The History

of

GEBCO

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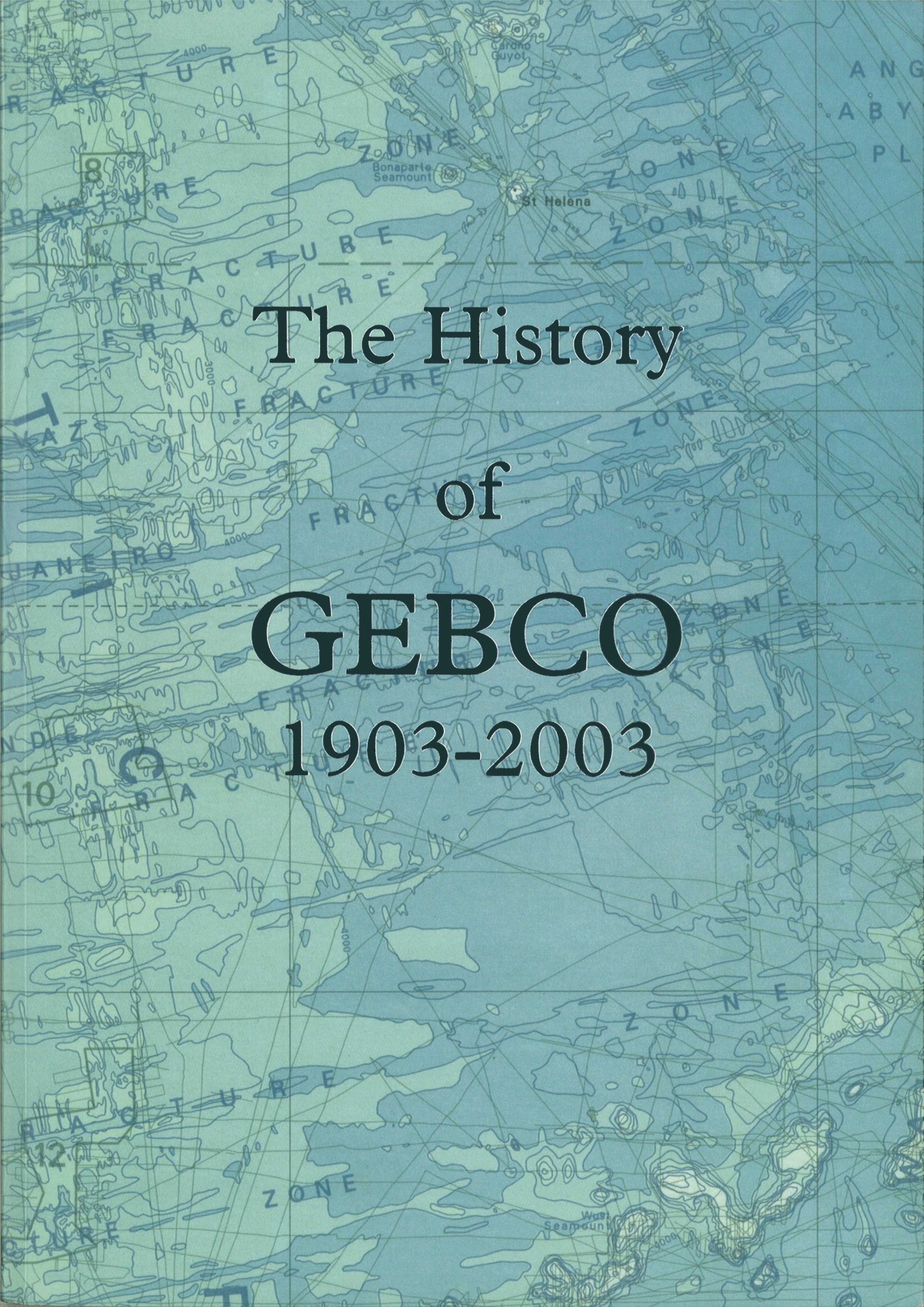

The History of GEBCO 1903-2003

The 100-year story of the GENERAL BATHYMETRIC CHART OF THE OCEANS

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The History of GEBCO

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The History of GEBCO
1903-2003

Palais de Monaco

The history of the General Bathymetric Chart of the Oceans is the result of the persevering endeavours of my great grandfather, Prince Albert I, to achieve the publication of its first edition. Its subject matter covers many fields of interest.

Within the history of science, beginning in 1870 through to the First World War, oceanography became autonomous from geography of which it originally seemed to have been a subdivision.

For an uninterrupted period of a century, there are but few instances attesting to a close interdependence between science and technology. At the beginning, the Chart was written to satisfy a legitimate scientific curiosity. Also, the possibility then of drawing up a Chart and to insert therein accurate information required the following 'sine qua non' conditions: the ever improving oceanic precision instruments and methodology. The evolution of technology at an accelerated pace during the 20th century (sounding, positioning, gathering and interpretation of information) was one of the most remarkable demonstrations derived from the progress achieved in precision instruments and oceanographic methodology.

During and after the Second World War, the importance of underwater navigation added a military value to bathymetric information. As a result of this situation, particularly during the 'Cold War', bathymetric information was 'classified'. This was, in effect, detrimental to scientific research and made it all the more difficult to elaborate new accurate and up-to-date editions of the General Bathymetric Chart of the Oceans.

More recently, new economic and legal dimensions have resulted in an increased interest of the Chart. Bathymetric science was thus encompassed within the rules of the «The Law of the Sea» relating to areas in which States exercise their sovereignty and their rights of exploitation of the seas.

Those successive developments demonstrate the difficulties encountered in the realization of the Chart. Its international status, present from the beginning, increased: however, the competence and the good will of a restricted number of specialists could no longer control the influx of information gathered at a time when sounding and ultra-sounding techniques were being used. Dr. Richard, following Prince Albert's instructions, used clever judgement in transferring his responsibilities to the International Hydrographic Bureau which, in 1921, the Prince established in Monaco.

