

OCEAN *Challenge*

The Magazine of the Challenger Society for Marine Science

EDITOR
Angela Colling

ASSOCIATE EDITOR
John Wright

Angela Colling and John Wright are both
at the Department of Earth Sciences,
The Open University, Walton Hall, Milton Keynes,
Buckinghamshire MK7 6AA

SCOPE AND AIMS

Ocean Challenge is a new periodical which keeps its readers up to date with what is happening in oceanography in the UK and 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.

The views expressed in *Ocean Challenge* are those of the authors and do not necessarily reflect those of the Challenger Society or the Editor.

Printed in the UK by Tranby Printers Limited.

ISSN 0959 0161

Volume 4, Nos.1/2, 1993
Special James Rennell Issue

EDITORIAL BOARD

Chairman
Bill Prior-Jones
Specialist in Applied Marine Science

Martin Angel
*Institute of Oceanographic Sciences
Deacon Laboratory*

Dennis Burton
*Department of Oceanography
Southampton University*

Keith Dyer
*Institute of Marine Studies
University of Plymouth*

Peter Foxton
*formerly Natural Environment Research Council
(Marine Sciences)*

Tim Jickells
*School of Environmental Sciences,
University of East Anglia*

John Jones
*Department of Geological Sciences
University College, London*

John Scott
Defence Research Agency, Portland

Bill Turrell
*Scottish Office
Agriculture and Fisheries Department*

INSTITUTIONAL SUBSCRIPTIONS

Ocean Challenge is published four times a year. The subscription including postage by surface mail is £70.00 (\$140) per year for libraries and other institutions. New subscriptions, renewals and information about changes of address should be sent to Parjon Information Services, PO Box 144, Haywards Heath, West Sussex, RH16 2YX, UK.

Ocean Challenge is sent automatically to members of the Challenger Society for Marine Science. For more information about the Society, see inside back cover.

DATA PROTECTION ACT, 1984 (UK)

Under the terms of this Act, you are informed that this magazine is sent to you through the use of a computer-based mailing list.

CONTENTS

- 2 Letter from the Editor
- 2 Forthcoming Events
- 4 The Challenge of Europe
- 5 Memorandum by the European Committee on Ocean and Polar Sciences
- 9 News from the James Rennell Centre
- 12 More News ...
- 16 The North Sea Project in Retrospect
- 19 Other Meeting Reports
- 23 Letter from Lord Rennell of Rodd
- 24 James Rennell: the Father of Oceanography
Raymond Pollard and Gwyn Griffiths
- 26 James Rennell's View of the Atlantic Circulation: a Comparison with our Present Knowledge
John Gould
- 34 James Rennell and William Scoresby: their Separate Quests for Accurate Current Data
Gwyn Griffiths
- 41 James Rennell: Antiquarian of Ocean Currents
Michael Bravo
- 50 James Rennell: Time-Traveller
John Phillips
- 53 Wind Power versus Density Differences: a 19th Century Controversy about Ocean Circulation
Margaret Deacon
- 61 Book Reviews
- 64 The Challenger Society's Strategy for the 90s

The cover image shows the global phytoplankton distribution. Phytoplankton concentrations are low in the central gyres (purple, deep blue), and tend to be high along coasts (yellow, orange and red). The images, which were made by processing thousands of individual scenes from the Coastal Zone Color Scanner, have been used by courtesy of Gene Feldman. NASA/Goddard Flight Center, Space Data and Computing Division, Greenbelt, Maryland 20771, USA.

The cover was designed by Ann Aldred Associates.

Letter from the Editor

First let me apologise for the long gap that there has been between the last issue of *Ocean Challenge* and this one. We are now receiving lots of interesting articles, but the production process continues to be more time-consuming than we would like. Furthermore, it has become clear that thematic issues (like this one) will generally not fit comfortably into a 36-page format. For these reasons, the Council of the Challenger Society has decided that the most sensible course of action is to produce three issues a year, rather than four, but combining to give double issues when we have a large number of articles on a particular theme.

This special James Rennell issue therefore makes up numbers 1 and 2 of Volume 4, and number 3 should be with you in the New Year. By renumbering in this way we aim to rationalize the dating (which, as we started mid-year, has always been 'out of sync'); at the same time, by producing larger issues, we should still be providing members with the same 'value for money'. We are sorry to sneak this up on you, but hope that you will bear with us while we consolidate our strengths.

Meanwhile, we hope you will enjoy this issue in honour of 'the Father of Oceanography', with articles about various aspects of Rennell's life and work, and a special news item about the James Rennell Centre for Ocean Circulation.



FORTHCOMING EVENTS

EVENTS IN 1993

BRIDGE Annual Science Progress Meeting 27–28 November, Rupert Beckett Lecture Theatre, University of Leeds. Contact Dr Cherry Walker, Department of Earth Sciences, University of Leeds, Leeds, LS2 9JT. Tel. 0532-335241; Fax 0532-335259; Email cherry@earth.leeds.ac.uk

Sea-level Changes: Measurements and Analysis (Meeting of the Federation of Astronomical and Geophysical Data Analysis Services and the Royal Astronomical Society). December 9–10, Linnean Society, Burlington House, London. Anyone interested in attending the meeting, which will coincide with the 60th anniversary of the formation of the Permanent Service for Mean Sea Level (PSMSL), should contact PSMSL, Proudman Oceanographic Laboratory, Bidston Observatory, Birkenhead, Merseyside, L43 7RA, UK. Email PLW@UK.AC.NBI.UA; Omnet PSMSL,POL; Fax +44 (0)51-653-6269.

Exploring the Oceans (Royal Society Technology Lecture, to be given by Sir Anthony Laughton). Contact The Scientific Meetings Secretary, The Royal Society, 6 Carlton House Terrace, London SW1Y 5AG. Tel. 071-839-5561, extn 278; Fax 071-930-2170.

EVENTS IN 1994

Dissolved and Particulate Organic Matter The Union des Océanographes de France and the Institute Océanographique are organizing a series of lectures on this topic. Anyone wishing to participate in these lectures, which cover chemical, geochemical, biological or ecological aspects, should contact Dr J.F. Pavillon, Maître de conférences, Secretary general of UOF, Institute Océanographique, Fondation Albert 1, Prince de Monaco, 195, rue Saint-Jaques, 75005 Paris; Tel. (1) 43-25-63-10; Fax (1) 40-51-73-16.

Oceanology International '94 (Exhibition and Conference: 25th Anniversary Event) March 8–11, Brighton. Contact Spearhead Exhibitions Ltd, Rowe House, 55–59 Fife Rd, Kingston upon Thames, Surrey, KT1 1TA, UK. Tel. 081-549-5831; Fax 081-541-5657/5016; 081-547-2807.

Particulate Matter in Rivers and Estuaries (contribution to the International Hydrological Programme, organized by Sonderforschungsbereich 327, University of Hamburg, FRG, GKSS Research Centre, Geesthacht, FRG, and Hydrology, University of Trier, FRG, with DGL, IAHS, IHP/OHP National Committee, SIL German Section, and UNESCO). 21–25 March, Reinbek, near Hamburg. Contact Secretariat, Particulate Matter in Rivers and Estuaries, c/o Prof. Dr H Kausch, Universität Hamburg SFB 327, Bundesstrasse 55, D-20146 Hamburg.

Bordeaux Aquaculture 1994: Measure for Success – metrology and instrumentation in aquaculture management (organized by Association pour le Développement de l'Aquaculture, and the European Aquaculture Society). 23–25 March, Palais de Congres, Bordeaux, France. Contact Conference Secretariat Bordeaux Aquaculture 94, EAS, Coupure Rechts 168, B9000 GENT, Belgium, Tel. (32) 9-223-77-22; Fax (32) 223-76-04.

Intertidal Sedimentary Biogeochemistry 29 March, Reading. Contact Dr Joy Rae, PRIS, The University, Reading, RG6 2BG

Symposium on Global Warming and Public Health and Symposium on Energy Resources and their Impact on the Environment (Fifth Global Warming Science and Policy International Conference and Expo (GW5)). April 4–7, San Francisco, USA. Contact Dr Sinyan Shen, The Global Warming International Center, PO Box 5275, Woodridge IL 60517 USA. Tel. 708-910-1551 or 419-372 8207; Fax 708-910-1561.

Marine Geophysics (at the Annual Meeting of the UK Geophysical Assembly) 7 April, University of Liverpool. Contact Dr John Jones, Department of Geological Sciences, University College of London.

The Estuaries and Coasts of NE England (Estuarine and Coastal Sciences Association UK local meeting) 7–9 April, University of Durham. Will cover the rivers Tees, Tyne, Wear, Tweed and Blyth and their associated coastline. Contact John Pomfret, 8 Hillcrest, Durham DH1 1RB.

Instrumentation and Data-Analysis in Environmental Science (Warwick University Professional Updating Course). 11–22 April, University of Warwick, Coventry. This course is designed for those working in areas of emergency/contingency planning, terrestrial resource and coastal management, monitoring and clean-up. For more information contact the course organizer, Dr Steven Hicks, Short Courses Unit, Department of Biological

Sciences, University of Warwick, Coventry CV4 7AL. Tel. 0203-523540; Fax 0203-523701.

Biogeochemical Ocean Flux Studies (BOFS) in the Southern Ocean (Challenger Society Meeting) 14–15 April, Plymouth. Contact Dr Carol Turley, Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth PL1 3DB.

Hydrothermal Vents and Processes 20–21 April, London. Contact Dr Cherry Walker, Earth Sciences, University of Leeds LS2 9JT.

Electronic Engineering in Oceanography: Sixth International Conference in Electronic Engineering in Oceanography (Joint Meeting of the Challenger Society and the Institution of Electrical Engineers) 19–21 July, Churchill College Cambridge, UK. Contact Louise Bousfield, EEO 94 Secretariat, Conference Services, Savoy Place, London WC2R 0B; Tel. 071-240-1871, extn 222; Fax 071-497-3633; Telex 261776 1EE LDN G.

The South Atlantic: Present and Past Circulation (Symposium sponsored by WOCE and SCOR) 15–19 August, Bremen, Germany. Contact South Atlantic Symposium, Dr Barbara Donner, Fachbereich 5 der Universität, Geowissenschaften, Postfach 33-04-40, W-2800 Bremen 33, Germany.

UK Oceanography '94 28 August–3 Sept, University of Stirling, Scotland.

1994 ECSA Annual Scientific Symposium (ECSA24) Sept 4–10, University of Aveiro, Portugal. Major theme to be the comparison of northern and southern estuaries, lagoons and coastal areas. For further details contact the ECSA Meetings Secretary, V.N. de Jonge, Rijkswaterstaat, Tidal Waters Division, PO Box 207, 9750 AE Haren, The Netherlands.

EVENTS IN 1995

The Forth and Clyde Estuaries (Estuarine and Coastal Sciences Association meeting) April. Contact D.S. McLusky, Department of Biology and Molecular Science, University of Stirling, Stirling FK9 4LA. Tel. 0786 467755; 0786 464994.

Estuarine Symposium Sept. Hamburg, Germany. Further details will be available from D.S. McLusky, Department of Biology and Molecular Science, University of Stirling, Stirling FK9 4LA. Tel. 0786 467755; Fax 0786 464994.

EVENTS IN 1996

The Humber Estuary (Estuarine and Coastal Sciences Association meeting) April. Further details will be available from D.S. McLusky, Department of Biology and Molecular Science, University of Stirling, Stirling FK9 4LA. Tel. 0786 467755; Fax 0786 464994.

Behaviour and Ecophysiology of Marine Organisms. (Estuarine and Coastal Sciences Association meeting). April. Further details will be available from D.S. McLusky, Department of Biology and Molecular Science, University of Stirling, Stirling FK9 4LA. Tel. 0786 467755; Fax 0786 464994.

Joint Symposium of ECSA and the Estuarine Research Federation Sept. Further details will be available from D.S. McLusky, Department of Biology and Molecular Science, University of Stirling, Stirling FK9 4LA. Tel. 0786 467755; Fax 0786 464994.

OTHER MEETINGS BEING PLANNED

Chemical and Optical Sensors For more information contact Dr Alan Morris, Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth PL1 3DB.

WOCE in the Southern Ocean For more information contact Dr Ray Pollard, James Rennell Centre Southampton.

The Use of Aircraft in the Marine Sciences For more information contact Dr Simon Boxall, Department of Oceanography, University of Southampton.

If you are organizing a conference or meeting on any aspect of oceanography, you can publicize it through *Ocean Challenge*. Details should be sent to the Editor at: The Dept of Earth Sciences, The Open University, Walton Hall, Milton Keynes, Bucks MK7 6AA.

Challenger Society Membership List

Copies of the membership list are now available to members. If you would like a copy, please write to the Hon. Secretary, Dr Howard Roe, IOS Deacon Laboratory, Wormley, Godalming Surrey, GU8 5UB.

THE CHALLENGE OF EUROPE

From Tony Rice

IOS Deacon Laboratory, Wormley

The accompanying article, by Hjalmar Thiel of the Institut für Hydrobiologie und Fischereiwissenschaft in the University of Hamburg, appeared (in German) in a recent issue of *Mitteilungen der Deutschen Gesellschaft für Meeresforschung*, the nearest German equivalent to *Ocean Challenge*. Since its contents are of considerable potential interest to the European marine science community in general, and particularly since it encapsulates views that I hold myself, I asked Hjalmar to provide this English translation.

The case for improved links and collaboration between European scientists in general, and marine scientists in particular, surely does not need to be re-stated. Quite apart from the intellectual and logistic 'added value' to be obtained from such links, many of us are – as Hjalmar points out – already receiving common funding, for example from the EC. This type of supra-national funding is likely to increase in importance in the future. So keeping ourselves informed about what is happening across Europe, and possibly broadening our spheres of collaboration, has never been more important.

We all have our personal contacts, of course, through which we keep in touch with our equivalent research groups in other countries. And many of the big projects produce newsletters to keep their disparate participants informed. Finally, we attend workshops and conferences and have the opportunity to hear and read about the results of each others' endeavours.

But both Hjalmar and I think that this is not enough. The social, political and environmental importance of marine science has never been greater. So in addition to communicating with our fellow scientists, we need to get this message through to politicians, civil servants, administrators, conservationists, industrialists and, indeed, the general public. To do this I believe that we need a well-produced European journal with good graphics, carrying European news (of projects, funding, meetings, technology), and short, punchy, up-to-the-minute articles, the more informative (and even controversial) the better.

I find it very heartening that Hjalmar suggests that *Ocean Challenge* could

fulfil this role, despite its significant teething troubles, hopefully now over. I would strongly support this idea and would urge the Council of the Challenger Society and the Editorial Board of *Ocean Challenge* to consider it as a matter of urgency.

There are, of course, many potential problems. How could the journal of a national oceanographic society become a journal for the whole of Europe? In particular, how could this happen without it appearing to be a British take-over bid to the European sister societies? If this impression was given, it could be very counter-productive. Well, the Challenger Society was never intended to be a national organization, and it has always, as now, had a small but significant non-British membership. But even if the Society remains largely British, there could be a dual subscription, a full one, as now, for British members and a reduced one for non-Brits who wished only to receive the journal.

There are already moves to improve the co-ordination of European oceanography societies, possibly towards some sort of union in years to come. In the meantime there is agreement, in principle, for the exchange of journals and diaries of events between the existing societies. But I believe we could begin to improve the exchange of information much more quickly. At least let's make *Ocean Challenge* look a bit more European. Why not tell your non-British European colleagues about the journal – even lend them your copy? Suggest to them that they write articles for it – and help them with the English if necessary.

If we are really convinced, as we should be, that oceanography is international, and that in Europe our future lies in co-operation, then we should get our act together now and make some positive moves. It's no good waiting for the politicians. The 'Europeanization' (ugh) of *Ocean Challenge* would be a small step in the right direction.

Press • Stop Press • Stop Press • Stop Press •
At its meeting on 4 October, Challenger Society Council approved the mailing of a future issue of *Ocean Challenge* to members of DGM, in support of cooperation between European Oceanographic Societies, and in the interest of attracting articles from their members. If this initiative to Germany proves successful, similar approaches may be made to societies in other countries.

From Hjalmar Thiel

Institut für Hydrobiologie und Fischereiwissenschaft
University of Hamburg

Ocean Challenge Europe?

In recent issues, the information bulletin of our Society [Deutsche Gesellschaft für Meeresforschung] has reported repeatedly on marine science and Europe. Everyone knows that, in the future, funding for marine research will increasingly come from the EC. A lecture presented at the last annual meeting and a contribution in the last issue of the bulletin were entitled: 'Europäisierung der Meeresforschung aus der Sicht der Bundesrepublik' (Europeanization of marine science as seen from the FRG). Many of us are tied to European projects, which – in comparison with national ones – need high administrative efforts and, at the same time, suffer from poor communication between research partners. The European ocean already exists, and we must learn to swim in it.

In the bulletin, we have also been reading about marine science societies of other European countries, and even about a European association, which might come into existence in the next millenium. This may be quite nice, but participating in another annual meeting? Given shortages of funds and time, will anyone want to take part? Another symposium? All this seems unlikely to me, in view of the existing arrangements and obligations.

However, general communication between marine scientists of European countries appears to me of utmost importance, and this holds true for communication with national as well as international research funding agencies, organizations, administrators, societies, companies ... Already on national levels sufficient communication is often lacking, and on the European stage most marine scientists are rarely acquainted and do not know how to interact. In the European countries, prerequisites for cooperation are different. Information about institutions, projects, structures, funding, universities, curricula, summer courses, exchange programmes for students and scientists, connections with administration and companies, national cooperation, research concentrations and planning would all be useful, to europeanize marine science with a better understanding – and ultimately this

should finally not be restricted to members of the EC.

The only realistic communication vehicle seems to be an information bulletin, which, produced for a wide readership, should however have the character of a handsome journal. To my mind the single volumes should have a semi-hard and attractive cover, the first pages of each article should have some graphic design, there should be black and white photos (occasionally colour photos). The texts should be understandable for colleagues of other marine disciplines, for research funding agencies, for the marine industry, and for laymen. For this readership, the articles must be short and clear, and they need concise, informative summaries highlighting the main points and/or allowing rapid assimilation of results. Further contents should cover the planning of projects, announcements of events, reports from research funding agencies,

funding programme previews, descriptions of new techniques (although not in the form of advertisements), literature and other matters of general interest. Printing quality should be scientifically unpretentious, as for example 'Forschungen' of the Deutsche Forschungsgemeinschaft. The (main) language can only be English.

Financing of such a journal may be arranged through fees to national organizations, direct subscriptions, advertisements (Europe-wide circulation should be of interest to companies) and also probably through research funding agencies (at least during the establishment phase).

The existence of national communication bulletins or journals probably argues against the proposal of a European journal. We have our bulletin *Mitteilungen der Deutschen Gesellschaft für Meeresforschung*, the French have

their *Journal de Recherche Océanographique*, the British have their *Ocean Challenge*, and there may be others in Europe. However, none of these communication organs have any Europe-wide function. Certainly, national information bulletins remain important, but these may be produced in addition to a European journal and/or distributed together with the European one.

The foundation of an independent ocean journal seems to me, even Europe-wide, not realistic. It may be an idea to extend an already existing journal into Europe. Because *Ocean Challenge* in its form and character is in accordance with my ideas, because it is printed in the right language, and because for ocean science and for marine scientists it has already an appropriate and challenging title, this journal might constitute the suitable base for European communication – perhaps under the title *Ocean Challenge Europe*.

MEMORANDUM BY THE EUROPEAN COMMITTEE ON OCEAN AND POLAR SCIENCES

This memorandum is reproduced below, in full. It is of considerable and far-reaching importance, because the policies set out here are likely to determine the pattern of European collaboration in marine research well into the next millenium. We have already had one critique of the document, which we print after the memorandum itself, in the hope that other readers may feel moved to contribute to the debate about the policies, as set down in the document.

GRAND CHALLENGES IN EUROPEAN OCEAN AND POLAR SCIENCES THE ECOPS MEMORANDUM

European scientists were the first to explore the oceans and polar regions and they have since remained in the forefront. Their research has risen in priority since governments recognized that our planet must be better understood to support its growing population, with increased pollution and shortage of food. National expenditure on ocean and polar sciences has been increasing to meet this need, but some of the challenges are too large to be addressed by individual countries. This ECOPS Memorandum proposes that Europe promote a small number of research projects that will address some of the highest priority grand challenges in ocean and polar sciences. The projects have been chosen because they have intrinsic scientific worth, because European scientists in these areas are among the world leaders

and because success will bring special benefits to Europe. By taking the initiative in these projects, we shall be making an appropriate contribution to the international advance in ocean and polar sciences. Although promoted by Europe they will be truly international, offering opportunities for participation by scientists from industrialized and developing countries.

Grand Challenges

Scientific exploration of the oceans and polar regions poses special technical and logistic problems, and the great scientific expeditions in the past have been the grand challenges of their era, comparable with landing men on the moon in our time. Examples include the *Challenger* expedition (1872–76) which opened up the deep ocean, the Nansen's *Fram* drift across the Arctic Ocean (1893–1896), the first trans-Antarctic expedition (1955–58), the International Geophysical Year (1957/58) and man's first descent

12 km to the Challenger Deep (1960). The era of heroic expeditions may be past, but many locations, such as the Arctic Ocean and the mid-ocean ridges remain virtually unexplored scientifically and are expected to produce surprises, like the discovery of submarine smokers and sulphur-based life (1976). Equally there are important scientific problems that can only be addressed by collecting data in the extreme environments of the deep ocean and polar regions. The latest technology must be applied to developing instruments for such research. Its success is leading to the ultimate challenge: to use our scientific knowledge to predict change in the ocean and polar regions to the benefit of our common future.

As we approach the 21st century there are many grand challenges in ocean and polar sciences waiting to be addressed. However, the human and technical resources needed to prosecute them has

risen to the point where today it is becoming increasingly difficult for individual nations to pursue them alone. Even the richest countries have sought foreign partners for their most ambitious endeavours, as the USA has done with the Ocean Drilling Program. In other cases, such projects have been promoted by UN Agencies and by the International Council of Scientific Unions; notable examples include the World Ocean Circulation Experiment (WOCE, 1990-97) and the Joint Global Ocean Flux Study (JGOFS, 1991-97). International collaboration in developing new technology for ocean and polar sciences is focussed onto remote-sensing from space: there is as yet no such collaboration in developing new methods of measuring the interior of the ocean which cannot be observed and sampled from space.

A number of grand challenge projects have already been promoted at the European level in other fields of science (e.g. CERN, JET, ESA-ERS-1). Anticipating that this trend will accelerate the ESF and CEC established the European Committee on Ocean and Polar Sciences in 1990 to help identify grand challenges appropriate for promotion as European projects during the next twenty years. ECOPS is now ready to propose an initial set of projects which would best be pursued at the European level, because they are too large for any single country to support. They have been selected on two grounds: (1) because they have intrinsic scientific worth, (2) because the scientific community in Europe leads the world in the particular area of science, and (3) because the successful completion of the project would bring special benefits to Europe in high priority areas beyond science. The initial set of ECOPS projects are concerned with:

- Ice coring in Antarctica
- Ocean forecasting
- The Arctic Ocean
- Deep ocean floor variability

European Programme on Ice-Coring in Antarctica (EPICA)

Geographical location, ice thickness and climatology combine to make Antarctica the storehouse of the longest and most representative of the atmospheric records on Earth. Ice cores yield a wide range of direct and proxy measures including temperature changes and samples of ancient atmospheres. The data from ice cores provide a key to understanding past global changes, determining human impact on the atmosphere and assisting

the prediction of climate change. Deep drilling discoveries have already revolutionized understanding of how the climate system works; identifying, for example, the increase in anthropogenic greenhouse gas concentration, the close long-term association between greenhouse gases and climate, and the existence of abrupt climate changes. Deep drilling in Greenland has demonstrated an outstanding and effective European capability in this field. On July 12, 1992, the core drilling reached the ice bottom at 3 029 m. The European ice-drilling programme in Greenland has to be continued in order to develop a comprehensive reconstruction of the palaeoclimate of the North Atlantic region. To complete our record of climate development, a complementary programme, EPICA, has to be launched in Antarctica.

EPICA has the aim of reconstructing a continuous history of climate and environmental change in Antarctica, with global relevance on time-scales extending from centuries to several hundred thousand years by drilling through the Antarctic ice to a depth of 3-4 kilometres at two central sites, plus shallower drilling in complementary regions. Comparing the data from these Antarctic sites with those from Greenland will help clarify the nature of linkage between changes occurring in the Northern and Southern Hemispheres. EPICA will also provide key data on global changes in atmospheric chemistry and biogeochemical cycles, and on the mass balance of the ice sheet, which remains one of the greatest uncertainties in predicting sea level change.

This far-sighted scientific project will maintain European leadership in a high priority aspect of polar science and foster international cooperation. It will require the combined logistic resources of at least four countries operating in Antarctica and involve a broad community of scientists and technicians. The total cost of EPICA will be 50-70 million ECU over 6-7 years. It will be managed in three phases. A proposal for the first phase was submitted in January 1992 to the CEC.

Operational Forecasting of the Ocean and Coastal Seas

The recent success of European ocean modellers with projects such as the British and German eddy resolving models of the Southern Ocean, North Sea water quality models and the Hamburg global circulation models has given them the lead internationally. So

has the development of novel techniques for systematic collection of observations needed to run the models: notable examples include the ERS-1 ocean-observing satellite, shored-based radar for monitoring coastal currents and waves, continuous shallow water recording systems such as MERMAID, and the AUTOSUB project for long-range deep hydrography. Given these advances it is now timely to develop an operational capability for forecasting the global ocean and the seas around Europe, comparable with the European Centre for Medium Range Weather Forecasting (ECMWF). This will not be a minor task: it will be one of the grand challenges of our time. The effort will focus on three areas: refining the models, establishing an operational system of observations (the European component of the Global Ocean Observing System) and developing methods to assimilate the data into the models. Research will also be needed to determine the limits of predictability for each class of forecast. The programme will depend on availability of teraflops computers. Success will bring a new capability to forecast many aspects of the ocean and coastal seas, including:

- Global ocean circulation in support of climate prediction and as the offshore boundary condition for higher resolution coastal seas models;
- Regional forecasts in the open ocean including seasonal extent of ice cover, pollution dispersion and sonar conditions;
- Coastal seas forecasts of water quality, in support of fisheries and offshore environmental management;
- Deep ocean environment in support of environmental impact assessment preceding licensing of mining and waste disposal, possibly including CO₂ and mining.

The Arctic Ocean

The Arctic Ocean remains virtually unexplored. The technical problems of operating in an ice-covered sea make it one of the grand challenges of ocean and polar science. The World Ocean Circulation Experiment does not include the Arctic Ocean because existing techniques are inadequate. The scientific problem is to understand how the ice affects the circulation of heat, freshwater and dissolved chemicals in the nearly enclosed Arctic basin; their exchange with the atmosphere and with the Atlantic Ocean; and their influence on life in the sea and on neighbouring islands and land. Ocean-atmosphere

exchange is intense at gaps in the ice cover. Recent climate models suggest that greenhouse-induced warming will be greatest in the Arctic, where it may lead to substantial reduction in ice cover by the end of the next century. However, the models do not adequately represent poorly understood processes, such as water mass transformation on the broad continental shelves around the Arctic and in open-water mesoscale eddies, which may alter as the ice melts, inducing climate feedback. Monitoring the only deep water connection between the Arctic Ocean and the rest of the world's oceans in Fram Strait provides information which is crucial for the understanding of circulation of water masses in the North Atlantic and hence for climate in Europe. In the Greenland Sea, Arctic waters play an important role in the Earth's climate system. Winter convection influences the deep thermohaline circulation globally, and transports carbon dioxide into the deep ocean.

New technology becoming available in Europe makes it timely to prepare now for a major cooperative programme aimed at scientific understanding of the Arctic Ocean. Already the radars on ERS-1 are transforming our knowledge of its surface. Robotic instruments on the ice are transmitting data via satellite. And new tools are being developed for cost-effective surveying of ice-thickness and the underlying thermohaline, chemical and biological distributions: acoustic tomography has recently been tested under ice, and new long-range autonomous vehicles are being developed. By the mid-1990s we should have a new armoury of tools that will make Arctic oceanography a feasible proposition for the first time. A first component of such a major programme is the Norwegian initiative 'The Nansen Centennial Arctic Programme' which will focus on the past and present Arctic environment, in particular the climate changes. This programme will be staged from a drifting ship frozen into the ice over a two-year period from 1994 to 1996.

Europe has special interests in exploring the Arctic Ocean. It lies so close to our continent that inter-annual variations of Arctic ice-cover affect our winters and we shall directly experience the impact of any greenhouse-induced change in ice-cover. Better understanding of variation in ice-cover, leading to reliable prediction, could open up the (ten days shorter) route to Japan. Better understanding of Arctic circulation will benefit our

fisheries and management of the marine environment along Europe's northern boundary.

Recent political developments have opened access to all sectors of the Arctic, making it possible to embark on comprehensive scientific exploration.

Variability of the Deep Sea Floor

The deep sea, covering about 60% of the Earth's surface, is the largest environment of our globe but poorest known. The deep sea floor has generally a depth of more than 4 000 m. It was long looked upon as a very homogeneous environment, where influences from the processes at the sea surface take very long to reach the deep ocean floor and where the slow changes in environmental parameters were insignificant for the animals living there. Recent discoveries have changed this old picture dramatically.

A surprisingly rapid flux of material from the surface waters and the atmosphere, as well as from the terrestrial environment via shelf waters, has been found.

Since the discovery of hydrothermal vents the events taking place at the spreading zones of the deep sea floor have attracted the attention of many scientists. There is a definite need for development of better technological means to perform this research. Advanced technological competence and skill may be mastered within the European cooperative framework, but long-term and detailed studies of the mid-ocean ridges and of the abyssal plains and deep sea trenches are not yet possible because of lack of adequate techniques. Manned submersibles can only stay for very short periods at such sites. Therefore, *in situ* experiments are difficult to carry out.

Earthquakes and volcanism are linked to processes at the plate boundaries. Natural activities at the boundaries also form underwater mountain belts and sediment piles up to 30 km thick at the deep sea floor. Deep penetration seismics, including the use of 3D seismics, would provide unique information on these sedimentary piles, potentially containing significant oil reservoirs. Those studies are a European research topic for obvious reasons. They are also important contributions to the UN Decade of Risk.

Deep sea sediments hold an archive of the history of ocean circulation, sea surface temperature and other parameters related to past global change. The international Ocean Drilling Program

(ODP) using one single drilling vessel for a great number of research topics cannot adequately cope with the needs for an intensive study of the past history of European waters. New facilities are needed for obtaining undisturbed, high resolution cores of up to 300 m length. Special interest is in sampling the ice-covered Arctic Ocean, which is largely out of reach of the ODP vessel.

Furthermore, the deep sea often is looked upon as a potential source of mineral exploitation and waste dumping. Any environmental impact study will depend on a much better knowledge of the deep sea and its biota. Biodiversity in the deep sea is assumed to be higher than in many terrestrial habitats. Effects of sediment plumes in relation to deep sea mining operations have been studied in the Red Sea and the Pacific Ocean.

There is the risk of increased volumes of toxic waste deposition in the deep sea. Many scientists believe that we are already affecting large areas of this environment. With presently available equipment our research is restricted to studies of small scale. Controlled perturbation experiments are needed to elucidate immediate and chronic effects.

Most studies of the deep sea environment are still made in a relatively primitive fashion, e.g. using miles of steel wire to take a bottom sample while the research vessel is unable to handle other gear. New technology is in reach, thanks to technological advances, notably related to space research.

European research in the deep sea would gain momentum very rapidly with a closer cooperation between ocean scientists and engineers. There are at least two ways to achieve this. To create a European Centre for Marine Scientific and Technological Development or a Network of such centres with close connections between them. Such a Centre or Network would have to be a joint European venture because of the costs involved.

ECOPS has commissioned a study on the requirements for deep sea floor instrumentation in the expectation that it will lead to a major European initiative.

Funding

The minimum cost of each grand challenge project in the ocean and polar sciences is estimated by ECOPS to be 50 million ECU spread over ten years. Some will cost much more and take longer. It is proposed that the high priority grand challenge projects be prosecuted in an orderly sequence,

overlapping so that as one peaks and spending declines another grows. In any year there will be three active projects in different stages of development: one polar, one ocean and one for new technology. In order to support this level of activity, it will be necessary to establish a funding line of 25 million ECU per annum. ECOPS notes that this level of European funding for grand challenges would (when combined with the MAST line and relevant parts of the Environment line in the Framework programme) bring the level of European support for ocean and polar sciences to about ten per cent of the combined national spend, which is approximately 600 million ECU per annum. The leading position of Europe in the world of ocean and polar sciences, and the benefits we can expect, make that level of spend appropriate as a high priority in European R&D investment.

Conclusion

European ocean and polar scientists lead the world in a number of high priority lines of research, including ice core drilling, ocean simulation, Arctic research and benthic ecology. In order to maintain the momentum in these areas of research it is necessary to promote a number of grand challenge projects, each lasting about ten years and costing over 50 million ECU and therefore beyond the scope of national budgets for ocean and polar sciences. ECOPS has considered a number of candidate grand projects and proposes an initial set, prioritized by time.

Recommendation

The European Science Foundation and the Commission of the European Communities should establish a 25 million ECU per annum facility for promoting grand challenge projects in ocean and polar sciences.

July 1992

ECOPS

Prof. G Hempel (Germany) (Chairman)
 Prof. O. Michelsen (Denmark)
 CProf. B. Battaglia (Italy)
 Prof. W. de Ruijter (Holland)
 Dr E. Bonatti (Italy)
 Prof. J.-O Strömberg (Sweden)
 Dr D. J. Drewry (UK)
 Dr. J.D. Woods (UK)
 Prof. O. M. Johannessen (Norway)
 Dr. J. Boissonnas, CEC DG XII
 Prof. X. Le Pichon (France)
 Dr. M. Fratta, ESF
 Dr. C. Lorius (France)

COMMENT ON THE ECOPS MEMORANDUM A PELAGIC BIOLOGIST'S VIEWPOINT

This memorandum should be used as the basis for a debate about research priorities for future European ocean science. While I am in agreement with much of what is being advocated, I also feel that the memorandum seems to reflect the prejudices and personal interests of the committee members. Maybe this is because to keep it sufficiently succinct to be read by the bureaucrats in Brussels, the criteria whereby the agenda has been developed are not spelt out. For example, is there really no marine science of intrinsic merit that European scientists have the competence to conduct at low latitudes? As a pelagic biologist interested in ocean management problems, I see little or no consideration of the rich resources of European systematic expertise which could be devoted to the investigation of marine biodiversity and its links with ecosystem function.

There seem to be few roles for pelagic biologists to play in future European marine science, although world wide the pool of expertise is draining away. At a time when, both in Europe and in many developing countries, spurred by the threat of sea-level rise, there is a move towards developing coastal zone management policies, there is little recognition that the fundamental science needed to underpin these policies is still woefully inadequate. Here is a field of scientific endeavour in which the science is exciting, and the scale of the effort required gargantuan, and there is immense potential for making a significant contribution to keeping the Earth

habitable. There is no recognition that the complexities of environmental interactions give rise to multiple-scale problems with effects cascading up and down time/space scales. The results of whole-ecosystem manipulation experiments conducted on lakes and watersheds give full warning that responses in both chemical and the biological systems are often totally unexpected and may continue to reverberate for decades.

These are just some of the apparent oversights in this memorandum, and no doubt others with different background and interests will detect more. Is this the way the Challenger Society membership would want European science to go? If not then either in a formal meeting or through the pages of *Ocean Challenge* there needs to be an urgent debate of what we, the scientific community, would wish the priorities and the grand programme to look like. Then in collaboration with the European Societies representations could be made to ESF and CEC. If not, then major financial and logistic resources in Europe will be ring-fenced, with the result that if your science is not perceived as 'main stream' future support for it will be greatly limited.

There may be some members of the Society who consider that I am over-reacting to the memorandum, and some who consider my reaction to be inadequate. It would be appropriate if the pages of *Ocean Challenge* could be used as a forum for a debate about this influential document.

