughout the region. We also crossed a phytoplankton bloom – of the kind we would like to generate – just before entering the northern rim of the Southern Ocean.

We are now at the border between the Roaring Forties and the Furious Fifties but have so far been spared winds above Force 8. The crew takes great care to make us feel comfortable, the food is excellent and we are all working hard in preparation for 'Dusting Day'.

Week 2 (7–13 November)

The Antarctic Circumpolar Current (ACC) which encircles Antarctica can be subdivided into several belts separated from one another along fronts characterized by sharp temperature gradients. The Polar Front is the most prominent of these and divides the ACC into a northern region – the Polar Frontal Zone (PFZ) – and a southern region – the Antarctic Zone (AZ). The northern border of the PFZ has a tendency to subduct under the neighbouring sub-Antarctic zone. Because plankton growth in the ACC is iron-limited, huge amounts of dissolved nitrate and phosphate are entrained unused into the deep ocean. Were enough iron available, the algae would grow faster, take up more nutrients and fix much more carbon, which would then either sink out as a rain of particles or be carried down to the deep sea with subducting PFZ water. In both cases, it would disappear for some centuries. Simple models show that about 30 to 50 billion tonnes of CO_2 could be disposed of in this way over a few centuries – about the amount added to the atmosphere by humans in a decade.

Fronts are the 'fast lanes' of the ACC and appear on satellite images as narrow, meandering features. Eddies are sheared off on either side of the fronts, move away from them and slowly mix into the surrounding waters.



The author,* Polarstern*'s captain Jürgen Keil, Ulrich Bathmann and Johannes Post (from left to right) check over* ScanFish *before deployment.

Since the centres of eddies are protected from mixing for fairly long periods, we intend to carry out our experiment in the eye of an eddy.

Eddies are sheared off from fronts where density gradients (determined by temperature and salinity) are steepest, so their density differs from that of their new surroundings. The difference in height of the water column in the middle of an eddy can be a few decimetres lower or higher than at the edges, and this difference can be accurately measured by altimeters mounted on satellites. Eddies can also be located from a ship with an Acoustic Doppler Current Profiler (ADCP).

As we towed *ScanFish* south along the 20° E meridian from 45° S (the Sub-Antarctic Front) through the PFZ and across the Polar Front to 52° S (the Antarctic Zone), we also made measurements in the surface waters. Across a stretch of water around 48° S, we found low temperatures, high silicate concentrations and large diatom stocks. Water properties here matched those in the cold water of the southern Polar Front at 52° S. This was part of a water mass originating from the Polar Front that had drifted 400 km northwards, a conclusion supported by the ADCP profiles, which showed currents flowing towards the west and also that speeds were at their lowest where the currents changed direction. This was the core of an eddy! Further support came from satellite altimetry: we had cut across a circular eddy of about 150 km diameter, the centre of which lay about 10 cm lower than the periphery.

The area of low current speeds at the centre was rather small, so we planned to measure the extent of the eddy by laying a grid across it (five north–south transects 200 km long and 50 km apart). But time is running short (we only have three weeks left and are keen to observe the end of the bloom). So – despite warnings from the physicists that without proper assessment of the eddy we might lose our fertilized patch to subduction or disruption by current shear – we interrupted the grid and measured current speeds with the ADCP to pin-point the eddy centre. On the evening of 6 November, we deployed a free-floating buoy in the very centre of the eddy. It is a red spherical buoy attached to a drogue 'anchored' in subsurface water in the hope that it will drift within the eddy and not be pushed out of it by winds. We then spent the night making detailed measurements of the physics, chemistry and biology of the water mass, and started with the fertilization next day. The pre-conditions were good: very low iron concentrations throughout, a sparse but species-rich plankton community combined with a fairly shallow mixed layer. Measurements of the photosynthetic performance of individual cells showed the phytoplankton to be growing at only 30% of their potential rates – most probably constrained by iron deficiency since all other conditions were fulfilled. A cause for concern is the large numbers of copepods in the area – around 15 per litre, much higher than normally found even in the productive North Sea. Their grazing pressure could nip the bloom in the bud.

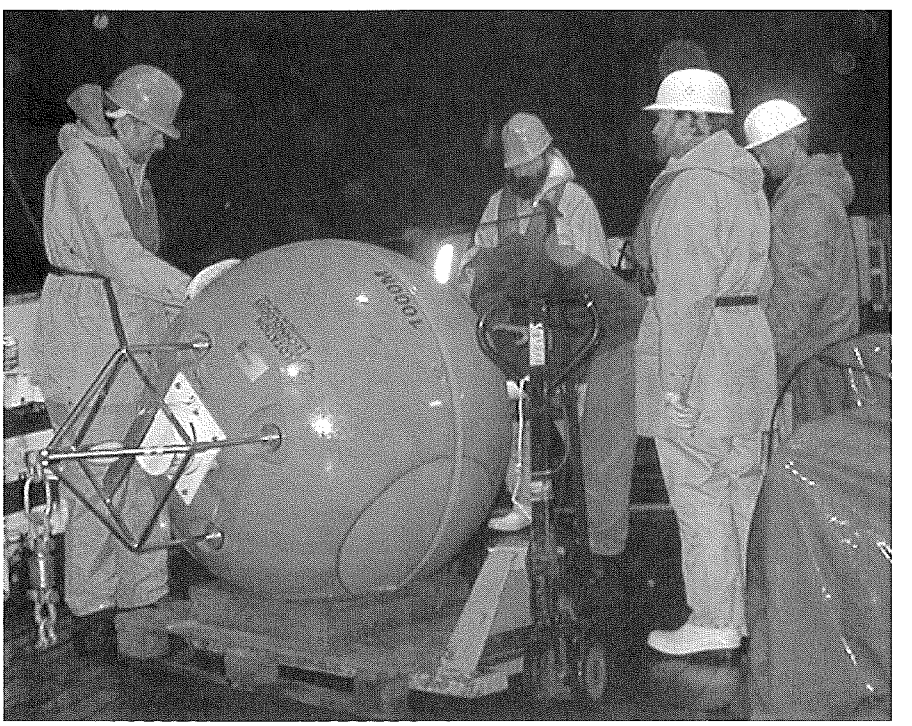
The weather has been favourable so far, although a storm is predicted for the weekend, four or five days after we finish the fertilization.

Week 3 (14–21 November)

In the words of the Chief Engineer, *Polarstern* has changed from a nomadic hunter to a sessile agriculturist tending a watery garden – the eye of an eddy spinning in this vast expanse of seemingly featureless ocean – and waiting for it to burst into bloom. Preparing the garden was a novel experience for the ship's navigators, who take pride in the straightness of the lines with which they have criss-crossed the Southern Seas so far. Now they have spent a whole night 'ploughing' ever-widening circles around a buoy drifting with the currents, while releasing 4 tonnes of iron sulphate (dissolved in 30 m^3 of seawater) through a 5 cm-diameter hose, around a spiral of about 70 km length and 7 km diameter. The distance between the spirals was less than a kilometre and the ship had to turn slightly every five minutes or so while maintaining a steadily increasing distance from the drifting buoy. The ship's navigators rose to the challenge and did an excellent job.

The iron salt added to the water is available in gardening shops as an anti-moss agent. This iron is in its reduced, soluble form which is stable only in acidic water. Natural seawater is slightly alkaline, so this form of iron is rapidly oxidized to the notoriously insoluble rust which eventually sinks out of the water column. However, the fertilized area can still be identified and tracked by means of an inert tracer – sulphur hexafluoride (SF_6) – which is also added to the water, and can be measured at incredibly small concentrations. Only 50 g of this inert substance was added to the 30 m^3 of concentrated iron solution, an amount sufficient to be traceable over more than 100 km^2 of ocean surface. SF_6 is volatile, so the iron and SF_6 mixture was released at 15 m depth in the wake of the ship's propeller, in the hope that much of it would be mixed down deep.

To give the fertilized streaks time to mix laterally, we measured a station in pristine water outside the patch, as a control to evaluate the results of our experiment. Each such station takes about 8 hours to complete because of the vast number of measurements we need to make. The most-used gear is the CTD, a bulky rosette of 24 plastic

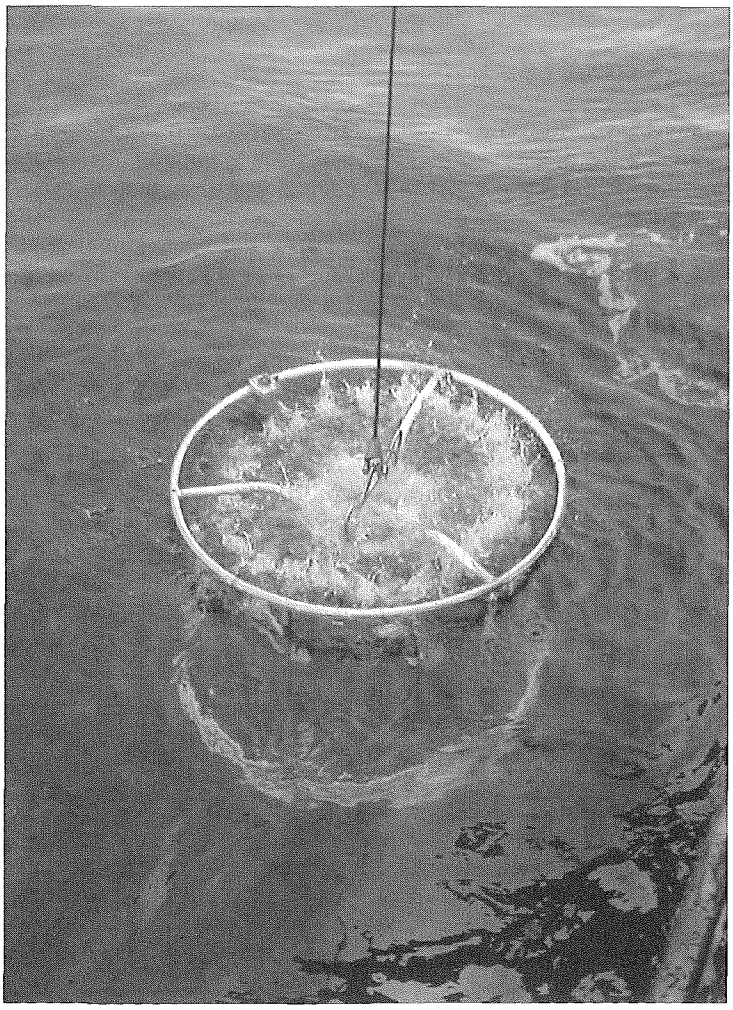


The marker buoy is made ready for emergency deployment at night. From left: Boris Cisewski, Ulrich Bathmann, Manfred Hagemann, Volker Strass, Reiner Loidl.

cylinders of 12-litre volume which can be closed individually at selected depths. Sensors on this rosette measure conductivity (= salinity), temperature, pressure (= depth), as well as fluorescence of the phytoplankton (a measure of the chlorophyll in the water) and transparency (determined by the total amount of suspended particles). As the CTD is lowered through the water column, traces from these sensors appear on a monitor in the control room.