It is appropriate at this time to mention the outstanding tasks performed by Prince Albert with regards to the conception and the realization of the first two editions of the General Bathymetric Chart of the Oceans. He referred to the Chart in the several conferences he held in many European countries. In 1903, the characteristics of the Chart having been defined at a meeting in Wiesbaden, he mentioned this enterprise in each one of his talks. In his 'Exposé about the Ocean' held in Washington in 1921, he emphasized the importance of the Chart and the upheavals that new sounding techniques would bring about in establishing it.

Due to his position and the relationships he maintained with other Sovereigns and Chiefs of State, the Prince was able to obtain bathymetric information rather quickly from a variety of ships, namely military, scientific, commercial and cable-laying vessels. Additionally, the confidence he placed in arbitration to solve delicate problems caused him to act as a mediator between the two scientific tendencies which clashed with one another regarding submarine nomenclature, namely an uncompromising dogmatism opposed to pragmatism, the latter hostile to a yet necessary standardization.

Professor Thoulet, the driving force behind the General Bathymetric Chart of the Oceans and close collaborator of Prince Albert, had perfectly foreseen the future of the Chart when he wrote: "The Chart is a document which aims continually towards perfection all along its successive publications, but it shall never be finished".

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This book is a legacy to the vision of Prince Albert the precursor in this and other domains. Let me express my thanks to its writers for their tribute to him, as well as to all those - in his time or since then - who pursued his task.

February 2003.

His Serene Highness Prince Albert I of Monaco (1848-1922)

(From the collections of HSH the Sovereign Prince of Monaco)

Preface

Maps and exploration go hand in hand. The one feeds off the other. Explorers need to know roughly where they are going, and in turn define better the territory they have explored. This is as true under the oceans as on land. The nineteenth century saw an explosion of interest in the natural world – expeditions to the remoter parts of the continents, the collection and classification of plants and animals, rocks and sediments – together with an increasing understanding of the processes creating it. But the greater part of the world's surface under the oceans was largely unknown. It was natural therefore, as attention turned to the geology of the ocean floor, to the movement of the waters in the oceans, to life in the deep and to the chemistry that supported it, that there should be a demand for maps describing the shape of this hidden world.

At the turn of the century, a group of far sighted geographers and oceanographers, under the leadership of Prince Albert of Monaco, initiated the preparation of a global series of charts which contoured the relatively few deep sea soundings taken by lead line, a project that became known as the General Bathymetric Chart of the Oceans – or GEBCO.

This year we celebrate one hundred years of GEBCO, not only looking back over its fascinating and varied history, but also looking forward to the increasing demand today for detailed and accurate charts of ocean floor morphology, in a form that can be easily used in the age of computers and process modelling.

The products of the last century have been achieved under the patronage of the Princes of Monaco, the International Hydrographic Bureau, the Institut géographique national of France and the Intergovernmental Oceanographic Commission. But little progress would have been made in the last three decades without the voluntary efforts of many other national and international organisations, and the dedicated enthusiasm of numerous individuals throughout the world, to whom GEBCO owes a great debt of gratitude.

This volume reflects the development of the project during the twentieth century and has been largely written by those who have been involved. The editor, Desmond Scott, as Secretary of the IOC, negotiated in 1973 with Rear-Admiral Steve Ritchie, President of the IHB, the coalition of oceanographers and hydrographers to ensure that science and technology worked together. Jacqueline Carpine-Lancre, specialist in the history of oceanography, presents the historical perspective of the early days of GEBCO. Later chapters have all been written by past and present members of the GEBCO family, reflecting their own input to the project.

I am honoured to have been involved with one of the longest standing hydrographic and oceanographic projects, and hope that this volume will provide a backcloth for understanding the historical development of ocean science.

Sir Anthony Laughton
Chairman GEBCO

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Introduction

The Seafloor

The seafloor occupies more than twice the area of the land; relative to sea level, its average depth is 3,800 metres whereas the average height of the land is 840 metres. Its flat areas are larger and flatter; mountains, valleys and trenches are more rugged, have higher relief and are more extensive. The continental blocks are very thick (more than 30 kilometres) and are as old as 4,500 million years, whereas oceanic crust is ~7 kilometres thick and is nowhere known to be older than ~200 million years. The incidence and intensity of earthquakes and volcanic activity clearly indicate that it is in the oceanic crustal areas and their Pacific margins that on a global scale there is the greatest activity.

From geophysical evidence gathered mainly from the ocean floors, the theory of plate tectonics, following on from Wegener's earlier theories of continental drift, was developed during the 1960s. It has provided a comprehensive and reasonably consistent explanation for the above, and many other, contrasting relationships between continents and ocean basins, and it revolutionized the earth sciences. Plate movements are driven by forces acting on the lithospheric plates which have continuously generated new oceanic crust at the site of seismically active mid-ocean ridges, and simultaneously caused the destruction of older oceanic crust in deep marginal seismically active trenches; these are a feature of Pacific bathymetry.

Some concentrated zones of thermal energy transfer and mineralization from subcrustal sources have been located on the mid-ocean ridge system where new ocean crust is being formed; the floors of some deep ocean basins are strewn with nodules enriched in manganese, nickel and cobalt; nodules rich in phosphate suitable for fertilizer production have been found on some continental shelves which are in addition the scene of intensive hydrocarbon exploration and, in some areas, are already being exploited in water depths of up to 2,000 metres. Movement of deep, and surface, ocean currents are modified by seafloor relief features.

As on land, a basic prerequisite for good planning and management of any area and its resources is a good topographic map constructed from familiarity with the terrain and the processes which have shaped it, and access to the maximum amount of accurate basic data. This has been provided over the past century, to the limits imposed by technological developments at the time, by the General Bathymetric Chart of the Oceans (GEBCO). The oceans and their floors are potentially exploitable on a larger scale than is the case at present and, especially in the case of renewable resources, further exploitation will require careful regulation based upon knowledge, understanding and good management under the legal structure provided by the United Nations Convention on the Law of the Sea, which confers responsibilities upon many States to which they are, as yet, unused.