Martin V. Angel
 IOS Deacon Laboratory

NEWS FROM THE JAMES RENNELL CENTRE

Introduction

The James Rennell Centre for Ocean Circulation was conceived in Spring 1990, as part of the UK contribution to WOCE, the World Ocean Circulation Experiment. Staff began occupying their new home at the Chilworth Research Centre, Southampton, in October of that year, and the Centre was formally opened in February 1991 by Lord Rennell of Rodd, a descendant of Major James Rennell. New staff were recruited to work alongside 'old-timers' who had transferred from IOS Deacon Laboratory, Wormley. This blend of youth and experience has enabled an excellent start to be made on the project. Strong links are maintained with Wormley staff, several of whom also work for WOCE.

The remit of the Rennell Centre is to lead, coordinate and participate in the UK WOCE programme. It carries out this work through several scientific teams (see below). Not only does the Centre carry out its own research programme but it provides a focus for the whole UK WOCE effort and gives support in various ways to other laboratories and university groups.

The Scientific Teams

The objective of the **Survey Team** is to conduct deep ocean hydrographic research, through participation in cruises to ensure world-class data quality, by conducting novel research into the

ocean's circulation, and by communication with the world's oceanographic community.

Recent cruise contributions include VIVALDI – a seasonally repeated survey to calculate heat and fresh-water budgets and investigate ventilation processes (Figure 1) and CONVEX – a 'Control Volume Experiment' to determine circulation over the entire depth of the ocean. Both VIVALDI and CONVEX took place in the North Atlantic.

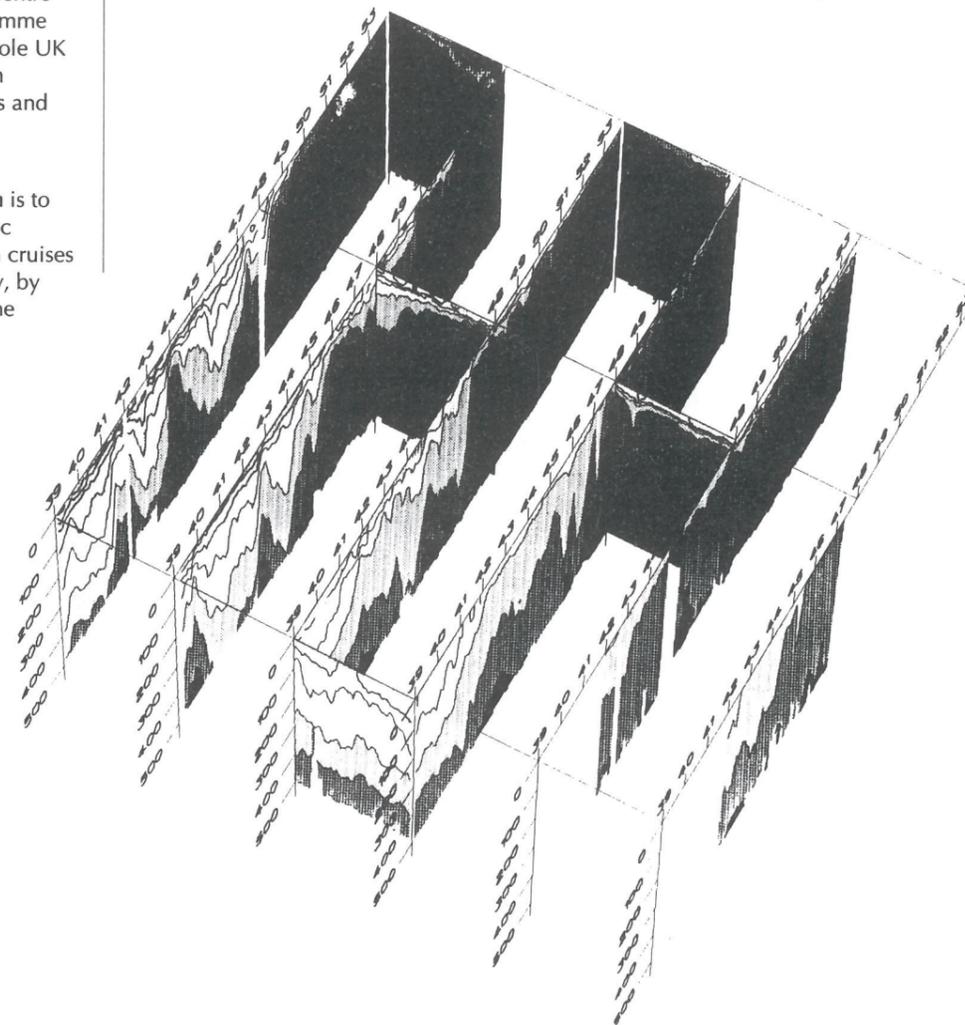
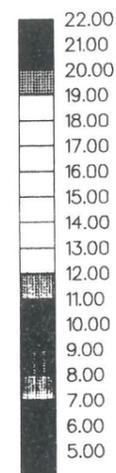
In the Southern Ocean, WOCE section A11 was occupied to determine the transports of heat and salt across 45° S in the Atlantic, ADOX, the Antarctic Deep Outflow Experiment, measured the volume transport of the abyssal circulation east of the Kerguelen Plateau, and the South-West Indian Ocean Experiment (SWINDEX) included observations of the interaction of the Antarctic

Circumpolar Current with the South-West Indian Ridge.

A synergistic approach, making use of many analytic techniques and exploiting data from other disciplines, has had notable success recently. The non-stationarity of the tracer distribution of Labrador Sea Water in the eastern North Atlantic has been demonstrated by combining hydrographic and chemical tracer data with dynamical and statistical methods of water-mass analysis. The success of the box inversion technique has been demonstrated through a novel means of correlating Doppler current estimates with the inversion solution. Also, starting from a first guess (which is wrong), the inversion solution can reproduce known features of the deep circulation in the North Atlantic.

Figure 1 Vertical sections of potential temperature in the North Atlantic derives from SeaSoar surveys made during VIVALDI 91.

Potemp



Coral Cay Conservation has moved ...

Its new address is
 'The Ivy Works'
 154 Clapham Park Rd
 London SW4 7DE

Tel. +44 (0)71-498-6248 (3 lines)
 Fax +44 (0)71-498-8447

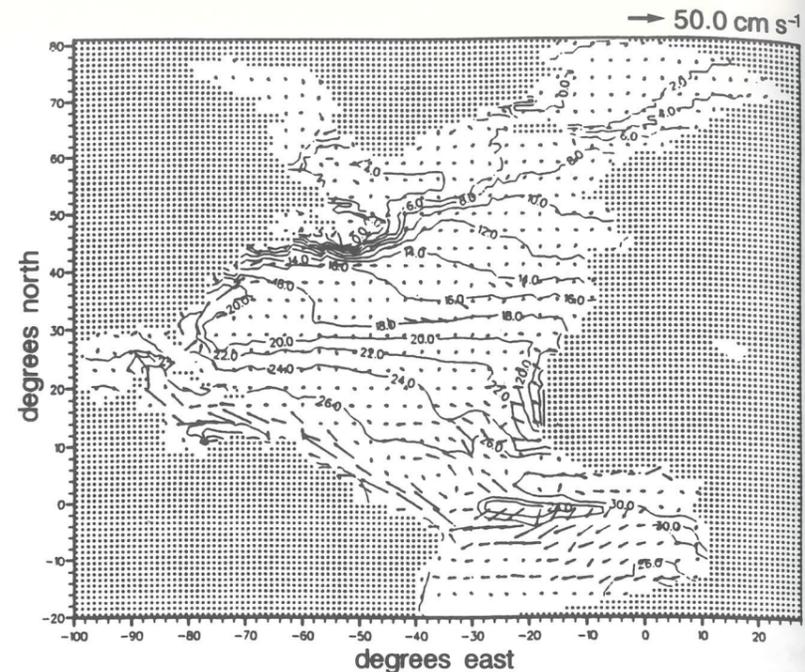
Figure 2 Surface temperature field and currents in 'year 30' from the Atlantic Isopycnic model

The aim of the **Chemical Tracers Team** is to study the distributions of various chemical species as a means of furthering our understanding of oceanic circulation and mixing. The tracers studied fall into two categories: the steady-state tracers (dissolved oxygen, the nutrients and oxygen isotopes) which have constant, natural input functions, and the transient tracers (CFCs) whose inputs are time-dependent and totally anthropogenic. The main work of the team is to collect and interpret oceanic data in support of the WOCE programme. Added to this is a commitment to development of techniques which will ensure continuing high data quality.

Over the past two years the Tracer Team has participated in three cruises – CONVEY in the North Atlantic, and A11 and SWINDEX in the Southern Ocean. The results from these cruises have allowed us to extend our understanding of circulation patterns in the areas concerned. For example, CFC data from CONVEY provide time-scale information that shows that present-day Labrador Sea Water has a maximum age of 25 years. This is consistent with other findings indicating a 'shut off' period in the late 1960s and early 1970s, and our data show that since its formation restarted, Labrador Sea Water has again spread across the entire North Atlantic. In addition, bottom waters at intermediate depth in the eastern basin are characterised by very low CFC values, implying ages in excess of 50 years, and high silicate concentrations, which indicate a significant Antarctic water component. The latter idea is supported by oxygen-isotope data which show that, although of polar origin, these waters do not originate in the Arctic.

Initial results from the recent A11 WOCE cruise, across 45° S in the Atlantic, show distinct patchiness in the surface waters, apparent in both the CFC and dissolved oxygen data. This shows the interleaving of cold waters, of southern origin, with warm, subtropical waters, together with the presence of 'rings' formed from meanders in the Aghulas Current and/or Brazil Current.

Within the **Physical Modelling Team** two projects are being carried out – development of the Atlantic Isopycnic Model (AIM) and Feature Modelling. The overall objective of the AIM project is to develop and test an eddy-resolving isopycnic-coordinate circulation model



of the Atlantic Ocean, and to study its output in order to increase our understanding of processes which affect the climate. Isopycnic models consist of a set of layers of constant density, the thicknesses of which can vary in time and space. This approach contrasts with that used in the more traditional type of model consisting of levels at constant depths. An important part of the present project is to make intercomparisons between the two model types, and to assess the possible benefits of each. Comparisons between low-resolution models (non eddy-resolving) are presently underway as a collaborative exercise with the Hadley Centre (which is part of the UK Meteorological Office).

The low resolution isopycnic model has been used to study the changes which occur in the subtropical gyre, south of the Gulf Stream, during the evolution of the model over a 30-year period (Figure 2). According to the model, the near-surface waters in the central Atlantic cool down, and this causes certain changes in the ocean interior on a decadal time-scale, such as – counter-intuitively – warming of the isopycnic model layers. The model evolution has been compared with observations between the late 1950s and early 1970s, and striking similarities have been found. The model indicates that the observed changes, which extended down to depth of about 800 m, were probably the result of changes in the near-surface water masses which were then subducted into the ocean interior.

Feature models are simple mathematical descriptions of physical oceanographic structures. These descriptions may have a number of variable parameters. For a given feature, the values of these parameters must be determined from the available data. For example, an AVHRR satellite image only provides information about the temperature of the sea surface, but from our knowledge of historical *in situ* observations, and of the equations of motion which govern the evolution of the temperature field, we may be able to infer the sub-surface structure of eddies and fronts identified by the image. This is analogous to the way in which weather-forecasters can identify warm and cold fronts from observations of clouds.

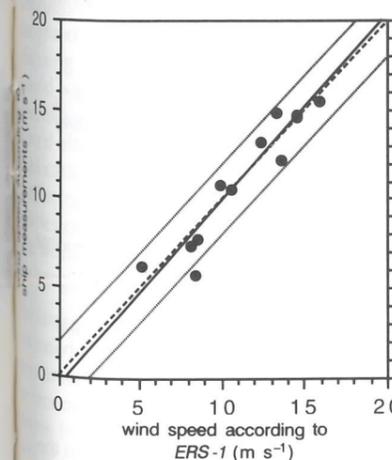
Such representations may provide a tool for assimilating data without having to specify explicitly the values of all variables on a model grid. The work of the feature modelling team is funded by a contract with the Defence Research Agency, and it is hoped that feature models will be used as a tool for the assimilation of data in FOAM (Forecasting Ocean–Atmosphere Model). FOAM is currently being developed by the UK Meteorological Office and the Defence Research Agency for operational use by the Royal Navy. Feature modelling trials using a two-layer reduced-gravity model are now underway.

The marine biota are intimately involved in the cycles of nutrients and carbon within the ocean. Recent concern about anthropogenic CO₂ emissions has focussed attention on the role of ocean

biology in the global carbon cycle. Moreover, it is important to realize that biology cannot be modelled in isolation from physical processes which control the export of substances from the mixed layer as well as the flux of nutrients from deep water to the phytoplankton. An important aim of the **Biological Modelling Team** is therefore to incorporate biological models into suitable physical models of the world's oceans in order to investigate the global carbon cycle. In a joint project with Princeton University, an ecosystem model has been embedded in a three-dimensional seasonal model of the North Atlantic and used to predict the seasonal cycle of surface phytoplankton concentration for comparison with observed values derived from satellite ocean-colour sensors. The results were encouraging, but they highlighted the sensitivity of biological production to the modelled vertical advection and the need to improve the accuracy of the physical models in this respect. The need to develop second-generation ecological models was also apparent, and this is being done for use in a world ocean carbon cycle being developed jointly with the Hadley Centre.

The transfers of heat, water and momentum between the air and the sea are an important component of the climate system. Values of these fluxes are needed for forcing numerical models of the ocean circulation and for verifying the fluxes in coupled ocean–

Figure 3 Comparison of wind speeds determined using ERS-1 altimeter data with *in situ* data. Also shown are the ERS-1 design accuracy of $\pm 2 \text{ m s}^{-1}$ (toned lines), the line of perfect agreement (dashed line) and the best-fit straight line (solid line).



atmosphere models. The work of the **Meteorology Team** at the James Rennell Centre is directed towards the development of improved estimates of the air–sea fluxes. The effect of sea state on the momentum flux (or wind stress) is being investigated using wind-stress estimates obtained by measuring the turbulence in the air using sonic anemometers mounted on ships. A buoy mounted system, the 'sonic buoy' has also been developed by the Ocean Instrumentation Group at IOS Deacon Laboratory. This work is receiving funding from MAFF under their Flood Defence programme.

Our present knowledge of the surface climatology of the ocean is based on meteorological observations from merchant ships. In a project based on data from a sub-set of the voluntary observing ships, the James Rennell Centre collaborated with the UK Meteorological Office and other marine meteorological agencies to determine the accuracy of merchant ship observations. A set of corrections was devised to remove bias errors from the data. These data have now been used to compare and assess previously published climate atlases. Under contract from the Hadley Centre a new global surface flux climatology will be produced at the James Rennell Centre.

Over the last decade or so, the ability to measure certain oceanographic parameters from space has become firmly established. Several missions are planned for the future which will ensure a wealth of data beyond the end of the century. The **Satellite Team** is concerned with the extraction of accurate information from these satellite missions and their application to ocean circulation and ocean processes; parameters being determined include infra-red sea-surface temperatures, sea-surface topography and waves derived from altimetry data, winds from satellite scatterometer and ocean colour. Most of the team's work is concerned, in one way or another, with the Middle and High Latitude Variability Study (MAHLOVS). MAHLOVS is one of the only eight non-US interdisciplinary projects selected by NASA for the Earth Observing System. This prestigious project will run until 2002. In addition to staff from the James Rennell Centre, MAHLOVS includes scientists from Southampton University, Edinburgh

University and the Remote Sensing Application Development Unit. This unit is a group run jointly by NERC and BNSC (British National Space Centre), and the oceanographic part is located at the Rennell Centre.

Present work includes examining variations in North Atlantic sea-surface temperatures over the last fifteen years, the relationship between the subsurface structure and dynamics and surface signatures observed by satellite sensors, a method of deriving absolute currents from altimetry and hydrographic data and, as part of the ERS-1 Special Topic, comparing sea-level determined from altimetry with that derived from models, and the derivation of wave-climate statistics. In September 1991, a major cruise was conducted to validate ERS-1, and this not only demonstrated the high quality of the satellite data (Figure 3) but showed how the combined ERS-1 and subsurface dataset could be used to further knowledge of the Iceland–Faroes Front.

The Future

Recently, the Centre's remit was extended to include research directed towards operational monitoring and forecasting of the ocean, with an eye to the post-WOCE era. In 1995, the Centre will move across Southampton to the Empress Dock to form part of the new Southampton Oceanography Centre, a joint enterprise between NERC and Southampton University. Building is already well advanced.

Trevor Guymer
James Rennell Centre

Stuart Cunningham, Steve Boswell, Adrian New, David Smeed, Mike Fasham, Peter Taylor and Peter Challenor are gratefully acknowledged for their assistance in the preparation of this article.

MORE NEWS ...

UK DIGITAL MARINE ATLAS

The Second Edition of the *United Kingdom Digital Marine Atlas* is now available for purchase. This latest edition builds upon the foundations laid in 1991 by the first ('beta test') release; it has a greatly expanded data content, which is more evenly distributed throughout the range of marine topics, and places greater emphasis on environmental conservation and reference material.

Content

The *Atlas* presently contains 462 charts covering a wide variety of maritime themes under the following general headings:

General Reference (18 charts)

Marine Geology and Geomorphology (11 charts)

Marine and Coastal Parks, Reserves and Protected Areas (15 charts)

Marine and Coastal Conservation in Great Britain (8 charts)

Sea Birds (25 charts)

Sea Mammals (11 charts)

Marine Biology (29 charts)

Currents, Tides and Surges (19 charts)

Winds, Waves and Weather (21 charts)

Seawater Temperature, Salinity and Nutrients (162 charts)

Chemical distributions (33 charts)

Exploitation of the Marine Environment (12 charts)

Fishing Areas and Fish Spawning Areas (24 charts)

Fishery Statistics (50 charts)

British Oceanographic Data Centre Data Catalogues (24 charts)

Data contained in this edition of the *Atlas* concentrate upon the area 45° N to 65° N, 15° W to 15° E, although a number of datasets, particularly those concerned with coastal phenomena, are of more localised extent, and a few charts extend to a wider geographic area.

The user may browse through the *Atlas*, zooming in to areas of specific interest, and overlaying any chart with information from another chart for comparison, or with descriptive text. The text provides both educational information and reference information, such as the source of the displayed data together with any related datasets or expertise available from the source.

The true versatility of the *Atlas* is best shown by the 'queryable' datasets which it contains. When initially displayed, these datasets illustrate a maritime theme by the use of symbols which show, by their positioning and colour coding, the location of features related to that theme. Each symbol may then be 'queried' in turn, causing detailed information for that specific location to be displayed in an overlaid text window. In this way, information which would occupy many pages of printed text may be displayed upon a single chart within the *Atlas*.

Second Edition Enhancements

Improvements of the new edition include:

- An hierarchical, windowed, data-selection menu which permits the datasets within the *Atlas* to be grouped together under collective headings, increasing user 'overview' of the *Atlas* contents, and enabling the greatly increased number of datasets within the *Atlas* to be accessed by the user in a clear and logical manner.

- Mouse control throughout the *Atlas* system (although keyboard control may still be used as an alternative if necessary or desired).

- A system 'reset' facility which restores system default values after they have been changed by the user.

- A multi-point distance measuring option, with distance displayed in miles, nautical miles and kilometres.

- A dataset 'subset' facility (for both foreground and background datasets) which permits the user to turn off or restore the display of individual data items, and to control the colour and style in which they are displayed. This permits the user to 'customise' the display, and is particularly useful for those users who have only a monochrome printer, as features may be set so that they are distinguished by shape and style rather than by colour.

- The option to query a dataset to determine its source scale.

- The option to query a dataset to determine its date of origin.

- The option to 'drop' an overlay dataset and return it to the main selection list.

- Flexibility of print output destination both for screen dumps and for text output. Print output may now be directed to any serial or parallel port of the PC or, alternatively, to a disk file for

later printing or for transfer to a word processor etc.

- Incorporation of a simple 'printer driver' file which enables textual output to be 'customised' to the specific make of printer employed. Template files for Epson, HP laserjet and null printers are supplied with the system.

- Implementation of a 'system defaults' file which specifies the screen resolution to be used, directory locations etc.. This permits the flexibility required by network users working on differently specified PCs.

System Requirements

The software requires an IBM PC (or PC-compatible) with 640k RAM, and EGA or VGA display, and a hard disk with at least 10 Megabytes of free space in which to install and run the *Atlas* software. It is designed to run under DOS 3.0 or later, and will also run in the 'DOS Box' of the OS/2 operating system. The mouse (Microsoft compatible; the IBM PS/2 mouse is incompatible) is highly desirable, but not essential.

How to Obtain your Copy of the *Atlas*

The *Atlas*, including its display software, is distributed on floppy disk, and is accompanied by a printed User Guide and other documentation. Both sizes of IBM PC format disk are available, but at high density only (i.e. 1.2 Mb 5.25", and 1.44 Mb 3.5").

The Second Edition of the *UK Digital Marine Atlas* is being distributed at a price of £48.00 plus VAT, inclusive of postage and packing (i.e. £56.40 VAT inclusive). To obtain your copy, please send your company's official order (or send a cheque with order for personal copies) to:

UKDMAP Orders
British Oceanographic Data Centre
Proudman Oceanographic Laboratory
Bidston Observatory
Birkenhead
Merseyside L43 7RA

Please ensure that you clearly state what size and density of floppy disk you require. Cheques should be made payable to the Natural Environment Research Council.

Special Upgrade Price

Users of the First Edition of the *UK Digital Marine Atlas* may upgrade to the Second Edition for the special price of £28.00 plus VAT (i.e. £32.90 VAT inclusive).

NEW IRANIAN NATIONAL CENTRE FOR OCEANOGRAPHY (INCO)

INCO is a newly established organisation founded under the auspices of the Iranian Ministry of Culture and Higher Education and UNESCO (IOC). It has a variety of functions within its terms of reference at both the national and international level. Nationally it will support marine studies and co-ordinate marine activities among marine scientific organisations and administrative bodies. It provides opportunities for fundamental research with the emphasis on those scientific areas not covered by other marine organisations. INCO also has an educational role in the teaching of marine science at the undergraduate and postgraduate levels and will be a key body in the design and implementation of a national strategy for marine resource management. Internationally, INCO will be the main contact point for any regional oceanographic activities based in the Iranian waters of the Caspian Sea, Persian Gulf or Oman Sea.

At present, INCO has staff members with interests in geophysics, marine geology, marine biology and ecology, hydrography, physical oceanography, ocean engineering and international law. There are 5 or 6 MSc or PhD students associated with the centre and around 15 scientist in other institutions who have co-operative links.

As a relatively new, but rapidly expanding body, INCO is extremely keen to develop international links. Its source base is rapidly increasing from only one person in early 1992 to nearly 20 in late 1993; however, it still has a long way to go to meet its ultimate objective of becoming a major, active oceanographic institution. INCO staff would be delighted to hear from anyone who is planning work in the region and who would welcome collaboration and possible access to Iranian waters. They would also like to hear of meetings, publications etc. They will shortly be producing their own journal (English articles or Farsi with English Abstracts) and would be very willing to enter into exchange agreements with libraries.

Iranian science has gone through an extended fallow period from which it is now emerging. The Iranian marine environment has suffered to a major degree from the effects of regional wars; and, of course, the Persian Gulf is a region of major economic and oceanographic interest. On a couple of recent visits I have been impressed with the level of enthusiasm and drive that INCO

is showing. If anyone would like to make contact with INCO they may be reached at: PO Box 14155, 4781 Tehran, Iran (Fax (21) 6419075).

Martin Preston

University of Liverpool

THE CHALLENGER EXPEDITION A VISUAL INDEX

In 1872 HMS *Challenger* put to sea "for a prolonged and arduous voyage across the oceans of the world". The naval (i.e. geographical) aims were to be subordinate to the scientific aims and a large proportion of those on board were civilians. Unusually, space was provided for a photographic dark room, and one of the instructions given was that "Every opportunity should be taken of obtaining photographs of native races to one scale." The end result was that in excess of 800 photographs were taken; but little was written about them and no recognition was given to the photographers. Eileen Brunton, the author a new 'visual index' of the *Challenger* Expedition, has done extensive research to reveal the identity of this small group of photographers.

The voyage itself is dealt with only briefly in this publication, and the emphasis is on the photographers and their equipment. The participants and the diary of the voyage are given in full.

This work is, in essence, the reproduction of the official photographs deposited in the The Natural History Museum, London, a very small number of which have been reproduced since the voyage. However, the photographic collection also includes additional photographs located by the author in other collections around the world, which are not duplicates of those held in The Natural History Museum. There is a full descriptive catalogue accompanied by a full subject index.

The publication will be of interest to historians of science and oceanography, anthropologists, naval historians and curators of photographic collections; it should also be useful to picture researchers and film-makers. It is produced in the form of an A4, laser-printed, perfect bound paperback and includes a brief history of the photographs held at the Natural History Museum, details about 'missing' images, a map of the voyage, a pictorial index with approximately 760 images, a copy of part of the original

manuscript catalogue, and a fully cross-referenced subject and location index.

In summary, this is not yet another narrative of the *Challenger* Expedition. It is a unique collection of topographical and anthropological photographs taken during a circumnavigation of the world by a naval and civilian expedition to which, for the first time, an official photographer had been attached.

THE DOLPHIN TIME-CAPSULE

'Britain cannot be world leader in every scientific discipline, but by concentrating on what we are best at we can be world class and European leaders in a small number of subjects that have particular relevance to our national needs. Oceanography is one of them.'

With these words, Dr John Woods, Director of Marine and Atmospheric Sciences at NERC, set the scene for a ceremony earlier this year at which Mr William Waldegrave, Minister of Public Services and Science, laid a time-capsule in the foundations of the new Southampton Oceanography Centre, due to open in 1995.

The time capsule is a one-metre scale model of the *DOLPHIN* AUTOSUB vehicle, presently being developed at IOS Deacon Laboratory, and described as the "work-horse of 'inner-space' monitoring in the future, a role similar to that of today's weather satellites". The time-capsule contains reports, predictions, datasets and so on, upon which it is hoped that future scientists will look with interest – and perhaps some surprise? – when the lease expires in 125 years' time.

TIME AND TIDE WAIT FOR NO-ONE

There were red faces among physical oceanographers at Menai Bridge a few months back. A seminar on tides was to be held in part of the School of Ocean Sciences that is sited on the nearby islet just offshore in the Menai Straits. It is joined to the main island (Anglesey) by a pedestrian causeway, which is submerged only during highest spring tides. There are about 10–12 occasions during the year, when the causeway becomes impassable for a few hours.

You've guessed it. The date chosen for the seminar coincided with one of those occasions, and the event had to be postponed. How embarrassing.



GAIA QUEST

The Gaia Quest Trust is a registered charity whose aim is to provide logistic support at a reasonable cost, to facilitate long-term scientific monitoring of various marine environments around the Indian Ocean. If you have a project which could be undertaken with the help of Gaia Quest, the Trust would like to hear from you (see below). Preference will be given to projects that could contribute to understanding of global warming and climatic change, and consequent changes in sea-level, coral-reef degradation and mortality; also to projects investigating pollution, loss of biodiversity and indicator species for the general well-being of the environment.

The Vessel

The original plan of acquiring a custom-built vessel has had to be abandoned, but with the help of a generous donation from Paul Getty, Gaia is hoping to find a vessel suitable for conversion to an inshore research vessel. The ideal vessel would be 45 m in length, with relatively shallow draft. In addition to the professional crew's quarters, there will be accommodation for up to twenty scientists, as far as possible in double cabins. Part of the holds will be converted into laboratory, storage and workshop space.

Research Equipment

Researchers will be expected to provide specialist equipment for their individual projects, but the vessel will carry basic oceanographic and marine biological equipment. There will also be space allocated for a darkroom.

There will also be five outboard powered workboats (at least two of which will be semi-rigid inflatables) and equipment for diving. Electronic equipment will include two PCs linked by *Inmarsat* satellite modems to a land database and Email system. *Inmarsat* have offered to sponsor global communication system that will include telephone, fax and global positioning facilities.

Continuous monitoring of basic chemical and physical oceanographic parameters will be conducted using through the hull probes and specially designed, low-speed towed 'fish'. The Gaia team have been offered support in designing and building this equipment by NERC,

Bristol University and IGBP. Data will be recorded in a data-acquisition system linked to the GPS facility.

Provision will be made for a small wet chemical laboratory and specimen preparation area. There will be a deep freeze dedicated to sample use, possibly down to -70°C .

A microlight seaplane is also being considered. Microlights take a variety of forms now, but the most suitable seems to be a French 'Petrel', a biplane with a pusher type propellor, capable of taking off from land or sea carrying a pilot and an observer. This aircraft is robust and inexpensive to run and would enable monitoring of areas such as mangrove swamps, seabird surveys on coral flats, reconnaissance of large patch reefs (some of which are 20 km by 3 km), and could also produce low level aerial photographs and video coverage. The aircraft could also be used for emergency evacuation of injured personnel, a possibly vital function in areas where the boat will often be operating a day or more's journey from medical assistance.

Overall, the Gaia team visualise a small but efficient scientific platform, capable of supporting a wide range of research in a flexible manner in otherwise inaccessible areas.

The Operating Cycle

Few useful results can be achieved by one pass over an area, or by one look at a particular phenomenon. It is almost invariably necessary to examine any project broadly at first, gather data, and return after this has been assessed, to evaluate what has arisen during the first pass. However, to date, much oceanographic research has been gathered on costly expeditions that have been mounted on a one-off basis. Gaia hopes to overcome this problem by running its vessel continually over an indefinite number of years. In this way, a detailed picture can be built up and, most importantly, trends and changes can be monitored and described.

The ship will operate on a two-year cycle. In the first year, she will start from East Africa, go over to the Seychelles in March, continue to Madagascar in May and return to East Africa in October. During the second year she will go further afield, taking in the Maldives, Chagos, Gulf of Aden, the southern Red Sea and Mauritius.

This voyage plan places the ship in good working conditions throughout the year and avoids the dangerous cyclone season. At any one time, about twenty

scientific personnel will be aboard, divided equally between local researchers and those from overseas institutes and universities.

Several different aspects of each area will be studied during the one to three months that the boat spends at each site. It is hoped that the sharing of facilities between groups working in different disciplines will lead to the cross-fertilization of ideas.

Co-ordination of Research

Gaia has not been set up specifically to do research itself but to fulfil the need for logistic support at a reasonable cost that will enable research to be carried out. However, it is vital that the research carried out on board should be of the highest academic standards and of the greatest practical value both to the local community and the world at large.

In order to assure itself of the value of projects and to achieve a balance approach, the Trust will establish scientific advisory committee. The members of this group will include specialists in wide range of oceanographic, marine biological and geographical fields relevant to the area. It will also include the Directors of local institutes. The purposes of this committee will be to vet projects and advise on their value and likelihood of success.

The Trust will also organise the compilation of regularly updated atlases and reports on certain research themes, broadly applicable across the area, and to other oceans. Examples are:

- Compilation and updating of an atlas of coral reef mortality and condition.
- Compilation of a population distribution and breeding site atlas for the seabirds of the region.
- Contributions to the International Geosphere-Biosphere Project of continuously monitored chemical and physical data from coastal seas, including pollution assessment.

Naturally, a great number of other themes can be developed, including classification and state of mangrove areas, sea-grass beds, fish stocks, turtle populations, etc.

Help in co-ordinating these atlases will be sought from independently funded post-doctoral specialists in relevant fields. Data will be abstracted from individual projects to build up these theme reports and atlases. In addition an annual report of the activities and findings will be produced.

Local Co-ordination

Host organizations within the countries in whose waters the vessel will be operating will develop local programmes based on their own interests and experience in the region. Organizations that have already agreed in principle to do this include Kenya Marine and Fisheries Research Institute, the University of Dar Es Salaam, the Marine Research Station in Zanzibar, the University of Mauritius, and the Albion Fisheries Research Centre in Mauritius. As a guiding principle the vessel will operate in areas which are least accessible from the landward side, so that the best use can be made of its unique capabilities.

Coordination within the Trust

The scientific activities of the Trust will be coordinated by Richard Speir (address below), and logistic and administrative coordination will be the responsibility of Vice-Admiral Sir Geoffrey Dalton.

Costs

These are still under discussion, but the aim is to charge less than \$US 2000 per person per month on board. This will include food and accommodation and the use of facilities. Final estimates will be available by Autumn 1993.

Initial Two-Year Research Voyage Cycle

This plan outlines the schedule for the vessel during the first two years operations. Possible research projects, already discussed, are indicated.

1994

October

Arrive Mauritius

Investigations of reefs in Cargados Crajos Shoals area and other remote shallow banks north of Mauritius

Investigation of upwelling phenomena south of Mauritius

late November/December

Move to East African coast

East African natural history programme

1995

Coastal waters between Dar Es Salaam, Mafia and Kilwa Kisiwani, Tanzania

Surveys of migrant shore-bird population

Evaluation of reef damage from dynamiting and silt run-off; acquisition of data for establishment of marine parks;

reconnaissance surveys of mangrove habitats in the Rufiji Delta

mid-March

On passage to Seychelles

April to early May

Cetacean survey on north edge of Seychelles bank;

fish-sampling off the adjacent waters, which are very deep

Data-collection for a 'reef atlas' for the Seychelles

Remainder of May

Natural History voyage through Amirantes via Aldabra to Comores and Madagascar

June through September

West coast of Madagascar

Study of the relationship between coastal people and turtle population

Assessment of sea-bird breeding sites

Cataloging of Madagascar fishing eagle nesting sites

Search for new lemur species in coastal forests

Assessment of damage to coral reefs, as a result of runoff

October

Return to Tanzanian coast

late October to end November

North Kenya coast: littoral studies; migrant wader populations; mangrove use

December

Annual refit and leave in Mombasa

1996

early January

East African natural history tour.

late January

On passage to Chagos Archipelago, BIOT

February through March

Survey of coral reefs and fish stocks

Evaluation of damage caused by Crown of Thorns starfish

Census of introduced mammals with aims to their eradication

April through May

Return to Seychelles

Continue with projects above

end May

On passage to southern Red Sea

June through September

Reef studies in remote islands and along the southern coast of Saudi Arabia

Monitoring of seabird breeding sites in the southern Red Sea and subsequently Gulf of Aden

Investigation of gazelle population in islands of the southern Red Sea

The cycle then repeats along broadly similar lines

In addition to the above projects, a number of continuous data-collecting programmes would be conducted. These include: gathering of physical and chemical data both of the sea-surface and aerosols; recording of oil and tarball pollution; distribution of pelagic seabirds and cetaceans. Proposals for these types of research are also welcomed.

If you would like to know more about Gaia Quest, and in particular if you have

a project that could benefit from links with Gaia, please contact: Richard Speir, Glensellagh, Ballydehob, Cork, Ireland; Tel/Fax (Ireland) +353 (0)28-37-29-4.



A NONSENSE TALE (INSPIRED BY A LECTURE AT UK OCEANOGRAPHY)

GLORIA was depressed, even though PICES was in the ascendant. SCARface IABO, her PRIME suspect for the GLOBEC job was getting away with it again, because Inspector NERC was GLOSSing over evidence and not telling her the SCORE.

'I feel really GOOSed by that OSCAR, he's a real SUDO,' she said. 'It's not as if IODE him anything. IMOaned about it all night, got through far too many FAGS, and played my whole VIVALDI collection. All it did was GIPME even more'. She took a stiff TOT from the BATNEC dispenser.

'GARP' growled TOBI sympathetically.

'Never mind' said LOIS, 'JASIN and his Spanish chum SAREZ won't let you be WOCEd, they'll prevent any IREparable harm. HABib will probably try to get away by sea with the ICES on him. We'll watch him through the SCOPE, and as soon as he clears the BRIDGE and hoists the DISCOL on his MAST, to navigate through the MIASma, we'll release the trained DOLPHIN to give him such a BOFS it will knock the STOFing out of him. Our DOGGIE can retrieve the GEMS, and the EDLR will have to be a real IUGG not to agree to IOC him up in the CONVEX.'