The profiles of the water columns we sampled were surprisingly jagged. The weather had been exceptionally calm, so the surface layer was not mixed. Layers containing chlorophyll extended down to 80 m depth, indicating that they had been closer to the surface and were subsequently 'buried' by lateral encroachment of adjacent water (such water columns require precision closure of the bottles to ensure representative sampling). The rosette was hauled back on board four times during each major station, and samples were taken from the bottles for analysis. Specially cleaned water bottles ('Go-Flo' type) attached to a kevlar rope were used to collect water samples for measurement of the several different forms of iron in natural seawater.

After completing the control station we returned to the patch, a day after releasing the iron. The marker buoy had described a promising curl of a few km, but then suddenly picked up speed and appeared to be travelling with the wind. We found it lying lop-sided on the surface, apparently because the rope (which can hold 4 tonnes) had snapped and the drogue, two attached instruments plus the weights which kept it upright and low in the water, were gone. Although disappointed at the loss, we were more anxious about losing the patch, so a spare drogue was tied to the buoy and we commenced criss-crossing the region, 'sniffing' SF_6 in the surface water to locate the centre again. We completed another station within the patch and found the first signs of a response in the phytoplankton, two days after fertilization and a day or two earlier than we had anticipated. An instrument called the 'fast repetition rate fluorometer' (FRRF), which measures the photosynthetic efficiency (and hence growth rate) of algal cells, showed that the algae in the patch had increased their efficiency significantly, a finding that was greeted with jubilation, especially as we also found very high iron concentrations.



The CTD rosette being lowered into a calm sea

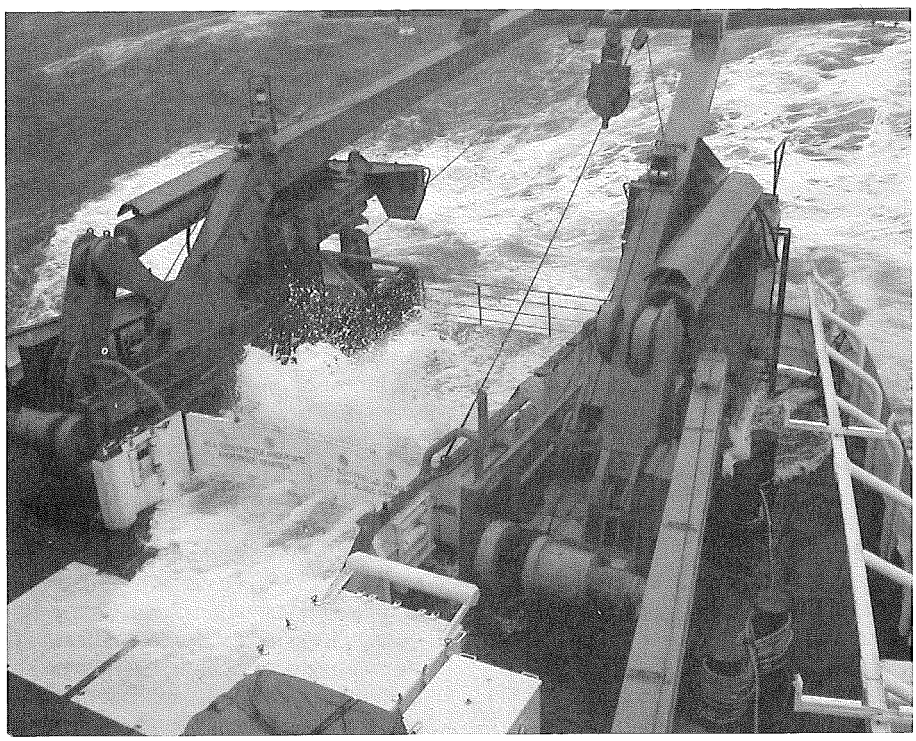
On Saturday, four days after fertilization, we carried out a systematic grid comprising four rows of six stations at each of which the CTD was lowered and sample bottles were closed at many depths. We found that in the eastern corner of the patch, the SF_6 and iron were located between 40 and 60 m depth, indicating that a 20–30 m layer of non-fertilized water had slid over a portion of the patch. Luckily, there was still a large area with SF_6 and iron at the surface. The grid survey enabled us to find most of the patch again, but we were now anxious for strong winds to mix the iron through the entire water column. Our wish was more than granted when a short but hefty storm (the first severe storm of the cruise) hit us next day (Sunday) and we had to stop work. A wave came over the side and caused some damage, which was quickly repaired by the crew after the storm abated and before the next one buffetted us. By Tuesday, with the ship now rolling gently in fairly calm weather, the water column was well-mixed. Chlorophyll concentrations had doubled relative to the surroundings and the patch had stayed in the eddy and was now moving west after having described a semi-circle. The results of the survey showed that the crew had done a very good job of drawing accurate spirals around a moving object.

The bloom has begun: and we now have to keep track of it and unravel the multifarious interacting processes controlling its development. We are keeping our fingers crossed that it will peak before the end of the cruise.

Week 4 (22–29 November)

The calm, sometimes even sunny weather during the first half of our cruise was very uncharacteristic of the Roaring Forties. As a result, the surface layer was not mixed homogeneously down to 60–80 m depth, as is normally the case here, but consisted instead of 'slices' of 10 to 20 m thickness that 'slid' horizontally above or below each other. This interleaving also affected our 7 km-diameter fertilized spiral. Within a few days it was 'tilted' by a layer of water encroaching from the north-east, as evidenced by SF_6-rich layers between 60 m depth and the surface. Despite the favourable light climate for the phytoplankton, chlorophyll levels throughout the region as a whole stayed more or less constant, but within the fertilized patch they more than doubled over the first five days.

In the storm that hit us five days after fertilization, the westerly winds buffeted the buoy along a south-



One of the major storms that hit RV* Polarstern *during EisenEx. At such times, deck work was impossible.

eastward course towards the region where strong southerly currents had been indicated by the ADCP. We were apprehensive that the patch was also going in the same direction and that we would lose it in the great blue yonder. After the storm, a few long transects were made to measure SF_6 concentrations, and there was much relief when we found strong signals to the west of the buoy. The patch was still within the eddy's eye! We retrieved the buoy and replaced it in the centre of this patch. The transect also showed that we now had at least one smaller patch separated by a few kilometres from the bigger one. The storm had homogenized the iron and SF_6 within the upper 50 m of the water column, but probably also pushed this smaller patch away from our original spirals, which had now submerged below the mixing level.

Wind speeds had now slackened, but heavy cloud cover reduced light levels and constrained growth of the phytoplankton. It also rained heavily and a 5–15 m thick surface layer of low salinity water capped the area. After carrying out a series of long stations within and well outside the main patch, we decided to add another few tonnes of iron in its centre because, although iron concentrations were still high, they had dropped in the week since the first fertilization. Another complete spiral was fertilized on Thursday night (16 November) and by the weekend the highest chlorophyll levels within the patch had increased to > 2 mg chl m^{-3}, which qualifies for bloom status in the Southern Ocean. Values in the surrounding waters were still at about 0.5 mg chl m^{-3}.

After assessing the approximate extent of the patch with surface measurements along some long transects, we started to lay out a grid of 24 stations 3 km apart on Sunday, but were interrupted by another storm on Monday. Results from the (incomplete) grid showed very close congruence between SF_6 and chlorophyll concentrations in an elongated coherent patch at least 15 km long and 10 km across, sharply delineated from pristine water to the west but merging gradually with surrounding water along the eastern boundary. We found the highest values in the northern part of the grid, but bad weather prevented our assessing the northward extent of the patch. This storm was so severe that we were forced to ride it out by travelling slowly into the wind, and by the time it abated sufficiently for us to turn the ship, we had moved 30 km west of the buoy. Again there was the worry that the patch might have been pulled apart by the fierce winds because we found only traces of SF_6 when we reached the buoy. However, much to our relief, we located the patch and found that it had moved northward with the eddy and was now more or less in its centre, after completing a full circle since fertilization two weeks ago.

The sea was still too rough for station work, so we spent the time mapping the surface expression of the patch which has now increased in size. Chlorophyll concentrations have declined slightly because of the deep mixing but are still three times higher than background in the central region. For the last three days we have been riding out one storm after another, and our only comfort is that we are on board *Polarstern* and not on a smaller or lighter vessel.

We are also using the time to work up our data, and we present them during the daily evening meetings attended by all scientists, also the captain, the chief engineer and the doctor. The discussions are sometimes lively but good humour generally prevails at the end. In an interdisciplinary exercise such as our's it is essential for all participants, including the younger scientists, to be aware of the considerations that guide the daily planning, and how the efforts of the various discipline groups contribute to the common goal. Presentations of the latest results by those groups who can measure their samples on board keep everyone informed of the unfolding drama of our experiment.

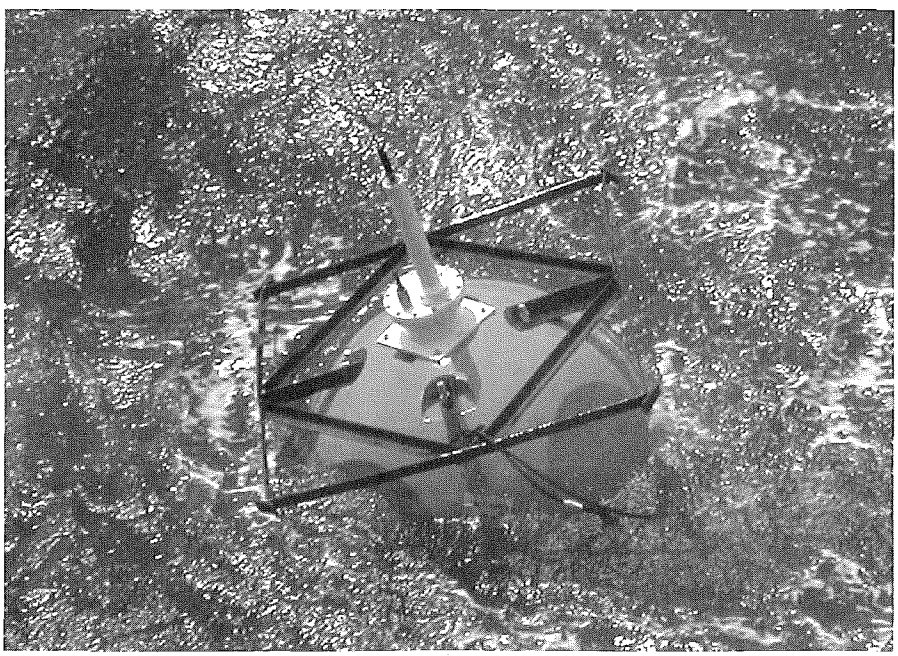
Preliminary results suggest that although the iron-enriched plankton are growing at least twice as fast as those in the surroundings, the accumulation of biomass has been kept in check by the poor light conditions of the past week in combination with the heavy grazing pressure exerted by organisms, ranging from protozoans to crustacean zooplankton, that feed on phytoplankton. A series of distinct traces on the echosounder output, with which their vertical migration (dusk rise, dawn descent) is monitored, indicates that the various species or larval stages move upward and downward in concert. A series of vertical net tows, carried out one evening to identify the animals responsible for the different traces, turned up a 41 cm-long fish in one of the hauls. It turned out to be a 'drifter fish' of the family Centrolophidae which has been collected only seven times before from the Southern Ocean, our's being the first record from the Atlantic sector. It is known to be a passive fish, confirmed by its very flabby body and the fact that it was caught by a net of only 150 cm diameter. Its head and mouth are incongruously small for its wide body and since its gut contained only slime, we assume that it feeds on jellyfish, large numbers of which we observed drifting by the ship at night when the sea was calm. They had purple tentacles and were several decimetres in diameter.