GEBCO - A Century of Ocean Mapping

During the 18th and 19th centuries there had been a number of individual initiatives, two of which should be particularly mentioned: publication of the 'Physical Geography of the Sea' (1855) by Matthew Fontaine Maury which included an updated version of his first bathymetric chart of the North Atlantic (fig.16), and the highly successful achievements of the "Challenger" Expedition (1872-1876).

Following these initiatives, a proposal was made by two German geographers, Professor Hermann Wagner and Professor Otto Krümmel, to the 7th International Geographic Congress held in Berlin in 1899 for the development of an international agreement on nomenclature and systematic terminology for sub-oceanic relief features. In response, the Congress nominated a Commission which was 'charged with the preparation of a bathymetrical map of the oceans, in accordance with the purpose of the committee' (sic English text only).
The importance with which this project was seen is clear from the fact that eight of the leading geographers and scientists of the day were appointed by the Congress to form the Com-

mission. With one death and some minor changes, the members of the Commission, though having different levels of interest and participation, set about developing the first edition of the GEBCO.

However, as has been the case with the GEBCO over its whole history, little in the way of financial support was forthcoming and it was not until the April 1903 meeting, that, due largely to the scientific competence and experience of Professor Julien Thoulet of the University of Nancy, His Serene Highness Prince Albert I of Monaco offered to organise and finance the production of a new series to be designated 'la Carte générale bathymétrique des océans' (the General Bathymetric Chart of the Oceans): GEBCO. This then was the origin of the GEBCO.

A remarkable photograph (fig.1) from the archives of the Musée Océanographique, Monaco, of the first meeting of the international Commission, Wiesbaden, 15-16 April 1903, chaired by HSH Prince Albert, shows five other members, together with Enseigne de Vaisseau Charles Sauerwein, later to become Prince Albert's aide-de-camp. It is this date that has been taken into account in declaring the centenary of GEBCO, and the decision to hold a Centenary Conference in Monaco, 14-16 April 2003, 100 years to the day from this inaugural meeting.

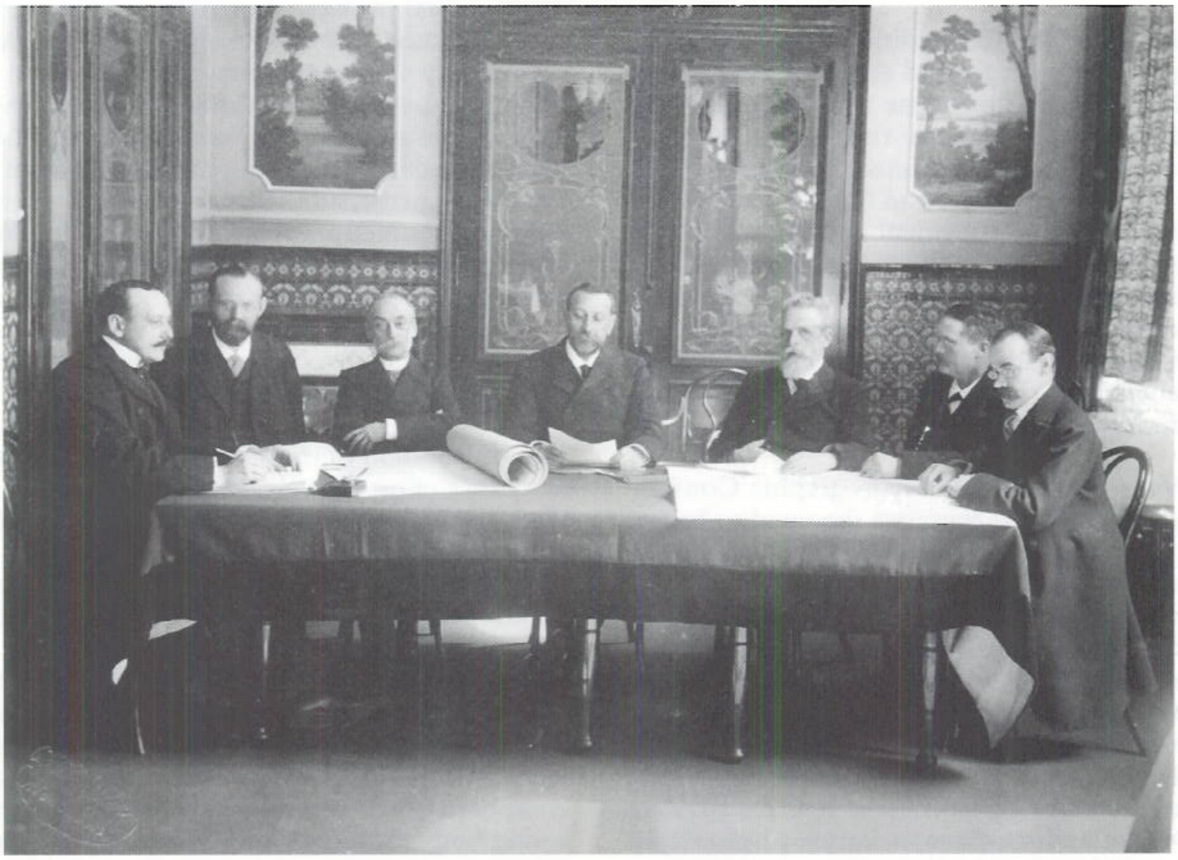
The first edition of GEBCO was based largely on listings published by the French and British Hydrographic Offices, the great majority of which came from cable-laying ships, together with data from many oceanographic cruises and polar expeditions. Its production in just on two years resulted from the energy and drive of the Chief Cartographer, Alphonse Tollemer, his deputy Jean Morelli, and their team of draughtsmen. The resulting chart series was received with satisfaction (and thanks to Prince Albert), by the 8th International Geographic Congress in Washington DC and New York, and the first edition was published in May 1905. However, it came in for some criticism, in particular from two of the Commission members, Professors Alexander Supan and Otto Krümmel, and also from another leading geographer/geologist of the day, Professor Emmanuel de Margerie, who subsequently became responsible for inserting the land relief on the second edition. Prince Albert's 'Cabinet scientifique', now under the direction of Lieutenant de vaisseau Henri Bourée, had continued with their compilation work; they had by now double the amount of data to work with, and they were also able to take into account the criticisms made about the first edition.