They NEARly succeeded, but had reckoned without the wily GEBCO, whose agents were waiting at the GATE and pulled off a JONSWAP by wearing their TOGAs. All the POLice got was a load of used IAPSO - and OSNLR - because the UNEP turned out to be an ICSU after all, and UNESCO had got away with it again.

You think it's all a load of FAO? Well, perhaps. But ITSUp to you to tell the true story of how MABs and her MAM used the ATOMIC ETRAC to HYDrolyse the FISH and ... EUREKA.

The Editor wants *your* version for the next issue!

THE NORTH SEA PROJECT IN RETROSPECT

WATER-QUALITY MODELLING IN SHELF SEAS LOOKING BACKWARDS AND FORWARDS AFTER THE NORTH SEA PROJECT

The Royal Society discussion meeting of 4 and 5 November 1992, entitled 'Understanding the North Sea System', effectively marked the end of the five-year UK North Sea Project. Having been involved continuously, from the planning stages in '86 through to this finale, I shall leave the proclamations of success and achievements to disinterested observers. For me, one of the most promising outcomes of the Project was the formation of a group of marine scientists resolved to make further use of numerical models. A significant factor behind this development was the provision by Proudman Oceanographic Laboratory (as part of its host laboratory core-support role) of a 'user-friendly, entry-level' North Sea computer model. While marine 'Community Programmes' abound both in the UK and through EC funding, these are invariably targeted to achieve specific goals over finite time intervals – aims that easily overshadow the need to train and support marine scientists in the cross-disciplinary skills required to tackle marine environmental problems.

Observationalists and Modellers: Two Communities

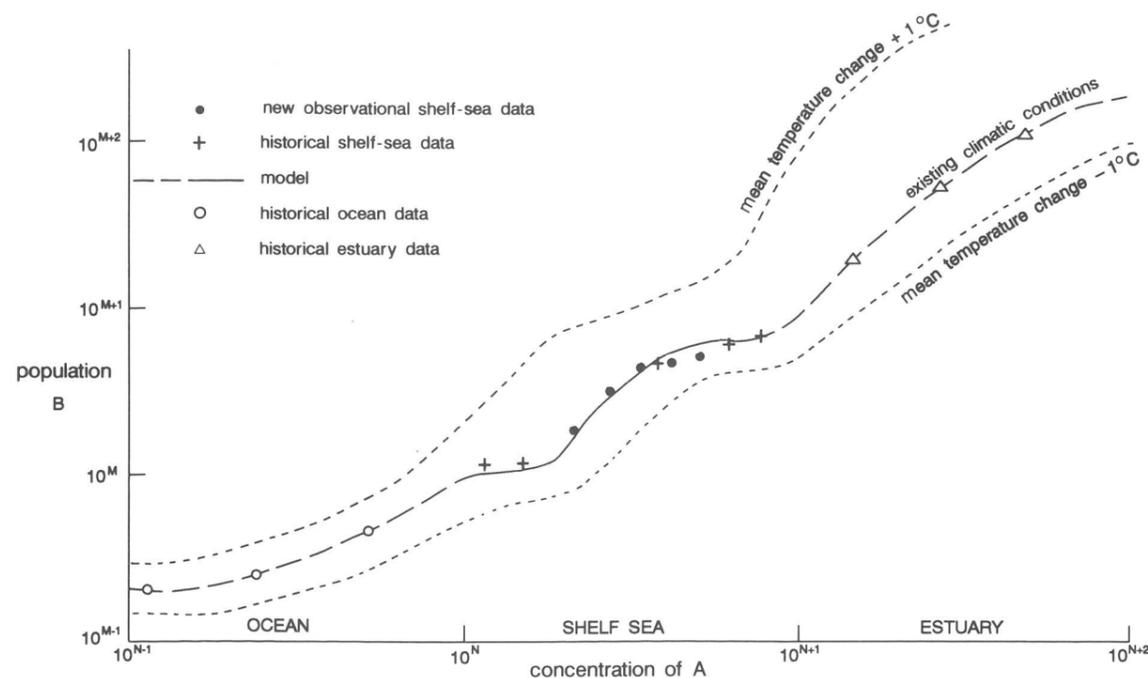
In Volume 1 of *Ocean Challenge*, David Pugh reviewed a 1990 Challenger Society meeting on the 'Balance between observations and modelling in marine science'. He contrasted 'real' oceanographers returning from the sea to a hero's welcome with numerical modellers, with their proclivity to remain tucked up in their warm, safe offices. This portrayal of observationalists and modellers as different animals is reinforced in the same Volume by Steve Thorpe who contrasts our burly, bearded hero with the nervous, highly strung modeller.

David concluded that no speaker had offered guidance as to how to make choices between these two approaches, but in fact we need not think in terms of choices at all. While specialists are needed in both disciplines, scientific progress depends not on choices between them but on careful evaluation of agreements and discrepancies between 'model' and 'observed' by scientists with an appreciation of both. The ultimate aim of a single integrated model is essentially to synthesize knowledge – a challenge which is not yet a preoccupation of the numerical

specialist. In the North Sea Project, progress in this direction was achieved by providing simple 'hands-on' models to scientist 'non-modellers'. The single integrated model is likely to be best achieved when scientists have the opportunity to use simple models to advance their own specialism and thereby perceive more clearly, and support more wholeheartedly, the integrated model development.

Working in tight communities with fellow specialists, we often overlook the need to explain our fundamental aims to out-siders. Figure 1 – which is intended to summarise the modeller's dream – is an attempt to remedy this. Starting with some basic theory (i.e. algorithms) that conveniently fit a few observations in a particular place, a model can test such theory over a broader range of parameters in other locations. A need for new observations to better define specific processes is then often identified. Thence the limits of 'robustness' (i.e. the range of parameters over which the model remains valid) and 'portability' (i.e. the applicability to other geographical areas) of the model can be defined by simulation of historical data. Finally, predictions of the impact of future climate scenarios etc. can be made.

Figure 1 The modeller's dream, applied to the relationship between the concentration of some constituent A and some population B. The basic theory underlying the model (which is consistent with shelf-sea data) can be tested for other locations (i.e. oceanic areas and estuaries). Eventually, the model can be used to simulate the situation under different atmospheric change scenarios.



The POL User-Friendly, General Purpose Model (UFGP)

The North Sea Project involved some 100 scientists at more than ten locations. The POL UFGP numerical model of tidal and wind-driven flows was developed along with appropriate datasets for simulating horizontal mixing processes in the North Sea. Initially, there were many headaches in training chemists and biologists to use this model, but by the end of the project an enthusiastic modelling community had developed (with users at almost every location involved in the Project, and at many others outside).

The perceptions of the physicists as to the relevant modelling requirements to be accommodated by the UFGP were greatly expanded beyond the initial aim of simulating the seasonal cycle. In particular, simulation of vertical exchange rates proved a priority for shorter-term episodic processes, such as plankton blooms.

Training Modellers

Occasionally, established scientists migrate successfully from one discipline to another, but in the North Sea Project, it was almost invariably young researchers who provided the linking mechanism between such established scientists and the modelling support at POL. Regular attendance at interdisciplinary workshops broke down the jargon barrier between the disciplines and led to a basic understanding of respective aims and methodologies. Subsequently, extensive new observational datasets became available and these served as the springboard to 'serious' modelling since (for example) observed data on temperature and turbidity could be directly specified in the development of a nutrient-cycling module.

Given the pressures in scientific research nowadays, the mechanism described above, of training marine scientists in modelling as an *intrinsic* part of achieving specific goals, is likely to be the route adopted. For the future, some exposure to the opportunities and excitement of modelling would be a beneficial contribution to the training of all marine scientists.

Conserving Momentum

The finite life of Community Research projects is both a strength and a weakness. The North Sea Project has shown us that it is important to recognize how the availability of the extensive survey measurements (recorded in years 1 and 2) served as a catalyst to forming interdisciplinary communities in the latter

years of the Project. Scientists may promise to co-operate in funding applications, but they will only co-operate *effectively* when they see that the science that really interests them can be advanced thereby. Experience from the North Sea Project suggests that benefits that cement a community include: common comprehensive datasets, access to facilities/equipment (ships, laboratory facilities for data analyses, large computers), attendance at workshops and support and training to access new technologies. Community Research Projects can facilitate all of these and provide funds for new researchers – the unresolved problem is to provide a long-term career path for these researchers.

David Prandle

Proudman Oceanographic Laboratory

who thinks that, to encourage collaboration between modellers and observationalists, modellers should be prepared to eat more, grow beards, but ... as for going to sea

UNDERSTANDING THE NORTH SEA SYSTEM

A discussion meeting was held at the Royal Society on 4–5 November 1992 to present the results of the NERC North Sea Project. The meeting set out to consider the results in the context of previous knowledge about the North Sea, and in the light of what is known about similar shelf-sea environments elsewhere.

The presentations opened with Professor John Simpson, the Chairman of the Project Steering Committee, describing the objectives of the Project. These were to obtain a full set of data on the seasonal variation of the physical, chemical, biological and sedimentological characteristics of the southern part of the North Sea, and to use these data in the development of a suite of models leading towards a fully prognostic water-quality model. In addition, more detailed experiments were to examine specific processes so they could be parameterized as well as possible in the modelling. The basis of the field-work programme was a series of monthly cruises around a grid of over 100 stations which covered the Southern Bight of the North Sea up to 55.5° N, but with some concentration in the regions of fresh water influence close to the mouths of the major rivers, and in the area of the summer thermal front.

These cruises were interspersed with experiments to investigate specific processes. (For a summary of the thinking behind the North Sea Project, see *Ocean Challenge*, Vol. 1, Spring 1990.)

The results of the monthly cruises in terms of temperature, salinity, suspended matter, dissolved oxygen, nutrients, and phytoplankton biomass were described by John Howarth, Keith Dyer, and Ian Joint. 97 per cent of the surface temperature variance was found to be in the seasonal cycle, with the spatial variations relating to contrasts between waters off north-east England and in the German Bight. The salinity seasonal cycle was small, with spatial variation governed by changes in river input. The main feature of the suspended sediment distribution was the presence of a plume eastwards from East Anglia, the magnitude of which varied with the seasonal wind patterns. Estimation of the fluxes involved led to the conclusion that a large proportion of the sediment eroded from the English coast was exported across the North Sea. A budget for dissolved nutrients in winter showed the importance of river input, while overall the input from the sediment porewater was usually dominant. The greatest phytoplankton productivity occurred in the waters off the European continent, and production off the UK coast was only a third of that in the German Bight.

David Prandle described the results of long-term measurements of surface currents in the Dover Straits, which revealed a large residual eddy adjacent to the French coast. He also made more general points about the modelling concepts that could be used in a shelf sea such as the North Sea. Using various models he showed that some conservative elements (e.g. cadmium and zinc) are dominated by advective processes averaged over quite long time-scales, and can be treated reasonably by flushing-time concepts. On the other hand, non-conservative constituents (such as resuspended sediment or lead) require investigation using models with a short time resolution, their transport being dependent on the local vertical mixing rates.

Jurgen Sündermann presented a comparison of the observed distribution of suspended particulate matter with results from modelling and with satellite-derived data. Though there was limited resolution in the areas with higher concentrations of suspended matter, there was nevertheless encouraging agreement.

Despite many years of study, there has been a dearth of observations of the velocity fields associated with tidal fronts. Ed Hill presented measurements taken off Flamborough Head using simultaneous high-frequency radar, acoustic Doppler, drifting buoys, and undulating CTD systems. These gave unequivocal confirmation of a jet-like flow along the front, at times with significant convergence at the front. Eddy-resolving models generated very realistic simulations of the development of wave-like perturbations and eddies on the front. Following Ed's presentation, Bill Loder described similar features which have been observed over the Georges Bank off Nova Scotia. An along-front residual jet was present, and internal waves associated with the front appeared to contribute to the vertical mixing. However, due to the close proximity of deep water, complex non-linear effects were present.

One of the features of the North Sea is the presence of extensive sand waves and numerous sand banks. David Huntley examined the effect of tidal currents and waves on the frictional drag over sand waves. The average value of the drag coefficient coincided with the generally used value of 0.003, without significant enhancement during times of high waves. On the contrary, periods of high waves were associated with a decrease in the drag coefficient. David suggested that this was due to the stabilizing effect of sediment suspended by the waves. In the vicinity of the sand banks similar measurements showed drag within the expected range, but with enhancement during strong winds. Sand tracer measurements showed movement of sand around the bank, in agreement with predictions and consistent with the asymmetry of the sand waves.

Colin Jago compared the resuspension processes at three sites with different substrate characteristics and different exposures to currents and waves. At a sandy site with a mixed water column, fluxes were dominated by tidal resuspension, and little metal exchange occurred with the bed. Again, high waves were associated with a decrease in the drag coefficient, as it was apparent that the boundary layer characteristics were affected by high near-bed concentrations during storms, which tended to suppress further suspension. At a muddy site in seasonally stratified deeper water, conditions were modified by the presence of sea-bed organisms. Tidal resuspension was rare, but resulted in the addition to the water column of metals

dissolved in pore waters. There were three components in the suspended matter: a highly organic fine background fraction, a low organic resuspension fraction, and a layer of decomposed phytoplankton which formed a thin surface cover during the spring bloom and which was resuspended at low bed shear stresses. Each of these components would need consideration in a model of resuspension dynamics.

Paul Tett discussed the role of tides in controlling the distribution of phytoplankton in the southern North Sea. There are effectively three zones, with different determining mechanisms. Close to the coast, buoyant nutrient-rich river discharge has a significant effect on maximum phytoplankton biomass; in the well-mixed offshore zone, tidal resuspension of sediment limits primary productivity; and in the clearer stratified water, nutrient limitations occur during the summer.

The use of models of water-column processes in explaining planktonic ecosystems was reviewed by Gunter Radach. He showed that there is an apparent contradiction in observations that suggest that the phytoplankton abundance is insufficient to support the zooplankton. Model simulations show that the apparent gap in food availability can, theoretically at least, be met by pelagic detritus.

David Nedwell presented the results of intensive studies of fluxes across the sediment-water interface at six stations. The sediments showed significant rates of benthic mineralization, the highest rates being on the Dogger Bank and off the Dutch coast. Aerobic mineralization accounted for 47–92 per cent of the turnover of organic carbon in the sediments. This appeared to account for up to half of the organic production, and was highest in the summer stratified northerly area. Nutrient fluxes varied from site to site and with season, but were consistently into the water column for silicate and ammonium; for nitrate and phosphate, however, the direction of the flux varied. Discrepancies between the fluxes and the nutrient concentrations in the water column suggest that advective processes were important.

In addition to exchanges at the sea-bed, there are also very significant exchanges with the atmosphere. Peter Liss described the trace gas distributions made on nine of the survey cruises. A number of gases were studied, with dimethyl sulphide (DMS) being the most interesting; for DMS, the concentration was

highest in May along the Dutch–German coast. A double-tracer technique was used to estimate the transfer velocity which, together with the gas concentrations either side of the air–sea interface, enabled calculation of the sea–air fluxes. The flux of DMS was highest in spring and summer, with a maximum in June. Concentration maxima and flux maxima were not coincident, illustrating the importance of the transfer rate. It was concluded that during the summer plankton contribute up to a quarter of the sulphur in acid rain.

Roy Chester then described the atmospheric distributions of trace metals, organics and nutrients. For trace metals, the atmospheric fluxes appear to contribute substantially to the total input to the North Sea, with both wet and dry deposition being important. The dominant source of hydrocarbons is air which has recently passed over the UK, despite concentrations being greater in air from Europe. At least 25 per cent of the terrestrial inputs of nitrogen species (nitrate and ammonia) come from the atmosphere, which may be the main source in the central North Sea; in general, however, the main source of nitrogen species is the inflow from the North Atlantic. For those wishing to study inputs of constituents to surface waters, the difficulty of sampling adequately over such a wide and rapidly changing area remains a major problem.

A number of trace metals were also measured in the water. Dennis Burton showed how only nickel and copper distributions are related to salinity. For the other metals, biological or particle interaction processes (adsorption/desorption reactions) had an important influence. Examination of the plume off the Humber showed clear seasonal variations in the particle-reactive elements, manganese, iron and cobalt; their concentration in dissolved form increased during the spring and summer periods of low river flow.

The objective of the North Sea Project was to link the field observations with mathematical models of varying degrees of complexity. John Huthnance explained the philosophy of the model construction. An initial step was the setting up of a two-dimensional generalized flow model which had been widely used by the community. A three-dimensional flow model had been developed from which a number of derived parameters had been obtained. Finer grids for the models will be required for a variety of purposes. Coarser grids will need to be retained for ecological and water-quality

models. Use of the data to aid the development of models for exploring the characteristics of the North Sea, and forming the basis for prediction, will extend well beyond the North Sea Project itself. NERC is considering a special project to ensure that these developments continue and are given adequate priority. (For more about the use of modelling during the North Sea Project, see the preceding discussion by David Prandle.)

John Simpson concluded the meeting with an assessment of the success of the Project. The cruise philosophy had been proved to be sound, and a unique dataset had been obtained. These data have been compiled on a CD-ROM which is available from the British Oceanographic Data Centre. The cruises had needed an interdisciplinary team approach and this had developed a real community spirit, fostered by frequent workshops at which some very productive brain-storming had been done. The results of the work are appearing in the refereed literature and further studies are being carried out to try to answer some of the questions the Project has raised. Future research priorities are to quantify the boundary inputs from the land, sea-surface and sea-bed, to detail inter-annual variations and the influence of intermittent processes such as storms, and to investigate non-linear processes, and those problems that require an interdisciplinary approach.

In his closing remarks, John Woods congratulated all who had been involved in the Project. It was an important venture which had kept NERC at the forefront of science at a time when funding was under constant review. The results are important both nationally and as a fundamental step towards understanding complex and interesting oceanographic processes.

Keith Dyer
University of Plymouth

Some of the meeting reports which follow were submitted shortly before the previous issue went to press, but could not be included because of the lack of space resulting from the length of the report on UK Oceanography 92.

OTHER MEETING REPORTS

BIODIVERSITY IN MARINE SYSTEMS

A joint meeting between the British Ecological Society and the Challenger Society for Marine Science was held at Lancaster University on 15 December 1992; the meeting was also a contribution to SCOPE (Scientific Committee on Problems in the Environment).

Martin Angel (IOS Deacon Laboratory) opened the meeting with a discussion on oceanic pelagic diversity. He began by emphasising that the term biodiversity is so broad that it is often unclear what aspect is being discussed. He identified five levels of diversity: *genetic*, or intraspecific diversity; *physiological diversity* – the variety of physiological solutions that have evolved to solve the problems of survival in natural systems; *species diversity* – the number of species in a community or taxon; *functional diversity* – the variety of roles played by species within ecosystems; and, finally, *ecological diversity* – the variability at the community level which leads to the formation of mosaics at medium to large spatial scales.

In the pelagic oceanic environment, ecological diversity is generated by interactions between the physics of the ocean and the nutrient supplies which affect both the overall levels of productivity and its seasonality. In the open ocean, levels of total annual productivity are higher in temperate and subpolar regions than in subtropical and tropical regions.

Assessments of species richness are influenced by the sampling effort, but even so pelagic faunas appear to be well known; for example, repeated sampling at depths of 1 000 m and the identification of about 10⁴ specimens of both ostracods and decapods yielded all the expected species but not a single novelty.

Globally, species richness of pelagic communities is low but locally it may be high. Bathymetrically, it reaches a maximum at a depth of 1–5 km. Along 20° W in the north-eastern Atlantic, fish, euphausiids, decapods and ostracods all show a poleward latitudinal decline in species richness, similar to that seen in many terrestrial taxa. Regionally, maximum species richness occurs at the boundaries between different water masses, each of which tends to contain its own characteristic fauna. However, since the geographical location of these boundaries shifts seasonally, any conservation protocol based purely on species richness runs the risk of diverting attention away from the zones where the processes which underpin both local and

global processes are most active. Is this true for other ecosystems?

Tony Rice (IOS Deacon Laboratory) discussed the deep-sea benthos, asking if it really is highly diverse, and if so, why, and whether such knowledge is important. Knowledge of diversity of deep ocean benthic communities has progressed from the belief that the deep ocean is totally lifeless, through a stage in which it was thought to be uniformly monotonous, to the more recent hypothesis that the global diversity of the abyssal benthos may even exceed that of the tropical rain forests. This change has resulted from improvements both in sampling technology (e.g. the introduction of anchor dredges and box corers) and the efforts of key taxonomists (Jerry Barnard, for example, single-handedly almost doubled the numbers of described deep-sea amphipods).

Two main hypotheses emerged to explain this richness – the time-stability hypothesis in which richness increased through evolution of finer and finer niche discrimination, and the reduction of competition through predation. However, as it became recognized that deep-sea habitats are subject to disturbance at all time- and space-scales, it was realized that there is an empirical relationship between species diversity and the extent and frequency of perturbations, such that species richness reaches a maximum at intermediate levels of disturbance. Mike Rex showed that in many taxa, benthic species richness reaches a maximum at depths of 1–2 km. More recently, Fred Grassle and Nancy Maciolek have published a synthesis of macrobenthos data from 233 box cores (equivalent to just 21 m² of sea bed) sampled along the 2 000 m contour off New Jersey. They identified 90 000 individuals which they attributed to 798 species, 58 per cent of which were new to science. Each time they extended the survey by a kilometre, an additional species was encountered. Assuming this to be equivalent to adding an extra species per square kilometre, they estimated global deep-sea macrobenthic species diversity to be a staggering 10⁶ species. Although, as Tony pointed out, Grassle and Maciolek were sampling in a perturbed slope region at the depths where species richness is at a maximum, there is no escaping the fact that deep ocean benthic communities contain a richness of species which rivals that of any other ecosystem on Earth.

The third paper was given by Gordon Paterson (Natural History Museum, London) in conjunction with Peter Lamont and John Gage (both from Dunstaffnage Marine Laboratory), and Brian Bett and Mike Thurston (both from IOS Deacon Laboratory) on 'Patterns of abundance and diversity of polychaetes from the abyss'. As a contribution to an EC MAST programme, comparisons have been made between the polychaete faunas from a wide range of abyssal stations underlying dramatically different surface productivity regimes. All the sites were from depths >4 000 m and have been sampled using 0.25 m² box corers, although the comparisons have been complicated by the variations in the sorting protocols employed. Maximum abundances were observed at the highly perturbed sites – the HEBBLE site off the eastern seaboard of USA where there are frequent benthic storms, and in the Aleutian Trench where there is high seismic activity. At these highly disturbed sites a single family dominated the community, whereas at the quieter sites abundances were low and more evenly distributed between the various families. When comparisons were made between the taxonomic composition of the species sampled in four cores from the Tagus Abyssal Plain off Portugal their diversities proved to be similar but their species composition quite dissimilar. When data from a single core from the Porcupine Sea Bight was added in, it nested within the dendrogram for the Tagus Abyssal Plain samples. Thus the degree of similarity between cores remained the same even though the scale of sampling had been increased from a few tens of kilometres to over a thousand. The species pool must be distributed over a very wide area, but neither the scale over which the pool remains the same nor the rate at which it turns over is known.

John Lamshead (Natural History Museum, London) gave a joint paper with Guy Boucher (Musée Nationale d'Histoire naturelle, Paris) on 'The biodiversity of marine nematodes: a comparison of temperate, tropical and deep-sea regions'. Nematodes are not only as diverse as any other metazoan group, but also numerically account for about 80 per cent of *all* metazoans (virtually all the rest are beetles!). They can attain abundances of up to 10⁷ per square metre. According to their reproductive biology each species should have a very limited distributional range, but many appear to be cosmopolitan. The authors have analysed data

from over 200 samples involving more than 500 taxa and have assumed a uniform taxonomy. The localities sampled ranged from estuaries, to tropical, subtropical and temperate littoral and sub-littoral habitats, to upper and mid-slope regions; they also included a trench locality. Rarefaction curves were used to compare the varying relationships between numbers of species and sample size. Samples collected from the San Diego Trough and the Rockall Trough had curves with overlapping ranges, although the Rockall communities were rather less diverse. The trench community had an even lower diversity. Some of the results are unexpected; for example, in the estuarine samples diversity is not correlated with grain size. Comparisons of the ranges of the rarefaction curves (a way of assessing the number of types of community in each habitat type) showed that tropical communities are extremely varied relative to temperate littoral and sublittoral communities which are fairly similar. The deep-sea communities have a limited range, especially if the data for the trench are omitted. When other measures of diversity are used, the ranges have quite different relationships. In contrast, estimates of equitability look universally similar. Dr Lamshead drew three conclusions: (1) the tests are inadequate, (2) the textbook story is wrong, and (3) the processes that determine what the communities are remain to be elucidated.

Rony Huys (Natural History Museum, London) then discussed 'Large-scale community structure and latitudinal trends in biomass and diversity of North Sea meiobenthic copepods'. Ten years ago, the North Sea Working Group was set up to organize a complete survey of the meiobenthos of the North Sea (the macrobenthos had previously been quite thoroughly studied, but the data for meiobenthos were very sparse). The area covered by the survey stretched from the Dover Straits to the 100 m depth contour in the north. Institutes from five nations collaborated, each studying a different area, and methods were standardized by inter-calibration. It was found that, generally, nematodes are dominant north of 53.5° N, whereas the interstitial harpacticoids are dominant in the sandier sediments to the south. Copepod diversity decreases northwards into the Norwegian Deep. Overall, the nematode/copepod ratio (suggested by Raffaelli and Hall to be a measure of pollution inshore) turned out to be more a measure of habitat than of

pollution, since the ratio was lowest in the southern North Sea. The latitudinal trends were for the Shannon diversity index (*H'*) to decrease and individual weight to increase from south to north.

Various approaches to analysing the data by cluster analysis were tried. In some, the clusters (although determined largely by rare species) revealed five regions inhabited by 'communities' each with a characteristic composition at family level. Further analyses succeeded in relating the distributions of these communities to environmental variables. Not only do the densities and biomasses of the faunas vary geographically but there are also strong parallel responses in the composition of the communities at higher taxonomic levels. Feeding strategies appear to be the dominant interacting influence related to environmental variables such as sediment grain size. Perhaps one of the more sobering statistics was that 45 % of the species found were new to science, even though the North Sea had previously been the most intensively studied coastal sea area.

Continuing on the theme of shallow environments, John Taylor discussed 'Trophic diversity in coral reef environments'. Using a Coastal Zone Color Scanner image of the Indian and Pacific Oceans, John emphasized the variability of tropical coastal regions, which results from broad differences in nutrient regimes and availability. As nutrients become more available, the communities shift from dominance by coral reefs, to being dominated by littoral algae and then by phytoplankton. John discussed the changes seen in predatory gastropods when moving from oligotrophic (nutrient-poor) to eutrophic (nutrient-rich) environments. Some of the species are highly specialized – for example, some species of the Coniidae eat fish, other gastropods eat holothurians, and species of one genus eat only chaetopterid worms. A reef near the marine station at Guam was home for eight common gastropods, one a specialist predator of sipunculans, five predators of the small gastropods which graze the algal turf, and two others predators of polychaetes; none ate bivalves or barnacles. Evidence from a number of food-webs shows that on such oligotrophic reefs there are many specialist feeders but few generalists.

The coastal waters of Hong Kong are highly eutrophic, with phytoplankton dominating the production cycle, and there is a depth succession in the sub-foodwebs. In the littoral region, the shores are covered with a great diversity

of barnacles and bivalves which are preyed upon by the only two species of gastropods. In deeper water, the food-webs are complex with many more cross-links, and most gastropods feeding upon suspension-feeding or detritivorous prey. Time-series observations off Hong Kong show that substantial changes can occur in the extent to which one or more species dominate, dramatic collapses in the community structure being associated with major storm events which lead to heavy fresh-water run-off.

It has been predicted that generalist genera and families will be species-poor and have low rates of speciation and extinction, whereas those which are specialist-feeders will be rich in species and have high rates of both speciation and extinction. These predictions appear to be fulfilled in the comparison between the genera *Conus* and *Babylonia*. The former has 600 extant species all of which tend to be specialists, and shows a very high turn-over of species in the geological record. *Babylonia*, a genus of generalists which first appeared in the fossil record during the Eocene, has never been very diverse and has shown little change in its numbers of species since the Miocene.

Rupert Ormond then presented his paper on 'Processes in reef fish biodiversity: a resolution?' Reefs with their great diversity of fishes present a greater variety of vertebrates than any other habitat. There are two main hypotheses to explain this diversity:

Resource partitioning: communities are predictably structured, resource partitioning allows coexistence, and the partitioning increases over time.

Lottery effect: there is high variability in larval recruitment which at times leaves vacant niches and so reduces interspecific competition.

The existence of resource partitioning is supported by the close similarity in species composition between different large patch reefs. Also some families, such as the Holocentridae, show clear partitioning both in resource-utilisation and spatially. Conversely, the lottery hypothesis is supported by the low similarities exhibited by apparently otherwise similar small patch reefs (10-m scales), and by the differences in the colonization of small artificial reefs and species removal. In the pomacentrids, recruitment is stochastic.

In the Red Sea observations show that predation often involves highly

specific behaviour (e.g. in the serranids). There is a clear zonation of species over the reef (e.g. in pomacentrids). In some families (e.g. pomacentrids and chaetodontids), there is a clear north/south segregation of species, which is clearly non-random. There is resource-partitioning in spawning sites in pomacentrids. Moreover, in the northern region of the Red Sea, comparison between large areas of reef show high levels of similarity.

Along these northern fringing reefs the reported low similarities observed between small patch reefs was critically examined. Sections of reef 200 m long were each surveyed for 150 minutes. After this initial survey less than one additional species was added per 10 minutes of further surveying. The between-reef similarities proved to be much higher, which could either be the result of examining larger areas of reef, or of the more enclosed nature of the region. It became clear that abundant species showed a higher degree of similarity and predictability between reefs, whereas rarer species were less predictable and showed low inter-reef similarity.

The final paper by Antony Jensen, Ken Collins and Peter Lockwood on 'Artificial reefs: a tool for managing biodiversity' was delivered by Ken Collins. Artificial reefs are widely used to enhance local fisheries. They range in construction from simple opportunistic materials to massive and complex structures. In Japan an artificial reef programme has been supported by a budget of 480 billion yen over the last five years. The artificial structures can provide new habitats, restore damaged habitats or protect existing ones.

Habitat creation has for the most part been the provision of hard substrates in regions where formerly there were none, as in the case of culch laying for shellfish culture. An experimental reef in Poole harbour has attracted in 250 species where formerly there were only about 100 (infaunal) species. Epibiota settling on the reef provide food for a range of predatory species including lobsters (see *Ocean Challenge*, Autumn/Winter 1991).

An example of habitat restoration occurred off Kerala in southern India, where development aid had funded a commercial trawl fishery at the expense of the local inshore artisanal fishery. Artificial reefs are being used not only to improve habitat diversity and so restore catches, but also to deter the trawlers.

Off Loano (north-west Italy) massive 1.5-m concrete blocks have been used to 'police' an area of *Posidonia* sea-grass and so protect the nursery grounds for the local commercial fish stocks.

Martin Angel
IOS Deacon Laboratory

RESEARCH MEETING MARINE GEOLOGY AND GEOPHYSICS

The first meeting of those involved in 'Postgraduate Research in Progress in Marine Geology and Geophysics', organized by the Marine Studies Group of the Geological Society, was held on 24 February, 1993, at Burlington House, London. The main aim of the day was to provide marine research students from a variety of fields with an opportunity to meet and talk on their recent work, in a way that British Sedimentological Research Group meetings and conferences of their ilk, do not afford.

Opening the meeting, Dr Ernie Hailwood (Southampton) commented that Britain's marine geoscience community is widespread both geographically and in terms of specialist knowledge. This was reflected in the range of talks given by postgraduate researchers.

In a lively opening talk, Gerard O'Sullivan (Cardiff) discussed the sediments of the Japan Sea, concentrating on the cyclical sedimentation of organic-rich layers found in ODP cores. Following, Ian Brodie (Southampton) discussed the sediments under the Peruvian upwelling system, commenting on the use of backscatter electron microscopy to study these finely laminated sediments. Leo Dodd (Bangor) described a geotechnical case study involving sediments from the Var submarine canyon, France, and outlined her ideas as to why a large sediment failure – which had caused freak waves and fatalities – had occurred. Moving nearer shore, the next contribution by Jonathan Thomas (Cardiff) concerned his shallow seismic work in South Wales, and the evolution of the channel systems in the Burry Inlet.

Two magnetostratigraphy talks completed the session, with Guy Rhodes (Southampton) tying in his work on the North American seaboard with research already completed on north-west Europe. Paul Montgomery (Southampton) proposed a magnetic stratigraphy for the Cretaceous chalk of the Isle of Wight and

attempted to use this to calibrate the chalk–flint–chalk cycles found on the Island.

After a BP-sponsored lunch and a poster session, the afternoon started with Tim Rodgers (Imperial) talking about his geochemical work on ferromanganese crusts from the southern Pacific; Tim suggested that his future work will correlate chemical variations in these crusts to basin rock geochemistry. David Maddison (Cardiff) and Kate Lawson (Durham) presented *TOBI* data from two consecutive *Darwin* cruises. David's work centred around the channels found on the Saharan continental rise and their relationships with the turbidites found in that area. Kate concentrated on her research on the Kane Fracture Zone, where her geochemical studies are being used in an attempt to distinguish between the different volcano morphologies seen by *TOBI*.

The last batch of papers considered geophysical work from around the globe. Amanda Lothian (Birmingham) described her work in the area of the Chile Triple Junction and the Louisville Seamount, comparing the effects of ridge subduction on fore-arcs and the effect sedimentation processes have on tectonics. Rosemary Edwards (Durham) presented data recorded off the coast of Ghana, where her seismics, gravity and magnetics work revealed a complex, previously unknown trend in the margin. Finally, Tim Henstock (Cambridge) discussed his work with BIRPS in producing an integrated database from which it is possible to examine oceanic crustal structure in a region of the Cape Verde Abyssal Plain.

Summing up, Dr Hailwood thanked the contributors and congratulated them on the excellent quality of presentation and content. He suggested that a number of supervisors might take leaves from their books!

Although the meeting was successful, the rather smaller than expected turnout detracted from what could have been an excellent open discussion. Nevertheless, it was hoped that a 1994 meeting would take place and be as interesting and of as high a quality as this year's.

Paul Wright

Anyone interested in joining the Marine Geosciences Research Group should contact Professor Robert Kidd at the Department of Geology, University of Wales College of Cardiff, PO Box 914, Cardiff CF1 3YE.

CHANGES IN FLUXES IN ESTUARIES A JOINT ECSA/ERD CONFERENCE

Last autumn, at the recently established Plymouth University (formerly Polytechnic South West), almost 300 scientists from 20 nations attended the first international conference to be jointly organized by ECSA – the Estuarine and Coastal Sciences Association – and ERF – the Estuarine Research Federation. The meeting was organized in such a way that hard science was addressed first, to be followed by its application and use in specific locations and predictive models. The discussions culminated in a consideration of management strategies. A poster session was also included in the meeting.

Such was the number of presentations that parallel sessions were operated, generally following the daily keynote presentation. The theme for individual sessions included fluxes and residence times, particle–water interactions, estuarine eutrophication, microbial transformations, responses to toxicants, storm events, estuarine management, changes in river inputs, larval recruitment, estuarine modelling and tropical systems. A high proportion of the presentations originated from North America, but there was also a strong representation from continental Europe, notably Denmark. The standard of the presentations was consistently high, and the meeting was extremely successful not only for the exchange of ideas and information but also for establishing links between groups of scientists and individuals.

Phil Balls
SOAFD, Aberdeen

FIFTY YEARS OF SCIENCE AT WORMLEY

This meeting was held in King Edward's School, Wormley, on 4 June, 1993.

For the first few years of its existence as a site of scientific endeavour, Wormley (confusingly known as Witley, after another village a mile to the north), housed the Admiralty's radar research establishment, which accounts for some of the peculiar architectural features of the original building. Nevertheless, this event was of primarily oceanographic interest, being the fortieth anniversary of the transfer to a single site (left vacant by the radar scientists' departure after the war) of the National Institute of Oceanography, which had been formed in 1949 by a merger between Group W (for Waves) of the Admiralty Research

Laboratory and the scientific staff of the *Discovery* Investigations. There followed reorganization under NERC in 1965 and the subsequent combining of NIO, the Institute of Coastal Oceanography and Tides (Bidston) and the Unit for Coastal Sedimentation (Taunton) in 1973 to form a three-centre Institute of Oceanographic Sciences, from which emerged the present IOS Deacon Laboratory in 1987.