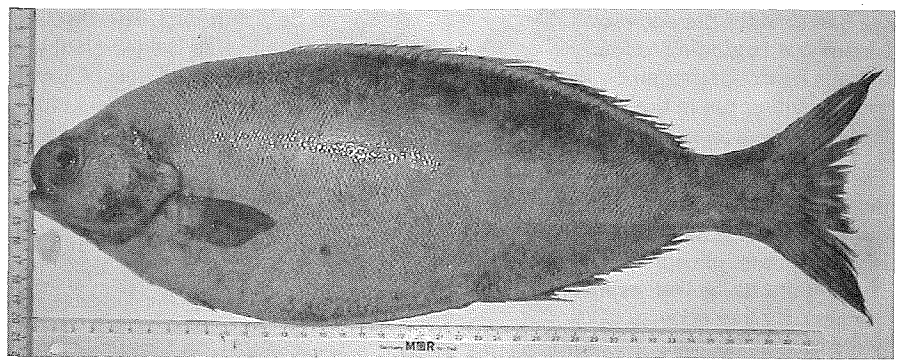
The mood is good despite the storms, and on Saturday night a party in the ship's hold, specially decorated and converted into a 'restaurant' by the crew, lasted well into the night We again mapped the eddy with the ADCP and with only a week left to follow our bloom we are hoping for at least a few sunny days to turn the water green.

Week 5 (1 December)

In the first two weeks after iron fertilization, we were reluctant to leave our plankton garden to carry out the control stations because we were worried that we might not find the patch again. Last week, however, we had to go many miles before we reached water without SF_6, the tracer with which we marked the fertilized water. Since our patch was being diluted on its way around the eye of the eddy and iron concentrations were very low throughout, we again re-fertilized its centre, where SF_6 concentrations were highest, on Wednesday. This third fertilization was carried out in the same manner as before (though with smaller quantities): In a container on the upper deck, three scientists clad in red plastic overalls with hoods and gas masks (the powder is non-toxic but irritating) dumped the contents of 30 plastic bags of 25 kg iron sulphate powder into a large funnel and flushed it down with a seawater hose into one of the two 10 m^3 tanks welded to the working deck below. The slurry was dissolved with giant stirrers and the contents pumped into the sea at a rate of one tank in about 2 hours, while the ship spiralled at a speed of 10 km hr^{-1} around the drifting buoy.

A buoy was used to keep track of the fertilized patch in the eddy





The drifter fish (family* Centrolophidae*). Although found in all oceans, it is a rare species. It has been caught only seven times near Antarctica, mostly near islands

The SF_6 tracer was added only during the first fertilization.

Drifting marker buoys are essential for such small-scale studies as our's, because the ship is pushed by the wind during stations and has to be relocated in relation to the buoy between casts, to ensure that the gear deployed over several hours samples the same water mass. The storms, however, proved too much even for the strong ropes tethering the buoy to its drogue, and we lost the second drogue on Monday, and did not deploy another buoy. We have had several sunny days with stiff winds, also some gales, so the water column has been thoroughly mixed and the bloom has continued to build up biomass, despite being diluted with water from below. During a bout of bad weather, when the waves were too high to risk deploying gear, we mapped SF_6 concentrations and other properties in surface water of the entire patch with a grid of latitudinal transects 5 km apart, working our way down from the north.

The results showed close correlation between chlorophyll and SF_6 concentrations, demonstrating beyond doubt that our bloom is a result of iron fertilization. The region with significantly elevated chlorophyll was 15 km long and 10 km broad, and there were several patches with concentrations around 2 mg chl m^{-3}, four times that of the non-fertilized water, where little change has been observed so far.

As predicted by the physical oceanographers, the eddy has stood its ground in the current for over three weeks because it extends down to the bottom: a rotating disc of water about 150 km across and 4 km deep. Our bloom has circled its centre a couple of times, increasing in size as it mixes with surrounding water. The track of the buoy circling the eddy's eye is about 120 km in three weeks. A parcel of water in the swift currents either side of the eddy would have theoretically moved about 500 km to the east in the same period.

A final survey on Tuesday (grid plus major stations inside and outside the patch) revealed that fertilized water now covered an area of 500 km^2 and extended over the entire eye of the eddy. Streaks and patches of higher biomass several kilometres across within this region are presumably the result of the second and third fertilizations. Sampling the largest of these high biomass zones, without a buoy to use as reference, involved precious hours in a nerve-wracking search to locate our target. The highest chlorophyll concentration we measured was 2.84 mg chl m^{-3} with a standing stock of over 200 mg m^{-2}, which is a very large algal biomass by any standard.

These values are only a very rough measure of the total biomass built up by iron fertilization because they have to be corrected for dilution with surrounding water. The correct estimate of the carbon actually taken up as a result of iron fertilization will require budgetary calculations of the total area covered by the bloom. That final estimate will be conservative, because

we had to leave the eddy just when the bloom was beginning to 'take off' and there is no doubt that much more growth will ensue in the coming weeks, based on the iron we added.

The budgetary calculations will incorporate many measurements made during EisenEx. These include deficits in CO_2, nitrate, phosphate and silicate concentrations, as well as increases in biomass of other ecosystem components such as bacteria, zooplankton and their waste products (faeces) which were measured continuously throughout the experiment. In the water column with highest chlorophyll concentrations, nitrate and phosphate declined by only 10%, whereas silicate decreased by 30%. The lowest CO_2 concentration we found was equivalent to an uptake of about 7 gC m^{-2}. If all the nitrate were converted into algal biomass, the equivalent chlorophyll concentration would be around 50 mg chl m^{-3}, and the total amount of CO_2 converted to organic carbon in a 60 m deep water column would be over 80 gC m^{-2}. These figures indicate the enormous potential of Antarctic waters for building up biomass and hence removing CO_2 from the atmosphere.

During the first two weeks after fertilization it was not clear which of the many groups represented in the phytoplankton of the eddy were mainly responsible for the tripling in chlorophyll within the patch. It seemed that the iron functioned initially as an elixir for all the species present. The diversity of the plankton was unusually high, because the eddy had spun off from the Polar Front in the south and carried with it large diatoms and presumably also the colonial flagellate *Phaeocystis*, both typical of the cold water of the Antarctic Zone. Lighter surface water encroaching from the north carried typical sub-Antarctic species – dinoflagellates, coccolithophorids, also minute cyanobacteria – that were mixed into the surface layer with the southern plankton.

There is so much beauty and variety in the ocean of which the general public is still largely unaware. The variety of shapes and patterns among the phytoplankton easily surpasses that of land plants, for phytoplankton are the dominant life form of our planet. From an evolutionary viewpoint, planktonic algae are much more diverse than land plants, which all stem from a common ancestor. The smallest cells in our patch belong to the cyanobacteria (blue–green algae) which are about 1 micron (0.001 mm) in diameter and the largest is a rod-shaped diatom which can be 5 mm long. This thousandfold range in size is equivalent to that between mosses and trees! Growth rates, ecological preferences and life cycles of these phytoplankton species differ widely. Since the fate of the carbon fixed by the fertilized community depends largely on which size class and group accumulates most biomass, it is essential to follow the changes in community composition closely, and many scientists are engaged in this task. The smallest cells are counted and assessed by an instrument called a flow cytometer, which was developed for blood research. These small cells are eaten by a large variety of unicellular protozoans, which are being studied using different techniques. However, the ACC is best known for its large diatoms whose shells accumulate in the underlying sediments to such an extent that this region is estimated to be the largest sink of silica in the entire ocean.

Initially, it appeared that cells in the intermediate size class (10–20 µm) belonging to various groups had increased their numbers the most, but during the third week of the experiment an as yet unidentified species of the cosmopolitan diatom genus *Pseudonitzschia* (a very common genus in the ACC) clearly attained dominant status. Its cells are needle-shaped with their tips attached to each other in chains that are several millimetres long and consist of 50 or more cells. Another, very different looking species, *Fragilariopsis kerguelensis*, also started increasing its chain length (this species dominated the fertilization experiment carried out in February – austral autumn – last year from a New Zealand ship). Its cells are elliptical, but their sides appear rectangular, and it is remarkable for the thickness of its silica cell walls, particularly when compared with the slender, thin-walled cells of *Pseudonitzschia*. The cells attach to one another in chains that look like cartridge belts. Initially the chains were short, but in the last days of our experiment up to 150 cells per chain were found, and the shells of this species are the dominant component of the underlying sediments. Many other algal species contributed to our bloom, but in smaller numbers.

Preliminary results indicate that bacterial growth was also strongly stimulated by iron-addition, but the extent to which the protozoans and zooplankton responded to the increase in food supply still needs to be analyzed. Metabolic products of the plankton that are volatile and can have an impact on atmospheric processes, such as dimethyl sulphide and halogenated hydrocarbons, were also monitored during the experiment. A sensitive technique employing natural radioactive tracers to estimate sinking out of particulate material from the surface layer to the deep ocean indicates that there was little difference in loss rates between patch water and the surroundings. This is likely to change drastically in several weeks' time, but unfortunately the cruise was too short to follow the fate of the bloom, so the only method left to monitor it is satellite imagery. So far, every time the satellite (which measures ocean colour) passed over us, the eddy has been obscured by clouds. The images we managed to acquire on sunny days show glimpses of the bloom shimmering through the clouds.