On the occasion of the inauguration of the Musée Océanographique at Monaco in 1910, Prince Albert called together another international commission of experts to discuss the guiding principles to be followed for the second edition. This edition was then started and eleven sheets were published between 1912 and 1914 before production had to be halted owing to the First World War. Emmanuel de Margerie became heavily involved in this production and Gerhard Schott became the main reviewer of the bathymetry.

Prince Albert died in 1922 and, in accordance with the wishes expressed in his will, responsibility for the GEBCO then passed to Dr Jules Richard, Director of the Musée Océanographique. His achievement in completing the series deserves considerable credit, though it was not until 1931 that the final sheet of the Second Edition could be published.

By now the days of the echo-sounder had arrived and the sheer volume of sounding data was overwhelming the resources and handling capacity of the Musée Océanographique. The International Hydrographic Bureau had been established in 1921, and Dr Richard soon looked to the Bureau to take over responsibility for the GEBCO; however he accepted that this would not be until his own task of producing the second edition had been completed.

At the 1st Supplementary International Hydrographic Conference in 1929 the Bureau was charged with 'keeping up-to-date' the GEBCO and this led to the development of a logistical system to handle the increasing volume of data that was becoming available. The third edition was compiled by the IHB staff, while Hydrographic Offices of Member States were requested to supply all available oceanic soundings. Discrete wire soundings were still being collected by ships that could stop on station for lengthy periods of time, and they were few enough for it to be possible for them to be published in the form of lists by the major national Hydrographic Offices. Echo-soundings, however were submitted on a new series of plotting sheets on Mercator projection at a scale of 1:1 million, and were then collected on to a worldwide series of master sounding sheets maintained by the Bureau. This system lasted until 1962 when responsibility for maintaining the 1:1 million scale plotting sheets was divided



Commission de nomenclature sous-océanique
pour une Carte générale bathymétrique des océans
Wiesbaden, 15 - 16 avril 1903
(Au centre le Prince Albert 1er de Monaco,
á sa droite MM. J. Thoulet, O. Krümmel, C. Sauerwein
á sa gauche MM. A. Supan, O. Pettersson, H.R. Mill)

Fig. 1. (Collection: Musée Océanographique, Monaco)

amongst eighteen Volunteering Hydrographic Offices (VHOs).

Publication of the third edition started in 1932 but again work progressed slowly. There was a lengthy hiatus due this time to World War II, and this, together with the rising flood of new data, were contributing factors. However, the main reason was the lack of financial support which restricted deployment of resources to a single draughtsman, so it was not until 1955 that the edition was declared finished. Even then only 18 sheets had been actually published, though three of the polar sheets were published later (1968-69) after the fourth edition had been started.

The Sixth International Hydrographic Conference in 1952 had recognised the need to bring out a fourth edition of the GEBCO and, due to the rapidly increasing amount of new data becoming available, the Conference had proposed a 5-year cycle for updating the various sheets. However it soon became clear that this was beyond the resources available to IHB, so in 1962 responsibility for the maintenance of the plotting sheets was transferred to the VHOs and in 1965 an agreement was reached between the Bureau and the French *Institut géographique national* (IGN) by which the latter took over responsibility for drawing the contours, cartographic compilation, printing and sales of the GEBCO, with the IHB acting as co-ordinator for the whole project. A GEBCO Committee was formed to take responsibility for verification and correction of geomorphological details. With this structure the final three sheets of the third edition and four sheets of the fourth edition were published between 1966 and 1970. However by this date adverse criticism from the scientific community had resulted in a complete fall in demand, and suggestions were being made that the whole GEBCO project should be abandoned.

It was at this time that the oceanographic community first became actively involved. A world bathymetric chart was clearly needed but the GEBCO, as then being provided by the third and fourth editions, was unsuitable for their (or, as it appeared from the sales figures, anyone else's) requirements. The International Council of Scientific Unions (ICSU) had formed a Special (later Scientific) Committee on Oceanic Research (SCOR), initially to oversee the International Indian Ocean Expedition, and in 1972 SCOR Working Group 41 - Morphological Mapping of the Ocean Floor - was established 'to determine a rational scheme for the reduction and presentation of sounding data that would constitute a framework in which the international geological mapping of the sea floor could proceed.' The Working Group reported on 1st May 1973 and a new structure for GEBCO, including members of the oceanographic community, was formed based on these recommendations, leading to abandonment of the existing structure and to the preparation of a new, and much more acceptable, fifth edition which was completed in 1982, followed by a world sheet two years later.

The GEBCO Structure

The preparation of the Fifth Edition was a collaborative effort between the International Hydrographic Organization (IHO) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO, with the IHO responsible for co-ordinating the efforts of the Hydrographic Offices in its Member States and the IOC responsible for attracting eminent marine geologists and geophysicists to collaborate in the work of GEBCO. Supervision of the project was provided by a Joint IOC-IHO Guiding Committee, composed of ten members, five from each sponsoring body. Amongst the IOC members were representatives of the Scientific Committee on Oceanic Research (SCOR), the Commission for Marine Geology (CMG) of IUGS and the International Association for the Physical Sciences of the Ocean (IAPSO). This series was printed by the Canadian Hydrographic Service.

Initially, the IHO collection of bathymetric data was still being hand plotted on a worldwide series of hard copy Collected Soundings sheets, maintained by a network of Volunteering Hydrographic Offices, each with its own area of responsibility. However as data volumes increased, it became increasingly more difficult to keep the sheets regularly updated. To overcome the problem, an IHO Data Centre for Digital Bathymetry was set up, co-located with the US National Geophysical Data Center in Boulder, Colorado, taking advantage of their well-developed computerized system for the banking of underway geophysical data on a global basis.

The GEBCO has also inherited international responsibility for the naming of undersea features falling outside territorial waters, working closely with appropriate national authorities, and a digital Gazetteer of Undersea Feature Names is maintained on behalf of GEBCO by the International Hydrographic Bureau in Monaco.