1993 provides a significant juncture at which to review forty years of oceanography at Wormley, in view of the forthcoming move to Southampton in less than two years' time. This prospect might have led to a premature wake, but in fact the occasion was one in which nostalgia mingled with pride. Nostalgia for the relatively unfettered days of NIO in the Deacon era, when staff could apparently follow their own instincts in an atmosphere more tolerant of open-ended research than today's more stressful climate, and before the increasing bureaucracy that came with reorganizations, bigger science and the safety culture, not to mention the ongoing and seemingly endless financial stringencies of recent years; pride in the many successes achieved under both types of regime.

Looking ahead, there were mixed feelings of excitement and apprehension about the uncharted waters beyond 1995, when IOS Deacon Laboratory ceases to exist as such and becomes part of the Centre for Deep-Sea Oceanography at Southampton, sharing major new facilities with the University's departments of Geology and Oceanography. Although there are bound to be personal costs in the shape of upheaval and uncertainty about future terms of employment, the long-term benefits should be great. Proximity to research vessels and, indeed, to the sea itself; the intellectual synergisms to be expected from a mixed culture of teaching and research; a wider range of youth and experience and the increased mobility that goes with it – all these should secure for UK deep-sea oceanography a future in which the existing multidisciplinary blend of field scientists, engineers and theoreticians makes an increasingly valuable contribution to our understanding of the oceans and their relevance to human concerns.

John Phillips
The Open University

Articles based on papers presented at this meeting will appear in a future issue of *Ocean Challenge*.

Letter from Lord Rennell of Rodd

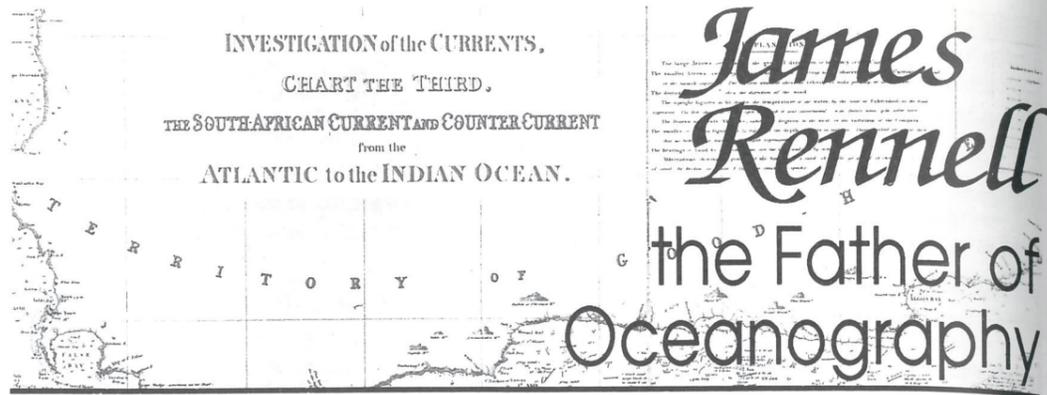
Major James Rennell FRS might have remained one of my lesser known ancestors were it not for a telephone call from Dr John Woods in January 1991. Until then, my upbringing had led me to consider Captain James Stirling, the leader of the first non-penal colony in Australia, as my most distinguished ancestors of the period in question. The telephone call seeking permission to name a new NERC centre the 'James Rennell Centre for Ocean Circulation' brought with it a new perspective. However, my grandfather, a scholar, poet and diplomat, had been well aware of the significance of the Rennell connection to our family as it was he who took the title Baron 'Rennell' of Rodd. It was Jane, James Rennell's daughter, who first united Rennell and Rodd, through her marriage to Tremayne Rodd in 1809.

The occasion of the Challenger Society meeting on James Rennell was a delight to my wife, my son James and me. It was both educational and enjoyable, and those attending were so enthusiastic about the subject. I imagine James Rennell would have been quietly delighted with the gathering of scientists and historians that honoured his contribution to the study of ocean circulation. Their approach to gathering high-quality data echoed his scientific method, and there was a deep sense of continuity – as shown by the papers in this issue – that impressed my family.

The articles which follow are based on talks given at a meeting entitled 'James Rennell and his place in ocean–atmosphere circulation studies', held jointly by the Royal Meteorological Society Specialist Group on the History of Meteorology and Oceanography. The meeting was held at the University of Southampton in March 1992, and was organized by Tony Rice and Margaret Deacon.

As the articles are on a theme, there is obviously a small amount of overlap between them. To minimize repetition, maps that are used to by a more than one author are reproduced in only one article, and referred to elsewhere by the appropriate page number.

To provide a context, we begin this group of papers with a modified version of 'James Rennell: the Father of Oceanography' by Raymond Pollard and Gwyn Griffiths, which appeared in an earlier Volume of *Ocean Challenge*.



Raymond Pollard and Gwyn Griffiths

In the spring of 1990 the Natural Environment Research Council announced that the James Rennell Centre for Ocean Circulation was to be established at Southampton. The Centre was named after Major James Rennell FRS who, 200 years ago, conducted pioneering work on ocean circulation.

Rennell was born in 1742 in Chudleigh, near Exeter, and showed his skill as a cartographer while still at school (a copy of his school-boy map of Chudleigh is in the archives of the Royal Geographical Society). Soon after his 14th birthday, he joined the Navy as a 'captain's servant', and for the next seven years he sailed the world, saw active service, and learnt his art as a surveyor – mapping coasts and harbours even in the midst of battle. So strong was his talent that, after leaving the Navy, he was appointed Surveyor-General of Bengal by the East India Company. The year was 1767, and Rennell was only 24 years old!

During the next 13 years, under Lord Clive and other Governors, Rennell surveyed and mapped Bengal, rising to the rank of Major by 1776. The period was not without accident. In 1766, his career was nearly terminated by a severe sabre-cut which he received in a fight with a fanatical tribe. He recovered, but his health was permanently impaired. In 1772 he married Jane Thackeray (aunt of the great novelist), with whom he found happiness for nearly 40 years until her death in 1810.

In 1777, when the Bengal survey had been completed, Rennell and his wife sailed for home from Calcutta, arriving in Portsmouth in February 1778. During the long voyage round the Cape of Good Hope, he mapped "the banks and currents at the Lagullas"; his daughter Jane was born in October 1777 during a stopover at St Helena. Rennell's map and memoir on the Agulhas Current (as it is now known) was first published in 1778. In 1895, Rennell's biographer, Clements Markham (then President of the Royal Geographical Society), wrote that this memoir was the "very first contribution to the science of oceanography", and that Rennell "was the founder of oceanography: the branch of geographical science which deals with the ocean, its winds and currents".

During the next 50 years, until his death in 1830, Rennell was the leading geographer in England, if not in Europe. He was elected a Fellow of the Royal Society in 1781, and became a great friend of its President, Sir Joseph Banks. In 1791, he received the prestigious Copley medal. Four years later, he was offered the new post of Hydrographer of the Admiralty, but he declined it to continue his academic research and the post was accepted by Alexander Dalrymple, another great friend and colleague of Rennell.

In 1810, at the age of 68, Rennell returned to his hydrographic work, and it was to occupy him for the last twenty years of his life. He was before all things a sailor, and his numerous naval friends furnished him with a great mass of data from their logs and notebooks, which he sifted and assimilated in order to chart the currents of the Atlantic Ocean. As Rennell himself pointed out, the work could not have been undertaken earlier because until the invention of the chronometer (in the middle of the previous century) it had not been possible to determine longitude at all accurately, and accuracy was essential so that current drift could be inferred from the offset between dead-reckoned and observed ship positions. In 1822, while writing his chapter on the Gulf Stream, Rennell recognized that "The want of simultaneous observations is an incurable defect" – even today, many oceanographers would agree with him. In an attempt to secure data from sources other than British vessels, in 1819 he asked Sir Joseph Banks to approach US sources for data from ships' logs. As no mention is made of such American data one concludes that the attempt was unsuccessful.

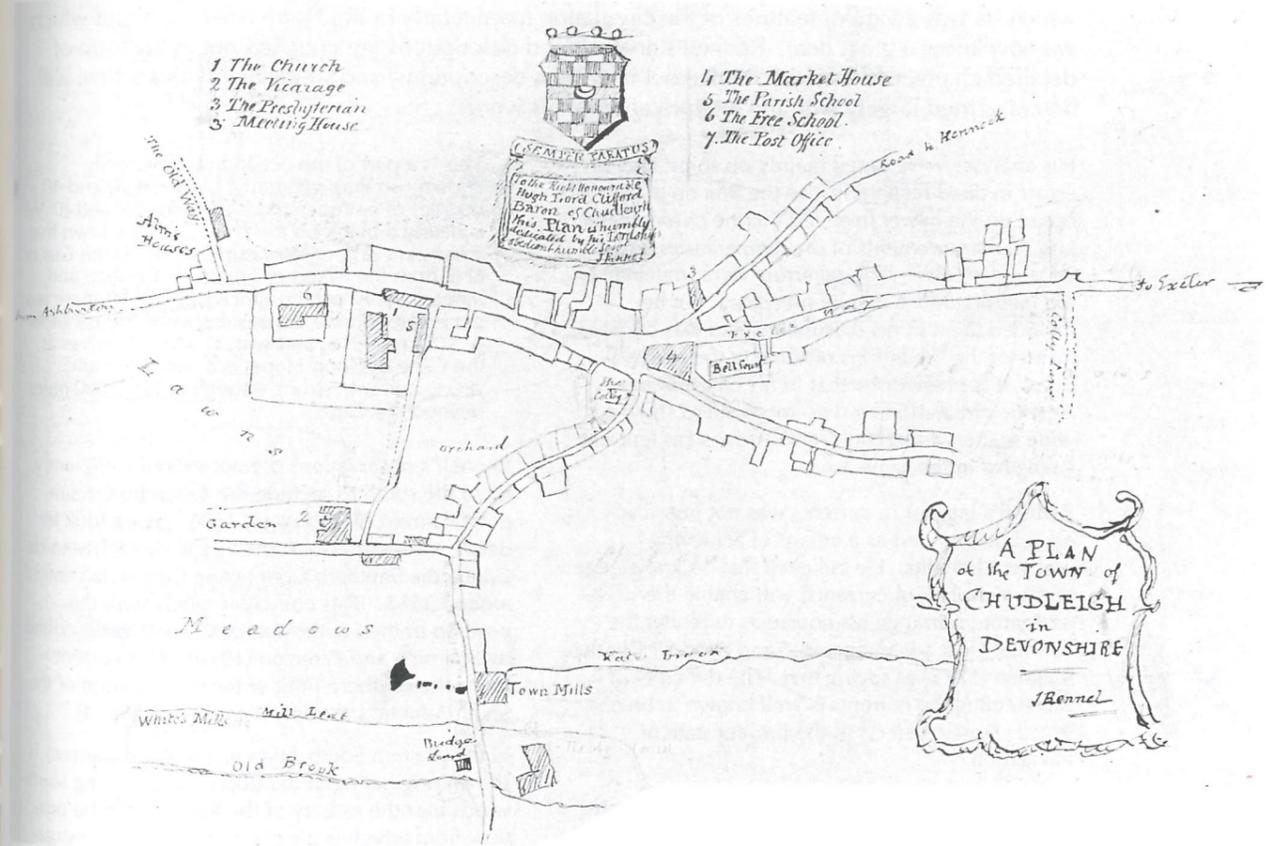
Rennell looked upon the Gulf Stream as being in the nature of an immense river descending from a higher level onto a plain. The idea was adopted and amplified by Maury in his *Physical Geography of the Sea*, but the original idea was Rennell's; it is

described in his final work, *Currents of the Atlantic Ocean*, published posthumously by his daughter Jane in 1832 (the Index Map is reproduced on p.27). He noted the meandering of the Gulf Stream and discussed the formation of large eddies with cold cores, noting that the Stream "divides into branches, which have cold water between them".

Richardson, writing in *Oceanography: The Past* in 1980, and describing the Gulf Stream charts of Franklin and Folger (p.42), states that "The next two significant improvements in charting in the Gulf Stream were by Rennell (1832) and Iselin (1936)". It is surely a tribute to Rennell that his work was not significantly overtaken for more than a century. Indeed, his application of scientific method to geography and hydrography was perhaps his greatest service to those fields. Rennell carefully examined and sifted all data and theories, and discarded either when unsupported. In consequence, his data were accurate, his methods logical and his conclusions were right "in almost every instance".

In addition to Jane, Rennell had two sons, but both died childless. In 1809, Jane married Captain Rodd, later Vice-Admiral Sir John Tremayne Rodd KCB. The Rennell name has continued in the Rodd family, and Jane's first son was named James Rennell Rodd. In 1933, Rennell's direct descendant, a poet and diplomat, took the title Lord Rennell of Rodd when he was raised to the peerage. The present incumbent is the third Lord Rennell.

It was the informal meetings of geographers and scientists that took place regularly in the houses of Rennell and his friends between 1780 and 1830 that led to the formation, two months after Rennell's death, of the Royal Geographical Society. The Society received the patronage of King William IV, to whom Jane Rodd dedicated Rennell's final book. The book's opening statement, that "the winds are to be regarded as the prime movers of the currents of the ocean" remains unchallenged to this day.



From small beginnings ...
Rennell's school-boy map of Chudleigh
(By courtesy of the Royal Geographical Society)

Raymond Pollard is the Head of the James Rennell Centre for Ocean Circulation; Gwyn Griffiths was head of the Rennell Centre Survey Team and now leads the Ocean Instrumentation Team of IOS Deacon Laboratory. The James Rennell Centre was set up in 1991 to act as a focus for UK contributions to the World Ocean Circulation Experiment and was opened by Lord Rennell of Rodd in February of that year.

James Rennell's View of the ATLANTIC CIRCULATION

A comparison with our present knowledge

John Gould

James Rennell's book, published in 1832, was for many years the definitive treatise on the circulation of the Atlantic Ocean, and the North Atlantic in particular. Subsequent publications such as that by Matthew Fontaine Maury (1855) added little to what Rennell already knew and indeed one might say that Maury's treatment of the subject was much less scientific than Rennell's. Given the quality of Rennell's work it is therefore worthwhile to try to see the extent to which he was aware of features of the circulation (particularly in the North Atlantic) about which we now know a great deal. Rennell's analysis and descriptions are couched not in the form of detailed charts, tables and formulae but in written descriptions, and so inevitably this article will be concerned largely with the interpretation of his words.

His analyses were based mainly on ships' logs of errors in dead-reckoning (see the Box on p.38) based on the newly invented marine chronometer, and on measurements of sea temperatures. To a large extent observational errors were irrelevant to the interpretations that he presented, but he included them in his discussions and was clearly aware of the limitations of some of the observations. It is noteworthy that in his charts of the Atlantic circulation he was not afraid to show a wide scatter of directions and arrow sizes (current strengths) in the same area.

Rennell's interest in currents was not just academic but intended as a means of achieving practical benefits. He believed that "A knowledge of the truth [about currents] will enable the navigator to arrange his course as to render the currents most advantageous," and cited Sir Charles Blagden (1778) as saying that "The difficulty of ascertaining the currents is well known to be one of the greatest defects in the present state of navigation."

Currents of the South and Equatorial Atlantic
Rennell's overall view of the Atlantic currents (Figure 1) is seen to contain many of the features with which we are familiar today. In the south, we have off South Africa an Agulhas Current that was the subject of a specific study and chart by Rennell. West of the Agulhas and crossing the South Atlantic is what Rennell refers to as the "Southern Connecting Current". Rennell stated that the area was poorly surveyed:

This is a part of the ocean but imperfectly known; so that, generally, between 30 and 40 degrees of latitude, and longitudes 25° and 40° W is nearly a blank on the chart ... It is known that a constant drift or slow current runs to the East or ENE from the island of Tristan da Cunha; and, indeed, every circumstance proves that there is a general motion to the east between the parallels of 30° and 40° S, and which, when it arrives at the Cape of Good Hope, is a very wide and strong current; strong enough to run 2 000 miles beyond the Cape.

Rennell's observations did not extend sufficiently far to the south to include the Antarctic Circumpolar Current (Webb *et al.*, 1991). If we look in detail, we see that near the longitude of Tristan da Cunha the Southern Connecting Current is centred around 35° S. This coincides nicely with the position of the South Atlantic Current as described by Stramma and Peterson (1990). This current forms the southern limit of the recirculation of the South Atlantic subtropical gyre (cf. Figure 4).

In the western South Atlantic, the Brazil current is shown originating in the tropics and flowing southwards past the estuary of the River Plate, the outflow from which is clearly marked. An investigation of modern views of the circulation in the area (Reid, 1989) shows that the region of Rennell's offshore flow from the River Plate coincides with the offshore flow formed by the confluence of the southward-flowing Brazil Current and the northward-flowing Falklands Current. Could it be that it is this confluence that Rennell confuses with the water from the River Plate?

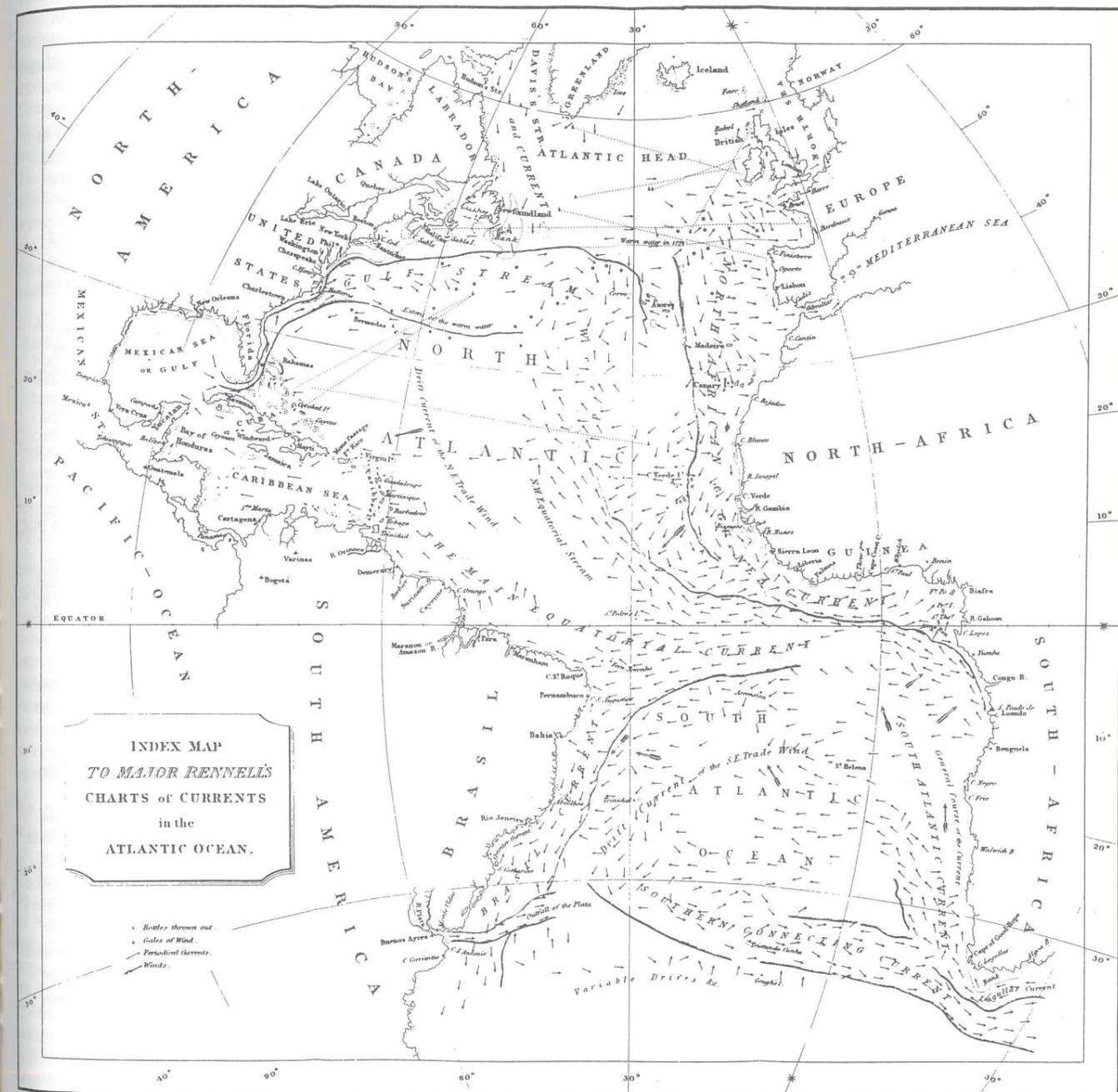


Figure 1 Index Map to Rennell's Charts of the Currents of the Atlantic Ocean, published in 1832. The outflow from the River Plate can be seen to the south of Brazil, at about 60° W; Tristan da Cunha is at about 10° W in the Southern Connecting Current.

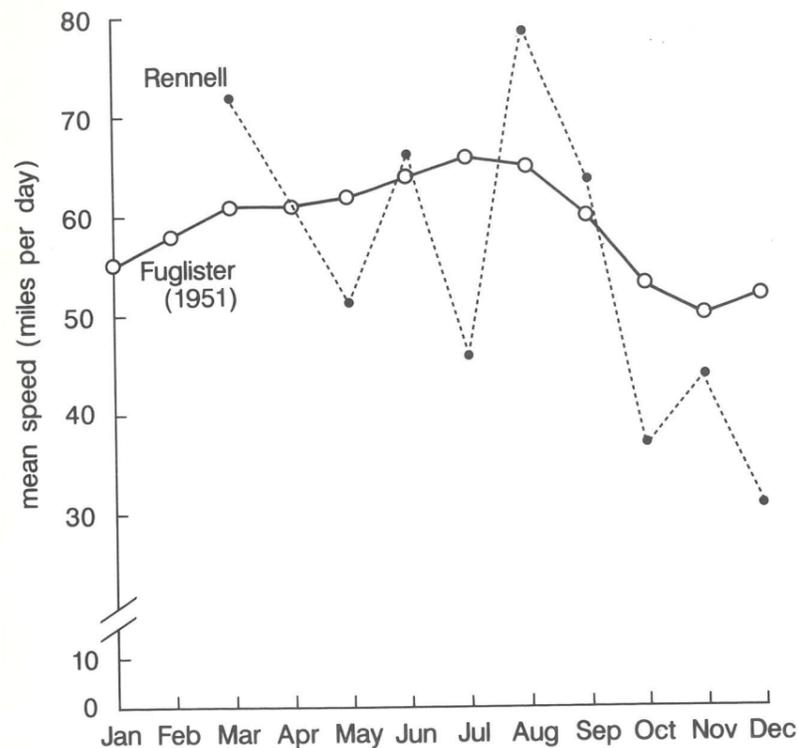
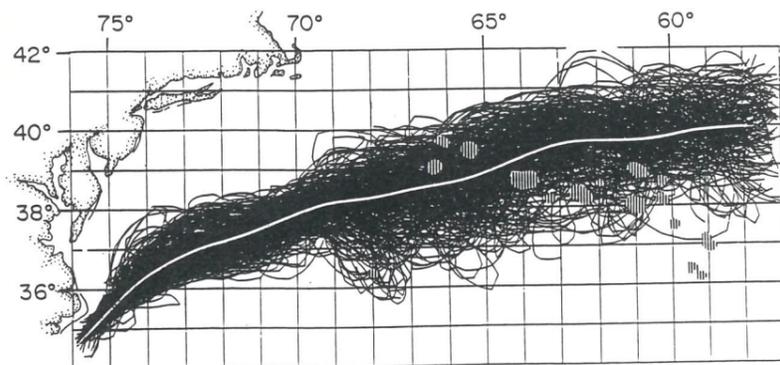


Figure 2 Comparison of Rennell's measurements of speeds in the Florida Current with those of Fuglister (1951). (Values plotted are monthly means.)

Surprisingly, in Rennell's book the outflow from the Amazon is not shown. However, as Gwyn Griffiths has pointed out, an early manuscript version of the chart does show it with the caption "Supposed current of the Amazon".

As we turn our attention to the equatorial and North Atlantic we see a westward-flowing equatorial system curving northwards into what we now refer to as the Guiana Current (all of this is referred to by Rennell as the Main Equatorial Current). Inputs to the Caribbean are shown through the Windward Islands and, although the Caribbean and Gulf of Mexico circulations are not illustrated,

Figure 3 Northern edges of the Gulf Stream from 2.5 years of satellite imagery. The white line is the mean position and the grey areas show the positions of seamounts. (From Cornillon, 1985)



a closely confined Florida Current is shown heading northwards at the start of the Gulf Stream.

The Florida Current and Gulf Stream

The Florida Current is perhaps the only place in which we can make a quantitative comparison between modern measurements and Rennell's data. Included in his book is a summary of ship-drift observations (a measure of surface current - see the Box on p.38) in the Florida Current. In Figure 2 we see the means of Rennell's monthly observations overlain on data reported by Fuglister (1951). Clearly one would prefer to make comparisons with more modern and comprehensive measurements but these are usually presented in terms of volume transports and so provide a less meaningful comparison than Fuglister's surface velocity observations.

The overall agreement is surprisingly good and, furthermore, Rennell sees the highest speeds in summer and the lowest around October-December, which is consistent with our view of the seasonality of the Florida Current. Elsewhere, Rennell comments particularly that the Stream reaches its maximum between June and September.

The separation of the Stream from the coast at Cape Hatteras is well documented in Rennell's book:

At Cape Hatteras, the coast falls back suddenly from the N.E. to the westward of north. The western border of the Stream ... expands on that side, and takes a more northerly direction, whilst the main body continues in its former course. When first turned off, the central part of the stream takes a direct eastwardly course, and finally to the southward of east, at the same time expanding to a great width.¹

¹ There is no portion of the Gulf-Stream less known, which ought to have been better known, than that between Cape Hatteras and the banks of New York and St George.

Rennell's description of the Gulf Stream is extensive and detailed. Much of his description is based on the results from many transects across the Stream that are well documented, and include a set of 17 by a Captain Tozer between Bermuda and Halifax, Nova Scotia, over a three-year period. Pages 234-7 of Rennell's book provide a summary of his major conclusions concerning the Gulf Stream and many of these conclusions can be seen to refer to features that we now recognize, even if Rennell's interpretation (based on relatively few observations) is at odds with present thinking.

Rennell states that variability of Gulf Stream position seen in repeated transects between 63° and 72° W shows that the northern limit varies by 1.5° of latitude and the southern by 2.5° of latitude. Figure 3 (from Cornillon, 1985) shows positions of the Gulf Stream Front accumulated over a two-and-a-half year period; a similar picture is given by Niiler and Robinson (1967). These modern studies bear out Rennell's conjecture with considerable accuracy. (Captain Tozer reported that only in one case was there easterly flow north of 41° N and in no cases any south of

37° N; the most rapid part of the current was between 38° and 39° N. This latter observation is well in accordance with the modern view of the Gulf Stream in the vicinity of 63° W.)

Gulf Stream variability is due to the presence of meanders now routinely monitored by satellite imagery but not resolvable by the observations of Rennell's time. We are now familiar with the meandering of the Gulf Stream and the frequent formation of cold- and warm-core rings by the pinching off of meanders and the trapping of water from north and south of the stream (The Ring Group, 1981). The cold-core rings enter the Sargasso Sea, are advected in a generally south-westward direction and ultimately coalesce with the Stream. Rennell provided abundant evidence of intrusions of cold water into the main body of warmer waters of the Gulf Stream and Sargasso Sea, most particularly through his temperature descriptions based on repeated sections. For example, he writes:

A circumstance occurred in the course of this traverse which deserves notice. After Mr Napier had advanced northward 36 miles through Gulf water of 70° to 71° of temperature, (i.e. 7° or 8° above ocean temperature), he came into water of 66° and 67°, and which continued 32 miles, onward to 38° 48', where the temperature again increased to 71° to 72°, until he arrived at lat. 40° 12'.

This can easily be interpreted as a description of the crossing of a cold-core eddy.

Rennell gives no detailed discussion of the connection between water temperature and the position of the current, and he clearly was not aware of the existence of frontal boundaries. This latter point is perhaps surprising in that we now know that frontal boundaries are often marked by the accumulation of flotsam, and such a phenomenon would be easily observed from a slow-moving sailing ship, as indeed would the local current shear across the front.

The stream eastward of Cape Hatteras is described as a broad warm current that heads towards the Azores but is also transferring warm water towards the Bay of Biscay. This is somewhat at odds with the present-day view that the Gulf Stream becomes the North Atlantic Current or Drift, flowing north-eastwards towards north-west Europe and the Arctic, with a recirculation around the Sargasso Sea (Figure 4). This scheme, following Krauss (1986) has only a relatively small branch heading towards the Azores, which ultimately crosses the Mid-Atlantic Ridge and forms the Azores Current. Rennell is persistent in his description of the main course of the Gulf Stream as being towards the Azores.

One can readily explain Rennell's lack of description of the North Atlantic Current in terms of the small number of ship observations that would have been available to him from the area between the Grand Banks of Newfoundland and the region north of Britain where the North Atlantic Current heads towards the Norwegian Sea. The 1950

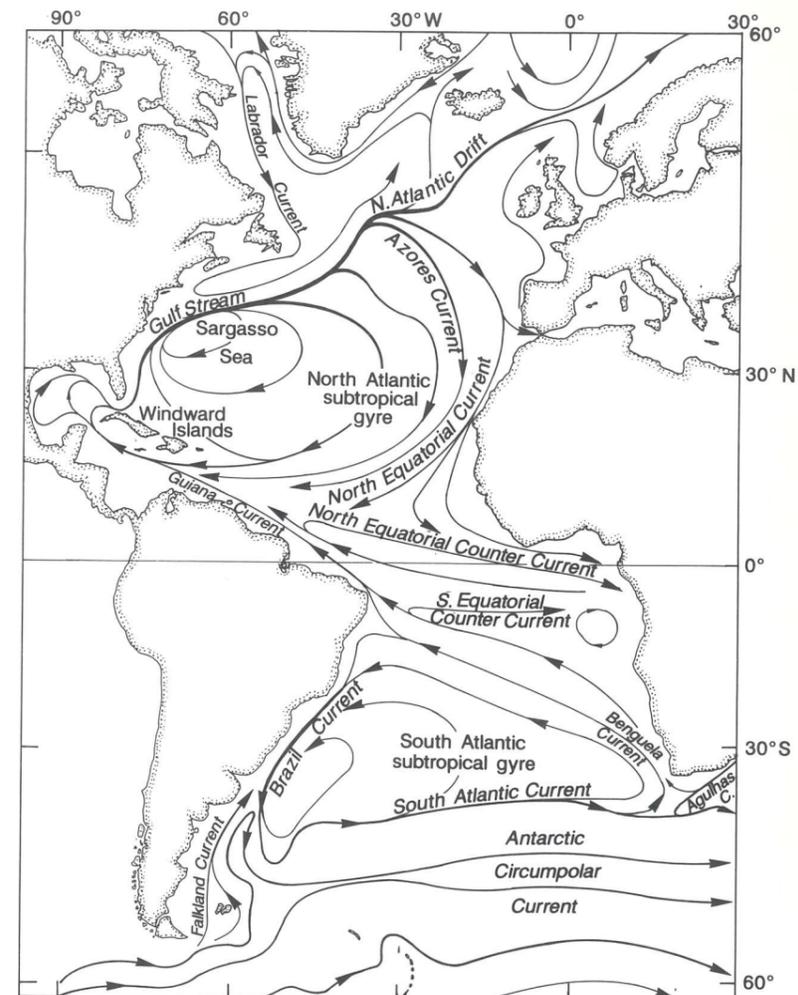


Figure 4 Schematic representation of the Atlantic current system. The North Atlantic subtropical gyre, and currents in high northern latitudes are taken from Krauss (1986), and currents in the South Atlantic are taken from Stramma and Peterson (1990).

Admiralty sailing instructions (Figure 5, overleaf) show the recommended routes for sailing ships on trans-Atlantic crossings. As it is unlikely that the recommended passages for sailing ships would have changed since Rennell's time, the map suggests that there would have been almost no observations north of a line between the south-west tip of Ireland and the Flemish Cap. As Rennell himself wrote: "Materials are wanting for the filling up of one large proportion of this great extent of course; nor is it surprising considering the vastness of the whole." Rennell comments on the tracks of drift bottles and wrecks which he suggests demonstrate that water from the north of the Gulf Stream continues towards Europe whereas that to the south ultimately recirculates to the West Indies.

In a separate section, Rennell described evidence for the "EXTENSION of the GULF WATER to the COAST OF EUROPE". He went on to say that it is regarded as being a rare event and that evidence for it is based primarily on the records of Dr (Benjamin) Franklin on his voyage from Philadel-

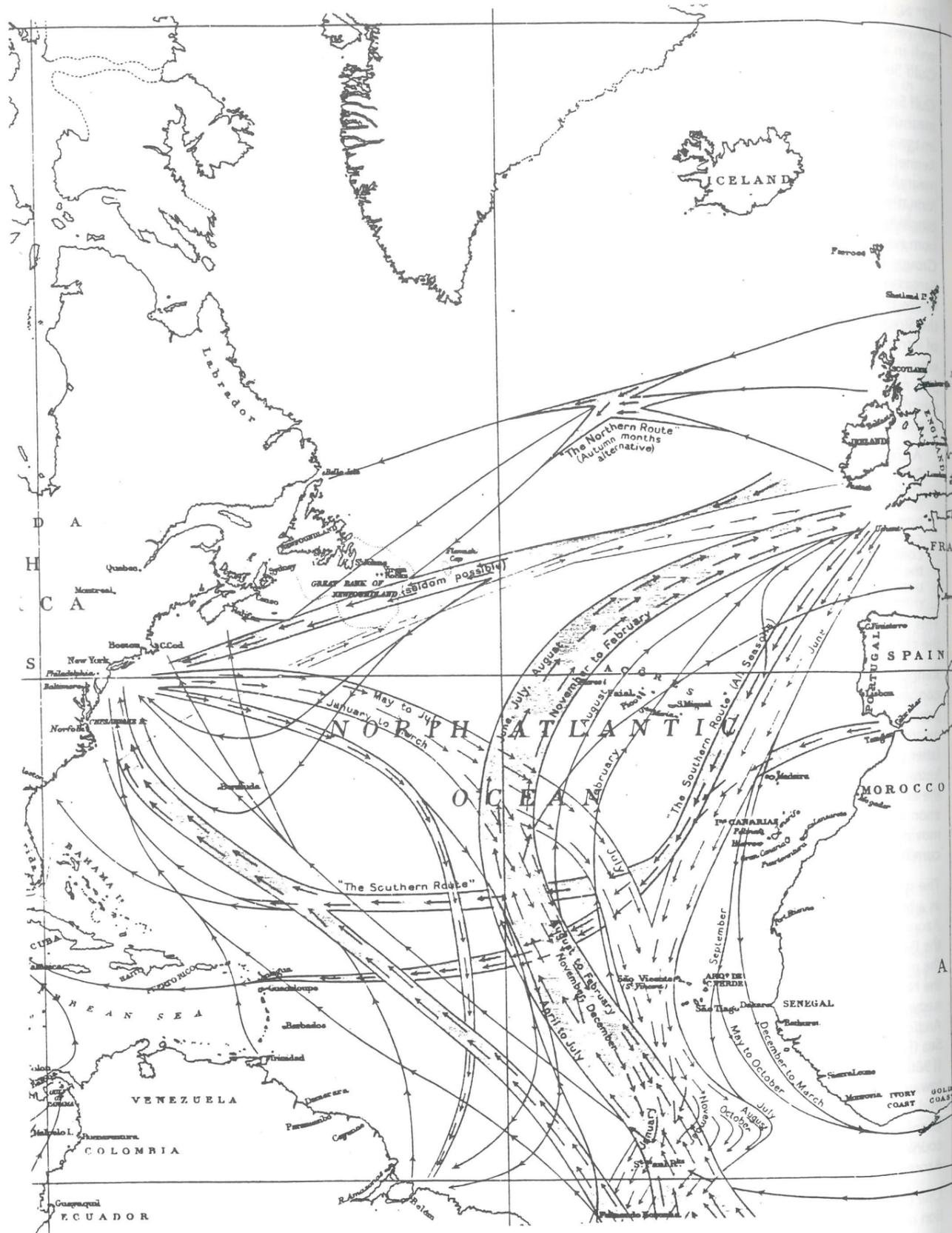


Figure 5 The recommended passages for ships sailing across the North Atlantic (Admiralty Hydrographic Department, 1950). Though taken from a 20th century source, this effectively shows ship routes used in Rennell's time.

phia to France in November 1776, but with additional support from Capt Edward Sabine's passage between Plymouth, Madeira and the Cape Verdes in January 1822. The evidence for the extension lay in the persistence of warm water throughout Franklin's voyage: Rennell refers repeatedly to the concept of ocean temperature (the present equivalent would be a climatological average) and presents in tabular form the fact that temperatures for most of Franklin's voyage were around 7 °F (c. 4 °C) above ocean temperatures. As Rennell stated:

It may well be supposed that, at times, under increased degrees of velocity, the Gulf Stream may advance more or less, beyond its accustomed place of termination near the Azores, towards the coast of Europe, although it has been detected in this single instance only. Had it happened frequently, it could hardly have escaped observation; considering the number of experiments made by ships in these times, in their courses from our parallels southward.¹

¹ Captain Scoresby ... expresses the opinion that the northern branch of the Gulf Stream after reaching the coasts of Britain, pursues its way to that of Norway. But he does not produce any facts to show on what authority he grounds an opinion contrary to those which commonly prevail.