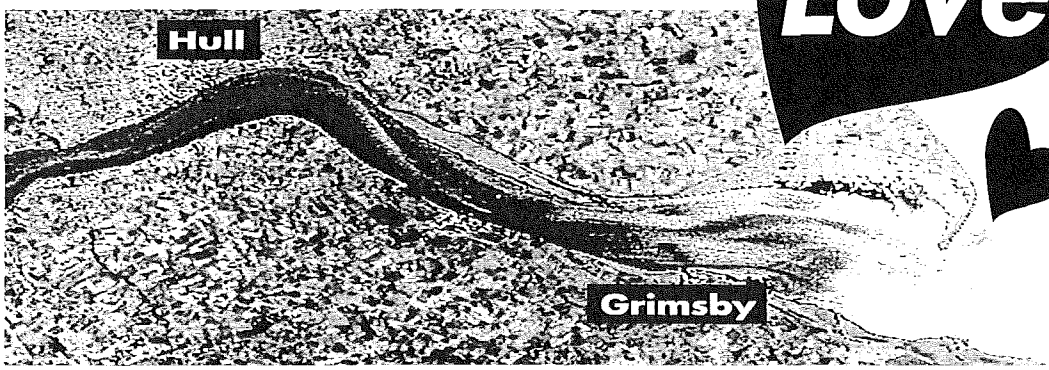
We are now steaming back to Cape Town, packing our instruments, gear and samples. Although the cruise was too short to assess the magnitude and fate of the bloom we created, EisenEx has nevertheless been a great success. We have shown that plankton growth in the ACC is limited by iron availability and that addition of this element led to quadrupling of biomass within a period of three weeks, despite heavy grazing and poor light conditions characteristic of the austral spring. We have also demonstrated that it is possible to carry out an iron fertilization experiment and follow bloom development for a prolonged period in the Southern Ocean despite the stormy weather. It is too early to speculate on the role of the Southern Ocean in removing atmospheric CO_2 during glacial periods, but certainly the results obtained so far warrant further investigation.

The crew have been remarkably patient with us, and appreciate the novelty of what we have accomplished, even before the greenish tinge of the waves in our water garden became evident. Their good humour and willingness to help at every hour of the day and night has contributed greatly to the success of our venture. The food has been superb and served with great friendliness. This has been a great cruise despite the many storms we have had to endure and the many changes in plans that we all have had to put up with. It has certainly been more than worth the hardship.

Warm regards from a ship heady with success, reluctantly parting from its green-eyed eddy!

Victor Smetacek, *Chief Scientist*

Another Reason to Love



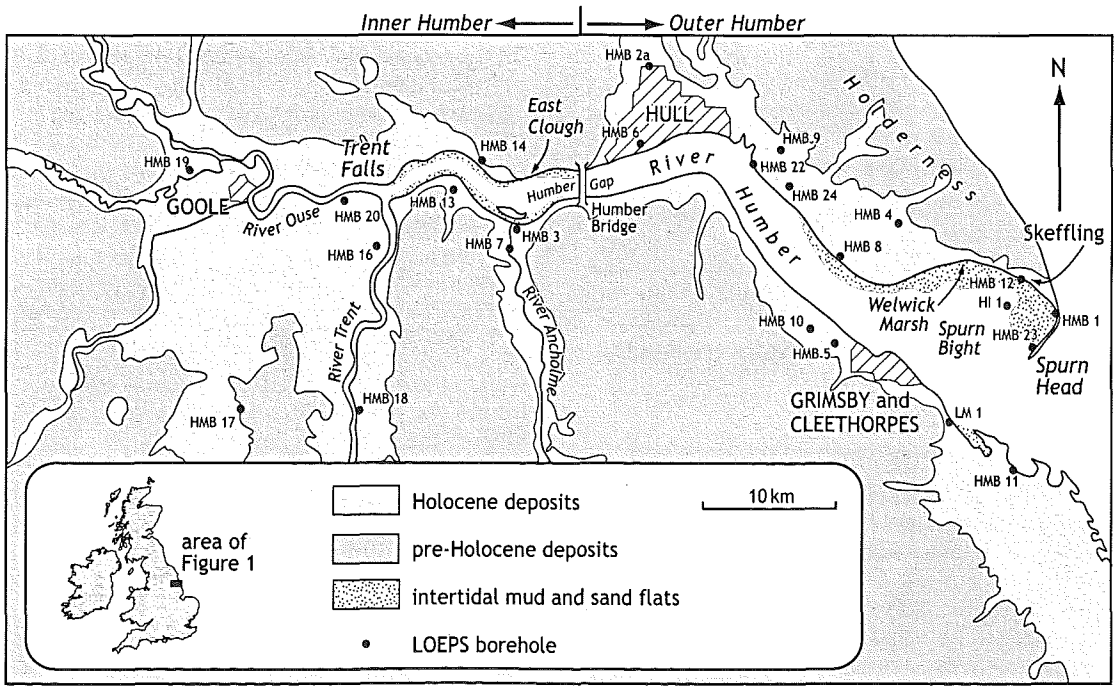
Salt Marshes and Mud Flats

Tim Jickells, Julian Andrews, Greg Samways and Steve Malcolm

In northern Europe we have grown used to sailing up and down estuaries looking at banks protected by coastal defences and often dominated by docks and warehouses now being 'yuppified' into marinas and expensive flats. Faced with these developments it's often difficult to imagine what the landscape looked like before human intervention. Here we describe an attempt to understand how one estuary used to look and function.

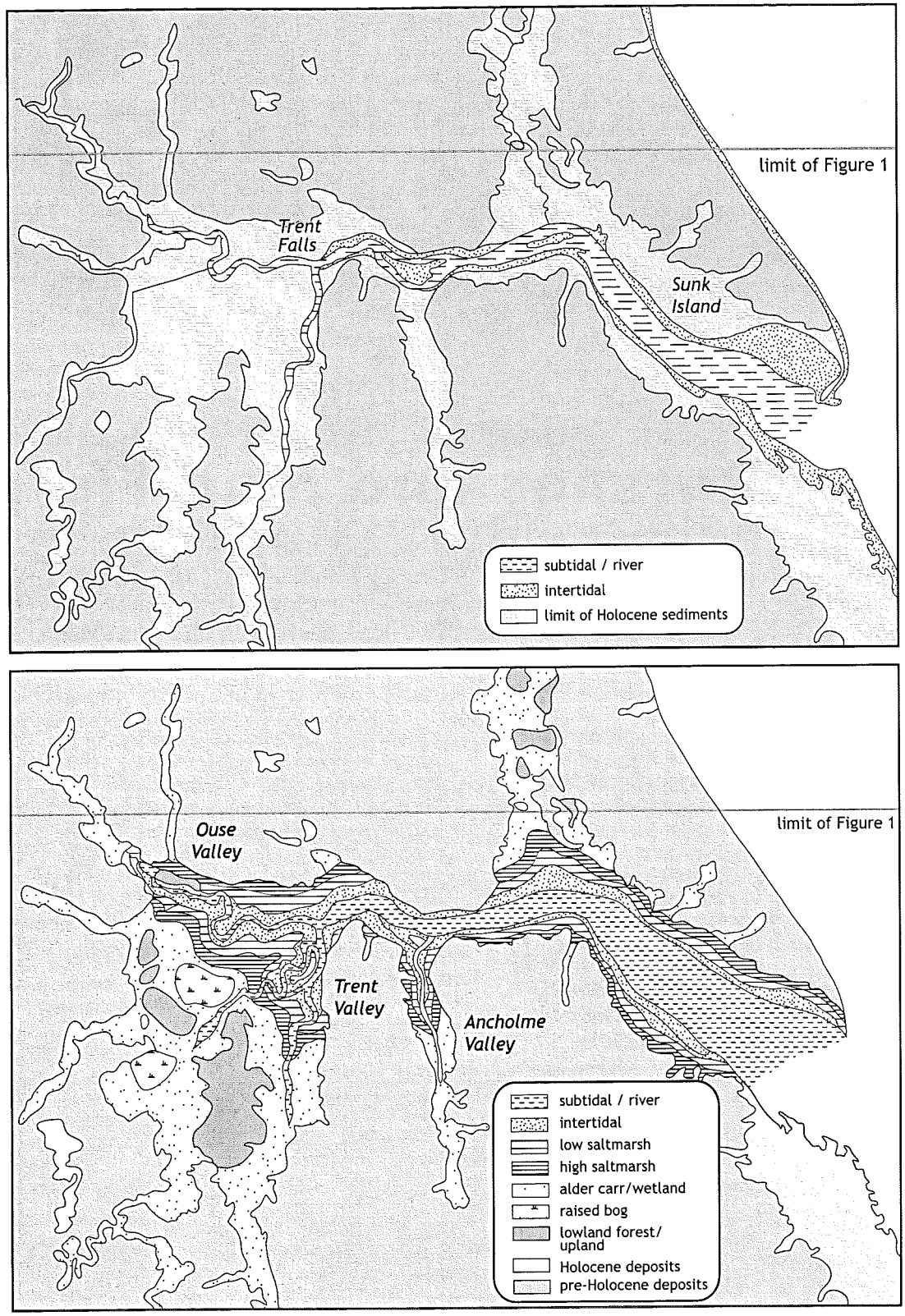
As part of the NERC LOEPS programme (Land–Ocean Evolution Perspective Study) which was a part of the larger LOIS (Land–Ocean Interaction Study) we have been involved in recreating the geography of the Humber estuary 3000 years ago. The Humber is a large estuary by UK standards, draining 20% of the land surface of England. Sediment cores were collected from sites throughout the basin (Figure 1). These were examined to determine the type of environment which existed at specific times in the past (determined by various dating techniques), the rates of sedimentation at those times and the chemical composition of the sediments. Armed with these data, we can now contrast the present day Humber with the situation 3000 years ago. By then, sea-level had risen from its glacial low level to approximately its present position. Humans lived in the catchment of the Humber and some forest clearance had probably taken place, but otherwise there had been little disturbance. The reconstructed 3000-year-

Figure 1 *Map of the modern Humber estuary and adjacent area. Boreholes used in reconstructing palaeogeography are also shown.*



The Humber drains about one-fifth of England's land area

Reproduced from Andrews et al. *(2000) with kind permission of the Geological Society of London.*



3000 years ago, the environment around the Humber was much more varied, with extensive areas of mud flats, salt-marshes, wetland/ alder carr forest and peat bogs

Figure 2 *Map of coastal sedimentary environments* ***(a)*** *around the modern Humber estuary and* ***(b)*** *around the Humber 3000 years ago.*

old estuary is shown in Figure 2(b) along with the modern estuary (Figure 2(a)).

The changes between these two times are dramatic but have mostly occurred over the last 300 years as a result of land reclamation. In total, 93% of the natural wetland environment has been lost. This loss includes the complete disappearance of some habitats such as wooded wetland dominated by alder (such as still fringes the Norfolk Broads) and raised bog. 98% of the saltmarsh has been lost. This former wetland is now in some cases urbanised (e.g. Hull and Goole), other areas are now farmland, while the areas of raised bog are being dug up to provide peat for horticulture. The tensions between preserving intertidal areas and human use of the estuary continue to this day, with opposition to English Nature's proposal to give the Humber special conservation status.

This kind of wetland loss has been replicated in almost all the northern European estuaries. The effect of such loss of habitat on wildlife is obvious and has been discussed elsewhere. Here we focus on the effects on the biogeochemical functioning of the estuary.