The GEBCO Digital Atlas (GDA)

In order to establish a digital base for the updating of GEBCO, and to provide a more flexible product for users, the GEBCO Guiding Committee decided in 1983 that the printed sheets of the Fifth Edition should be digitized and published as a CD-ROM, known as the GEBCO Digital Atlas (GDA). The bulk of this work was carried out by the British Oceanographic Data Centre (BODC) and the *Bureau gravimétrique international* (BGI) in Toulouse, France, although invaluable contributions were also made by the Natural Environment Research Council (NERC) Unit for Thematic Information Systems, Reading, United Kingdom, the Head Department of Navigation and Oceanography, St Petersburg, Russian Federation, the Alfred-Wegener-Institut für Polar- und Meeresforschung, Bremerhaven, Germany, and the Japan Oceanographic Data Center, Tokyo. Final editing, quality control and reformatting into a uniform data set was carried out at the BODC.

The updating of GEBCO through the GDA will be a continual process and the atlas will be published regularly as a product in its own right. Without the scale and projection restraints of the printed chart, it is envisaged that improved bathymetric compilations will be merged into GEBCO at scales ranging from 1:10 million up to 1:500,000, depending on the density of sounding coverage. New data will be 'stitched in' so as to maintain a seamless global data set. With each release the vector contours of certain areas where new data have become available are updated, and in addition new products are being added, starting with a global gridded dataset, required as a tool for oceanographic modelling.

Conclusion

The General Bathymetric Chart of the Oceans (GEBCO) has achieved its current status thanks to decades of co-operation by a number of institutions and agencies in Member States of IHO and IOC. There is a growing need for improved knowledge of the bathymetry of the world's oceans, particularly amongst modellers studying the role of the oceans in the global climate system, and both bathymetry and sea floor topography have been recognized as essential components for the Global Ocean Observing System (GOOS).

Swath mapping systems and improved navigation by Global Positioning Systems have resulted in spectacular increases in the rate of sea floor area coverage. Satellite altimetry missions provide invaluable insights into the nature of the topography in uncharted waters or where bathymetric data are sparse. However, the detailed mapping of the sea floor will continue, for many decades to come, to depend on a small band of scientists across the world who are prepared to apply their skills to the interpretation of random tracklines of data from a multitude of sources, having highly variable data quality and coverage.

1- Pre-GEBCO History of Deep-Sea Sounding

by Rear Admiral G Stephen Ritchie CB DSC FRICS

An early attempt at deep sounding

A description of this attempt, together with a woodcut illustration, appears in a *History of Northern Peoples* published in Rome, in Latin, by Olaus Magnus, a Catholic priest who had been virtually exiled by King Gustav Vasa of Sweden when the king accepted the Lutheran creed.

Magnus had travelled widely in Scandinavia, including north-west Norway, so he was able to use his copious sketches and notes for his book published in 1555 to impress southern Europeans that Scandinavia should be saved from the Reformation. In his Book Two, Chapter 12, may be found the illustration (fig.2) and the following paragraph: "Such is the immeasurable depth of water off many of the mountainous coasts of Norway that however long the sounding lines with which they can fill the largest ship, if a leaden plummet is let down no bottom may be found."

An early Oceanographer

Possibly the first man of science to discover that there is a continental shelf that terminates in a steep descent to the abyssal plain was Count Luigi Ferdinando Marsigli who, having studied the surface and sub-surface currents flowing in the Bosphorus, in the years 1706 and 1707 made an oceanographic study of the Gulf of Lions, working from temporary headquarters that he established in the small port of Cassis. The local fishermen, who were employed in trawling for coral from small boats, were willing to take the Count to sea with his lead and line, thermometer and water sampler.

He ran fourteen lines of soundings from different places along the shoreline across the continental shelf, from which he drew profiles. A few soundings between 100 and 150 fathoms showed him where the slope towards the abyss began. He assumed that the continental slope would rise off the North African coast in a similar way to what he had observed off the Gulf of Lions; he forecast in his book *'Histoire Physique de la Mer'* in 1725 that the deepest part of a traverse across the abyss, could it be made, would be found in the latitude of Malta. He regretted that it was presently impossible to run such a traverse. 'Unless', he wrote, 'some Prince orders special ships and adequate instruments for the purpose, this will probably never be done'.

One hundred and sixty years later the Prince of Monaco took up this challenge and pursued it for over thirty years. Captain, later Admiral, Magnaghi, the Italian Hydrographer, made a number of oceanographic voyages in the survey ship *'Washington'* in the 1880s. He was particu-

Fig. 2. Deep-Sea Sounding off Norway, Olaus Magnus

larly interested in the deep areas of the Mediterranean and in 1887 found his deepest sounding of 4,067 metres at 18°E. on the latitude of Malta, as Marsigli had forecast.

Geographical co-ordinates of deep-sea sounding

No deep sea sounding would be of value for the compilation of a bathymetric chart unless its geographical co-ordinates were known. Although the finding of latitude at sea had long been possible using first the astrolabe, then the backstaff, quadrant and sextant, to measure the altitude of celestial bodies, finding longitude was still a problem in the mid-18th Century.

However in 1753 lunar distance tables which forecast the angular distances of certain stars from the moon were devised by Tobias Meyer of Gottingen University; on his death his widow passed these tables to Nevil Maskelyne, the British Astronomer Royal, who published them in 'The Nautical Almanac' in 1767. Meyer had designed an instrument capable of observing the very wide angles often to be observed in lunar observations; the French scientist Jean Charles Borda developed from Meyer's design an instrument known as the 'reflecting circle' which navigators could use for lunar sights, provided they were prepared to undertake the tediously long calculations involved.

A better method had to be found which would entail the invention of a clock which could be used to carry time accurately at sea. John Harrison in England, motivated by an Act of Parliament of 1714 offering a £20,000 reward, and Pierre Le Roy and Ferdinand Berthoud in France, with the incentive of a prize offered by the Académie des Sciences, began inventing timepieces that would operate satisfactorily at sea.