Here I think we have evidence that William Scoresby Jr, who was particularly familiar with northern latitudes through his links with the Greenland whaling fleet, actually had a better grasp of the Gulf Stream extension (North Atlantic Current) than did Rennell. (For more about William Scoresby, see the article by Gwyn Griffiths, on p. 34.)

The Arctic Current

Rennell described the currents that originate in the Arctic region and recognized two separate sources, in the Davis Strait and on the East Greenland coast. The contrast between the cold ice-bearing Arctic Current (that we now refer to as the Labrador Current, cf. Figure 4) and the warm Gulf Stream off the Grand Banks is striking, but Rennell also remarked on the variability: "At one time the warm, and at another the cold, current, occupies the space exclusively; and at others, the waters of both are intermixed, in different degrees of proportion."

Rennell was concerned mainly with defining the width and strength of the Arctic Current and with speculating whether the Davis Strait current and Greenland current remained separate or coalesced. He came to no conclusion, writing that: "Still, however, a doubt remains whether there be one collective stream, extending from the eastern extremity of the cold water, found in long 44°, to the coast of Newfoundland; or whether there be two distinct streams, which unite with the Gulf Stream."

Surprisingly, there is no mention in the discussion of the confluence of the Gulf Stream and Arctic Current of the persistent fogs in the area of the Grand Banks. Such occurrences must have been reported in the ships' logs that were the source of

Rennell's information on currents and water temperatures.

Rennell's Current

An Appendix to Rennell's book contains a paper read before the Royal Society in June 1793, along with a further paper on the same subject read in April 1815. The papers were both entitled "Observations of a current that often prevails to the westward of Scilly, endangering the safety of ships that approach the English Channel; and now generally known by the name of Rennell's Current"; the chart from the second paper is reproduced on page 46, in the article by Michael Bravo.

Many ships while heading for the mouth of the English Channel found themselves instead set towards the mouth of the Bristol Channel, often resulting in an unexpected and fatal encounter with the rocky coast of Cornwall. Rennell made an investigation into the reasons for this navigational problem but started to seek its origins somewhat further afield. He stated that it is well known that there is always a current setting round Capes Finisterre and Ortegal into the Bay of Biscay, and a set to the eastward along the north coast of Spain. Using continuity arguments, Rennell concluded that this inflow from the west must ultimately turn northward and be the source of the so-called Rennell's Current.

Recent confirmation of this is given by Pingree and Le Cann (1990) who show this current system to vary seasonally and on 10–20 day time-scales with peak measured currents of the order of 0.6 m s⁻¹. They see this as part of a poleward eastern boundary current of the type documented by Neshyba *et al.* (1989). Elements of an eastern boundary current are found over the continental margin from North Africa to Norway, but the current's continuity is still a matter of conjecture.

The question is then whether the current identified as Rennell's Current is in fact the poleward eastern boundary current. Rennell's charts show the current predominantly over the continental shelf, which suggests that the two are not the same. However, Rennell cites a number of instances of vessels encountering strong westward- and northward-setting currents when approaching and leaving the English Channel. Some reports were rather vague as to the position in which the current was encountered and many described how a current was inferred after a long dead-reckoning run in bad weather with few position fixes. However, a few are more precise, particularly the *Hector* in 1778:

We arrived within 60 or 70 leagues [180–210 nautical miles] of the meridian of Scilly between the parallels of 49 and 50; and about this time we began to feel a current, which set the ship to the north by near half a degree in 2 days ... We not only were sensible of the current by the observations of latitude but by the rippings of the surface of the water, and by the direction of the lead line.

The point at which the current began would have been near the 1 000 m depth contour close to the

Goban Spur and hence was on the continental slope. The current appeared to persist across the width of the slope. A number of other ships' logs comment on the current being noticed at the start of soundings (namely at the shelf edge). On the basis of these observations we would have to conclude that Rennell did actually detect the poleward eastern boundary current, although his chart shows a current spanning the entire width of the continental shelf and slope.

The comments on rippled water are interesting. The northern part of the Bay of Biscay is noted as one in which there are strong internal tidal signals. These have been seen to manifest themselves as 'slicks', banded changes in surface roughness, that can be seen by eye, by radar and from satellite by using synthetic aperture radar (Pingree, 1984).

Conclusions

Rennell's book presents a view of the Atlantic circulation that has many similarities with the features we know today. The detail with which he recorded features is remarkable, if somewhat repetitive. What is striking is the scientific approach that Rennell used in solving very practical navigational problems using the wealth of data from ships' logs, based on the newly invented marine chronometer. His powers of observation and deduction meant that he was aware of features of the North Atlantic circulation which, to this day, are still the subject of scientific investigation and debate.

Further Reading / References

The following references give, for the most part, recent references on the subject matter covered by Rennell's book; the list is far from comprehensive.

Admiralty Hydrographic Department (1950).

Ocean Passages for the World (2nd edn)
Hydrographic Department, Admiralty, London.

Cornillon, P. (1985) Gulf Stream envelope and mean path between 75° W and 58°, pp. 11.182 to 11.194 in *Gulf Stream Workshop Proceedings. 23-26 April 1985*. University of Rhode Island.

Fuglister, F.C. (1951) Annual variations in current speeds in the Gulf Stream system, *Journal of Marine Research*, **10**, 119-27.

Krauss, W. (1986) The North Atlantic Current, *Journal of Geophysical Research*, **91**, C4, 5061-74.

Maury, M.F. (1855) *The Physical Geography of the Sea*, Harper & Bros. New York.

Neshyba, S.J., Mooers, Ch N.K., Smith R.L., and Barber, R.T. (1989) *Poleward Flows along Eastern Boundaries*, Springer-Verlag, New York.

Niiler, P.P. and Robinson, A.R. (1967) The theory of free inertial jets II: A numerical experiment for the path of the Gulf Stream, *Tellus*, **19**, 269-91.

Pingree, R.D. (1984) Some applications of remote sensing to studies in the Bay of Biscay, Celtic Sea and English Channel, in *Remote Sensing of Shelf Sea Hydrodynamics*. Ed. J.C.J. Nihoul. Elsevier, Amsterdam.

Pingree, R.D. and Le Cann, B. (1990) Structure, strength and seasonality of the slope currents in the Bay of Biscay region, *Journal of the Marine Biological Association of the UK*, **70**, 857-85.

Reid, J.L. (1989) On the total geostrophic circulation of the South Atlantic Ocean: flow patterns, tracers and transports, *Progress in Oceanography*, **23** (3), 149-244.

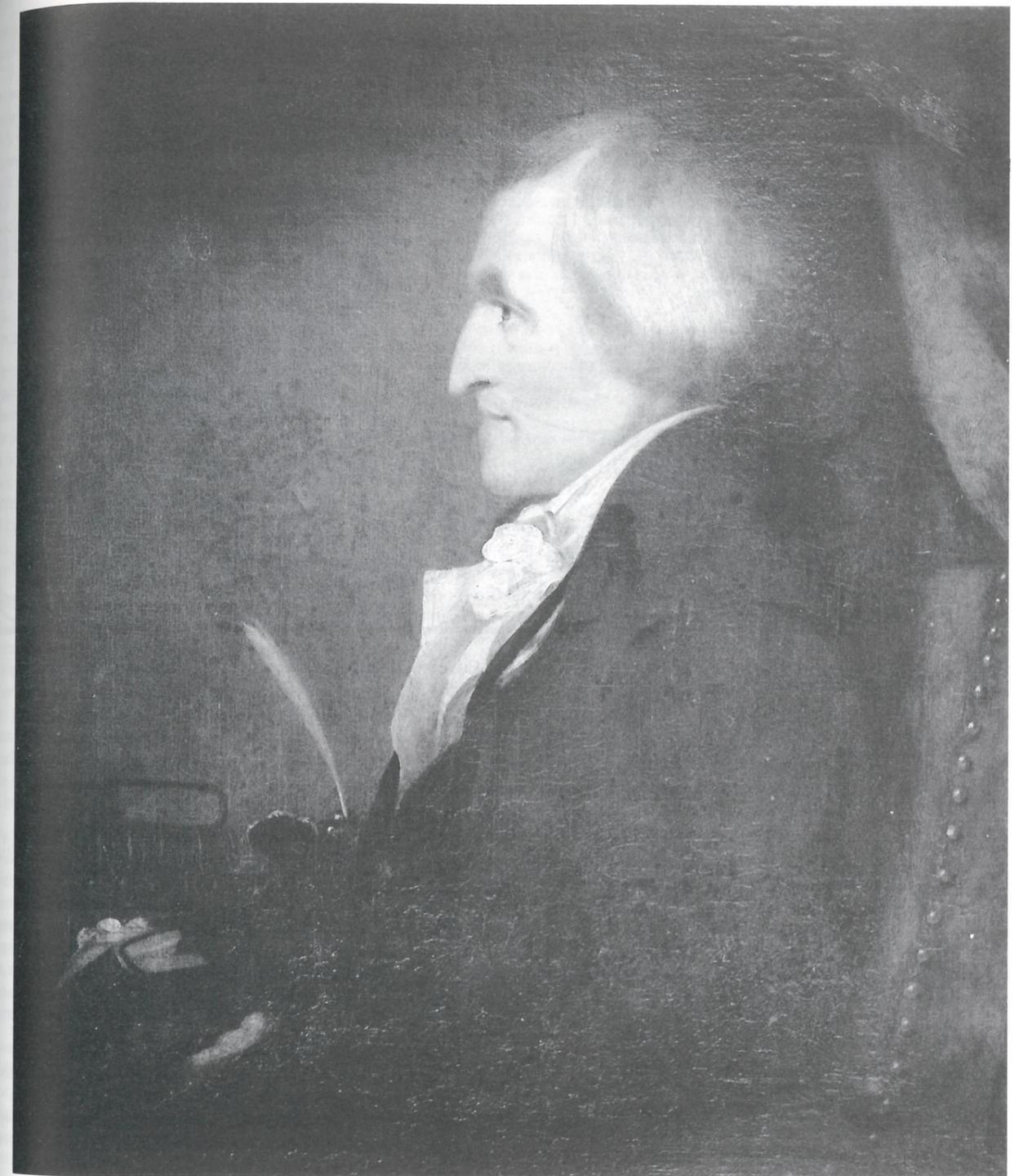
Rennell, James (1832) *An Investigation of the Currents of the Atlantic Ocean and of those which prevail between the Indian and Atlantic*, J.G. and F. Rivington, London.

Stramma, L. and Peterson, R.G. (1990) The South Atlantic Current, *Journal of Physical Oceanography*, **20**, 846-59.

The Ring Group (1981). Gulf Stream cold-core rings: their physics, chemistry and biology, *Science*, **212**, 1091-100.

Webb, D.J., Killworth, P.D., Coward, A.C. and Thompson, S.R. (1991) *The FRAM Atlas of the Southern Ocean*, Natural Environment Research Council, Swindon.

John Gould is a scientist working at the IOS Deacon Laboratory. His scientific interests are focussed mainly on the circulation of the North Atlantic and the role of the Atlantic circulation in the global climate.



James Rennell, the 'Father of Oceanography'



James Rennell & William Scoresby

Their separate quests for accurate current data

Gwyn Griffiths

Like James Rennell, William Scoresby Jr (1789–1857) was a significant figure in the emerging science of oceanography during the early years of the 19th century. Rennell and Scoresby had much in common, including a love of the sea and a background of practical seamanship. Both were meticulous in their treatment of data and in their search to eliminate errors of observation. Curiously, however, there is no record of any exchange of ideas between these two pioneer oceanographers, even though they were both avid letter-writers.

Scoresby was the son of a whaling master. When he was born in 1789, Rennell had been retired from the East India Company for more than ten years and was already a senior, respected gentleman of science. Scoresby studied at Edinburgh University, but interspersed his academic education with an apprenticeship to his father and, in his turn, became a whaling master. He became intent on understanding the nature of the seas, particularly of the Arctic Ocean, which he visited on whaling voyages.

Although Scoresby was Rennell's junior by 47 years, age as such would not have been a barrier to correspondence or friendship. Rennell had many naval friends of Scoresby's age, including Francis Beaufort, Basil Hall and John Franklin. Perhaps the barrier was their different standing with the Admiralty. Rennell was a friend of Sir John Barrow, Second Secretary to the Admiralty, and a friend of Earl Spenser, First Lord of the Admiralty from 1794 to 1801. Scoresby, in contrast, was shunned by the Admiralty, and by John Barrow in particular. According to the sympathetic biography by Tom and Cordelia Stamp, after the death of Joseph Banks, Scoresby

"had no powerful friends in the Royal Society and not being a naval man he could not count on the support of the naval authorities".

Scoresby became further distanced from the Admiralty when, in the late 1820s, he began to move away from marine science – as others in Europe were doing – and immersed himself in the problems of terrestrial magnetism. This subject had always been close to his heart, though earlier in his life it had been part of a search for improved accuracy in both chronometers and compasses.

Rennell's Use of Scientific Method

The scientific method consists of eliciting knowledge from observations and experiments, critically tested, systematized and then assembled into a set of general principles: it is the formulation and testing of hypotheses. James Rennell certainly followed the scientific method in his work on ocean currents. He sorted, sifted and tested the observations brought him; as the first stage in the process he considered data only from trustworthy sources. The essential requirement was that the observations were made from vessels with chronometers, to simplify the accurate determination of

longitude. Although the marine chronometer, perfected by John Harrison, was well tested from 1736 onwards, its general introduction into British merchant shipping was slow. 1768 saw the first publication of the *Nautical Almanac*, but whilst this enabled the determination of longitude using lunar distances to be simplified, the procedure was still slow and difficult. Rennell therefore restricted the observations he considered to journals (i.e. log books) of "those of His Majesty's ships, those of the East India Company, and of foreign ships equipped for discovery, with the trifling exceptions of a Government packet, and of those of a scientific commander of Glasgow, latterly of Liverpool," because these vessels used chronometers.

Despite his rigorous selection criteria, Rennell managed to accumulate enormous numbers of observations. John Purdy, the editor of Rennell's book on the circulation of the Atlantic, later wrote in his own memoir on the currents of the Atlantic, that Rennell had used 7 500 observations, and that "We have an excellent repository of a vast number of current observations in the elaborate charts of Major James Rennell, a great mine of facts in surface current theory."

Obtaining information from the journals of His Majesty's ships was to a large extent eased through Rennell's connections at the Admiralty. In the advertisement to the book and map collection, 'Currents of the Atlantic Ocean' Rennell's daughter, Jane Rodd thanks Sir John Barrow for providing data: "I may not omit to thank Mr Barrow for his ready communication of any thing that could be of use to the Work, as well as for his kind endeavours to bring it to the notice of the Admiralty."

We know from letters written by Rennell that among the many naval captains providing him with observations were his son-in-law Captain Tremayne Rodd ("Capt Rodd ... has brought me some new & Characteristical Notices") and Captain Francis Beaufort ("I ought in Gratitude to have written to you, long ago, to acknowledge the Advantages which I have derived from your excellent Journals").

Aware that an important part of the scientific method is to understand sources of error, Rennell discussed accuracy and methods with the naval captains who provided data. As a result he was wary of drawing conclusions. For example, Rennell wrote to Francis Beaufort that "These Anomalies ... warn us not to be too positive respecting the forming of Systems & to content ourselves with knowing that such & such things occur generally." Rennell was fully aware of the potential for error in individual observations and so, by amassing a series of observations, he used their mean to reduce the random error associated with the current measurements: In his book, *An Investigation of the Currents of the Atlantic Ocean*, he wrote: "And it would appear that the journals may be regarded as a series of reports, which taken at large [i.e. as a group], are by no means discordant amongst themselves: and from whence useful practical results may be drawn."

This statistical treatment of averaging employed by Rennell remains a standard method for the treatment of random errors. Bias errors could also be a problem and Rennell also carefully considered the instrumental errors associated with the observations:

But it is obvious that a *part* of these differences may, and no doubt does, commonly arise from various causes of error, to which reckoning is subject; such as bad steerage, imperfect compasses, faulty measurement of distance, and erroneous judgement, in making allowances for leeway and drift; and finally, in the calculation of the traverse. To each and all these errors, a reckoning is, doubtless, subject, and some one or more of them, may be continually operating. The question then seems to be, "how near an approximation to the truth may be made, by the means of ordinary judgement and care, and in ordinary weather?"

Clearly, he was well aware of the human element involved in errors of observation – the "ordinary judgement and care". As a practical sea-farer, he was also plainly aware that the weather at sea, the motion of the ship (and, not least, their effect on the observers), could reduce the accuracy of the observations. He quotes an authority of the day on the accuracy limit obtainable given care: "Captain Flinders ... has given it as his opinion, that, under favourable circumstances, a reckoning might be kept within five miles of the truth, in point of distance, and in bearing, to half a point."*

Rennell was quite capable of explaining the causes of error in straightforward language. Indeed, he wrote to his grandson, James Rennell Rodd (then aged 12), on the errors that occur in a chronometer because of the effects on gravity of the Earth being an oblate spheroid rather than a perfect sphere: "our globe is flattened a little at the Poles, the difference being 35 miles, if my clock was carried to the Equator it would lose 2½ minutes a day if the pendulum wasn't lengthened".

For Rennell, an important point was the difference in accuracy between the estimates of north-south and east-west currents. This difference arose from the need for accurate time-keeping in determining longitude in order to infer an east-west current, while it was not necessary to determine latitude in order to infer a north-south current. Rennell was aware that, even half a century after the introduction of the chronometer, more observations were needed on the easterly component of currents, even in an area so frequented as the Gulf Stream: "that part of the Gulf Stream that takes an Easterly Course, in about 40° & 40½° ... is much stronger here than I could have possibly expected & requires more chronometer Journals ... the Easterly set has not been sufficiently attended to".

Through restricting the observations he considered to those of careful navigators, James Rennell ensured that his charts would remain useful for a considerable time. His work was referred to, more than 40 years after his death, in the introduction to

*With 32 points on a compass card, half a point is 5° 37.5'.

the narrative of the report of the voyage of HMS *Challenger*, published in 1885:

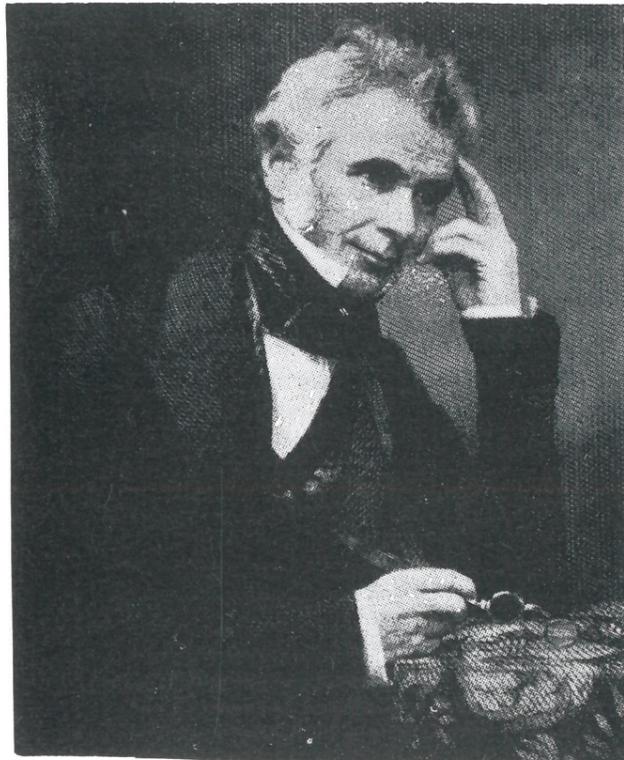
Rennell had been collecting particulars of the currents, prevailing winds, and general meteorology of the ocean from 1810 to 1830, and his *Investigation of Currents* etc, is still a valuable book of reference.

Furthermore, as John Purdy observed, Rennell's deductions were not invalidated by the age of the observations he used:

In founding any theories of circulation or movement of the ocean waters upon the basis of the acknowledged to be, imperfect observations used by Major Rennell, it may be objected that many of them are now old and therefore less trustworthy. To this may be replied that they were mostly taken in wooden ships by careful navigators in an age when great pains was taken with the dead-reckoning.

A method of systematically surveying surface currents occurred to James Rennell that is used today by vessels using such instruments as the *SeaSoar* towed undulator and shipboard acoustic Doppler current profilers: "The Gulf Stream ought to be surveyed, by making zig-zag Courses across it; especially the part North of Cape Hatteras ... A Sloop or Frigate would do it in a Summer: making land occasionally to correct TKs [i.e. Time-Keepers or chronometers]." There is no reference in his book to such surveys having been carried out, but in suggesting the technique he certainly showed foresight. Henry Stommel, in his book on the Gulf Stream, illustrates a 1951 survey of the same area using the precise form suggested by Rennell, in this case to estimate currents using towed electrodes.

William Scoresby Jr,
who in later life became a clergyman



By courtesy of the Whitby Literary and Philosophical Society

The Care taken by Scoresby in his Observations

Like Rennell, William Scoresby was well aware of the judgement and care needed to make observations at sea. Through his practical apprenticeship to his father, and through his education in the natural sciences at Edinburgh, he had been well trained to inquire into the sources of error, and to make observations of the highest accuracy. Limited financial means, and a none-too-co-operative attitude by the Admiralty when it came to loaning equipment to private ships, meant that he was often reliant on one chronometer rather than several.* Whilst recognizing this as a disadvantage, he was careful to make comparisons with other vessels' chronometers and with the lunar distance method of determining longitude.

As mentioned earlier, another of Scoresby's abiding interests was magnetism, in particular the effect of magnetism on the accuracy of observations made at sea. He was aware of the strong effect of the local magnetic attraction of his ship, *Baffin*, on the magnetic compass, and found a solution by fitting a compass at the mast-head of the ship. As he wrote in his *Journal of a Voyage to the Northern Whale-fishery*:

Several plans have been suggested for the solution of this important proposition ... It appeared to me, however, that a situation might be found at the mast-head of a ship, free from local attraction, where the deviation of the steering or binnacle compass might be at once ascertained by comparative observations.

He proceeded to fit a compass within the *Baffin's* crow's nest, which had no iron used in its construction. His experiment of comparing the compasses was made over 20 out of the 32 points of the compass whilst on steady courses, and he made observations of the others during turns. He found the maximum positive error (i.e. with the steering compass reading higher) to be 17½ degrees and the maximum negative error (with it reading lower) to be only 8½ degrees. He ascribed the large difference between the two to the closeness of an iron tiller and rudder works to the binnacle compass. To add weight to the results, he took a set of azimuths with the ship on different tracks. In this way he convinced himself that the bearings taken from the crow's nest were indeed accurate.

Scoresby was also concerned about the effect of the Earth's magnetic field on the steel parts of his chronometers. On land, the rate (that is, gain or loss in seconds per day) would be measured with the chronometer at rest. At sea, with changing ship's heading, the magnetic field acting on the chronometer would change, so that its rate would also change. He was aware that:

This action on chronometers, whose balances have accidentally acquired magnetic properties (and there are scarcely any that are not more or

*In 1819–20, Captain Edward Parry RN on HMS *Hecla* carried eleven, four government-owned and seven belonging to individuals.

less magnetic), is considerable and is probably the principal cause of the difference of the land and sea rates of these instruments.

His advice was to 'rate' each chronometer ashore aligned with each of the cardinal points of the compass. This would give a mean rate, thereby reducing the error when used at sea. With the aid of a watchmaker he made a series of experiments on "twelve or fourteen" chronometers, "where the position of each was changed once a week". He found an observable variation in rate in about half of them. Typical variations in rates were of one to two seconds a day, but one instrument had a rate varying from a retardation of 4.4 seconds a day to an acceleration of 9.5 seconds a day as it had its orientation changed from south-west to north-east. Upon examination, this chronometer was found to have a strongly magnetized balance, "acting with great energy on a small needle, at the distance of more than an inch". This extreme change of rate, continued over 30 days without correction, would result in an error in longitude of over 1.5°. Scoresby was right to be concerned about this effect.

The plan that he devised to overcome this source of error was to "preserve the uniformity of position, by means of a floating needle". He placed the chronometer in a card case, "supported by a long pin or point, in a compass-bowl, on a little cross of thin brass, from the arms of which was suspended a perforated rhomboidal compass-needle". This arrangement kept the chronometer aligned with the magnetic meridian.

As mentioned above, Scoresby also used to maintain the accuracy of his observations by comparing his chronometers with those of other vessels, and by comparing longitudes obtained using his chronometer with those obtained using the method of lunars (see the Box on p. 38). Concerning comparison of chronometers he wrote:

"I was visited [on the *Baffin*] by my Father (5th July), and also by the captains of the *John* and *Venerable*. With Captain Bennet, of the latter ship, who had a chronometer with him, I compared the time, and found to my satisfaction that our chronometers only differed fifty-five seconds."

And concerning the method of lunars:

"... it fortunately happened, that the moon, at a convenient distance from the sun, for determining the longitude, became visible. This was a circumstance of great importance to me, and was instantly embraced, for correcting the rate of my chronometer; it being impossible altogether to depend on the going of a single time-piece. The weather was uncommonly favourable, so as to enable me to take the distances with the greatest precision. From six sets of distances and altitudes, I obtained the mean longitude of 17°54' 30" W, for the place of the ship on the 14th of June, and found the error of the chronometer to be nearly four minutes of time."

In a footnote, Scoresby added a comment on a double comparison, which shows his thoroughness in attempting to make his observations as

accurate as possible: "This lunar observation was afterwards proved, by comparing my chronometer with one of Captain Bennet's, and by correcting its rate by subsequent observations."

Conclusions

From vessels belonging almost exclusively to the navy or the East India Company, James Rennell obtained the raw material required to compile his charts of the currents of the Atlantic Ocean. His access to data was privileged, his connections and his status as a gentleman of science being essential elements of his study of original ships' journals. But Rennell was no mere chronicler, he synthesized material and, following careful sifting of the data, he provided an interpretation. It is this application of scientific method to the study of ocean currents that may well have been his greatest service to the science of oceanography.

As we have seen, Scoresby paid great attention to detail, had scientific insight into the measurements that he was making, and made intercomparisons of chronometers and lunar distances. Despite this meticulous approach, his data do not seem to have been used by Rennell for estimating currents. Was Rennell right to restrict his sources of data to naval and East India Company ships such that there is only passing reference to Scoresby in *Currents of the Atlantic Ocean*?

Scoresby often had a better physical insight into the three-dimensional ocean than did Rennell, who concentrated on surface currents (this could be why Rennell's understanding of the path of the Gulf Stream was not as good as Scoresby's – see the article by John Gould on p.26). Scoresby's physical understanding coupled with Rennell's meticulous sifting of data would have been a powerful combination in advancing the study of oceanography in Britain in the early part of the 19th century.

Acknowledgements

I thank Margaret Deacon and Tony Rice for their encouragement when writing this paper. Permission to quote from manuscript material held at the Huntington Library, San Marino, California (Beaufort Collection) and the Bodleian Library, Oxford (Rennell of Rodd Trustees), is gratefully acknowledged.

Further Reading / Bibliography

- Stamp, T. and C. (1975) *William Scoresby, Arctic Scientist*, Caedmon of Whitby.
- Martin, C. (1988) William Scoresby Jnr (1789–1857) and the Open Polar Sea – Myth and Reality, *Arctic*, 41(1), 39–47.
- Deacon, M. (1971) *Scientists and the Sea 1650–1900*, Academic Press.
- Rennell, J. (1832) *An Investigation of the Currents of the Atlantic Ocean*, (ed. J. Purdy). J.G & F Rivington, for Lady Rodd.
- Purdy, J. N. (1865, 12th edn) *Atlantic Memoir*, (ed. A.G. Findlay).
- Stommel, H. (1958) *The Gulf Stream*, Cambridge University Press.

Report of the Scientific Results of the Voyage of HMS Challenger during the years 1873-76. (1885) p. xliii in the Narrative, Vol. 1, Part 1, London HMSO.
 Scoresby, W. (1980 reprint of 1823 edition) *Journal of a Voyage to the Northern Whale-fishery*, Caedmon of Whitby.

Gwyn Griffiths is presently Acting Head of the Ocean Instrumentation Group at IOS Deacon Laboratory. His interest in James Rennell developed whilst he was project manager of UK WOCE at the James Rennell Centre for Ocean Circulation, at which time he wrote an article on James Rennell and the British Arctic Expeditions of 1818-29, published in the July 1993 edition of *Polar Record*.

☆ Navigation by Stars and Clockwork ☆

Once seamen ventured out of sight of the coast, and away from predictable and well known winds, they needed an independent method of knowing their position. The Sun, Moon and stars have been used for navigation since at least the time of the Phoenicians in the first century BC. However, celestial navigation is only possible when there is a clear sky, and so the system of dead-reckoning developed. Dead-reckoning (DR) involves charting the ship's position on the basis of the distance travelled through the water from a known (or estimated) starting position and the course steered (compasses consisting of a floating magnetized needle pivoted above a compass card were developed in the 13th or 14th century). Although seamen became skilled at compensating for the effect of current (ship's drift) and wind (leeway) on a ship's course, positions estimated by dead-reckoning (Figure A) could be very inaccurate; even so, when the stars again became visible, a helmsman who had been relying on dead-reckoning would have to use the dead-reckoned position in making the celestial position fix, because he would have no more accurate information to go on. Dead-reckoning was for centuries the only method of open-ocean navigation when celestial navigation was not possible.

The most obvious way of determining the latitude using celestial bodies is to measure the height of the Sun in the sky at noon (Figure B(a)). To use the Sun in this way, a navigator needed a clear sky, and an almanac to tell him the declination of the Sun, which varies over the course of a year; applying the correction for the declination was not straightforward, as it depended on whether the observer and the Sun were in the same or different hemispheres. In fact, the easiest way to estimate latitude was to use the Pole Star, as shown by Figure B(b).

Figure A Diagram to illustrate the relationship between the current, a ship's track as steered, and the actual track followed (as would be determined by, say, celestial navigation). In this example, the track has been steered straight according to dead-reckoning, but in reality the vessel has been displaced to the south by a current between fixes 1 and 2, and again by a (stronger) current between fixes 2 and 3. This diagram illustrates why Rennell estimated currents by concentrating on those points where (according to the ship's log) the track according to celestial navigation and that according to dead-reckoning departed from being parallel; see Figure 3 on p. 46. In the case shown, the speed of the current acting on the ship between fixes 3 and 4 would be given by the ship's southward displacement between the two fixes divided by the time between them. (The effect of displacement by the wind has been ignored.)

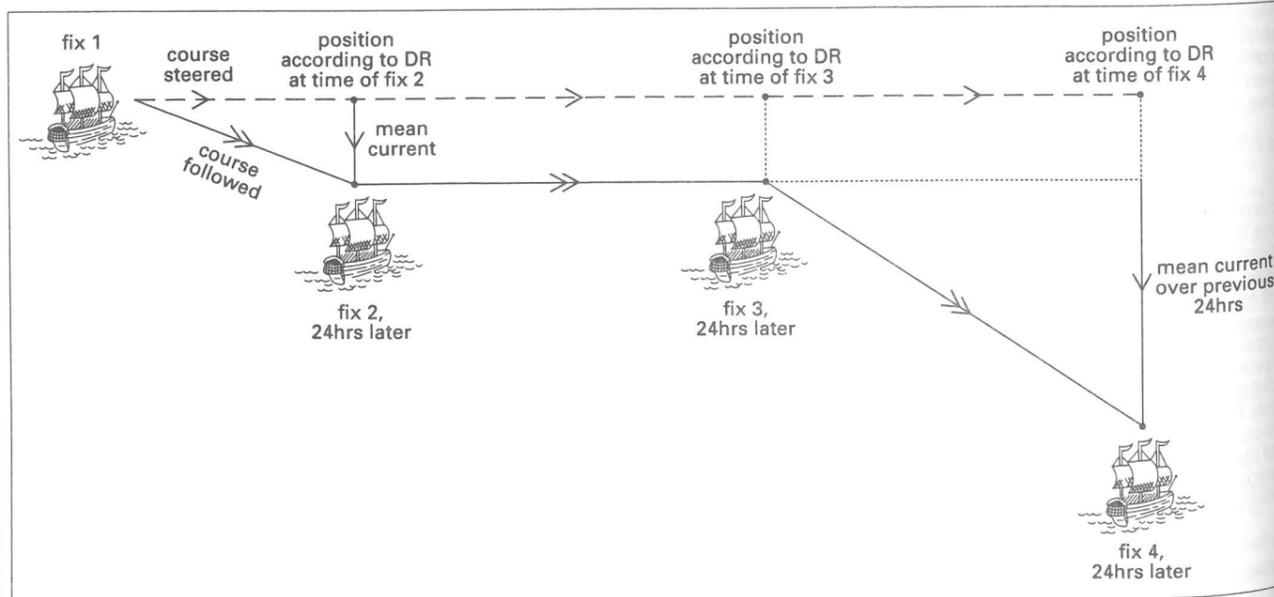
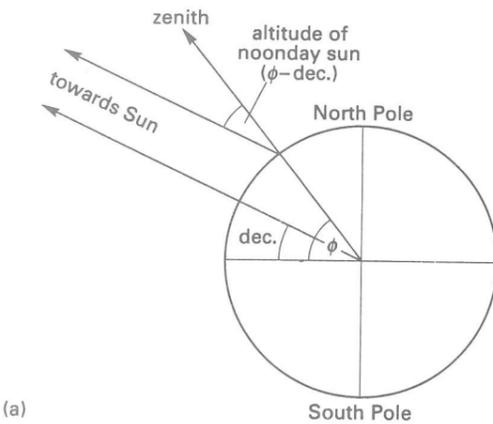
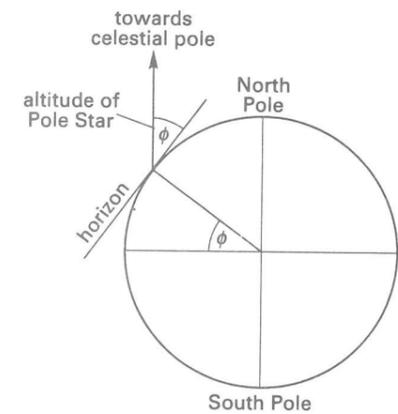


Figure B (a) The estimation of latitude ϕ using the altitude of the Sun at local noon. The example shown is for summer in the Northern Hemisphere, and observer and the Sun in the same hemisphere; the latitude is therefore the declination plus the angular height of the Sun; if (say) the observer were in the Southern Hemisphere in winter, the latitude would equal the the angular height of the Sun minus the declination. **(b)** Estimation of latitude using the Pole Star. As the celestial pole is effectively infinitely far away, the angular altitude of the Pole Star gives the latitude. Note that these methods require both the horizon and the celestial body to be visible.