Saltmarshes and other intertidal areas represent sites where suspended sediments can be trapped and buried. The loss of intertidal habitat and the creation of artificial sea walls has removed almost all the sediment storage capacity from the Humber. 3000 years ago, 2.9 million tonnes of sediment were deposited each year in the estuary, but it is now basically full and only stores 7.5% of this amount. Sediments are eroding rapidly from the Holderness cliffs (immediately north of the Humber) and washing into the estuary, but they are not being trapped there because of the loss of sediment-storage capacity. They are carried backwards and forwards by the tides, contributing to the very high turbidity in the estuary, and eventually return to the North Sea, to be deposited in deep areas such as those off the coast of Norway.

The loss of sediment-storage capacity also affects the storage of carbon. 3000 years ago, the estuary used to trap and bury 0.3 million tonnes of organic carbon every year, some of it from the rivers but most produced in saltmarshes and other wetland habitats; it now traps less than 1% of this amount, the rest being lost to the North Sea where it is probably oxidized to CO_2. In a world where carbon management and carbon tax credits are becoming a reality, such losses develop an extra importance.

The situation with regard to fixed nitrogen (i.e. excluding largely inert N_2 gas) and phosphorus is complicated by the significant increases in inputs to the estuary in recent years, from human activity in the catchment. As part of the Joint Nutrient Study (JONUS) we have been investigating nutrient cycling in the modern Humber and we can contrast our results with the situation 3000 years ago. We estimate that fixed nitrogen inputs to the Humber are 25–50 times higher now than 3000 years ago, and the increase for phosphorus may be even greater. 3000 years ago the Humber stored more phosphorus and fixed nitrogen than was supplied by the rivers. The estuary therefore imported material from the North Sea and was a net sink for phosphorus and fixed nitrogen (Figure 3, top). Since that time, river inputs have increased dramatically and the storage capacity of the estuary has been lost to reclamation. Denitrification is a process that takes place in organic-rich muds and marshes; it converts nitrate to the gases N_2 and N_2O. On a per square metre basis, rates of denitrification are high in the Humber today, but the area of sediments is too small for this process to be important. The result is that nowadays the estuary exports to the North Sea essentially all of the riverine phosphorus and nitrogen inputs (Figure 3, bottom), and North Sea waters may be in danger of eutrophication.

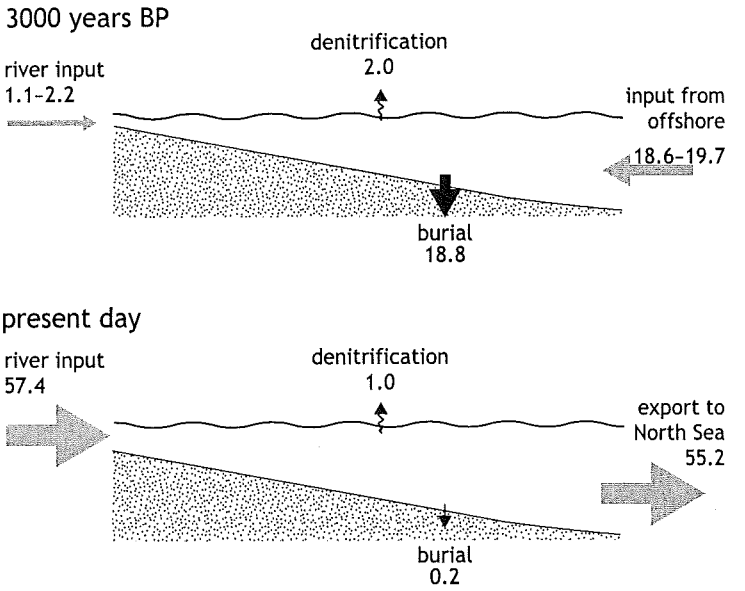


Figure 3 *Schematic representation of fixed nitrogen fluxes through the Humber estuary 3000 years ago and today. Units are metric tonnes $N yr^{-1}$. Modern day river inputs and exports to/from the North Sea are primarily as nitrate.*

So the changes over the last 300 years have been dramatic. Sea-level is still rising and will continue to do so as climate warms. Sea defences in the Humber and elsewhere on the UK east coast are becoming increasingly unsustainable, providing opportunities for managed realignment of coastal defences. Positive results could include enlarged intertidal areas which would provide valuable ecological habitat, and improved protection from flooding behind the re-aligned defences. In addition, we argue that there are extra benefits of enhanced carbon storage and nutrient retention from recreating intertidal areas such as saltmarshes. We have estimated that had the Humber not lost its intertidal areas to reclamation, it would now retain more than half of the modern fixed nitrogen input and more than a quarter of the modern phosphorus inputs. Clearly restoration of the entire Humber wetland is now impossible, but this calculation shows that managed re-alignment can bring important additional benefits, including reduced marine eutrophication pressures.

Our conclusions, then, are that intertidal wetlands are immensely important habitats ecologically, biogeochemically and probably economically. We need to value them, conserve them and extend them as part of a rational approach to 'development' that works *with* the environment rather than against it, to benefit society.

Acknowledgements.

You can read more about this work on the Humber in two articles.

Andrews, J.F., Samways, G., Dennis, P.F. and Maher, B.A. (2000) Origin, abundance and storage of organic carbon and sulphur in the Holocene Humber Estuary: emphasising

human impact on storage change, *in* Shennan, I. and Andrew, J. (eds) *Holocene Land–Ocean Interaction and Environmental Change Around* the North Sea. *Geol. Soc. of London Special Publication* **166**, 145–70.

Jickells, T., Andrews, J., Samways, G., Sanders, R., Malcolm, S., Sivyer, D., Parker, R., Nedwell, D., Trimmer, M. and Ridgeway, J. (2000) Nutrient fluxes through the Humber Estuary – past, present and future, *Ambio* **29**, 130–35.

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This is LOIS publication No. 827.

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Book Reviews

Mapping the Deep: The Extraordinary Story of Ocean Science by Robert Kunzig (2000) Sort Of Books, 344 pp. £8.99 (*but see below*) (flexicover, ISBN 0-9535227-1-7).

This book made me cross; not just a little bit irritated but really cross. I was completely engrossed in it and just a third of the way through when I left it behind on Air France flight 276 to Japan. My only hope is that it will have brought as much excitement to the cleaning staff of Tokyo airport as it was bringing to me. Finding another copy in Tokyo was impossible, a fact which I shall raise with the publishers.

This is a great read, a really cracking story covering almost all of the thrilling developments in oceanography since the start of this science, and should in my view be on all undergraduate reading lists. Kunzig plays on our fascination not just for facts but for insights into the characters of the main players, and it is this which will widen the appeal of his book to a very great extent. These days, facts are relatively easy to acquire, but it is much more difficult to appreciate the sense of excitement and passion which grips those who are involved in the discovery of these facts. That is not to say that the book lacks factual content. I have certainly learned a great deal about a subject on which I am supposed to be knowledgeable. The author has obviously spent a lot of time researching this book, talking to the great and the good and reading the relevant literature, and in general he is factually right on the ball.

The penalty for this strategy of focussing on personalities is of course that only a selection of them can be described; we all know that there is an army of supporting characters who have made crucial contributions to the development of the field, those who have provided the corroborating evidence required before major steps forward are possible. The impression may therefore be acquired that our understanding of the oceans has been gained as a result of the efforts of only a few dozen scientists. My own feeling is that this price of a misconception is well worthwhile if we are to build public enthusiasm for our science, which this book will surely help do. The book is clearly aimed at the American market with American-English text and a strong focus on the contribution made by scientists in the USA. I felt this was sometimes slightly unbalanced, and it is in fact a bit surprising, as the author is European editor of *Discover* magazine and lives in France.

Kunzig takes us through oceanography right from the very beginnings of water creation in space to the formation of ocean basins, and then through the physical, chemical and biological processes which take place in these basins. There are excellent chapters on hydrothermal vents, on the thermohaline circulation and climate change, and on the vast populations of gelatinous organisms which are so poorly understood. The historical perspective is always present as the author takes evident pleasure in recounting how we reached our present level of understanding, dropping in on some of the failures which led up blind alleys or retarded the rate of progress. These are important points to make in a story of discovery, and draw attention to the fact that the path leading from ignorance to knowledge is very rarely a straight one. He also points out a number of the areas where knowledge is still sparse and sometimes surprisingly so, such as the uncertainties in the number of seamounts in

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This book made me cross; not just a little bit irritated but really cross. I was completely engrossed in it and just a third of the way through when I left it behind on Air France flight 276 to Japan. My only hope is that it will have brought as much excitement to the cleaning staff of Tokyo airport as it was bringing to me. Finding another copy in Tokyo was impossible, a fact which I shall raise with the publishers.

This is a great read, a really cracking story covering almost all of the thrilling developments in oceanography since the start of this science, and should in my view be on all undergraduate reading lists. Kunzig plays on our fascination not just for facts but for insights into the characters of the main players, and it is this which will widen the appeal of his book to a very great extent. These days, facts are relatively easy to acquire, but it is much more difficult to appreciate the sense of excitement and passion which grips those who are involved in the discovery of these facts. That is not to say that the book lacks factual content. I have certainly learned a great deal about a subject on which I am supposed to be knowledgeable. The author has obviously spent a lot of time researching this book, talking to the great and the good and reading the relevant literature, and in general he is factually right on the ball.

The penalty for this strategy of focussing on personalities is of course that only a selection of them can be described; we all know that there is an army of supporting characters who have made crucial contributions to the development of the field, those who have provided the corroborating evidence required before major steps forward are possible. The impression may therefore be acquired that our understanding of the oceans has been gained as a result of the efforts of only a few dozen scientists. My own feeling is that this price of a misconception is well worthwhile if we are to build public enthusiasm for our science, which this book will surely help do. The book is clearly aimed at the American market with American-English text and a strong focus on the contribution made by scientists in the USA. I felt this was sometimes slightly unbalanced, and it is in fact a bit surprising, as the author is European editor of *Discover* magazine and lives in France.

Kunzig takes us through oceanography right from the very beginnings of water creation in space to the formation of ocean basins, and then through the physical, chemical and biological processes which take place in these basins. There are excellent chapters on hydrothermal vents, on the thermohaline circulation and climate change, and on the vast populations of gelatinous organisms which are so poorly understood. The historical perspective is always present as the author takes evident pleasure in recounting how we reached our present level of understanding, dropping in on some of the failures which led up blind alleys or retarded the rate of progress. These are important points to make in a story of discovery, and draw attention to the fact that the path leading from ignorance to knowledge is very rarely a straight one. He also points out a number of the areas where knowledge is still sparse and sometimes surprisingly so, such as the uncertainties in the number of seamounts in

the Pacific. Are there 10 000, or nearer to a million of them?