During his lifetime Harrison built five timekeepers, each of which was exhaustively tested on Royal Navy vessels, before he received his award. Even then he had to take his final timepiece to pieces in front of six potential chronometer makers; this then led to active commercial production of seagoing chronometers. In France, Le Roy's timekeeper won the Académie Prize, whilst Berthoud was appointed Inspector of commercially made chronometers supplied to seagoing vessels. Nevertheless it was nearly mid-19th Century before chronometrically controlled sights finally eliminated the lunars.

Maury's contribution

From 1850 when the tug *Goliath* succeeded in laying a cross-channel telegraph cable between England and France, the call for the smoothest and flattest sea bed routes to be found for telegraph cables was the major stimulus for seamen to devise methods for exploring the depths of the ocean. Matthew Fontaine Maury was the Director of the United States Navy's Depot of Charts and Instruments from 1842 to 1861 when, on the outbreak of the Civil War, he resigned and left his office to support the Southern States. He was famous for his 'Wind and Current Charts' and his 'Sailing Directions' which were so beneficial for seamen, but he had an equal interest in the depths and sea bed deposits in the North Atlantic. He had at various times three surveying vessels carrying out deep sea surveys, including the brig *Dolphin* with an excellent surveyor in command.

Using a variety of ropes, and lines stowed on reels on deck, Lieutenant Berryman took a large number of ocean soundings, with which he brought up sea bed samples with either the Cup sounder invented by Henry Stellwagen in 1842 (fig.3) or with the Brooke sounder (fig.4), invented by a midshipman of that name ten years later. The latter apparatus was carried to the sea bed by a considerable weight which drove a sampling tube into the sediment before becoming detached, allowing the tube, with only the weight of the sample, to be recovered inboard. By 1852 Maury had collected enough deep soundings for him to prepare a contoured chart of the North Atlantic (fig.16), which, in an improved form, was included in his book 'The Physical Geography of the Sea'. Among those interested in Maury's chart was Cyrus Field, an American paper manufacturer, who formed the Atlantic Telegraph Company in 1856.

Searching for North Atlantic cable routes

In June and July the following year, the British Hydrographer sent Commander Joseph Dayman in *H.M.S.Cyclops* to sound out a suitable cable route from the west of Ireland to Newfoundland. In August the first attempt to lay a cable along this route was made but the cable parted during the lay, and a year's delay followed.

In 1858, *H.M.S.Agamemnon* and *U.S.N.S. Niagara* met in mid-ocean, joined their sections of cable and connected Ireland to Newfoundland successfully. There was much

Fig. 3. Stellwagen's Cup Sounder

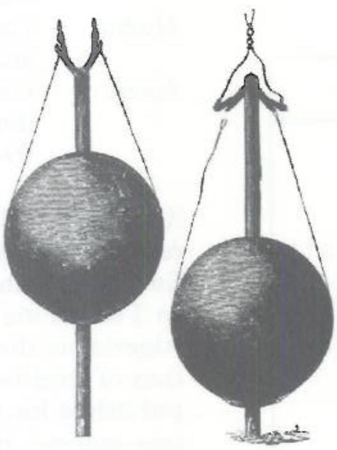


Fig. 4. Brooke Sounder

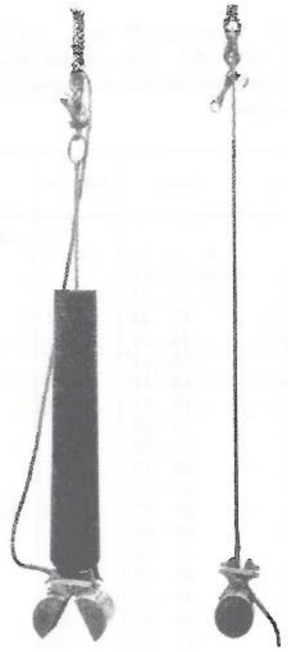


Fig. 5. Bulldog Sounder

rejoicing and passing of congratulations along the cable from the Old World to the New, whilst Commander Dayman received the gift of a gold watch from the Mayor of New York. Unfortunately though, the cable failed to carry signals after about a month's operation. Meanwhile Dayman in *H.M.S.Gorgon* was already sounding out an alternative route from Newfoundland via the Azores to the English Channel. In 1860 Sir Leopold McClintock in *H.M.S.Bulldog* was sounding out yet a further possible route via the Faeroes, Iceland and Greenland, perfecting the Bulldog grab sounder (fig.5), to the delight of Dr George Wallich, the scientist aboard, who welcomed the opportunity to obtain some excellent sea bed samples.

In 1862 Mr Hoskyn, Master of *H.M.S.Porcupine*, was engaged in making a detailed survey off the west coast of Ireland, to locate the most gradual route down the continental slope by which a cable could reach the abyssal plain. Hoskyn discovered the Porcupine Bank, which would have been a cable hazard, and surveyed the extensive 'Rockall Bank'. So all was ready when the Civil War was over in 1865 to lay the 3,700 kilometres of cable, which Cyrus Field had prepared. It was loaded into the *Great Eastern*, the only vessel large enough to take it, and finally laid successfully from Valencia in Ireland to Trinity Bay in Newfoundland.

Deep sounding by the timed interval method (fig.6)

Dayman was already on his next task, to take a line of deep soundings from *H.M.S.Firebrand* along a route for a cable to be laid from the English Channel across the Bay of Biscay, through the Strait of Gibraltar and the Mediterranean to Malta. Until 1870 both American and British naval officers relied for deep sounding on lowering a weight, or apparatus for taking a bottom sample, on a line marked at every 50 fathoms. They carefully timed the intervals between the passage downwards of each mark until a sudden increase of the interval denoted that the weight had reached the sea bed. Hauled taut the depth could be read from the line. A great variety of lines and ropes, each stowed on their respective reels, were used with various sinkers; the British and Americans would test the various combinations of line and sinker recording the increasing time intervals during a descent between 400 and 1,400 fathoms to familiarise themselves as to how each combination would react to sea conditions.