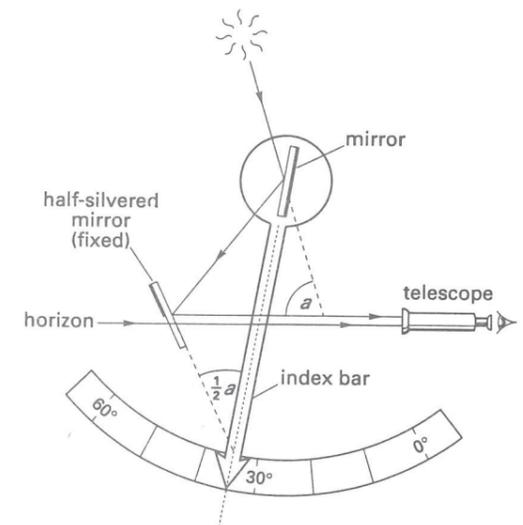
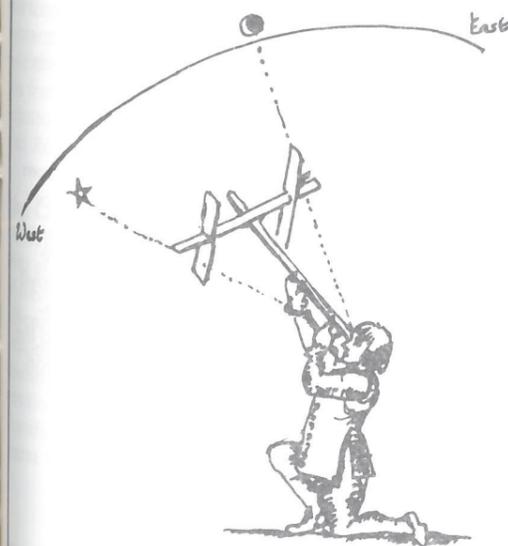
(a)



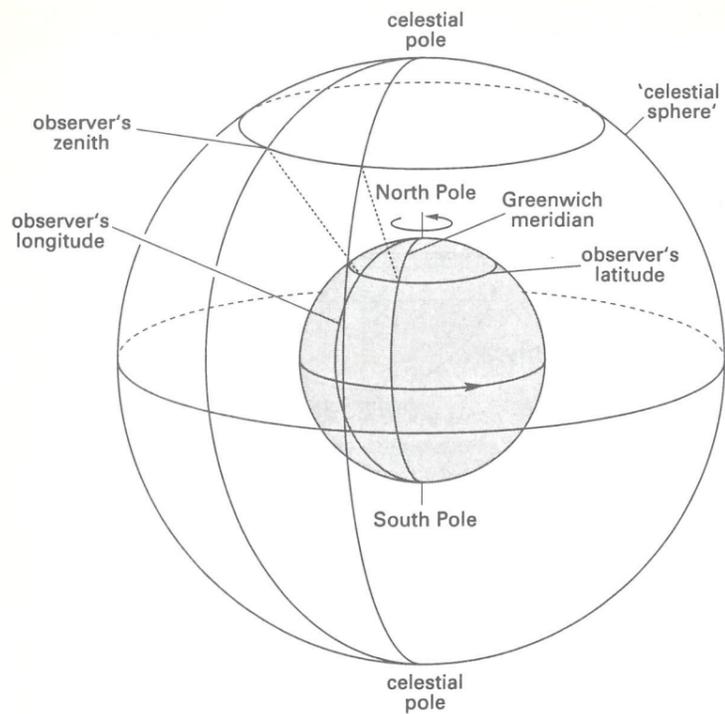
(b)

Figure D (below) The optical principles of the sextant. With this design the altitude was obtained by doubling the reading on the scale; here the altitude of the heavenly body is $\sim 68^\circ$, so the scale reading is $\sim 34^\circ$. (Another arrangement, which used an artificial horizon in the form of a bowl of mercury, produced a reading on the scale equal to the altitude.) The modern sextant in perfect adjustment is capable of an accuracy of better than one minute of arc.

Figure C Measuring astronomical 'distances' (i.e. angles) using a form of cross-staff.



aligned to the index bar when the bar is set a 0° on the sextant scale. This fixed mirror is only half silvered, so that the horizon can be seen through the plain half and the reflected object seen in the silvered half. A second mirror is mounted on the index bar which is pivoted at the centre of the sextant, so this mirror swings with it.



Even after the introduction of the chronometer (by which longitude could be easily obtained and lunar observations made unnecessary), the sextant was retained in use as its additional measurement capability was still found to be of value in the measurement of horizontal angles.

Figure F Harrison's chronometer made during 1728–35, which was taken on board *HMS Centurion*. The four chronometers made by Harrison are now preserved in working order at the National Maritime Museum, London.

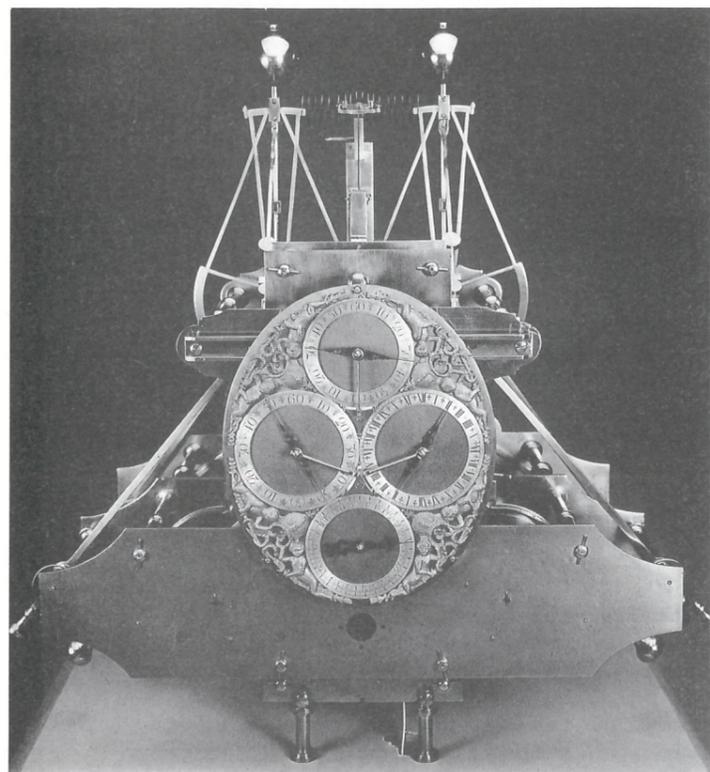


Figure E Because the Earth rotates, it is necessary to know the time if celestial observations are to be used to determine longitude.

However, for the accurate determination of longitude a reliable chronometer or 'time-keeper', which could bring Greenwich time permanently on board, was essential (cf. Figure E). To determine the longitude of a ship at sea, it is necessary to compare the local time and the corresponding Greenwich mean time (at longitude 0°). It is a relatively simple matter to compute *local* time by astronomical observation, but until the advent of an accurate marine time-keeper it was by no means an easy matter to ascertain Greenwich time.

In 1714, to encourage the invention of a means of accurately determining longitude at sea, Parliament established a Board of Longitude. The Board offered a prize of £20 000, and to win the full amount, the invention would have to achieve an accuracy of within 30 miles after a six-weeks' voyage to the West Indies. With his eye on this prize, John Harrison (1693–1776), a carpenter and self-taught mathematician and clockmaker, constructed the first sea-going chronometer sufficiently reliable to enable longitude to be calculated at sea. Between 1713 and 1726 he and his younger brother James built a number of remarkably accurate long-case clocks incorporating many unique features, including the first bimetallic pendulum, to overcome errors due to temperature variation. This contrivance, known as the compensated balance, became an essential feature of all traditional chronometers made subsequently.

Between 1735 and 1760, John Harrison completed four time-keepers, the first a massive mechanism of brass and wood (Figure F), the last about twice the size of a pocket watch. Although this last chronometer easily fulfilled the conditions for the prize, the Board of Longitude paid Harrison only £10 000, withholding the balance until they were satisfied with fresh proof of the watch's 'general utility at sea'. Eventually, in 1773, the Board paid up, but Harrison's last years had been embittered by his struggle to obtain his just reward.

By the 19th century, chronometers were being made to a generally high standard, and a sharp reduction in the cost of production brought them within the reach of every navigator.

For more about the history of navigation see *From Sails to Satellites: the origin and development of navigational science* by J.E.D. Williams, published in 1992 by Oxford University Press; for a more general discussion see *The Story of Maps* by Lloyd A. Brown, published in 1979 by Dover Publications Inc. *The Oxford Companion to Ships and the Sea* has useful entries on all aspects of navigation, ancient and modern.

Photo by courtesy of the National Maritime Museum

James Rennell ANTIQUARIAN OF OCEAN CURRENTS



Michael Bravo

As Margaret Deacon has pointed out in her classic, *Scientists and the Sea*, scientific interest in observations made at sea rapidly increased in the second half of the 18th century. Natural philosophers and hydrographers paid unprecedented attention to studying the oceans, their density, their salt content, their circulation and – above all – their currents. Major James Rennell (1742–1830) was one of the principal proponents of mapping ocean currents and, more than anyone else, pursued their study with a systematic fervour for some fifty years.

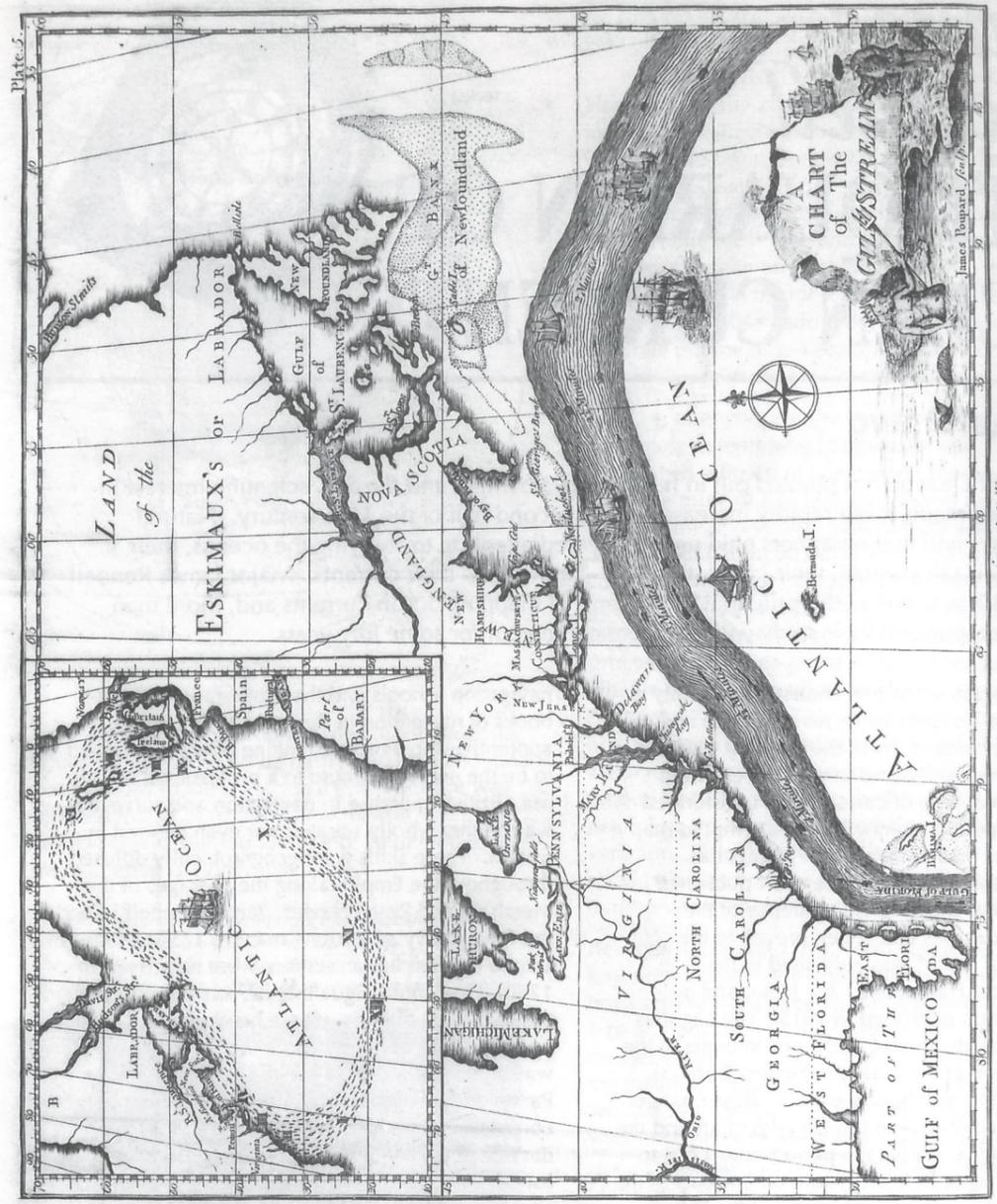
Rennell's legacy of current charts is not simply a testimony to his remarkable perseverance and industry. A comparison of the charts at different periods of his work demonstrates the extent to which the mapping of currents was transformed during this period. Rennell's first attempt to map currents was made off the Bank of Lagullas (Agulhas Bank), and led to the chart published in 1778. A chart showing the existence of the dangerous currents that "often prevail to the Westward of Scilly" was published in the *Philosophical Transactions* for 1793, and a revised version published in 1815. The Lagullas and Scilly charts present a contrast in terms of the representation of the currents (Figures 2 and 3). The aim of this article is to explain those changes that took place between the Lagullas chart and the Scilly charts (i.e. during the period from 1778 to 1815) by placing Rennell's work on currents in the context of the economic concerns of the British Empire in the 18th century. More specifically, I will discuss the stages by which Rennell succeeded in extracting the knowledge of currents from the world of sea-faring captains, organizing it within the framework of élite gentlemanly science, and eventually disseminating it through the Merchant and Royal Navies in the form of sailing directions.

The Ownership of Navigational Knowledge

Throughout most of the 18th century, apprenticeship at sea was a prerequisite for learning the skills of navigation. It was at sea that most young officers learnt such practical skills as taking the altitude of the Sun with quadrant or sextant, reading the compasses, or working out a ship's position by dead-reckoning. Relatively few of the manifold aspects of seamanship were actually learnt from books. Even with the advent of

navigation schools and the proliferation of textbooks of navigation in the early 19th century, apprenticeship as a low-ranking officer continued to be the necessary route to a professional life at sea. British expertise in navigation and surveying was neither wholly situated nor even centred in Britain. These skills were geographically diffused throughout the Empire along the passages of the Merchant and Royal Navies. James Rennell joined the Royal Navy as a young man (in 1756) and was sent to the East Indian station, where he arrived in 1760. One could argue that he was educated off the east coast of India, where he worked his way up to the rank of lieutenant in the Royal Navy. It was under the watchful eye of Captain Hyde Parker and, subsequently, Alexander Dalrymple, consultant to the East India Company, that Rennell developed a keen interest in marine surveying, using every spare moment to develop the skills of surveying harbours and coastlines, as well as drawing charts.

There was no central British depot for Admiralty sea charts until 1795, when the Lords instituted the new Hydrographic Office (they offered the position of Hydrographer to Rennell but he declined to give up his much cherished independence). Even then, sea charts were predominantly purchased and sold privately. They were the property of individual officers, who would frequently annotate them from the experience of their voyages and often kept them closely guarded under lock and key. This was in part a reflection of the value of proprietorship over navigational knowledge. For the East India Company or the Hudson's Bay Company, the possession of charts was a crucial aspect of exercising control over trade routes and important harbours. It was in this context that ocean currents were recorded, either



REMARKS
Upon the Navigation from
NEWFOUNDLAND to NEW-YORK,
In order to avoid the
GULPH STREAM

On one hand, and on the other, the Shoals that lie to the Southward of
Nantucket and of St. George's Banks.

AFTER you have passed the Banks of Newfoundland in about
the latitude of 43° 30', you will find the Gulf Stream, but
you draw near the life of Sables, which we commonly pass in
latitude 43°. Southward of this life, the current is found to extend
itself as far North as 41° 30' or 30', then it turns towards the E.
S. E. or S. E. 4° E.

Having passed the life of Sables, shape your course for the St.
George's Banks, so as to pass them in about latitude 40°, because
the current southward of those banks reaches as far North as 39°.
The shoals of those banks lie in 41° 33'.

After having passed St. George's Banks, you must, to clear Nan-
tucket, form your course so as to pass between the latitudes 38° 30'
and 40° 45'.

The most southern part of the shoals of Nantucket lie in about
40° 45'. The northern part of the current directly to the south of
Nantucket is felt in about latitude 38° 30'.

By observing the direction and bearing between the stream
and the life of Sables, the Banks of Newfoundland, the Banks of
New York, Delaware, or Virginia, may be considerably short-
ened; for by you will have the advantage of the eady current, which
moves contrary to the Gulf Stream. Whereas if to avoid the
shoals you keep on to the southward, and get into that stream,
you will be retarded by it at the rate of 60 or 70 miles a day.

The Nantucket whalmen being extremely well acquainted with
the Gulf Stream, its course, strength and extent, by their con-
stant voyages to the coast of Europe, and their frequent jour-
neys from the Bahamas to the coast of Europe, they have made
one of them, Capt. Folger, and caused to be engraved on the old
chart in London, for the benefit of navigators, by
B. FRANKLIN.

Note, The Nantucket captains who are acquainted with this
stream, make their voyages from England to Boston in as
short a time generally as others take in going from Boston
to England, viz. from 20 to 30 days.

A stranger may know when he is in the Gulf Stream, by
the warmth of the water, which is much greater than that
of the water on each side of it. If then he is bound to the
westward, he should cross the stream to get out of it as soon
as possible.

B. F.

By sailing with the Gulf Stream when travelling east, and avoiding it by taking a more southerly route when travelling west, journey times could be significantly reduced (Map reproduced by courtesy of Cambridge University Library)

Figure 1 (opposite) Benjamin Franklin's current map published in 'Remarks Upon the Navigation from Newfoundland to New York in order to avoid the Gulph Stream', from Transactions of the American Philosophical Society, Vol. 2, published in 1786.

as part of a vast body of tacit knowledge in the heads of senior officers stationed around the world, or pencilled in on private charts.

The Economics of Currents

In the same decade that saw the publication of Adam Smith's *Wealth of Nations* (1776) and the birth of political economy, British and American planners first turned their attention to the economic importance of the currents of the oceans. Attempts to map the oceans' currents were motivated in one way or another by the desire to facilitate imperial trade and to reduce the frequency of shipwrecks. For example, Benjamin Franklin believed that charts of the Gulf Stream would enable mariners to reduce the average time of an Atlantic passage, either by riding the current or by avoiding it, depending on the direction of crossing (Figure 1). As a senior administrator in the colonial postal service and an advocate for the American colonies (1770), Franklin argued that charts engraved with their currents would contribute to greater overall economic efficiency. However, these arguments appear to have held little sway among the captains of the packet ships who mocked his attempts to regulate their navigation routes. While acting as an army surgeon in the British fleet, the physician and natural philosopher, Charles Blagden, made his own surface temperature measurements of the Gulf Stream (1776-77), hoping that the thermometer might "come to be ranked among the most valuable [instruments] at sea". He, too, pointed to prospects of increased economic efficiency in terms of reduced sailing times. Both Franklin and Blagden put forward their arguments with strong moral overtones by claiming to address the great evil of shipwrecks, which annually accounted for an enormous loss of life, labour and cargo. In that sense, the imputed ignorance of mariners regarding currents was deemed to be a moral problem for which the science of charting currents was offered as an enlightened solution.

The Surveyor-General of the Bengal Engineers (1764-1777)

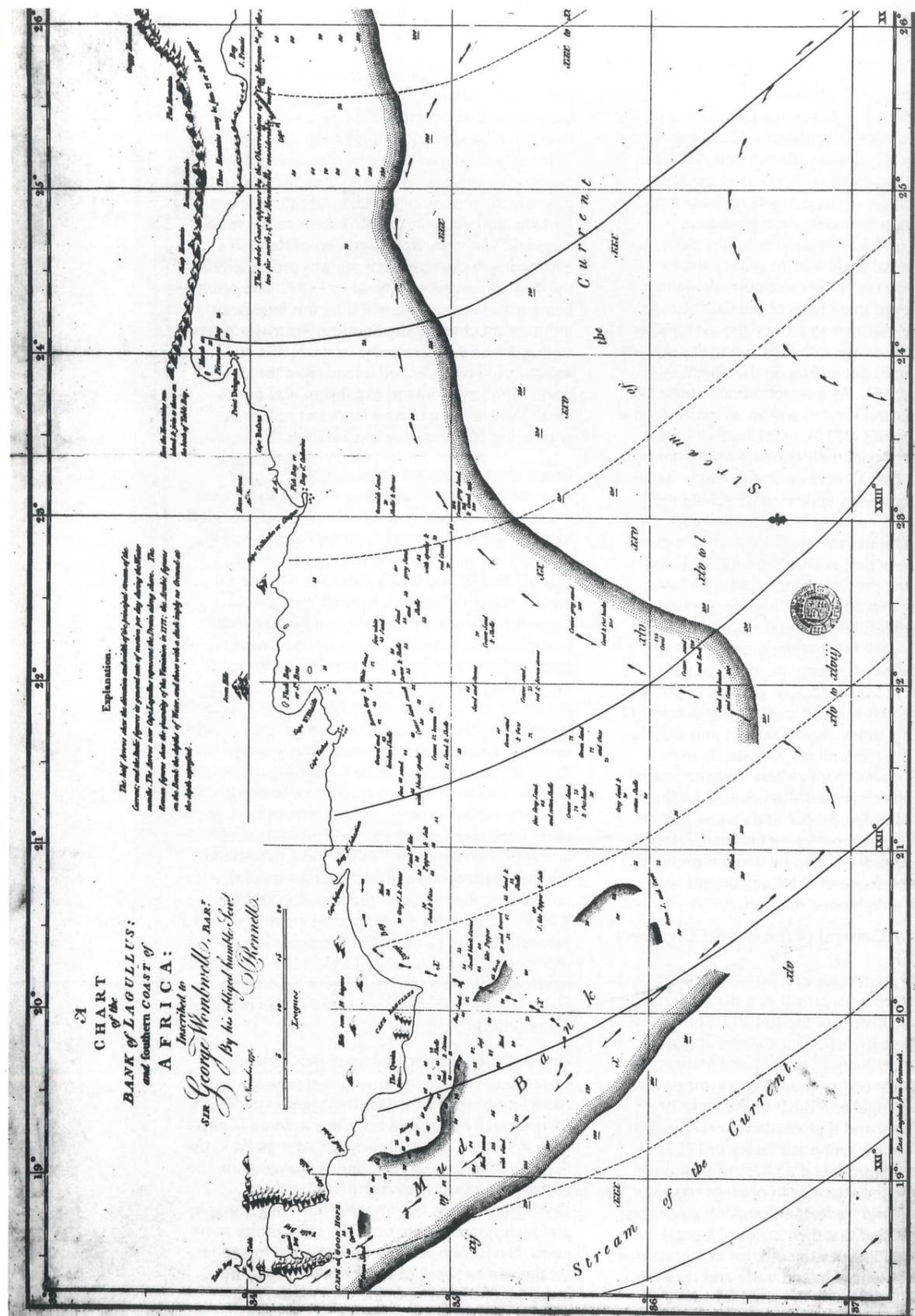
The historical significance of Rennell's career derives partly from his arrival in India at a critical juncture in the history of the British Empire. The East India Company's trading stations at major ports like Fort William (Calcutta) and Madras, won the right to carry out revenue surveys (for taxation purposes) in Bengal and Bihar in the wake of a series of military and diplomatic victories, beginning with Clive's triumph at Plassey in 1757. This effectively introduced a phase of economic expansion into the interior. In order to regulate and control inland trade, the Company governor, Vansittart, decided that their corps of Bengal Engineers should survey the interior as a precursor to the development of inland trade and revenue surveying. In appointing the youthful James

Rennell as their chief surveyor, the Company acquired someone who, at the age of 21, was already an accomplished naval surveyor with a repertoire of surveying skills exactly suited to mapping the great rivers of India. Equipped with only a quadrant, a compass and chains, Rennell spent the next thirteen years with a small team under his command, making route surveys of the Ganges, the Hoogli, the Brahmaputra and the Indus. This task involved measuring the relative distance and direction of the towns on any given river, and the same principles were later extended to include the network of towns connected by roads. The surveys were calibrated, where possible, by the use of the quadrant to measure latitude, and the compass to determine the local magnetic variation. In recognition of Rennell's extraordinary perseverance, he was promoted to the rank of Surveyor-General in 1767. The point being made here is that mapping the interior of India meant charting the course of its major rivers so that the Empire's network of navigable sea-routes could be extended inland from the coastal ports. The key to inland expansion was not so much the claiming of new land, but rather the embracing of rivers as new coastlines.

From the Ganges to Soho Square

After suffering life-threatening wounds in an anti-imperial skirmish with the Fakirs, Rennell decided to retire from the Bengal Engineers and to sail for England, where he arrived in February 1778. Having enough money to purchase a house on Suffolk Street in London, Rennell was able to support his family comfortably on his East India Company pension. His talents as a surveyor were once again recognized, this time by Sir Joseph Banks, who had achieved the Presidency of the Royal Society in November 1778. Banks, like his friend Blagden, had no doubts that science should serve the cause of Britain's economic expansion. Rennell's unique experience in probing the interior of India seemed an obvious resource to use in planning further exploration and expansion into other continental interiors: the Empire's most accomplished surveyor had left India to settle in the great metropolis and had become available for consulting. Rennell was quickly adopted into Banks' inner circle. From Rennell's point of view, joining this elite circle of the Royal Society represented an opportunity to view the intellectual landscape of geographical science in its most respected, gentlemanly forms, both modern and antiquarian.

One of the by-products of these gentlemanly endeavours was the formation of the African Association which oversaw the Niger expeditions carried out by educated travellers such as Thomas Ledyard from Cook's last voyage, Mungo Park, the Scottish physician, and Frederick Hornemann, the renowned physician and philosopher from Göttingen. In fact, this imperial form of geography and hydrography were opposite sides of the same coin. Navigation was the fundamental metaphor for the vast network of trade which linked the mapping of the Ganges, the exploration of the



Published according to an Act of Parliament by J. Rennell, 64, Strand, 1778.

Rennell's first current map (Reproduced by courtesy of the British Library)

Figure 2 (opposite) Chart of the Bank of Lagullas, researched in 1778 and published the same year. The parallel curves sweeping across the chart from north to south-south-east are lines of equal magnetic variation. Theoretically, an unexpected decrease in variation could warn a captain of a westward-sailing ship that his vessel was being swept towards the Lagullas Bank.

Niger and the tracing of the oceans' currents. These were three aspects of the same imperial project. The fundamental building block of navigation was the 'passage' or navigation route. The word 'passage' symbolized nothing less than the naturalization of trade. In India, this involved the great rivers, and in England, the system of canals and rivers. For the oceans, Rennell believed that the natural passages of sea-scapes were their currents.

The Iconography of the Lagullas Chart (1778)

As mentioned earlier, Rennell made his first attempt at producing a chart of ocean currents during his stop-over at the Cape of Good Hope on his return journey from India to England in 1778 (Figure 2, opposite). The Cape was notorious for its fast, dangerous currents and legacy of shipwrecks. Equipped with instruments and a small boat in the Strait of Lagullas, Rennell's preferred method of measuring the effect of the current was to triangulate offshore to measure his displacement over a given period of time, ideally during a calm. By dropping a lead line, he could chart the depth. The direction in which the bow of the boat was pointing while anchored with the lead line gave a reliable indication of the direction from which the current was coming.

Rennell fashioned his own iconography for the current, giving it a corporeal identity by depicting it as a body of water bounded on each side by parallel lines of split arrows. His label 'Stream of the Current' reflects his understanding of currents which he had modelled on inland rivers.

The parallel curves sweeping across the chart are lines of equal magnetic variation in the tradition of Edmund Halley's variation chart (1701). These lines could be used to infer a ship's longitude, and as chronometers were still rare, in general this could have been useful; but it is doubtful whether the small changes in variation that would result from a ship being deflected by the current would actually provide a warning of an impending shipwreck. A more reasonable interpretation of their inclusion by Rennell is that they signalled his devotion to raising hydrography to the level of a science, and his admiration of Halley as his precursor for this project.

In any way, Rennell's Lagullas chart signified his transition from the field to the metropolis. Having taken responsibility for all stages of constructing the chart, Rennell promoted and published it himself, dedicating it to Sir George Wombwell, the Chairman of the East India Company.

An Antiquarian Perspective on Currents

How should we explain the transformation of Rennell's work from his highly individualistic Lagullas chart to the much more elaborate and

detailed charts published in the *Philosophical Transactions*? One might suppose that the increase in data in the later charts corresponds to a great increase in the number of measurements being made at sea, but this would be incorrect; in Britain, the mapping of currents did not show signs of becoming an experimental science based on systematic observation until Edward Sabine's voyage around the Atlantic Ocean in 1822. I would suggest instead that the answer lies in Rennell's scholarly techniques of antiquarian science, applied to the study of ordinary ships' logs, with a surveyor's devotion to systematic discipline and detail.

Rennell, like Banks, was remarkable for his capacity to bridge the rarefied atmosphere of science in the salons and the commercial bureaucratic networks of navigation and trade. Each of these men drew on the experience of his scientific travel in younger days. Although Banks was born a wealthy aristocrat, like Rennell he had been self-educated in the course of his travels. Where Rennell had surveyed the rivers of India, Banks had surveyed the botany of the South Pacific. Each had arrived in the metropolis having acquired a fortune measured in terms of economic knowledge of the Empire's natural resources. Thereafter, neither man ever left Britain on an extended journey. For Rennell, the only effective means of accumulating information about currents was to build a network of naval informants which included erudite hydrographers such as Alexander Dalrymple and naval officers like William Bligh and Matthew Flinders, who were experienced and reliable navigators. Over the years, Rennell expanded his circle. Throughout the Napoleonic Wars, he acted as a consultant to the Government over the complex current movement in the British Channel and, with the help of Sir Joseph Banks, eventually gained access to the log books of the Royal Navy's surveyors.

It seems that during the 18th century only a handful of officers in the Royal Navy actually undertook the measurement of currents at sea. Compared with exploits in battle, hydrography and surveying were a relatively poor means of scoring promotion points until post-war reforms began to take effect in the middle of the 1820s. These sciences had a relatively low priority for the Lords of the Admiralty and the Navy Board, who ensured that the time of Royal Navy officers was taken up by other duties. In more practical terms, discerning the presence of a current was a very difficult skill. Unless it was characterized by a peculiar colour, temperature, surface disturbance or seaweed, like the exceptional Gulf Stream, a current would be invisible to the eye of a navigator. Rennell's specific problem was therefore to find a means of making visible the motion of currents.

Rennell's preferred method for measuring the relative motion of the sea was to compare a ship's progress as estimated by dead-reckoning (i.e. using compass and log) with its progress by



CHART of the TRACKS of the HECTOR and ATLAS EAST INDIA SHIPS, in 1778 & 1787, Exhibited with a Design to prove the Existence of a CURRENT, between USHANT and IRELAND.

'Design to Prove the Existence of a Current between Ushant and Ireland' (Map reproduced by courtesy of Cambridge University Library)

astronomical fixes (see Figure 3 and its caption). This demanded philosophically-minded officers capable of using the sextant to take solar altitudes for latitude, and lunars for the complex longitude calculations (see the Box on page 38). The technical problem of estimating a ship's position by dead reckoning with any measure of confidence was made still more difficult because the traditional purpose of this method was to provide only an approximate indication of location. A ship's average velocity was dependent on many variable factors that were difficult to measure: for example, its changing lee-way, the effect of the ocean swell, and of variations in the wind velocity.

The business of calculating and identifying currents took place at Rennell's home in Suffolk Street. Borrowing log books through his network of friends, he scoured them from beginning to end, searching for evidence of currents. Calculating one's position from the astronomical measurement was easy enough. However, it was virtually impossible to assess the certainty of the dead-reckoning records or the care with which they were taken. Hence Rennell made it his purpose to seek out the rare conjunction of a ship finding itself in a prolonged calm (where the dead-reckoning could be completely discounted) and a fast current caused by a strong gale, along with weather conditions sufficiently clear to allow astronomical measurements on consecutive days. In order to enlarge his collection of currents, he also procured and studied logs from earlier voyages.

Rennell's critical tools were derived in part from his own experience as a surveyor, but also from French antiquarian geography in the tradition of Jean-Baptiste Bourguignon-d'Anville. He treated the logs like artefacts, whose secrets were to be unlocked in the quiet atmosphere of a study or a

Figure 3 (opposite) 'Chart of the tracks of the Hector and Atlas East India Ships in 1778 and 1787, with a Design to Prove the Existence of a Current between Ushant and Ireland' from *Philosophical Transactions of the Royal Society*, Vol. 104, published in 1815.

Towards the end of January, 1787, the Atlas sailed out of the Channel, following one of the busiest shipping routes in the world. Initially, she sailed south-west, but like the Hector nine years earlier, was battered by heavy winter gales, and was pushed off course to the north-west. By the 11th of February, the vessel was able to make good progress to the south, as originally intended.

The vessels' tracks according to dead-reckoning are shown by the broken lines and the tracks according to celestial fixes by the full lines. Rennell examined the tracks, looking for points where they diverged. For the Atlas, this occurred between 30 January and 31 January; working from the log books, Rennell calculated the difference between the two tracks on 1 January at noon, and subtracted from it the difference between the two tracks on 30 January at noon. In the case of the Hector, Rennell used the tracks between 29 January and 31 January. (How this worked is explained in the Box on p. 38.)

Surprisingly, for the Atlas, there is no northerly displacement of the 'celestial' track from the dead-reckoning track, as would be expected. Rennell attributed this to the fact that the latitude readings - which had not been taken regularly - were unreliable.

library. In much the same way that he organized his comparative geography of Herodotus on the one hand, and the contemporary observations of Mungo Park on the other, Rennell reduced the disparate observations of navigators, past and present, to carefully annotated charts. Just as D'Anville had insisted that every antiquarian map should be published with a memoir describing the sources used to construct it, Rennell insisted that every navigation chart should be accompanied by a 'memoir' or a set of sailing directions, carefully laying out details about the sources, their credibility and the conditions under which the observations were made.

Rennell's task was further complicated by his realisation, generally shared by his contemporaries, that periodic winds, and often storms, were responsible for generating temporary or occasional currents. It was, however, as difficult as it was valuable to find a ship becalmed in a temporary current created by a strong gale. As an alternative strategy, Rennell also gathered information regarding the location and origin of beached bottles, or other debris washed up on the shore - pieces of driftwood or whalebone, for example. From such diverse pieces of correspondence, he pieced together currents with the same careful and sometimes brilliant inferences as when meticulously examining the fragmented texts of the ancient geographers. Modern and ancient geography were two very closely linked provinces. It was therefore not surprising that at the dawn of the 19th century, one of the finest and clearest articulations of the Equatorial Current of the Atlantic Ocean was to be found in Rennell's classic study, *The Geographical System of Herodotus*, published in 1800 (see Figure 5, p. 49). In undertaking this analytical work, Rennell was, metaphorically speaking, in dialogue with Herodotus. Both of these geographers were trying to show how a sea-power could exercise maritime control to dominate a continental or land-based power.