Perhaps the only area where some strongly held opinions seem to cloud the author's appraisal of the facts is when he discusses fisheries in Chapter 12. He focusses on the cod fisheries in the north-west Atlantic and the conclusion he most forcibly states is that the collapse of these fisheries has simply been a consequence of humanity's greed and willful disregard of the principles of population growth and control. How nice it would be if this were the whole story, as then it would only be a matter of assessing the population size and characteristics and applying proven laws of population dynamics. It is becoming increasingly apparent that variations of almost all populations, including those of commercial fish, can be considered as components of so called 'regime shifts' of our environment. These are rapid, coincident and persistent changes in both climate and marine ecosystems on the decadal scale, with forcing mechanisms which are very poorly understood. In my view, Kunzig is taking an approach which is far too simple, and possibly completely wrong, by stating that it is just a matter of overfishing, although his insights into the political and economic pressures which may contradict scientific advice are worthwhile.

As far as gaps in the coverage of the book are concerned, I was sorry not to see more about some of the major efforts that have been made in upper ocean biogeochemistry and air–sea interactions over the past decade: the JGOFS era (cf. the following book review). There are a number of possible reasons for this omission, one of which is that there are rather a lot of heroes and it is not easy to pick out one or two who have revolutionized our understanding. Another explanation is that there are still large uncertainties in our understanding of the way the system works, and it is therefore hard to distil a clear and concise account out of the vast body of data.

There are two other critical points I should make, of which the first concerns illustration. There are some excellent colour photographs which add greatly to the text and emphasize the reality of this vast hidden environment. However the monochrome photographs which are scattered throughout the book are, in the main, poorly chosen. This is a great shame as there were plenty of times when a graph or a different image could have clarified a point. A time-line could have been used to illustrate the occurrences of Heinrich events and the Younger Dryas. The fishery statistics could also have been clearly presented with a simple graph of the temporal variability of the catch per unit effort. This book is aimed at the intelligent and inquisitive reader and there is no need to follow the approach of most media sources in avoiding graphs.

My other complaint about the book is the title. Maybe it is I who have a problem with the term 'mapping', but I am afraid it still has a rather dull flavour for me. Of course, we have depended on mapping in its various forms, but the word itself does not reflect the thrills and excitements of discovery which are so well portrayed in these pages. The previous title of the text, *The Restless Sea: Exploring the World beneath the Waves* seems to me to sum it up just fine. This is a great read, and I recommend it to anyone with an interest in the seas around us.

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The story of JGOFS

The Changing Ocean Carbon Cycle – a Midterm Synthesis of the Joint Global Ocean Flux Study edited by Roger B. Hanson, Hugh W. Ducklow and John G. Field (2000). Cambridge University Press, 514pp. £35 ($55) (flexicover, ISBN 0-521-65603-6); and £75 ($120) (hard cover, ISBN 0-521-651999-9).

This useful volume was written by an international panel of scientists following the first Joint Global Ocean Flux Study (JGOFS) Scientific Symposium held at Villefranche-sur-Mer in May 1995. The book has therefore been five years in gestation and consequently has lost some of its impact as a mid-term synthesis of JGOFS. However, most authors have taken the opportunity to update the cited literature as far as 1998 (the year the Preface was written) so that the book retains its value as a series of authoritative articles on aspects of the ocean carbon cycle, despite some unevenness in coverage.

The book opens with an introduction (Part One) by J.J. McCarthy, which deals nicely with the scientific and social context that accompanied the first steps towards the establishment of the JGOFS programme in 1984. The bold aim of this international programme was 'to understand the biological, physical and chemical processes controlling the carbon cycle within the ocean and predict how this cycle might alter with global climate change'. Such an understanding could only be achieved by pooling the resources of many countries to study the dynamics of the carbon cycle in all the major ocean basins. Disappointingly little is said about the various national programmes that augmented the US effort in those early days and made JGOFS possible, despite the fact that the book itself has been written by authors from 13 different countries. Those of us who were involved in the birth pangs of JGOFS, and the related UK Biogeochemical Ocean Flux Study (BOFS), will remember, for example, the detailed work by the European partners that went into the 1987 SCOR meeting in Paris, and also the importance of the impetus given by the European programmes to the 1989 North Atlantic Bloom Experiment (NABE). However, full acknowledgment is made of the key role played by the Scientific Committee on Oceanic Research (SCOR) in providing an international home for the project, and later in negotiating joint sponsorship with the International Geosphere–Biosphere Programme (IGBP).

The material on the carbon cycle itself is presented in three sections dealing successively with Carbon Exchange Processes and their Variability (Part Two, which has seven chapters), Regional-Scale Analysis and Integration (Part Three, five chapters), and Global-Scale Analysis and Integration (Part Four, two chapters). Despite the title of the book, only two chapters deal explicitly with changes in the ocean carbon cycle and there is no discussion of palaeoceanography.

The emphasis throughout Part Two is almost entirely upon primary production, and relatively little is said about the dynamics of grazing and secondary production. It is a tribute to the rapid development of this area of science that nearly half of the chapters in this section consider the role of iron as a limiting nutrient in primary production. The hypothesis of iron-limitation was hardly considered when

the discussions over the JGOFS programme began in 1984, and it was not presented in the scientific press until 1988, on the basis of experiments carried out in August 1987. A richly detailed review of the evidence for iron-limitation is provided by H.J.W. de Baar and P.W. Boyd. The idea captured the public imagination as a consequence of the IronEx studies in the equatorial Pacific, where the artificial addition of iron was shown to have a profound (if temporary) effect on the oceanic ecosystem. This led to some wild speculation in the press (and even on the part of some entrepreneurial scientists) that the greenhouse effect could be neutralized by large-scale fertilization of the ocean. The results of the IronEx experiments are clearly and concisely presented in an article by P.S. Liss and S.M. Turner, and the modelling of the observed effects is considered in an article by F. Chai *et al.* These three chapters together provide a useful introduction to the iron story. A chapter by P.J. LeB. Williams considers the interconnection between net production, gross production and respiration, and summarizes some of the work carried out within JGOFS by UK scientists. Other chapters in this section consider the effects of wind on marine primary production, continental margin fluxes, and sediment-trap sampling in surface waters.

Part Three, dealing with regional scale analysis and integration, is somewhat unbalanced, since little is said about the Indian and Pacific Oceans. A theoretical discussion by S. Sathyendranath and T. Platt sets the scene for consideration of mixed-layer dynamics in primary production in the Arabian Sea, providing background for the interpretation of ocean colour images. A chapter by A.F. Michaels *et al.*, comparing the time-series measurements taken off the coast of Hawaii with those taken off Bermuda, provides some insight into the differences between the dynamics of these two locations, one in the subtropical Pacific and the other in the Atlantic. Two chapters (one by Doney *et al.* and the other by Morel) provide useful summaries of JGOFS studies of the workings of the carbon cycle in the North Atlantic. There is surprisingly little discussion of the 1989 North Atlantic Bloom Experiment, but there is a most useful chapter on the plankton ecology and biogeochemistry of the Southern Ocean by U. Bathmann *et al.*, which provides a good coverage of the literature and a series of useful summary tables of the characteristics of primary and secondary production in this area.

Part Four consists of two chapters dealing respectively with advances in ecosystem modelling (by Fasham and Evans), and the remote sensing of primary production in the ocean (by Platt *et al.*). The consideration of ecosystem modelling is necessarily restricted to the North Atlantic Bloom Experiment because of the timing of the original workshop. The chapter on remote sensing focusses on the interpretation of images from the Coastal Zone Color Scanner (CZCS) and provides some useful perspectives on the evolving concept of biogeochemical provinces, especially in the North Atlantic. It is not surprising that this is a short and primarily theoretical section of the book. In JGOFS, the modelling emphasis was on its use in the design of data-gathering strategies rather than on the elucidation of processes. In addition, the problem of data-management, and the evolution of the international database strategy, has been one of the most contentious issues that the organizers of programme have had to contend with.

The book is rounded off by a section (Part Five) on Future Challenges, which consists of a single chapter by K.L. Denman and M.A. Peña entitled 'Beyond JGOFS'. For me, this is the most interesting chapter in the book since it focusses on the components of the carbon cycle that are most likely to affect the feedbacks between ocean biology and climate in a warming world. It is a concise, clearly written and well referenced essay.

The concluding summary by the editors (Part Six) provides a historically interesting set of conclusions on the mid-term highlights and achievements of the JGOFS project. However, the late publication of the volume reduces their impact on contemporary research.

This book is less of a 'mixed bag' of ideas than one would normally expect from a published conference proceedings. Overall, it is consistently edited and well presented, and any errors that did catch my eye were annoying rather than having a serious impact on the value of the book. For example, all of the chapter numbers are omitted on the second page of the contents, and the various phases of the JGOFS–WOCE CO_2 survey are indistinguishable in Figure 12.1 (presumably because the figure was copied directly from a coloured original).

It is important to realize that this is primarily a book about the workings and findings of the JGOFS programme, rather than a presentation of our knowledge of the ocean carbon cycle. Consequently, the material presented is neither sufficiently rounded nor adequately structured to make this a useful textbook for undergraduate students. It is aimed more at those with a professional interest in the carbon cycle, and here it provides a broad, if somewhat unbalanced, sweep of ideas and analysis. I would recommend this book to those who could benefit from such a clear and authoritative description of some of the key issues addressed by the JGOFS programme – an exciting and pioneering venture in international biological oceanography. It should definitely be on the acquisition list of specialist marine libraries.

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The history of Everything

Origins: The Evolution of Continents, Oceans and Life by Ron Redfern (2000), Cassell & Co., Wellington House, London, 365pp. £35 (hard cover, ISBN 0-304-35403).

If I had to persuade anyone to get interested in marine science I think I'd recommend to them Rachel Carson's *The Sea Around Us* and Jacques Cousteau's *The Silent World.* If I had to tempt anyone into the realms of Earth Science and the history of, well, just about everything, I'd recommend them this book. Is is, quite simply, is a stunning book. A combination of outstanding photography of contemporary Earth features (of a quality up there with *National Geographic*), with sharp and vivid descriptions of the evolution of the world's landmasses, its ocean basins and the myriad life-forms (including humans) that have graced the planet since its formation. Comprehensive is an understatement; you could quite literally teach several entire university

modules using this book! And the most amazing thing of all is that it is written by an amateur scientist. Redfern is, by trade, a photographer, although he has picked up a lot of geoscience and natural history along the way. And he has done a mountain of research, visiting many of the world's top scientists – including our very own Malcolm Clarke (from the MBA) and Richard Fortey (Natural History Museum) – in the process. Redfern has taken on a formidable task, but has completed it with extraordinary success. And when you think of the price of many slim-line academic texts (pushing £100), this book is an ultra-bargain at £35. Maybe my bookshop made a mistake in the price!