The business of deep sounding, which took place every 100 miles or so, or more often over an irregular sea bed, required absolute concentration as the lead continued to descend for an hour or so. It also called for patience, the ability to accept temporary failure and complete dedication to finding the correct depth at every

Lat. 42° 16′ N., Long. 22° 32′ W.

12th October. Wind light, W. by N. [3.]
Bar. 30·360. Ther. 69°. Temp. air 69°, sea surface 68°.
Weight employed 188 lbs. lead, with albacore line.
Up and down cast.

Fathoms	Times.	Intervals.	Remarks.
	h m s	m s	A.M.
0	Eased down.		
100	6 12 45	Let go.	
200	13 35	0 50	
300	14 35	1 0	
400	15 42	1 7	
500	16 58	1 16	
600	18 21	1 23	
700	19 52	1 31	
800	21 29	1 37	
900	23 13	1 44	
1,000	25 8	1 55	
1,100	27 37	2 29?	Checked ?
1,200	29 44	2 7	
1,300	31 58	2 14	
1,400	34 12	2 14	
1,500	36 29	2 17	
1,600	38 49	2 20	
1,700	41 12	2 20	
1,800	43 39	2 27	
1,900	46 3	2 24	
2,000	48 33	2 30	Bottom.
2,100	52 8	3 35	
2,150	56 0	3 53	

Depth (with line taut up and down) 1,900 fathoms.
Line broke in hauling in with increasing strain at 1,885 fathoms.
Immediately after this sounding, sent down a deep sea lead, with cup for bringing up the bottom; paid out the line to the known depth and brought up specimen of the bottom, (oaze,) which is now in the hands of Professor Huxley, F.R.S.
N.B.—Time occupied in walking in 2,100 fathoms of line, with watch and idlers, one hour and a half.

Fig. 6. Typical Deep-Sea Sounding Record by Timed Interval Method HMS Gorgon (Cdr. Dayman)

cast. To obtain a bottom sample it was sometimes quickest to find the depth using a heavy sinker on a light twine which was not recovered, and then send down a Cup or Brooke sounder on a stouter line recoverable with the donkey engine. When a sample was particularly desired the line might be 'walked in', a lengthy business.

Searching for cable routes world-wide

Telegraph cable laying far beyond the North Atlantic was gathering pace in the mid-1860s and, with Rear Admiral George Richards as Hydrographer of the British Navy, a number of his ships were actively searching out the smoothest sea bed routes for prospective cables. Such voyages by H.M.Ships included:

Valorous (supply ship for the Arctic Expedition) - Captain Loftus Jones - from the English Channel to and from Davis Strait.
Medina - Captain Spratt - Malta to Alexandria.
Hydra - Captain Mansell - Alexandria to the Aegean.
Hydra - Captain Shortland - Bombay to Aden and other Indian Ocean profiles.
Egeria - Captain Aldrich - Several profiles in the Indian Ocean and south-west Pacific.

The French Service Hydrographique de la Marine (SHM) was active from 1855 searching for suitable cable routes from southern France to Tunisia via Corsica and Sardinia, and to Algeria via the Balearic Islands, under the direction of Ingénieur de ler classe Delamarche who published his manual *'Eléments de télégraphie sous-marine'*. In the early 1880s the French naval vessels *Talisman* and *Travailleur* made three oceanographic cruises in the eastern Atlantic with scientists onboard directed by Alphonse Milne-Edwards, professor at the *Muséum d'histoire naturelle de Paris*. Talisman carried a French-developed Thibaudier wire sounding machine which was hand operated. Prince Albert fitted similar machines in his two yachts but that in *Princesse-Alice* was operated by a small steam engine.

The advent of wire sounding

Sir William Thomson, the Scot who later became Lord Kelvin, had been greatly involved with the construction of sea bed cables, and had witnessed the somewhat inefficient way of deep sounding by timing the intervals between markings on a hempen line during the descent. He saw the advantage of piano wire and once he had found a manufacturer who could supply extended lengths, he devised a compact sounding machine incorporating 5,000 fathoms of wire on a powered drum, an internal accumulator and a measuring wheel.

When the load came off the accumulator as the lead reached the sea bed, the drum brake activated and the depth read off from the wheel. Commander Sigsbee U.S.N. in *U.S.S.Blake* was the first of a number of seamen to see the value of Thomson's revolutionary wire sounding device.

He fitted such a machine in *Blake* and began to make his own modifications. Carl Bamberg of Berlin began to produce a more compact version, resulting in a Bamberg sounding machine being supplied to Commander Belknap U.S.N. in *U.S.S.Tuscarora* for use in the Pacific during

1873-74 for the survey of a prospective cable run from California to Japan. Belknap was well pleased with Bamberg's machine, with which he made 483 successful deep-sea casts.

Telegraph cable companies take over

Tuscarora, which made several more profiles across the North Pacific, was really the last government survey ship to sound out routes for telegraph cables. By 1878 telegraph companies were being widely established, employing their own vessels for pioneering cable routes and for recovering defective cables from the sea bed for repair. Many commercially sounded lines may be recognised on the first edition of GEBCO as double lines, for such vessels proceeded sounding on a zigzag course to cover a wide swathe of ocean bed. Searching for cables for repair often provided quite a gathering of deep soundings as repeated operations with a grapnel tended to be protracted.
By the end of the century there were about a dozen telegraph companies world-wide employing about double that number of newly built or converted vessels. It is understood that Prince Albert enjoyed close co-operation with some of these companies, if only to avoid newly laid cables when trawling from his vessels, and he may have received deep-sea data from them.

From 1860 onward the Hydrographer produced annually an HD publication entitled 'List of Oceanic Depths and Serial Temperature Observations received at the Admiralty during the year from H.M.Surveying Ships, India Marine Survey and British Submarine Telegraph Companies'. In addition details of deep sea soundings were regularly printed in journals such as The Nautical Magazine, Annales Hydrographiques and Dr. A. Petermanns Mitteilungen. Although by 1899 British surveying vessels were no longer routinely involved in searching out telegraph cable routes, the Hydrographer continued to publish such lists which could be purchased for one shilling each.