Lessons from the Ganges

Rennell published his most important theoretical ideas about currents in the Royal Society's *Philosophical Transactions* for 1793. The currents of the ocean, according to Rennell, were equivalent to the flow in continental rivers and canals. The Gulf Stream, for example, was understood to be quite literally a 'stream' within the ocean. Conversely, in his analysis of the erosion of the banks of the river Ganges, Rennell had used the word 'current' as an expression to represent the force and direction of the river (Figure 4, overleaf). He also attributed the force of his ocean currents or rivers to differences in the elevation of different parts of the oceans and the effect of gravity. According to Rennell's hydrographical framework, ocean currents, rivers and canals were not only similar functionally, but also hydraulically. Drawing on Thomas Smeaton's experiments on the effect of winds in producing differentials in the water level of canals, Rennell supported his claim that winds were the primary cause of ocean currents. Waters would accumulate where they

consideration ought to stimulate those whom it may concern; that the lives of so many brave and useful men often depend on the mechanical perfection of this heavenly gift".

The relative impermeability of the Navy to hydrographical reform was underscored by the hydrographer, John Purdy. Nearly forty years after the publication of Rennell's chart of the Bank of Lagullas, Purdy was explaining in his *Atlantic Pilot* that for seaman, currents were "almost a New SUBJECT". Although Major Rennell had been able to take advantage of the Navy Board's centralized collection of log books to identify the oceans' currents, his scientific knowledge had not spread beyond a relatively small group of hydrographers and gentlemen of science

Only five years later, in 1822, and at the ripe age of 81, Rennell was described by his junior colleague, Edward Sabine, as "quite well and current mad". Rennell had devoted enormous energy to trying to place hydrography on a firm foundation, but the necessary political changes were taking time to come about. However, the liberal reforms of the 1820s and 1830s resulted in the Hydrographic Office under Francis Beaufort

being given a free hand and in the growing prominence of the Royal Navy in scientific surveys. Thus, in the last decade of his life, Rennell was witnessing the transformation of the study of ocean currents from a mostly personal and private concern to a central pillar of institutionalised hydrography, with the world's known ocean currents now beyond the means of any one individual to chart

Further Reading

- Deacon, M. (1971) *Scientists and the Sea, 1650-1900, a Study of Marine Science*, Academic Press.
 Miller, D.P. (1989) 'Into the Valley of Darkness': Reflections on the Royal Society in the Eighteenth Century, *History of Science*, 27, 155-66.
 Pratt, M.L. (1992) *Imperial Eyes: Travel Writing and Transculturation*, Routledge.

Michael Bravo is a Research Fellow at the Department of the History and Philosophy of Science, Cambridge University. He is currently working on a book about science and cross-cultural encounters in the period 1770 to 1840; his interests include the history of environmental sciences, the history of field sciences, oral history, and the history of technology.

James Rennell...Time Traveller

Although chiefly remembered as a geographer, Rennell took a keen interest in antiquity. These two themes were combined in *The Geographical System of Herodotus*, first published in 1800 and probably his longest single work. In it he undertook the explanation of the geographical aspects of Herodotus's famous account of the history of his world, written more than two thousand years earlier. Rennell's method of proceeding was "by a comparison with ... other ancient authors, and with modern geography".

The book is sprinkled with nautical asides in which Rennell brings his practical knowledge of the sea to bear on problems of interpreting the classical accounts of the voyages and military campaigns of the Ancients. For example, while discussing the bridges of moored ships built by Xerxes across the Hellespont during his invasion of Greece in 480 BC (see opposite), he comments on the improbability of the orientation implied for the vessels in one of them "because a strong current prevails for the most part, the water flowing out of the Euxine [Black Sea] into the Propontis [Sea of Marmara], and Mediterranean; and more particularly when northerly winds prevail; so that it would be difficult to keep ships in their stations, when presenting their broadsides to the wind and current."

In considering the number of vessels involved, he dilates on the subject of the sailing qualities of ships in ancient times: "... but it may be observed,

by the representations of ancient ships (and which appear to be generally ships of war), that they spread an exceeding small proportion of sail; which was doubtless owing to their want of breadth. This defect, together with the flatness of the bottom, rendered them unfit to ply to windward: so that when they wanted to proceed in that line of direction, the oars were the only means of accomplishing it. When sailing before the wind, the flatness had its advantages." He even interpolates opinions on the ships of war of his own day: "It may be conceived that no ships, at any period of the world's age, were able to spread so much canvas, in proportion to their length, as at present: a proof that the ancients were very far behind, in naval science." Again, this time in a footnote: "It may justly be suspected that our ships are very much over-masted: as proof of it, ships with jury* masts sail as well, under ordinary circumstances, as with what are termed proper masts. In light winds, it is certain that too much canvas cannot be spread: but, in this age of improvement, cannot temporary sails be invented, so as, in some measure, to compensate the defect? The savings, in point of stores, would be immense; in the wear of ships, incalculable!" Not surprisingly, he concludes with an appropriate classical quotation: "Vitruvius has said that it is better to have

*A jury mast is a (smaller) temporary mast set up to replace one lost or broken.

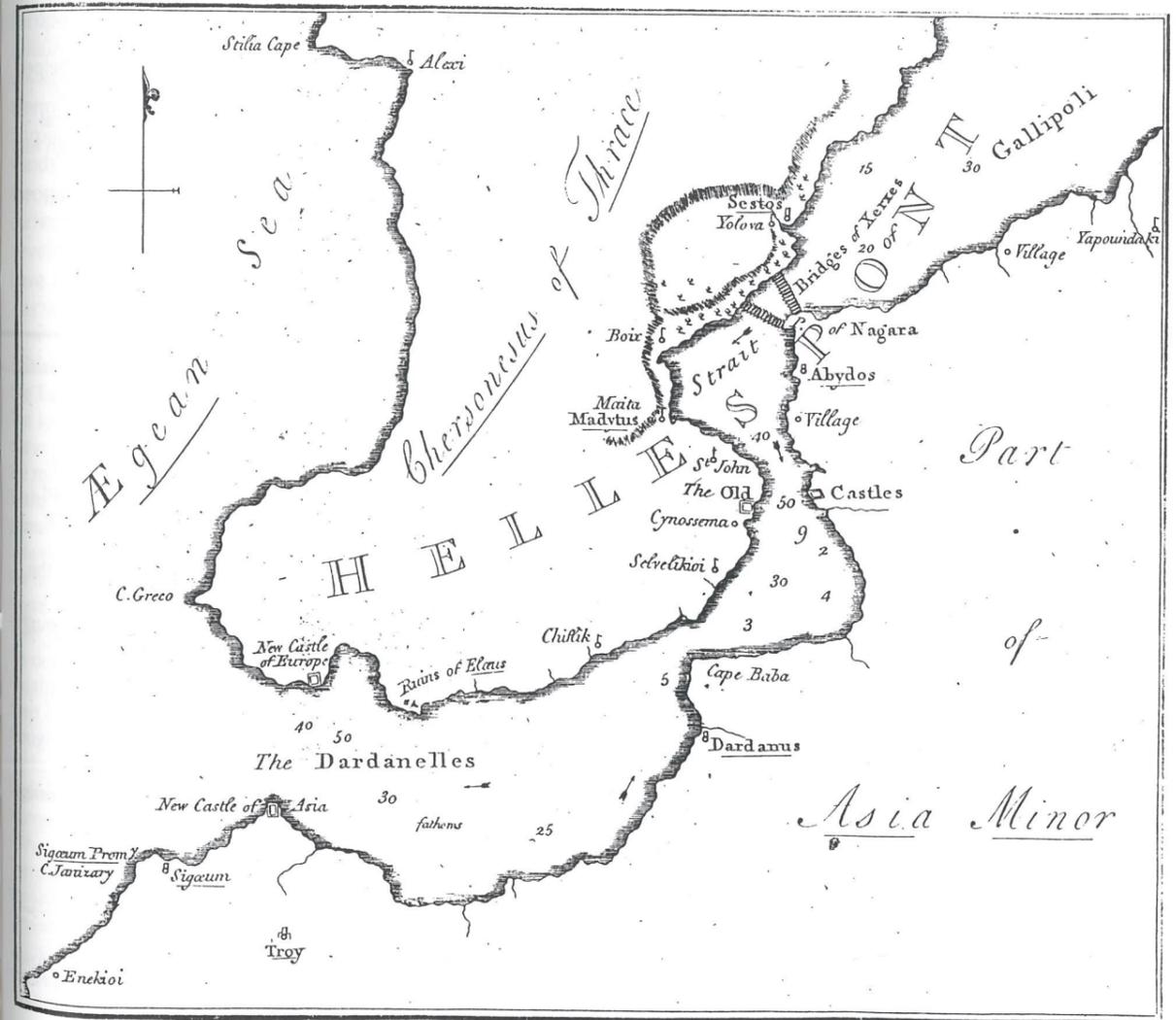
a house too small for a day than too big for a year: is not this saying, in some measure applicable to the present subject?"

This unhandiness to windward is taken up in a later chapter on the Syrtes (the land-locked corners of the Gulfs of Sirte and Gabès on the north coast of Africa; see Figure 5, p. 49), which includes the following observations on their hazards: "The north and east winds, of course, exert their full force on these shores, which are entirely exposed to them: at the same time that not only certain parts of those shores are formed of moveable sand, but the gulfs themselves are also thickly sown with shallows of the same kind, which yielding to the force of the waves, are subject to variation in their forms and positions. To this must be added the operation of the winds, in checking or accelerating the motions of the tides; which are therefore reducible to no rules. And from these causes, combined, the depths are so uncertain, that experience, it would appear, proved of no avail to

mariners." He continues, however: "It appears that the improved state of navigation, amongst the moderns, has stripped the Syrtes of the greatest part of their terrors; since most of the dangers must probably have arisen from the difficulty of working off a lee shore; for which purpose the ancient ships were very ill calculated, in comparison with modern ones. The slow progress of those ships, which kept them so long in the neighbourhood of dangers of every kind, would add to that risk; and these deficiencies combined, must very often have proved fatal, in stormy weather; although a modern ship, well fitted, would, under similar circumstances of situation, have been unconscious of any danger."

Rennell returns to the question of the rate of progress of ancient vessels in his discussion of the circumnavigation of Africa by ships of the Pharaoh Necho (c. 600 BC), using it in conjunction with his knowledge of winds and currents in the Atlantic and Indian Oceans to speculate on the timing and duration of the voyage. In this context he provides a concise summary of the contemporary understanding of circulation in the Atlantic (see Figure 5, p. 49), commenting that "Much knowledge respecting this

Rennell's map to show the positions of Xerxes' bridges over the Hellespont



subject, has been obtained, since the invention of time keepers; but even yet, the subject is new." He concludes, prophetically, "These are the general outlines of the streams of current, in the south and east parts of the Atlantic; and which, to explain in a detailed manner, would require a volume." That volume, of course, was published in 1832, two years after his death).

All this illustrates the link existing between modern and ancient geography at that time, as mentioned by Michael Bravo in the previous article. Rennell's historical approach to contemporary data was paralleled by his application of contemporary scientific knowledge to the study of the past. The historian's analysis of ships' logs was the mirror image of the hydrographer's treatment of voyages dating from classical times in the light of his own marine experience. This temporal synthesis is perhaps best symbolized in the plates of the *Herodotus*, where modern soundings and information on currents are sometimes combined on the same map with the sites of events in ancient history (see the map on the previous page). It might be said that in his writings Rennell hardly recognised the time dimension, but travelled freely across the centuries in his study at 23 Suffolk Street.

Rennell's work was quoted in the publications of many important 19th-century scientists, including Sabine, Lyell and Humboldt. Much closer to our own day, but in a continuation of Rennell's own approach, H.H. Lamb has used Rennell's compilation of Atlantic temperature data in a paper on climate change published in 1959 (*Weather* 14, 299-318). He writes: "I have recently come

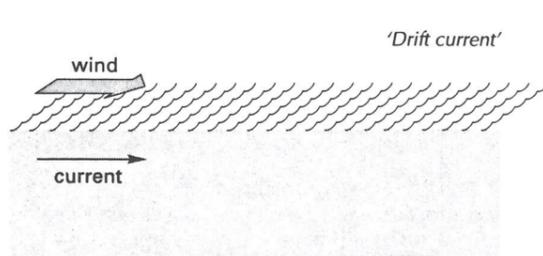
across in the Meteorological Office Library what I believe is the earliest survey of water currents and ocean surface temperatures carried out on behalf of the Admiralty [Rennell's *An Investigation of the Currents of the Atlantic Ocean* of 1832]. The water current observations, having been made from sailing ships, appear unreliable, except where the currents are very strong or very persistent. But the temperature observations look good; these make it possible to present a picture of the change of temperature of the surface of the North and South Atlantic Oceans between the epoch 1780-1820 and the present century ... The pattern shows that the Gulf Stream was farther south than now and tended to turn away south before reaching the coast of Europe; the Polar stream and Labrador current on [sic] the western Atlantic were broader than now; the equatorial current of warm water from the South Atlantic recurved south along the coast of Brazil more than now and supplied less warm water to the Caribbean and North Atlantic. These differences are in good agreement with other evidence that the northern Atlantic was colder, the ice more extensive and the depression track farther south than now whilst the south Atlantic was warmer and the Antarctic ice belt narrower (farther south)."

Thus Rennell's oceanographic studies have helped to illuminate vistas of time in both directions: back into the past by his own work on classical geography, and forward to the present through his successors' use of the data he compiled and evaluated, to interpret changes that have taken place since his lifetime.

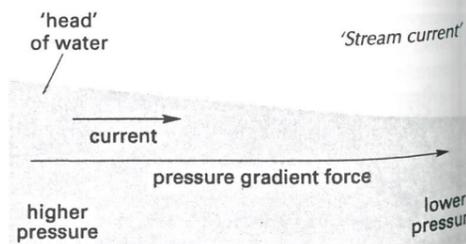
John Phillips

Drift Currents and Stream Currents

The diagrams below illustrate Rennell's idea that surface currents are either driven directly by the wind (in which case he described them as 'drift currents', see left-hand diagram) or are the result of a horizontal pressure gradient in the direction of flow ('stream currents', see right-hand diagram). Sir John Herschel, writing on drift currents in the *Encyclopaedia Britannica*, likened the action of the wind on surface water to that of a cue on a billiard ball. The names of some surface currents still retain the term 'drift'.



Both Franklin and Rennell considered the Gulf Stream to be a stream current: the 'piling up' of water against the coast of South America by the Trade Winds was thought to result in a flow 'downhill' through the Caribbean Islands, into the Gulf of Mexico and out through the Straits of Florida. (The Gulf Stream is still sometimes thought of as a 'jet' squirting out through the Straits of Florida.)



WIND POWER VERSUS DENSITY DIFFERENCES

A 19TH CENTURY CONTROVERSY ABOUT OCEAN CIRCULATION

Margaret Deacon

James Rennell's account of the currents of the Atlantic Ocean explained the surface circulation of the oceans in terms of a system dependent entirely on winds for its motive force. This model was so convincing that during the mid-19th century British writers on science, geography and seamanship were generally content to work within its framework. The idea that density differences in the ocean might cause internal circulation, popular in both American and continental European scientific traditions from the late 18th century onwards, made little impression in Britain. When William Carpenter sought to interpret temperature data obtained during the 1868 voyage of HMS *Lightning*, and on subsequent expeditions, as evidence for the existence of thermohaline circulation in the North Atlantic, his ideas were given a mixed reception. Carpenter's most outspoken opponent was James Croll, whose interest in defending the view that winds were primarily responsible for ocean currents arose from their crucial importance to his theories about long-term climatic change. The ensuing controversy over the cause of ocean currents, though fiercely argued at the time, is now seen as having contributed little to the development of modern dynamical oceanography. However, in a broader sense the debate did have important consequences for the progress of oceanography as a whole, and for this, Croll – as well as Carpenter – deserves recognition.

British Geographers and Ocean Currents in the Early 19th Century

The idea that density differences might lead to oceanic circulation can be traced back at least to the middle of the 18th century when Jacob von Waitz proposed that salinity differences were primarily responsible for an exchange of water between the Equator and the poles. Waitz's idea seems at first to have had little impact, but had found its way into textbooks by the early 1800s. Then new information about the temperature of the deep ocean led to the proposition that inequalities in heat were the main factor driving the deep circulation. However, these arguments, though quite widely discussed in continental works – including some that were available in English translation (Humboldt's *Cosmos*, for example) – are rarely referred to by British writers of the early and middle years of the 19th century. There were various reasons for this lack of interest, in particular the confusion that arose through the consistent recording of overly high deep-sea temperatures, through the use of thermometers insufficiently protected against pressure. This, combined with widespread ignorance of the

results obtained by chemists on the behaviour of salt solutions at low temperatures, resulted in the pervasive belief that the temperature of water in the depths of the oceans, as in lakes, never fell below 4 °C. Nevertheless, if continental ideas had little impact, it must at least in part be set down to the very success of Rennell's treatment of the subject of ocean currents. This was so "authoritative and exhaustive" (to quote Henry Stommel in *The Gulf Stream*) that it appeared to Rennell's successors, the mid-19th century compilers of sailing directions like Alexander Findlay, that only minor modifications to Rennell's general scheme were needed. Their task was largely to fill in the gaps where Rennell had lacked data, to correct the errors due to this lack, and to provide similar information for seas and oceans not covered in Rennell's published work.

When British geographers of the mid-19th century came to examine Rennell's account of the causal relationship between winds and ocean currents, they also found his work a satisfactory basis for their own descriptions of ocean circulation. They accepted his basic premise that the action of winds

blowing over the surface of the sea was responsible for currents, regarding the degree of correspondence between the pattern of the prevailing winds and of the major ocean currents as sufficient evidence of the power of the winds to set in motion the surface layers of the ocean. The seasonal reversal of currents as well as winds in the Indian Ocean monsoons was seen as additional confirmation of Rennell's views. They also adopted his distinction between drift and stream currents (see the Box on p.52).

This confidence in the role of the winds was one reason why writers like Sir John Herschel and Sir John Knox Laughton remained unimpressed by Maury's scheme of density-driven circulation outlined in *The Physical Geography of the Sea*. Herschel dismissed it on the grounds that if gravitational forces due to density differences were the cause of the Gulf Stream, a difference in level would be needed to set the current in motion, and this difference could only be large enough to create a trifling surface current, not a strong one. Laughton objected to Maury's ideas on the grounds that if density differences were causing large-scale movements, northerly flow would be detectable in surface waters right across the North Atlantic, not just in the Gulf Stream. He believed that such northerly flow was not observed because the tendency for higher temperatures to reduce density in the tropical regions of the North Atlantic was cancelled out by the area's higher-than-average salinity. He concluded that ocean currents were caused by the action of the wind setting the surface waters of the ocean in motion, in the way that Rennell had suggested. Maury's defence of his ideas in an energetic letter to Herschel (Royal Society, Herschel Papers, 31 July 1859) had no success in persuading the latter to abandon the views of "the 'Old School' of physical geography".

Not all British writers followed exactly the same line; some were more receptive to new ideas. Improved knowledge of the Pacific Ocean provided material for Mary Somerville's (1848) description of transport of water by the Pacific Equatorial Current into a current flowing round both sides of Australia into the Indian Ocean and thence into the Atlantic. In the 1849 edition of her *Physical Geography* she recast this account to give a still clearer picture of an interconnected network of ocean currents worldwide. Originating in the Southern Ocean, "a great oceanic current" flowed up the west side of South America, across the Pacific, through the East Indies and across the Indian Ocean, and finally into the Atlantic system via the Agulhas Current. In this account, currents are seen as the result of several different causes: the heat from the Sun, which alters the specific gravity of the ocean by evaporation and by warming and so disturbs its equilibrium; the force of the winds; and the effect of the Earth's rotation which modifies the motion caused by the other two. Up to the 1860s, however, the generally accepted view among both scientists and geographers in Britain

was still that only winds had any significant effect on the principal ocean currents, with topography as a modifying factor.

Currents and Climate Change – The Ideas of James Croll

James Croll's interest in ocean currents had a somewhat different origin and emphasis from those outlined above, arising as it did out of his work on mechanisms responsible for climate change. In papers published in 1864 and 1867, Croll suggested that the 'Ice Age', which mid-19th-century scientists were beginning to accept had taken place in the recent geological past, was not unbroken but made up of several periods of glacial advance, with milder episodes in between. Croll believed that the explanation for this was to be found in astronomy, and he identified the ultimate cause of climate variations as the combined influence of cyclical changes in the eccentricity of the Earth's orbit and the precession of the equinoxes (see the Box on p. 59). Herschel and other astronomers had concluded many years earlier that such changes would not affect climate but Croll believed that they could: he suggested that the mechanism at work was not the direct effect of reduction in insolation when the Earth was furthest from the Sun but the influence this had on how heat was distributed over the globe. This redistribution of heat was achieved through a series of feedback mechanisms which had the effect of changing the pattern of ocean currents (whose importance in transporting heat had, he believed, been overlooked by previous writers on climate such as James Forbes).

Croll was not primarily a geologist; in fact, he disliked the science on the grounds that it contained too many facts but not enough theory. His chosen field was physics, in which he was largely self-taught. The son of a Scottish stonemason, he began to suffer in childhood from ill-health which was to dog him in one form or another throughout his life. After leaving school at 14 he studied voraciously, to the extent that his work and possibly his health suffered. After trying a series of occupations, each it seems less successful than the last (as related in the biography by James Campbell Irons), he was fortunate in being appointed caretaker of the Anderson College in Glasgow (the forerunner of Strathclyde University). This gave him access to a library and sufficient leisure to publish scientific papers. His work attracted the attention of geologists, and in 1867 Archibald Geikie appointed him head of the office of the Geological Survey in Edinburgh, an arrangement which suited Croll as he could continue his own work in his spare time.

The reasons for the geologists' interest in Croll was that his theory of cyclical climate change not only offered both an overall solution to the problem they faced in accounting for the phenomenon of Ice Ages but also explained some hitherto baffling features in the geological

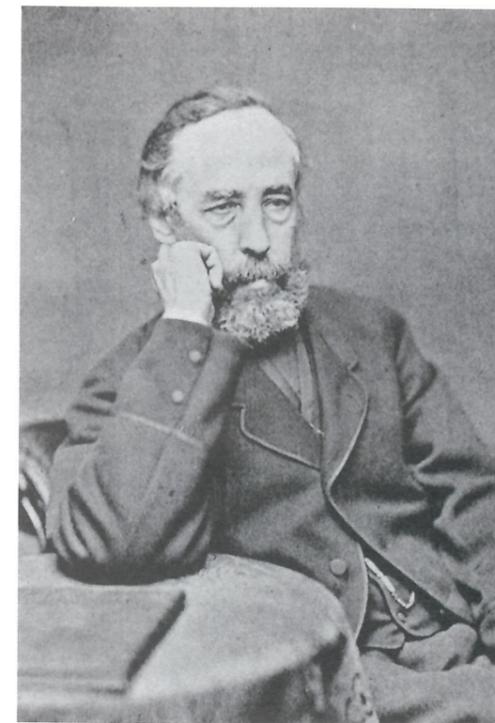
record of these events. By the middle of the 19th century it was generally admitted that there had been a cold period in the recent geological past, and evidence was also coming to light of similar episodes of greater antiquity, but there was still disagreement about whether boulder clay or 'drift' was deposited by a continental ice sheet or by floating icebergs in a period of higher sea-levels. The issue had been further complicated when the apparently chaotic glacial deposits turned out to contain stratified levels of water-borne material, sometimes including remains of vegetation and even animals. If the glaciers had advanced and retreated more than once then such events could be explained.

In his article 'James Geikie, James Croll and the eventful Ice Age', Christopher Hamlin argues that Croll's contribution was even more important. Far from just providing an explanation for a theory already suggested by field evidence, Croll's ideas, he believes, provided the key which enabled geologists to make a significant step forward in their understanding of a topic which had become bogged down in a mass of apparently conflicting details. Hamlin produces evidence to show that when, in a series of papers published in 1871–72, Geikie outlined the essentially modern view of the Pleistocene glaciation as alternating periods of cold climate with milder intervals between* he could not have had sufficient information to have arrived at this view from a purely inductive train of reasoning.

According to Hamlin, James Geikie realized that Croll's theory of advances and retreats of the ice provided an explanation for both the change in climate and the hitherto confusing stratigraphic remains, but to convince his fellow geologists he had to present his arguments as the product of inductive reasoning from field evidence, only acknowledging Croll's contribution in passing. However, in his book, *The Great Ice Age* (1874, second edition 1877), Geikie gave Croll's arguments much greater prominence, perhaps because by that time the wealth of new evidence coming to light to support the interpretation meant that the book's acceptance could no longer be endangered by such an acknowledgement.

The role of wind-generated ocean currents was central to Croll's hypothesis of how long-term cosmological variations might be translated into such dramatic climate change. In the first two sections of a long paper on ocean currents, published in the *Philosophical Magazine* in 1870, he gave a detailed account of how he thought this came about, considerably expanding the outline given in his 1864 paper. During these periods when the eccentricity of the Earth's

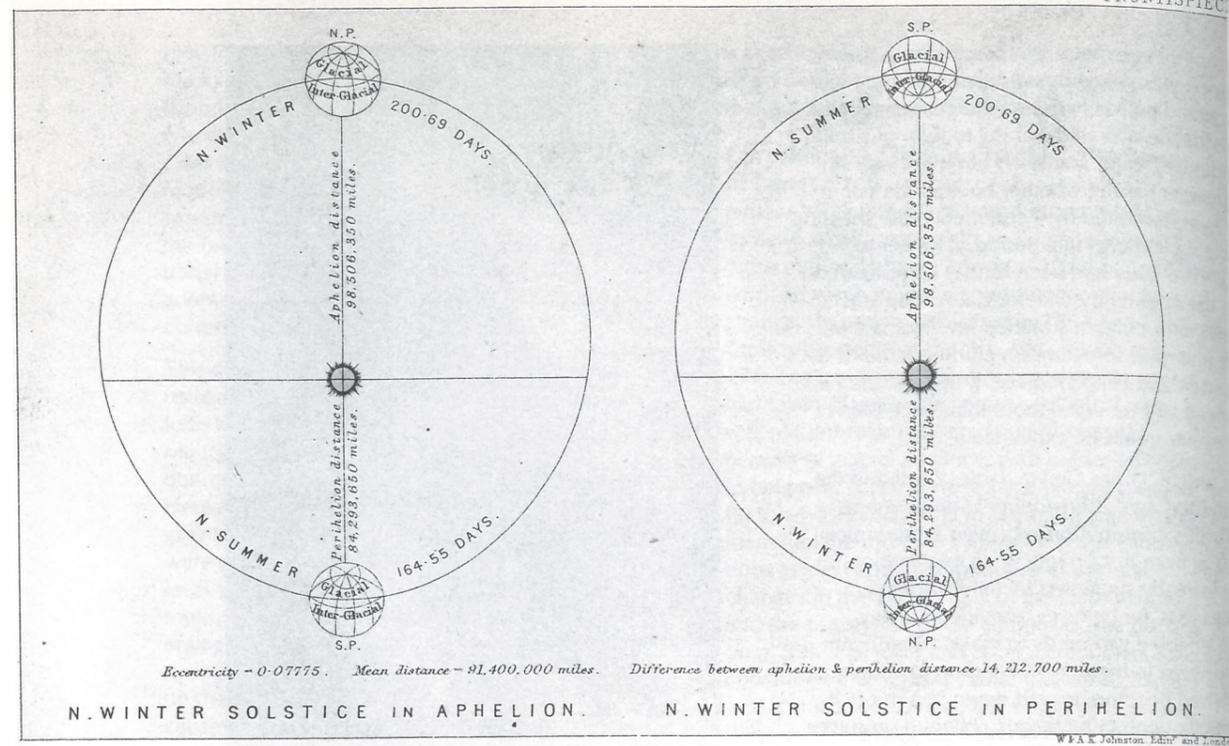
orbit was usually referred to as glacial and interglacial, respectively; both glacial and interglacial (terms which Croll himself used – see overleaf) occur within Ice Ages. When large parts of the globe are covered by ice sheets. See the Box on p. 59.



*James ever truly
James Croll*

orbit was high, when one of the solstices occurred at aphelion (i.e. when the Earth was at its maximum distance from the Sun) the winter hemisphere would experience longer and colder winters and precipitation in normally temperate latitudes would tend to fall as snow rather than rain. Because the winters were longer, the snow cover would be less likely to melt in summer, and this tendency would be reinforced by reflection of sunlight from the snow surface and the formation of fog. Croll cited accounts of weather prevailing in Arctic and Antarctic regions to illustrate the various processes at work. All this would lead to worsening climate but not to full-blown glaciation – this resulted when the effect of climatic deterioration on ocean currents caused yet further cooling.

Under non-glacial conditions, warm water from the South Atlantic would be pushed across the Equator by strong South-East Trade Winds, carried westwards by the Equatorial Current and then north-eastwards in the North Atlantic via the Gulf Stream, keeping temperatures above average for the latitude (cf. Figure 4 on p. 29). However, when – as in the recent Northern Hemisphere glaciation – Northern Hemisphere winter occurred at aphelion during periods of



The Frontispiece to Croll's *Climate and Time*, published in 1875. The diagram illustrates Croll's belief that glacial periods would develop in a particular hemisphere if the winter solstice for that hemisphere occurred at aphelion (meanwhile, the other hemisphere would be experiencing an interglacial).

high eccentricity of the Earth's orbit (see Croll's diagram above), the greater temperature gradient between Pole and Equator would have strengthened the North-East Trade Winds, shifting the Atlantic Equatorial Current well to the south of its present position. This, combined with the protrusion of the South American coastline, would cause the warm water of the Equatorial Current to be deflected into the Southern Hemisphere instead of flowing into the north-eastern Atlantic via the Gulf Stream, and this would be sufficient to cause the onset of glacial conditions in the Northern Hemisphere. A similar but less marked effect might be expected in the Pacific.

In his insistence on the importance of the ocean and its role in the transport of heat around the globe, indeed in the whole sequence of climatic change he describes, Croll was outlining a pattern of events very similar to that being suggested by some climatologists today (see the Box on p. 59). At the time, his ideas had the additional appeal of providing an explanation which could account for unexpected fluctuations in climate, at different periods in the Earth's history, through the collective operation of forces that individually were reasonably well known and understood. Geologists in the uniformitarian* tradition of Lyell felt relieved to be

*The basis of the doctrine "the Present is the key to the Past". It was originally coined to express the belief – based on contemporary observations – that geological processes have always operated at rates similar to those prevailing at present.

offered an explanation which did not entail invoking such "changes on the earth's surface of the most extravagant and unlikely character", as large-scale changes in the distribution of land and sea (as opposed to periods of high sea-level when large areas of continents are flooded) were then felt to be.

The Croll-Carpenter Controversy

Not surprisingly, any attempt to relegate winds to a secondary role in the production of ocean currents, or to deny their influence altogether, was perceived by Croll as a potential threat to a system which seemed to unite astronomical and terrestrial phenomena in a very fruitful way. When Carpenter proposed the adoption of a theory which attributed large-scale water movements in the ocean to internal density differences, Croll found himself not only defending his own interpretation but attacking a point of view which seemed to him unscientific. A long and bitter argument ensued. Others contributed to it from time to time, but Croll remained Carpenter's most remorseless opponent. The failure to get his ideas accepted infuriated Carpenter who defended them with an enthusiasm almost bordering on fanaticism. Had it not been for Croll's resistance it is unlikely that Carpenter would have continued to promote his own theories for so long, coming up with new arguments and evidence over a number of years.

Much of the Croll-Carpenter debate centred around whether it was physically possible for such relatively small variations in density to create large-scale movements. Croll never ceased to maintain that gravitational movements could only result from actual differences in water level and that in the oceans these were never great enough to set the sea in motion – a claim he sought to substantiate by calculations of the forces involved. His arguments

made little impression on those few who, like William Ferrel, were attempting to understand oceanic and atmospheric circulation in the light of recent discoveries about hydrodynamics and the effect of the Earth's rotation (thought by Croll to have little effect); however, many found them convincing, and not only geologists like Geikie. Alfred Russell Wallace, for example, saw in Croll's papers on ocean currents "a powerful application of the modern theory of heat and force, to show the fallacy of Captain Maury's explanation of the causes of oceanic circulation". As Martin Fichman has shown (see Further Reading), Croll's Ice Age theory also had great significance for biologists. It assisted their defence of the theory of evolution against Lord Kelvin's suggestion that the age of the Earth was much less than generally supposed. Furthermore, Fichman argues that Croll's ideas were of central importance in enabling Wallace to achieve his "magisterial formulation of zoogeography", *The Geographical Distribution of Animals* (1876), in which the Ice Ages are invoked to explain changes in the distribution of plants and animals over time.

Though the debate was about the possibility of ocean circulation in general, the argument centred (particularly during the early stages) on the North Atlantic, and especially on the significance of the Gulf Stream. Here the supporters of the wind theory were divided. Findlay, for example, maintained that it was wind-driven North Atlantic Drift that was responsible for the relatively high sea temperatures of the north-east Atlantic, even extending up into the Arctic Circle. Carpenter regarded warm water found by the *Lightning* in the surface layers of the northern North Atlantic as proof of the existence of a general oceanic circulation sustained by density differences between polar and equatorial seas, on the grounds that the Gulf Stream alone could not be responsible for such a sizeable body of warm water. Croll, on the other hand, believed that this was well within the Gulf Stream's capacity, disagreeing with both Carpenter and Findlay. To him, the temperature of the North Atlantic was proof of the efficiency of the system he advocated. It was the absence of such warming that would be one of the most important features in the onset of a glacial period.

In three further instalments to his paper on ocean currents Croll examined the alternative theories put forward to explain ocean water movements in terms of density differences, concentrating on the versions by Maury and Carpenter, and showed how he considered them to be inadequate to perform the work attributed to them. His opinions on the Gulf Stream were quoted by Wyville Thomson, who was not happy with Carpenter's account. More influential support came from the German geographer August Petermann who also believed the Gulf Stream to be responsible for the warming of the North Atlantic and whose evidence for this view, based on an impressive series of datasets, appeared in the *Geographische Mittheilungen* in the summer of 1870. Carpenter



William Ferrel

hoped that the investigation of the Gibraltar undercurrent (carried out shortly afterwards in the *Porcupine*) would provide an unanswerable case, but he reckoned without his opponents.

Ocean Exploration: The Fruits of Controversy

As early as 1869, Carpenter, in a letter to Edward Sabine, the President of the Royal Society, had suggested a voyage of circumnavigation which would undertake oceanographic research; however, it was not until the summer of 1871 that he presented to the Society the proposals that were to result in the *Challenger* Expedition. While the initial purpose of the voyages in the *Lightning* and the *Porcupine* had been to discover if life was present in the ocean depths, the intention now was to carry out scientific investigation of all aspects of the deep sea. As we have seen, Carpenter's personal interests now focussed on ocean currents.

The Expedition's departure in 1872 was a tremendous personal achievement for Carpenter. Two papers by Harold Burstyn (1968 and 1972) show just how much the initial process of getting the idea of an Expedition accepted was due to his ability to convince others of its importance. To persuade scientists was relatively easy; it was convincing the civil servants and politicians* that such a huge scientific project was in the national interest that was the difficult part.

Despite these successes, he was doubly disappointed, first in his hope of being appointed scientific leader, and secondly in the reaction of critics to his views on ocean circulation. The findings of the *Challenger* did not dispose Croll to

*In mid-Victorian England, such people were not generally known for their enthusiasm for supporting science; see Macleod (1976) in the Further Reading List.

By courtesy of the Natural History Museum

look any more favourably on the theory of density-driven currents. He returned to the attack, and in his book *Climate and Time* (1875) brought to bear his original counter-arguments, together with new material. On his side, Croll was equally convinced that the *Challenger* would vindicate his viewpoint, apparently undeterred by criticism from Ferrel. The American meteorologist had pointed out that it was unreasonable of Croll to rely on experiments on the flow of water in canals (so simulating a situation that was inapplicable to the ocean) while at the same time attacking Carpenter for relying on laboratory demonstrations of his own theory. (Ferrel had also pointed out that, according to Croll's calculations of the effect of gravity on water masses, tides as well as currents would be impossible.)

If everyone had agreed with Carpenter in the first place, he would probably not have felt it necessary to go on searching for new arguments and evidence, and it is likely that the *Challenger* Expedition would never have taken place. If the *Challenger* had never set sail, the development of oceanography would certainly have continued, albeit somewhat differently. The interest aroused among scientists in other countries by the recent discoveries was already leading to proposals for similar projects elsewhere (this was one of the points Carpenter used to gain support for his plans). It is worth noting that overseas scientists would later use the British government's generosity to marine science as a lever to obtain support from their own rulers.