Redfern takes us on a journey of epic proportions. In 13 evocative chapters, he leads us across deserts and mountains, dives into the ocean and soars over the polar regions, as he describes how our planet (and its biosphere) have evolved from its steamy origins. His landscape photographs are meant to be interpretive (Redfern refers to them as 'photo essays'), and each is carefully used to provide examples of Earth in its distant and not so distant past. He also uses excellent and colourful sketches to illustrate features and processes such as the structure of the Earth and the transformation of eukaryotes. Not only does he get the science across, but he also introduces us to all the great characters of the past who have discovered our world for us. And he has some nice touches too, using little palaeo-globes to locate 'geologia' (a word I invented: noun; pl.: *items or features of geological interest, big or small*) and landscapes, and he entitles two chapters from places in J.R.R. Tolkein's *Lord of the Rings.*

This book follows the major biological and physical changes occurring at the Earth's surface over the last 3.8 billion years. Thirteen chapters – First Light, New Look at an Old Planet, Iapetus and Avalonia, Tornqvist's Sea, The Third Age, Middle Earth, The New World, Atlantic Realm, Maritime West, Midland and Nordic Seas, Fountains of Youth, Children of the Apple Tree, and Between Two Waves – cover 92 separate themes, such as continental drift, the wandering of the poles, development of unicellular life, the rise of hominids, global catastrophes and so on. The breadth of Redfern's discussion is remarkable as he takes us on a compelling palaeogeographic and palaeobotanical rollercoaster. Each chapter is preceded by a photographic title spread, with an overview of the content. This is then followed by a chapter introduction that describes the palaeogeography of the time-frame under consideration, in which we can trace the drifting landmasses. The chapter is then basically split into two: a photo-essay covering selected geological themes such as those mentioned above; and a more lengthy, but very readable, narrative, where Redfern goes into greater scientific detail (this is where he's read the papers in the library like the rest of us!), and combines a wealth of background knowledge which helps us to understand the operative geological processes with quite a lot of science history. There is almost literally something for everyone, and the book is supported by a comprehensive index, a glossary of terms, a geological time-line and a detailed bibliography.

Let's take a closer look at a specific chapter. One of my favourites is Chapter 8, The Atlantic Realm, which deals with the marine world of the early Cretaceous (144–99 million years ago). Ah, the White Cliffs of Dover! Redfern's palaeo-globe shows the continental landmasses at the time when the South Atlantic began to open. A tenuous seaway existed between the Tethys and Pacific Oceans, and channels were beginning to form between Iberia and France and the British Isles and Greenland. The world was a series of vast continental shelves and shallow continental seas, with marine plants and animals basking in a relatively balmy climate. Redfern's themes in this chapter are: 1, The Central (and South) Atlantic; 2, The Anglo-Paris Basin; 3, Fringing Reefs; 4, Interior Platforms; 5, The Caribbean and Labrador Seas; and 6, The Bay of Biscay. Redfern's travels around the world to some of the greatest geological wonders are surely the envy of most of us. In this chapter he presents us with charming photographs of the White Cliffs of Dover (naturally!), lithified sediments and Tethyan carbonates on Fuerteventura and picturesque oolitic atolls in the Caribbean. Each of the themes is a short study in regional geology. In The Central Atlantic, for example, Redfern describes how presently exposed carbonate rocks comprise debris from reef and carbonate platforms that accumulated at the foot of the West African continental slope at the time when the proto-central Atlantic first separated Africa from the Americas. Volcanic activity is thought then to have raised parts of this sea-floor to the surface about 20 million years ago. His much longer (6-page) narrative begins in 1831, when the 22-year-old Charles Darwin was assigned to join the naval survey ship HMS *Beagle.* Darwin's voyages and the observations of other scientists (like Adam Sedgwick and John Hogg) serve to provide the framework for this chapter, the occurrence and distribution of microscopic plankton in the oceans and in the rocks on land. Redfern descibes these as 'the artisans of the geological world' as they are arguably the most prolific of rock-builders and their organic remains are responsible for around 70% of the presently known reserves of oil. He describes them, and their oceanic and geologic environments, in the finest detail. Then comes an explanation of kerogen formation (which was occurring extensively along the shores of the shrinking Tethys Ocean and in the grabens and valleys of the North Sea Basin), followed by the evolution of Cretaceous fishes, reptiles and nautiloids. He even mentions the Loch Ness Monster! (Well, he *was* talking about plesiosaurs.)

I'm not a geologist but I reckon Redfern covers every conceivable angle of geology in this book, and more besides. I haven't yet mentioned it, but the section on the rise of humans to terrestrial dominance is also excellent. This is truly a wonderful book – a fantastic and ambitious conception that should genuinely inspire something in each of us interested in the natural world, above and below the sea. In 1996, Redfern received the American Institute of Professional Geologists' Outstanding Achievement Award for the popularization of science, and rightly so. This will be my favourite book for a very, very long time.

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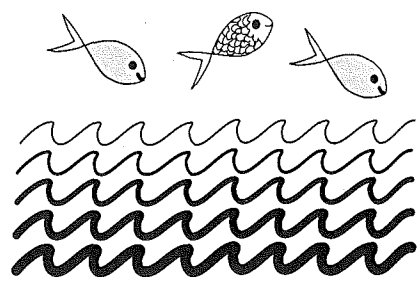

Hard science and soft sediments

Sedimentary Processes in the Intertidal Zone edited by Kevin S. Black, David M. Paterson and Adrian Cramp (1998). Geological Society Special Publication No. 139, 409pp. £79 (price for Geol. Soc. members, £39) (hard cover, ISBN 1-86239-013-4).

The large macrotidal estuaries of the UK have been the subject of scientific enquiry for almost as long as they have been exposed to the consequences of urban and industrial development. Only relatively recently have co-ordinated programmes of research been employed to tackle the difficulties posed by these large, dynamic and open systems. This Special Publication of the Geological Society summarizes the proceedings of a conference that followed one of the most intense field-based campaigns aimed at providing an integrated assessment of the processes that govern and depend upon the presence of intertidal mudflats.

A little less than half the book consists of 13 papers describing results of studies conducted as part of the LISP–UK (Littoral Investigation of Sediment Properties) project, part of the NERC-funded Land–Ocean Interaction Study (LOIS). Usefully, the organizers widened the scope of the conference, and the resultant volume, so as to include 16 contributions from other researchers working on a wide range of estuarine mudflat systems in both Europe and North America. Hence the volume contains a mix of papers that includes analyses of recent field programmes as well those with a wider and longer term perspective.

Notwithstanding the holistic objectives of the study, the focus of the volume is on better characterizing the nature of sediment supplied to and from intertidal mudflats and some of the principal processes involved. M.C. Christie and K.R. Dyer provide a very high temporal resolution analysis of the effect of the flood and ebb tidal edge on the erosion and transport of surface sediments, in the absence of strong wave effects. The highest concentration of suspended sediment above a mudflat in the outer part of the Humber estuary was observed within the first and last thirty minutes of tidal coverage, coincident with local erosion brought about by the highest current velocities. Linear relationships were consistently observed between suspended sediment concentration and current velocity, but these simple relationships varied considerably between sites and upon different days. These results not only indicate how much we still have to learn about the factors affecting erosion, but suggest that the variability may itself have important consequences for the net transport of sediment across tidal mudflats.

The particular emphasis of this volume is upon the role of biota in modifying the properties of cohesive sediment. Advocates of biology as a significant influence on the properties and the processes that lead to the deposition and erosion of mudflat sediments will find a considerable range of evidence presented here. This evidence challenges physical (and chemical) estuary modellers to start to incorporate the influence of biological variables on the values of the empirical parameters within their models. Until then, the significance of these biological processes, measured at a small scale, upon the sediment dynamics and morphology of whole estuaries, will remain the subject of opinion and conjecture.

One could carp about the lack of integration between the various project studies. There is (at least in this volume) little synthesis of results from the different sub-projects that made up the whole, notwithstanding some fairly heroic modelling of the sediment–water interface by Gavin Ruddy and co-authors. Nevertheless the book is an impressive achievement which has developed from what was a relatively small-scale project. It points the way to the benefits that can be achieved when different groups of scientists are able to bring together innovative methods, equipment, and ideas. The volume is produced to a very high standard and although (at £79) it will not appeal to everyone, it does provide a very valuable synthesis of current knowledge and new data in this area.

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Cold wet rocks

Antarctic Marine Geology by John B. Anderson (1999). Cambridge University Press, 289pp. £75 (hard cover, ISBN 0-521-59317-4).

The back cover of this book proudly proclaims that it is the first comprehensive single-authored book covering its field. This raises the question: why has no one attempted such a work before? The answer is that it is a very ambitious undertaking, involving a synthesis of results from many Earth Science disciplines, and requiring familiarity with a large and rapidly expanding body of literature (much of which is listed in a 38-page bibliography). With his long involvement in work on several sectors of the Antarctic continental margin, Anderson is as well placed as anyone to attempt such a project.

The book is sensibly organized into six chapters. The first two attempt to provide overviews of Antarctic glaciology, meteorology, oceanography (Chapter 1) and geological history (Chapter 2). These are followed by chapters on continental-shelf geomorphology, sedimentology, continental margin evolution, and Antarctica's glacial history. Each of these chapters begins with a concise introduction written in an accessible style, which is followed by sections concerned with general concepts, models and methods, followed by sections containing case-studies from different sectors of the Antarctic margin. Each chapter, except the one on sedimentology, finishes with a useful and well-considered summary.

My main criticisms of the book relate to details of its content and the illustrations. All of the photographs and satellite images are in black and white, and several seem poorly reproduced. Many of the seismic profiles included are of poor quality or have been poorly reproduced, or have been reduced to such a small size that they are of little value. Many of the location maps show crudely drawn coastlines. Now that accurate coastline data and software to plot it are openly available, there is really no excuse for the inclusion of such crude sketches.

As the opening chapter covers such an extensive range of subjects, it is not surprising that considerable simplification was necessary. Even so, it seems odd that this chapter includes only a brief mention of the Antarctic Circumpolar Current, which is generally thought to have

played an important role in Antarctic glacial history. Similarly, another brief paragraph about Antarctic Bottom Water formation omits to mention the widely held view that circulation beneath large floating ice shelves is an important part of the process. Furthermore, brevity is no excuse for the inclusion of several statements which are either highly contentious or erroneous, e.g. 'Retreat of ice shelves initiates increased discharge of outlet glaciers and ice streams flowing to sustain these ice shelves' (controversial); 'The [ice stream] bed has been subjected to such great stress that the basal material acts as a deforming layer along which the ice sheet slides ...' (deforming tills are associated with low basal shear stress); 'Ice Stream B is flowing several hundred kilometres per year ...' (several hundred metres per year); 'Bottom melting under the Ross and Ronne–Filchner ice shelves is significant only near the ice shelf front ...' (basal melting is also thought to occur near the grounding line).

In the chapter on geological history, the sections on the tectonic development of the south-east Pacific and Weddell Sea regions are very brief and fail to mention most of the recent literature. A specific error is that the name 'Aluk Ridge' is incorrectly assigned to the Pacific-Phoenix Ridge in the text and to both this and the Pacific–Antarctic ridge in the associated figure (the name actually refers to the Antarctic–Phoenix ridge, although its usage is declining).