Irrespective of the correctness of his reasoning, Croll, through his defence of his ideas on ocean circulation, played a crucial part in the events which led to the *Challenger* Expedition. Indeed, though the plan and its implementation were not his, it is not an exaggeration to describe his role as catalytic, as much here as in the other fields where his ideas led to new developments.

But what of the progress of scientific thought during this controversy? As Harold Burstyn observed in his not unsympathetic article on Croll in the *Dictionary of Scientific Biography* (see Further Reading list): "This argument generated more heat than light, since neither protagonist had the methods or the data to resolve it." The strong tradition of wind-generated ocean currents inherited from Rennell had benefited science in some unexpected ways, but progress towards a more integrated explanation of ocean circulation had to wait for another generation.

Selected Bibliography / Further Reading

- Burstyn, H.L. (1971) Croll, James, 1821–90, in *Dictionary of Scientific Biography*, Vol. 3, pp. 470–71.
- Burstyn, H.L. (1968) Science and government in the nineteenth century: the *Challenger* expedition and its report, *Bulletin de l'Institut Océanographique*, Special No. 2, 2, 603–11.
- Burstyn, H.L. (1972) Pioneering in large-scale scientific organisation: the *Challenger* expedition and its report. I. Launching the expedition, *Proceedings of the Royal Society of Edinburgh*, B72, 47–61.
- Carpenter, W.B. (1871) On the Gibraltar current, the Gulf Stream, and the general oceanic circulation, *Proceedings of the Royal Geographical Society*, 15, 54–88.
- Croll, J. (1864) On the physical cause of the change of climate during geological epochs, *Philosophical Magazine*, 4th series, 28, 121–37.
- Croll, J. (1875; 2nd edition 1885) *Climate and Time in their Geological Relations: a Theory of Secular Changes in the Earth's Climate*, Adam and Charles Black.
- Deacon, M.B. (1971) *Scientists and the Sea, 1650–1900: a Study of Marine Science*, Academic Press.
- Ferrel, W. (1872) Ocean currents, *Nature*, 5, 384–5.
- Fichman, M. (1977) Wallace: zoogeography and the problems of land bridges, *Journal of the History of Biology*, 10, 45–63.
- Geikie, J. (1874; 2nd edition 1877) *The Great Ice Age and its Relation to the Antiquity of Man*, W. Isbister.
- Hamlin, C. (1982) James Geikie, James Croll and the eventful Ice Age, *Annals of Science*, 39, 565–83.
- Herschel, J.F.W. (1861) *Physical Geography*, Adam and Charles Black.
- Irons, J.C. (1896) *Autobiographical Sketch of James Croll, LL.D., FRS etc. with Memoir of his Life and Work*, Edward Stanford.
- Laughton, J.K. (1870; 2nd edition 1873) *Physical Geography in its Relation to the Prevailing Winds and Currents*, J.D. Potter.
- MacLeod, R.M. (1976) Science and the Treasury: principles, personalities and policies, 1870–85, in *The Patronage of Science in the Nineteenth Century* (ed. G.L'E. Turner, Nordhoff), pp.115–72.
- Somerville, M. (1948; 2nd edition, 1849) *Physical Geography* (2 Vols.) John Murray.

Margaret Deacon is an honorary research fellow in the Department of Oceanography at Southampton University. She is working on the history of oceanography, mainly late 19th century expansion of marine science.

A Brief Word about Climate Change, Croll and Milankovitch

Although Croll's ideas became more acceptable during his lifetime, and much of his theory is now vindicated, his name is not well known. This is largely because of Milutin Milankovitch, a Yugoslav astronomer who, in the 1930s and 1940s, refined and improved Croll's theory. As a result of Milankovitch's work, the astronomical cycles which Croll had linked to the growth and decay of ice-sheets are usually referred to as Milankovitch cycles (or, sometimes, Milankovitch–Croll cycles).

As both Croll and Milankovitch understood, the amount of solar radiation reaching the Earth's surface varies periodically; this occurs as the result of cyclical changes of the Earth in its orbit, brought about by the varying gravitational attraction of the Sun, the Moon, and the planets (notably Saturn). There are three different cycles, having periods of about 22 000 years, 40 000 years and 110 000 years, superimposed on one another.

The longest cycle affects the *ellipticity of the Earth's orbit*. Over a period of ~110 000 years, the orbit changes in shape from longer and thinner (i.e. more elliptical) to nearly circular, and back again. At present, the orbit is fairly elliptical, so the Earth's distance from the Sun changes through the year; the positions on the orbit closest to and furthest from the Sun are called perihelion and aphelion, respectively. The Earth is in perihelion during the southern summer, just after the December solstice (when the noonday sun is overhead at the tropic of Capricorn), so that the Southern Hemisphere receives more solar radiation during its summer than the Northern Hemisphere does during its summer. When the orbit is nearly circular, perihelion and aphelion become irrelevant, and the total solar radiation reaching the Earth's surface will be the same for both hemispheres. (See Croll's frontispiece to *Climate and Time* on p.56.)

Figure B The component Croll–Milankovitch cycles: (a) the ellipticity cycle; (b) the tilt and precession cycles shown with winter in the Northern Hemisphere.

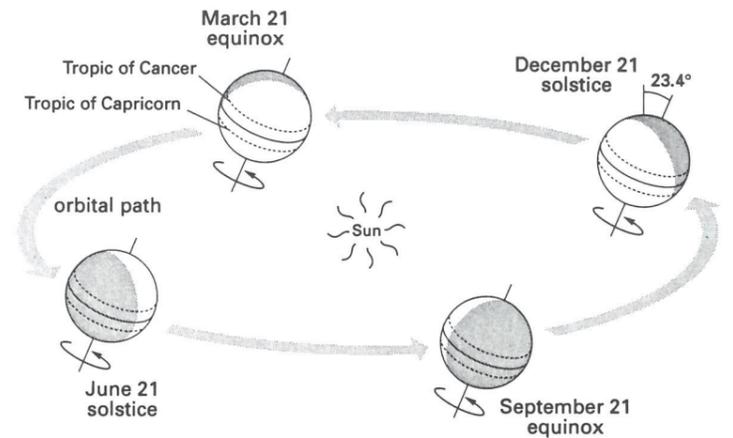
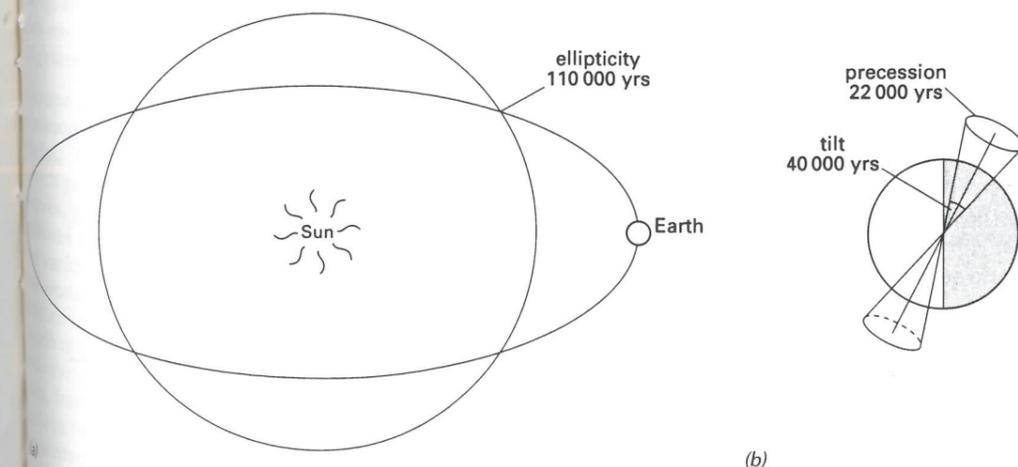


Figure A Schematic diagram (not to scale) to illustrate the Earth in its orbit and the seasons of the year.

The two shorter cycles involve the orientation of the Earth's axis, which varies so that the direction in which the North Pole points traces a circle in the sky (i.e. what we call the Pole Star has not always been an accurate indication of North). The time taken for a full circle to be traced on the sky – a phenomenon manifested by the *precession of the equinoxes* – is about 22 000 years. The precession of the equinoxes causes the seasonal position of the Earth in its (elliptical) orbit to change: the December solstice has not always occurred near perihelion, though it did 22 000 years ago and will again 22 000 years in the future. At the same time, the *tilt* of the Earth's axis (which is presently at about 23.4°) changes between 21.8° and 24.4° and back again, with a periodicity of ~40 000 years. The greater the tilt of the axis, the greater the difference between summer and winter: at present, the tilt is decreasing, so summers are very gradually becoming cooler and winters are very gradually becoming warmer.

continued overleaf...

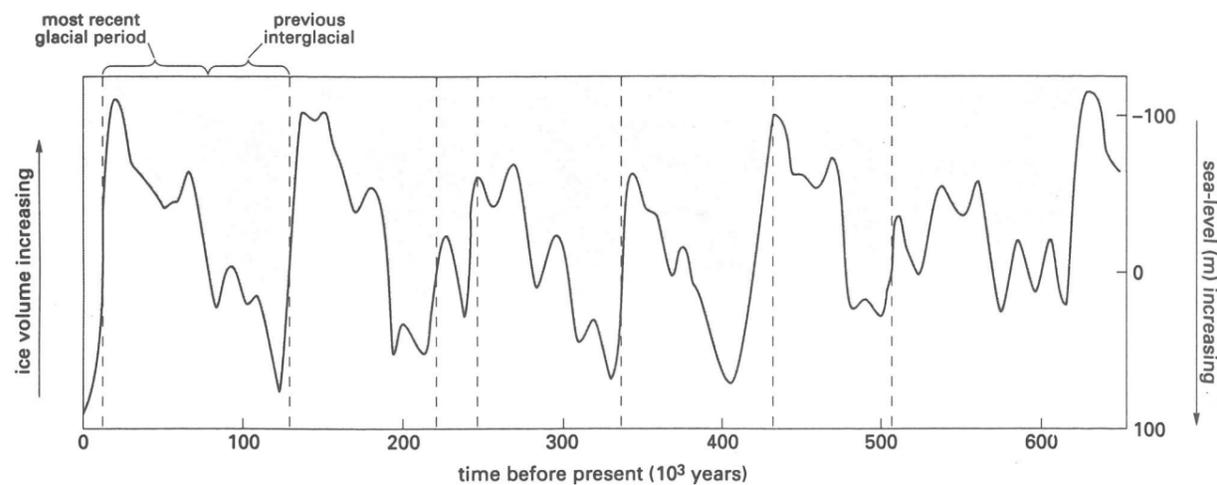


Figure C The variation in the amount of ice in the Northern Hemisphere ice caps over the last 600 000 years. Glacial maxima (indicated by dashed lines) correspond most closely with the 110 000 ellipticity cycle. (In fact it seems that the ellipticity cycle has only dominated over the last million years or so; before that the 40 000 year tilt cycle seems to have had the strongest influence.)

Figure C shows the variation in the amount of ice in Northern Hemisphere ice caps (and the resulting rises and falls in sea-level) over the last 600 000 years. The cycle that appears to be having most influence is the 110 000 ellipticity cycle. The effect of a very elliptical orbit with solstices near perihelion and aphelion (as now) is to intensify the seasons in one hemisphere and moderate them in the other, so it seems that it must be the intensity of the seasons in the Northern Hemisphere that controls the growth and decay of ice caps; ice caps in both hemispheres decline when northern summer sunshine levels are rising, despite the fact that northern winter sunshine levels must be falling. (Note that Croll believed that a glacial period in the Northern Hemisphere would be accompanied by an interglacial in the Southern Hemisphere, and vice versa; see the frontispiece to *Climate and Time*.)

The jury is still out on how the effect of Croll–Milankovitch cycles on seasonal variations in the Northern Hemisphere can be transmitted to the Southern Hemisphere. However, it seems likely that the answer lies with the ocean – either the rates at which it takes up CO₂, or the pattern of its vertical, density-driven circulation – the circulation whose existence was denied by Croll but so vigorously expounded by Carpenter.

As for the role of CO₂, the first person to link periods of extensive ice caps to astronomical cycles was John Tyndall. Tyndall measured the absorption of infra-red radiation by CO₂ and water vapour, and put down his thoughts about water vapour as what we would call a 'greenhouse gas' in a paper entitled 'On Radiation Through the Earth's Atmosphere'. This was published in the *Philosophical Magazine* in 1863, the year before Croll published his paper on 'the physical cause of the change of climate during geological epochs' in the same journal.

Today, the term 'Ice Age', which Croll used to describe a period of extensive ice caps, is used to mean any period when there are permanent ice caps on the Earth; when these ice caps are at a maximum, there is a *glacial* period, when they retreat there is an *interglacial*. Today we are probably still within the Pleistocene Ice Age, though experiencing the relative warmth of an interglacial. Ice Age (as opposed to glacial) are believed to occur when, because of the distribution of continents on the globe, one or both poles are thermally isolated from the warm currents which flow poleward from lower latitudes. Today, the vast continent of Antarctica prevents southward flowing currents from approaching close to the South Pole, while the Arctic Ocean is almost entirely surrounded by land, preventing most of the warm Gulf Stream/North Atlantic Drift Water from penetrating the Arctic Ocean. Croll's ideas about the importance of surface current flow appear to be vindicated.

International Geological–Geophysical Atlas of the Atlantic Ocean edited by G.B. Udintsev (1989–90). IOC (of UNESCO), Ministry of Geology of the USSR, Academy of Sciences of the USSR, Main Administration of Geodesy and Cartography, under the Council of Ministers of the USSR, Moscow (1989–1990) (hard cover, ISBN 5-85120-001-4)

This is a large book, both in physical form, and in breadth of concept. Even for an atlas, it is large at 65 cm x 45 cm and needs a generous amount of desk space to peruse when open. It presents a huge wealth of information on the Atlantic, ranging from a review of the history of oceanographic exploration to surveys of ocean floor sediment composition. According to the dust jacket, the Atlas was compiled under the auspices of the Intergovernmental Oceanographic Commission (IOC) of UNESCO and is thus the product of a truly international collaboration. It complements the similar Atlas of the Indian Ocean published in 1975, and that of the Pacific Ocean, which is still in preparation.

The costs of publishing the Atlas, which must have been very large, were heavily subsidized by grants from the USSR Ministry of Geology, the Academy of Sciences of the USSR, and the government of the USSR. Sadly, given the recent fragmentation of the USSR, it seems unlikely that there will be any similar large-scale scientific publication ventures from that quarter for a long while. The Soviet ancestry of the Atlas is evident in its presentation: the text is bilingual in Russian and English, as are the captions on all the numerous charts and figures. These are beautifully presented in full colour, and are clearly the products of highly skilled and committed cartographers. (Incidentally, the quality of the English translations is also excellent, unlike many books originating in the USSR.

Anyone with the most fleeting interest in oceanography would find the Atlas useful. There is an introductory section which provides an overview of techniques, giving, for example, illustrated outlines of deep-sea drilling methods and the various submersibles in use around the world. Several beautiful charts of bottom topography follow, covering the North and South Atlantic. These are intermingled with maps of geomagnetic data, free-air gravity anomalies and sea-surface heights. Some selected areas are presented in more detail, for example,

BOOK REVIEWS

the area off north-west Africa which includes the Canary Islands and Madeira. The last part of the Atlas deal largely with geological aspects, presenting structural cross-sections, maps of sediment thickness, chemical composition of bottom sediments. As a splendid additional bonus, the Atlas includes a loose-leaf copy of the *General Bathymetric Chart of the Oceans*, produced by the Canadian Hydrographic Service.

Without doubt, the Atlas is a major achievement, and will be invaluable for anyone seeking data on the Atlantic. It contains such a wide range of disparate data, so well presented, that it is a pleasure simply to browse through it, discovering fresh insights in each chart. There are some problems, however. Given its size, the Atlas is inevitably unwieldy, and difficult to consult on the average academic's cluttered desk. Secondly, there is no doubt that it is in places distinctly dated. The nominal publication date is '1989–1990', and it is clear that some of the figures and diagrams had been maturing for a long while prior to that. There are no references more recent than 1987 in the extensive bibliography, and most are much older, dating back to the 1960s and 1970s. Given that it is an archive of data, it is only proper that the Atlas should refer to so much non-current data, but science moves on rapidly, and readers looking for up-to-date observations and ideas will not find them here.

The coverage is also rather patchy. There are a lot of data, for example, on ocean-floor sediment thickness and composition, but almost nothing about the structure of the Mid-Atlantic Ridge, or indeed anything on seamounts or submarine volcanology. This omission is quite striking. One gets the impression that the compilers had somehow overlooked the fact that the Atlantic is actively opening. The nearest the Atlas gets to recognizing the existence of sea-floor spreading are charts of heat-flow data, earthquake epicentres, and basalt glass composition. These charts are excellent in themselves, but are only part of the story. They would have been much more useful if combined with results of recent studies of processes taking place on and off the ridge axis. In part, this omission may be merely an accident of timing, but it may also represent a philosophical bias on the part of the Soviet compilers. Plate tectonics

and sea-floor spreading took far longer to take root in the USSR than they did in the west, and this may have had a lingering effect on the compilers. Whatever the case, fresh breezes are now blowing through the research institutes of the former USSR. Where they bring new ideas and ways of thinking, they will be welcome. The tragedy is that these same breezes have swept away the stable funding base that permitted the production of this splendid Atlas.

Peter Francis
The Open University

Enquiries about purchasing this Atlas should be sent to the Secretary IOC (for the attention of Chairman CGOM), UNESCO, 1 rue Miollis, 75732 Paris, Cedex 15, France. (The UK price is £100 + postage and packaging.)

The Deep Sea Bed: its physics, chemistry and biology edited by H. Charnock, J.H. Edmond, I.N. McCave, A.L. Rice and T.R.S. Wilson (1990). The Royal Society, 194 pp. £42.50 (hard cover, ISBN 0-85403-411-0)

This volume is a compilation of papers presented at a Royal Society Discussion Meeting held in April 1989, so this review will appear rather late in the day for specialists on the deep sea who know about developments since publication. But for us ordinary mortals it is a wonderful book with all sorts of interesting information and lots of useful references. The benthic boundary layer of the deep ocean, on which this book focusses, covers over half the planet's solid surface, yet till a few decades ago nobody even knew it existed.

The benthic boundary layer is in some respects analogous to the mixed surface layer at the other end of the open-ocean water column. It is tens of metres thick and separated from the ocean interior by a steep density gradient; it is more-or-less homogeneous with respect to temperature and salinity, because of turbulent mixing caused by tides and currents which give rise to eddies ('abyssal storms') and re-suspend bottom sediment, so that the layer is more turbid than the ocean above (hence the commonly used term 'bottom nepheloid layer'). Interestingly, Ekman pumping causes thinning of the layer in anticy-

clonic eddies (and ejection of water and suspended sediment from the layer) and thickening in cyclonic ones, the opposite of what happens in the mixed surface layer. Fronts can develop in the layer, and internal gravity waves generated particularly along the density discontinuity at the upper boundary contribute to mixing of bottom water and, where the layer intersects the base of the continental slope, to sediment re-suspension.

Not surprisingly, perhaps, both biomass and diversity are much greater in the benthic boundary layer than in the ocean above, on account of the increased availability of food — after all, everything that survives descent through the water column ends up there. Current speeds near the bottom (centimetres to tens of centimetres per second) are an order of magnitude or two greater than settling velocities of particulate organic matter, so particles arriving at the sea-bed tend to be 'blown' at the benthic fauna rather than just raining down on them — more like a blizzard than a drizzle.

Deposit-feeders are mainly epibenthic, but in some regions bioturbation extends to a depth of 10 cm, with some burrows over twice that deep. Bacteria are known to occur down to at least 80 m below the sea-bed; these seem more likely to be bacteria that have migrated down through pore waters than to be descendants of those that colonised the sediments when they were deposited millions of years ago.

The sediment pile is oxygenated down to a metre or more, much more than the millimetre to centimetre thickness of oxic layers in shelf and inshore waters. Rates of consumption of oxygen in the sediments determine the distribution of manganese and other transition metals in pore waters as well as influencing rates of sediment diagenesis.

Much of the benthic boundary layer is below the carbonate concentration depth (CCD), so most of the dissolution of calcareous planktonic remains occurs within it (actually on the sea-bed itself). Rates of carbonate dissolution depend in part on rates of consumption of organic matter by benthic animals and micro-organisms, but must be determined largely by the amount of atmospheric CO₂ dissolved at the surface in areas of deep-water formation (carbonate dissolution neutralises this CO₂ and prevents rapid return to the atmosphere). Turbidity currents provide useful natural laboratories for the study of carbonate dissolution, as they transport carbonate-rich sediments from continental shelves to below the CCD.

The thirteen papers in this book include reviews as well as accounts of new work, and although most have interdisciplinary overtones, they can be broadly classified into three groups: five on physics of water and/or sediments; four on biology (including bacteria) both on and within the sea-bed; and four on chemistry, two about carbonate and two about manganese and other transition metals. There is not much for the geo-enthusiast, i.e. nothing about deep-sea volcanics or hydrothermals, but that is an observation not a criticism. As I said, it's a great book, one for dipping into rather than for bed-time reading. It deserved another plug — and this review is one way of providing one.

John Wright
The Open University

Souverains Océanographes: Dom Carlos I, Roi de Portugal, Albert 1^{er}, Prince de Monaco edited by Jacqueline Carpine-Lancre and Luiz Vieira Caldas Saldanha (1992). Foundation Calouste Gulbenkian, Lisbon. 178 pp. (paperback)

This volume tells the story of the oceanographic collaboration of two European sovereigns at the turn of the century, through their correspondence with each other. Prince Albert of Monaco already holds a distinguished place in the history of oceanography, both because of his own contributions to the science and because of his endowment of scientific institutions which are still active today. The work of King Carlos of Portugal is less well known outside his own country. His love of seafaring turned to a more scientific interest in the sea after his first meeting with Prince Albert in 1894. Albert's visit to Portugal was made at least partly in the hope of winning support for his project of founding a high-level meteorological observatory in the Azores but had the unforeseen result of establishing a close scientific collaboration and friendship which lasted until Carlos was assassinated in 1908. In the intervening years they corresponded frequently, and the letters dealing with oceanographic topics are reprinted in this handsome and well-illustrated volume. The editors are Jacqueline Carpine-Lancre, librarian of Prince Albert's sumptuous Musée Océanographique and an expert on his life and work, and Luiz Saldanha, ichthyologist and historian of marine science and natural history collections in Portugal.

The letters, arranged by year, and accompanied by full introductions, notes and references, give a lively picture of the interests of the two writers and show how the two men differed. Prince Albert was a world leader and innovator in oceanographic research for over 30 years and his expeditions ranged widely both in area and in the topics they covered. Dom Carlos was more restricted by the affairs of a larger and developing nation and died while still relatively young. He concentrated on investigating the seas off the coast of Portugal as an area of national importance and sought advice from his senior colleague about how this might best be done. The exchange of news and views about ships and expeditions, scientific projects, ideas and techniques, provides a fascinating insight into a period when oceanography was rapidly developing and into a scientific collaboration between two enthusiasts that must be unique in the annals of science.

Margaret Deacon
Department of Oceanography
University of Southampton

Souverains Océanographes is obtainable from Musée Océanographique, Avenue Saint-Martin, MC 98000 Monaco; the price of 250 FF (which includes post and packing) is payable in French francs only.

Oceanography in the Days of Sail
Ian Jones and Joyce Jones (1992). Hale & Iremonger (distributed in the UK by Turnaround Books), 288pp. £30 (hard cover, ISBN 0-86806-377-0)

This is not the general history of oceanography before about 1900 implied by the title. The authors' more limited aim is "to draw together into one volume the story of the development of physical oceanography in the waters of the southern hemisphere," considering that "the waters of the South Seas ... have played an important part in the development of the science of oceanography, not so much because of the contributions of local scientists but because Oceania was the focus of many European scientific expeditions in the enlightened eighteenth and nineteenth centuries."

Just so — the book cannot readily achieve its stated objective for the simple reason that physical oceanography didn't do much of its developing in the Southern Hemisphere; most of that took place in the heads of the European explorers and

scientists who pondered their results and wrote their reports after returning home. So it is not surprising that the book adopts a different strategy — a narrative approach tracing the investigation of these waters in a series of overlapping historical chapters, introducing oceanographic concepts, together with such background details of their development as are needed, by way of frequent digressions. Thus the evolution of knowledge about the temperature and salinity distributions and currents of the region is contained within an historical framework which also includes much about expedition politics and personalities, European naval history, shipboard conditions and navigation. The result is an entertaining medley without a strong theme. This is not to suggest that the story of these expeditions and the oceanographic observations they made around Australasia is anything but fascinating — far from it — and the scientific tale would be a thin one if not filled out with background, anecdote and quotation.

Chapter 1 covers most of the period up to the end of the 18th century (Dampier, Cook, La Pérouse). Chapter 2 deals principally with French explorers of the early 19th century (d'Entrecasteaux, Baudin, de Freycinet, Duperrey, Hyacinthe de Bougainville). In Chapter 3 the Russians appear (Krusenstern, von Kotzebue), together with French explorers of a slightly later period (Dumont d'Urville, Laplace, Vaillant, du Petit-Thouars). Chapter 4 enters more familiar waters with James Clark Ross, Flinders, FitzRoy, Owen Stanley and other British surveyors of the first half of the 19th century. The United States Exploring Expedition of 1838–42 is the main subject of Chapter 5 and Chapter 6 is

mostly about the *Challenger* Expedition. Chapter 7 is an account of the development of Australian marine science since Federation in 1901. The final chapter is a brief summary and the book concludes with a useful list of references and an index; a chronological table to tie the chapters together would have been a worthwhile addition.

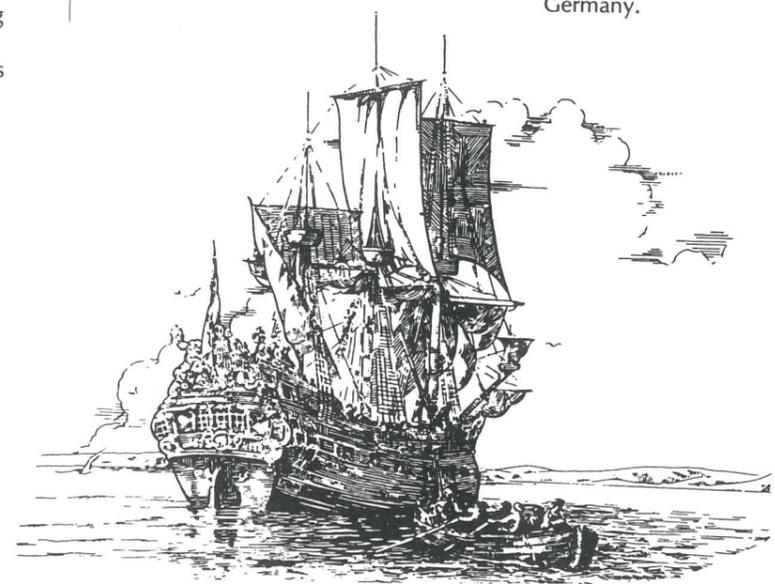
An important feature of the book is its comparison of results from the early expeditions with recent data, showing, for example, the detection of the East Australian Current by James Cook in 1770, and of the Bass Strait Front by the *Challenger* in 1874. The intriguing suggestion is made that 19th-century deep-sea temperature measurements could be used to expand the database for estimating rates of climate change. Due credit is given to the contributions of some less well-known oceanographers of the 19th century, particularly the Frenchmen François Péron and Urbain Dortet de Tesson.

The authors make some interesting comments on the advent of steam propulsion, to which they attribute a temporary decline of interest in ocean physics whilst observing that it also brought about a drop in the real cost of operating research vessels. They also remind us that the advantages of power for station-keeping and speed on passage could be outweighed by a shortage of bunkering facilities in remote areas — in Australia, oceanography's 'days of sail' were prolonged to 1960 by CSIRO's diesel auxiliary schooner *Derwent Hunter*.

Oceanography in the Days of Sail suffers from inelegant typography and poor layout. And how can the standard of book illustration in the 1990s be so much worse than it was two centuries ago? Nevertheless, this is a useful addition to the very small number of books on the history of oceanography written for a non-specialist audience, not least because of its fresh, antipodean, point of view. What Susan Schlee did for the USA with *A History of Oceanography* in 1973, the Joneses have now done for their homeland. But their work should have been sub-titled 'an Australasian perspective'.

John Phillips
The Open University

Readers interested in the history of oceanography might like to know about a relatively new publication, *Historisch-Meereskundliches Jahrbuch*, edited by Walter Lenz and Burkhard Waterman. Articles in the first Volume (1992; ISBN 3-496-005998) deal with polar whaling (G. Peters), early plankton research (B. Lohff), Anton Dohrn and Helgoland (P. Werner), the politics of the Gauss expedition (C. Lüdecke), testing of Knudsen's tables (J. Smed), the politics and science of the North Sea fishery (W. Lenz), and the fate of some German biologists under National Socialism. The volumes are published in Berlin and Hamburg by Dietrich Reimer Verlag. For further information contact Deutsche Gesellschaft für Meeresforschung, Bundesstrasse 55, 2000 Hamburg 13, Germany.



HMS Roebuck, in which William Dampier sailed in search of Terra Australis

THE CHALLENGER SOCIETY'S STRATEGY FOR THE '90s

Mission

The Challenger Society for Marine Science has the following objectives*:

To advance the study and application of marine science in all its disciplines through research and education, and in particular,

- (i) to hold, at regular intervals, scientific meetings for the discussion of all aspects of marine science;
- (ii) to set up specialist groups as required in different disciplines to provide a forum for deeper technical discussions;
- (iii) to disseminate knowledge of marine science to the public with a view to encouraging a wider interest in the study of the seas and an awareness of the need for their proper management;
- (iv) to contribute to public debate on the development of marine science;
- (v) to publish, among other things, news of activities of the Society and of the world of marine science; material intended to present new activities and developments in a way to bring them to public attention; such other papers as may from time to time be deemed appropriate; and
- (vi) to provide or arrange, in suitable cases, financial assistance to students in marine science.

Background

The Challenger Society was formed in 1903, and has a proud tradition of scientific discussion through meetings and through publications. In order to enable increased membership and a more representative and active role, the Society was re-constituted in 1988 as the Challenger Society for Marine Science, registered as a charity and incorporated as a registered private company, limited by guarantee.

Structure

The Society is managed by a *Council* of twelve, comprising a President, an Honorary Secretary, and an Honorary Treasurer (the *Officers* of the Society) and nine members. All Officers and other Council Members are elected by the membership at Annual General Meetings. Normal tenure of Council Membership is three years; Officers may serve up to six years, and the President may serve for no more than two years. The Council has power to co-opt. The Society is affiliated to the European Geophysical Society and is in correspondence with other European societies, The Oceanographer Society, The Royal Society, IAPSO, IACMST, the Royal Meteorological Society, the Society for Underwater Technology, and other societies with marine interests.

*Taken from the Society's Articles of Association.

Membership

In 1992/1993 the Society had about 400 members, representing a substantial proportion of the marine scientific community in the UK, especially in Universities, in Research Council Institutes, in Government Laboratories and also in commercial companies.

Society policy is to increase and broaden the membership to become a clear majority of this community. This will strengthen the Society and give it a stronger voice at both national and international levels.

Activities of the Society

Scientific Meetings

Meetings are an important forum for the dissemination of information and for the stimulation of intellectual debate. They are also valuable for keeping touch with modern developments in the subject as a whole.

The Society supports a wide variety of scientific meetings every year. These include meetings that are initiated by the Society, and also meetings that are co-sponsored with other societies having common interests.

The Challenger Society aims to create a balance between the different disciplines which make up the subject, while covering important trends in UK research in a timely manner.

An important meeting in the Challenger Society's calendar is the residential UK Oceanography meeting, held for one week in September in alternate years at different venues associated with marine science nationwide. Presentations are encouraged across the whole field of marine physics, chemistry and sedimentology and in biological oceanography. Students and young scientists are especially encouraged; an informal atmosphere is intended, and the *Norman Heaps Prize* is awarded for the best oral presentation by a young scientist. The *Cath Allen Prize* is awarded for the best poster presentation.

The Society welcomes suggestions from members for suitable meeting topics.

Ocean Challenge

Ocean Challenge, the Society's publication, is a vital part of Society strategy, aimed at educating people and promoting interest in the oceans and their management. Articles and news items cover the whole range of marine-related science, with the aims of keeping readers up to date with progress in oceanographers who wish to broaden their knowledge and to informed lay persons interested in the marine environment. With three-year publication experience in hand, the time is right for the Society to make greater use of *Ocean Challenge* in attaining its objectives.

A Voice for UK Oceanography

The Society consults its members and other interested societies on major issues concerning marine science, and respond on their behalf to the Inter-Agency Committee on Marine Science and Technology and to the Office of Science and Technology.

The Society advises the Royal Society on marine science affairs in the UK, and also prepares the UK National Report for the quadrennial meetings of IAPSO.

The Society seeks to promote greater cooperation with equivalent societies in other European countries, aiming towards some form of European 'Union of societies.'

Education

The educational activities of the Society are concerning mainly with school and popular marine science education. Responsibility for the training and formal education of professional marine scientists rests with employers and Higher Education Institutions. The Society's Education Committee includes representatives of the Committee on the Public Understanding of Science (COPUS), the British Association Youth Section, the Open University, the Society for Underwater Technology and the Geographical Association. The Committee's aim is to promote marine science education as widely as possible, focussing particularly on ways of arousing interest in primary schools, incorporating marine science in the *National Curriculum* and raising marine literacy and awareness among the general public. Seminars, courses and workshops for teachers and pupils will be organized, and educational material in the form of study packs, work sheets and resource guides will be prepared.

Affiliated Groups

An important role of the Challenger Society is the encouragement of specialist groups covering a diverse range of topics in marine science. There are at present six such groups: Air-Sea Interaction; British Group of Altimeter Specialists; Marine Chemistry; Ocean Modelling; Offshore Biology; and Sediment Dynamics. The Affiliated Groups provide a means of encouraging informal meetings in specialist areas of marine science, in many cases near boundaries of common interest to other societies. They also play a valuable role in encouraging young scientists.

A limited quantity of funds is normally available for sponsorship of Affiliated Group activities.

A Framework for New Activities

New ideas for progress in marine science can often benefit from informed advice and from endorsement by a nationally known body such as the Challenger Society. If such ideas or plans are in accordance with the Aims and Objectives of the Society, then the Council may be able to offer such support.

A Focus for Donations

As a registered charity with worthy aims in the public interest, the Challenger Society is well placed to receive charitable donations or legacies which are directed towards accomplishment of its activities.

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.

Membership provides the following benefits:

An opportunity to attend, at reduced rates, the biennial four-day UK Oceanography 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).

A list of names and addresses of all members of the Society.

MEMBERSHIP SUBSCRIPTIONS

The subscription costs £25.00 (£12.00 for students in the UK only). If you would like to join the Society or obtain further information, contact the Challenger Society Membership Secretary, IOS Deacon Laboratory, Brook Road, Wormley, Godalming, Surrey GU8 5UB, UK; Tel. 0428-684141; Fax 0428-683066

COUNCIL FOR THE CHALLENGER SOCIETY 1993/4

President

Brian McCartney
Proudman Oceanographic Laboratory

Honorary Secretary

Howard Roe
IOS Deacon Laboratory

Honorary Treasurer

David Carter
*Institute of Oceanographic Sciences
Deacon Laboratory*

Barry Heywood

Tony Heathershaw

John Jones

Vince Lawford (Marketing)

Martin Preston

Howard Roe

John Scott

John Simpson

Paul Tyler (Membership)

Simon Wakefield (Meetings)

Malcolm Walker (Chairman, Education Committee)



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). Manuscripts should be double-spaced and in a clear typeface.

For further information, please contact the Editor: Angela Colling, Department of Earth Sciences, The Open University, Walton Hall, Milton Keynes, Bucks MK7 6AA, UK. Tel: 0908-653647; Fax 0908-655151.