The introduction to the shelf morphology chapter is followed by a succinct presentation of the reasons why most workers now accept that the great depth and landward sloping profile of the Antarctic continental shelf result mainly from glacial erosion rather than lithospheric flexure. However, the table of detailed bathymetric maps in this chapter is incomplete. This selection includes some old maps which show highly imaginative contours drawn around poorly-located soundings and are perhaps best forgotten.

In view of Anderson's long experience of working on sediment cores, it is not surprising that the sedimentology chapter is the most authoritative. However, it is disappointing that recent advances in understanding the depositional regime on the Antarctic continental rise are poorly covered, both here and in the subsequent chapter on continental margin evolution.

It is quite understandable that Anderson should have incorporated examples of work by his graduate students among the regional case-studies. Sometimes, however, he has also included their speculative interpretations which go beyond what the data can support and which have not been published in mainstream journals. This is particularly the case in the chapter on continental-margin evolution. Such material is not really suitable for inclusion in a book which is being promoted as a reference work and textbook.

The chapter on Antarctica's glacial history includes a good introduction to various types of evidence which have been used to infer glacial history, followed by summaries of the evidence relating to each geological period from the Cretaceous to the Pleistocene. The chapter concludes with a good summary of the present state of knowledge on this subject. However, this is certain to become quickly outdated during the next few years as results are published from two recent legs of the Ocean Drilling Program (178 and 188), the Cape Roberts Drilling Project, and new work on the Tertiary glacial deposits on King George Island.

According to the back cover, 'The book is intended as a reference for all scientists working in Antarctica, and will also serve as a textbook for graduate courses in Antarctic marine geology.' However, a price of £75 will place it beyond the budget of most students. Many researchers will notice that there is considerable overlap between the contents of this book and that of four volumes of the American Geophysical Union (AGU) Antarctic Research Series published during the past few years (Volumes 56, 60, 68 and 71). AGU members can obtain all four volumes, which are collections of papers by experts in their respective fields, for little more than £100.

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Clouding the water

A number of important publications concerned with the behaviour of fine sediments were published during 2000. These should be of interest to a wide range of people, including scientists and engineers, municipal authorities with a responsibility for shoreline management, and environmental agencies concerned with estuarine and coastal sedimentary processes.

Elsevier are publishing the following three volumes, which were compiled under the auspices of the Scientific Committee on Oceanic Research (SCOR).

1. T. Healy and W. Ying (eds.) *Muddy Coasts of the World: Processes, Deposits and Function.* (ISBN 0-444-5046-2-1)

2. A. Mehta and W.H. McAnally (Eds.) *Coastal and Estuarine Fine Sediment Processes* (ISBN 0-444-5046-3-X)

3. B.W. Flemming, M.T., Delafontaine and G. Liebezeit (eds.) *Muddy Coast Dynamics and Resource Management* (ISBN 0-444-5046-4-8)

In addition, the results from the EC MAST III research programme 'INTERCOH', co-ordinated by Professor Keith Dyer at the University of Plymouth, have just been published in a double volume special issue by Pergamon in *Continental Shelf Research (Nearshore and Coastal Oceanography).*

1. Dyer, K.R. (ed.) *Intertidal Mudflats: Properties and Processes. Part I: Mudflat Properties. Continental Shelf Research* Volume **20**, Nos. 10–11 (ISSN 0278-4343).

2. Dyer, K.R. (Ed.) *Intertidal Mudflats: Properties and Processes. Part II: Mudflat Processes. Continental Shelf Research* Volume **20**, Nos. 12–13 (ISSN 0278-4343).

Finally there is another new book in the area of coastal processes, from John Wiley:

Coastal Geomorphology by Eric Bird (flexicover, ISBN 0471-89977-1; hard cover, ISBN 0471-89976-3)

which will be reviewed in the next issue of *Ocean Challenge.*

From time to time since the end of the Cold War, press reports have documented the dumping of tens of thousands of tonnes of nuclear waste in the Barents and Kara Seas, and described the aging and 'rotting' nuclear submarine fleet that awaits decomissioning in Russia's Arctic ports. While speculation about imminent nuclear catastrophe may be exaggerated, it could be argued that the Russians don't need any more problems with nuclear waste. So the message which follows might be of interest and concern to our readers. It came to us via Martin Angel in the form of a letter from Academician Alexsey Yablokov, former Adviser on Ecology to ex-Prsident Yeltsin and now Head of public and scientific programmes/ organizations for the protection of the environment in Russia and elsewhere. The letter has been translated from the Russian by V. Sevostianov, and we have edited it to extract the gist of the message (see next column).

A long mailing list accompanies the letter, but the main addressees are:

US Vice-President, Richard Cheney; Presidential Adviser for National Safety, Mrs Kondolina Rice; Congressman Kurt Weldon and other US Congress members.

On behalf of Academician Yablokov we ask anyone concerned about the deal described in the letter to ask Martin Angel for a copy of the original, which they should sign and re-send to: yablokov@voxnet.ru and anzuz@glus.net.ru

Here is the message:

The governments of the US and Russia have negotiated multi-billion dollar contracts for spent nuclear fuel from the US to be stored and processed in Russia. The arrival of large amounts of nuclear fission materials in Russia is undesirable for a number of reasons.

There is lack of public control over the activities of authority, which is not publicly accountable, and the machinery of government is in need of re-evaluation; there are burgeoning social conflicts, even civil wars; the Russian establishment has become corrupt, and this corruption extends to the Ministry for Atomic Engineering.

Russia is thus unsuitable for the storage of increasing amounts of fission materials that can be used for the manufacture of nuclear weapons. We fear that monies received by the Ministry will not be used for resolution of ecological problems, but for research and development of new nuclear weapons. We fear a new spiral in the arms race between our two countries.

By enabling Russia to import its waste nuclear fuel, the US will encourage relaxation of controls over the traffic in fission materials all over the world. Opinion polls suggest that 90 per cent of all Russians, as well as hundreds of public organizations and several politicians, are afraid of the dangers associated with the transport and storage of highly radioactive nuclear fuel.

Cessation of the export/import of nuclear fuel would make the whole world safer, and we ask for your support in our campaign to bring this about.

(*signed*) **A. Yablokov**
President of the Centre for Ecological Policy in Russia

Promoting an Interdisciplinary and Integrated Approach to Environmental Research

Course: 13–14 September, 2001 at the University of East Anglia (Co Directors: Prof. Brian Hoskins and Prof. Peter Liss). Guest lectures and poster sessions; provisional topics include: Earth's energy budget and climate change; the global water and carbon cycles; other biogeochemical cycles; implications of global cycles for chemistry and climate; palaeo-perspectives; climate variability; socio-economic aspects of global change; Earth system modelling.

Course fee £1000, accommodation/food £520 extra. NERC support available for selected graduate students and staff. For more information, please contact the co-ordinator: Louise Bohn, School of Environmental Sciences, UEA, Norwich, Norfolk, NR4 7TJ UK. Tel: +44-1603-593161; Email: l.bohn@uea.ac.uk; Fax: +44-(0)1603-507784; Web: http://www.uea.ac.uk/~f115

Forthcoming Events

Events in 2001

Detecting Environmental Change 16–20 July, London. Website: http://www.nmw.ac.uk/change2001/

Symposium on the Occasion of the 70th Anniversary of the Continuous Plankton Recorder Survey of the North Atlantic 7 August, Royal College of Physicians, Edinburgh. To be held in conjunction with the **2nd ICES Decadal Symposium** 8–10 Aug. *Website:* www.npm.ac.uk/sahfos/cprsymposium.htm *For more information contact:* Institut für Meereskunde, University of Hamburg, Troplowitzstrasse 7, D-22529 Hamburg, Germany. Website: http://www.ices.dk/symposia/decadal2.

Climate Conference 2001 20–24 August, Utrecht; includes workshop on 'Climate variability of the Southern Hemisphere ocean and atmosphere'. See the conference website: http://www.phys.uu.nl/~wwwimau/cc2001.html; or contact Will P.M. de Ruijter, Institute for Marine and Atmospheric Research, Utrecht University, PO Box 80.005, 3508TA Utrecht, The Netherlands: Tel. +31-30-2532306; Email: w.p.m.deruijter@phys.uu.nl

2001: An Ocean Odyssey (Joint Assemblies of IAPSO and IABO). 21–28 October, Sheraton Hotel, Mar del Plata, Argentina. *Contact* 2001 Secretariat, Instituto Argentino de Oceanografia; Fax: 54-291-486-1527; Email: iado@criba.edu.ar

Microbial Interactions in Aquatic Environment (Joint Synposium of the Society of General Microbiology and the British Phycological Society) 10–13 Sept., University of East Anglia. The emphasis will be on interactions between dissolved organic material and exo-enzymes and viral, bacterial, algal and protozoan componenets of aquatic assemblages, and will cover water column and benthic processes. *Contact* Graham Underwood, Dept of Biological Sciences, University of Essex. Email: gjcu@essex.ac.uk; Tel. +44-(0)1206-873337; Fax: +44-(0)1206-873337.

OI Pacific Rim: Singapore Expo 4–6 December, Singapore. See the website: http://www.oipacific rim.com or email angela.pederzolli@spearhead.co.uk

For a more complete list of events, please see the current **Challenger Wave**.

OCEAN Challenge

The Magazine of the Challenger Society for Marine Science

SOME INFORMATION ABOUT THE CHALLENGER SOCIETY

The Society's objectives are:

To advance the study of Marine Science through research and education.

To disseminate knowledge of Marine Science with a view to encouraging a wider interest in the study of the seas and an awareness of the need for their proper management.

To contribute to public debate on the development of Marine Science.

The Society aims to achieve these objectives through a range of activities:

Holding regular scientific meetings covering all aspects of Marine Science.

Supporting specialist groups to provide a forum for discussion.

Publication of a range of documents dealing with aspects of Marine Science and the programme of meetings of the Society.

Membership provides the following benefits:

An opportunity to attend, at reduced rates, the biennial five-day UK Marine Science Conference and a range of other scientific meetings supported by the Society.

Regular bulletins providing details of Society activities, news of conferences, meetings and seminars (in addition to those in *Ocean Challenge* itself).

The Challenger Society Website is www.challenger-society.org.uk

MEMBERSHIP SUBSCRIPTIONS

The subscription for 2000 costs £40 (£20.00 for students in the UK only). If you would like to join the Society or obtain further information, contact the Executive Secretary, Challenger Society for Marine Science, Room 251/20, Southampton Oceanography Centre, Waterfront Campus, Empress Dock, Southampton SO14 3ZH, UK; Fax: 023-80-596149; Email: jennifer.jones@soc.soton.ac.uk

COUNCIL FOR THE CHALLENGER SOCIETY

ADVICE TO AUTHORS

Articles for *Ocean Challenge* can be on any aspect of oceanography. They should be written in an accessible style with a minimum of jargon and avoiding the use of references. If at all possible, they should be well illustrated (please supply clear artwork roughs or good-contrast black and white glossy prints). Copy may be sent electronically.

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CONTENTS