The Lucas sounding machine invented

In 1874 Vice Admiral Sir George Richards retired as Hydrographer of the Navy to become a Director of the Telegraph Construction and Maintenance Company, the Chief Engineer of which was Francis Lucas who, with Richards' encouragement, invented and patented a compact and highly efficient wire sounding machine (fig.7), which bore his name.

It was to take over as the most widely used machine by naval and commercial ships seeking to sound great depths and recover ocean bed samples therefrom for the following fifty years.

It consisted of a drum from which piano wire ran out to a measuring sheave held between two double arms. The weight of the sinker and wire during the descent depressed the double arms against the pressure of two spiral springs.
When, on the sinker reaching the sea bed, the weight on the wire reduced, the springs raised the double arm and applied the brake to the drum. The depth was then read off on the face of the measuring sheave. The drum was power driven when used onboard ship but there was a smaller hand operated model for use in boats.

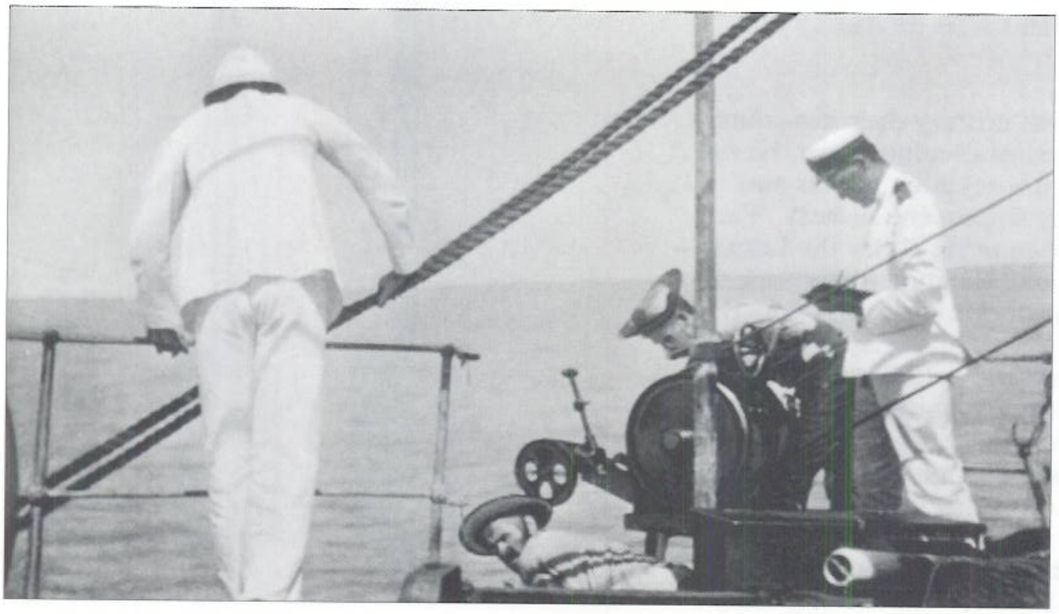


Fig. 7. Deep-Sea Sounding with the Lucas Sounding Machine HMS Egeria 1897 (Photo: Hudson and Kearns)

The Greenwich Meridian

That a number of maritime nations were using their own prime meridians from which to measure longitudes would have caused problems for marine cartography had not the United States called an international conference in Washington DC in 1884. This eventually led to the adoption of the Greenwich Meridian for international use. This was particularly hard on the French, who, having had a hydrographic establishment since 1720, had nearly 3,000 charts based on the meridian of Paris to be re-engraved.

Lists of sounding data

In 1910 the Scientific Cabinet of S.A.S.Prince Albert of Monaco published an inventory of bathymetric data used to compile each of the sheets of the first edition of GEBCO; this enables one to assess the quantity of deep-sea soundings available at the end of the 19th Century.

Four or five relevant Admiralty charts are listed as sources of data for each sheet, whilst the annual Admiralty lists of deep soundings are cited. There follows a catalogue of vessels contributing, including *Princesse-Alice* and *Hirondelle*, the United States ships *Tuscarora, Albatross* and *Blake*, the British survey ships *Goldfinch* and *Waterwitch*, the German naval vessel *Valdivia*, and *Investigator* of the Indian Marine. The ships of five different Telegraph Companies world-wide are named and, where relevant, the charts of Norwegian, Swedish and Nansen polar expeditions are mentioned.

The situation at the end of the 19th Century

At the end of the 19th century deep sea sounding in the oceans was proceeding apace. Naval surveying vessels, a few research vessels and many cable company ships were all busy. The crews would have been using either the Lucas, modified Thomson or Thibaudier wire sounding machines. As for bottom sampling apparatus, the Americans were employing refashioned Brooke sounders, and the British either Hydra or Baillie sounders (fig.8); both the latter used ring weights to drive the sounding tube into the sediment before being released to remain on the ocean floor.

Sir John Murray, who had sailed as Sir Charles Wyville Thomson's chief assistant on the 'Challenger Expedition', served as President of the Geographical Section of the British Association Meeting in Dover in 1899. As President of his Section it was not surprising that during his address he reviewed the current world-wide situation as regards ocean soundings: 'The soundings over the water-surface of the globe have accumulated at a rapid rate during the past fifty years. In the shallow water, where it is necessary to know the depth for purposes of navigation, the soundings may now be spoken of as innumerable; the 100 fathom line surrounding the land can therefore often be drawn in with much exactness. Compared with the shallow-water region, the soundings in deep water beyond the 100 fathom line are much less numerous; each year, however, there are large additions to our knowledge. Within the last decade over ten thousand deep soundings have been taken by British ships alone. The deep soundings are scattered over the different ocean basins in varying proportions, being now most numerous in the North Atlantic and the South-west Pacific, and in these two regions the contour-lines of depth may be drawn in with greater confidence than in other divisions of the great ocean basins.'

The International Geographic Congresses

The seventh International Geographic Congress, held in Berlin in 1899 under the Presidency of Baron Ferdinand von Richthofen, was attended

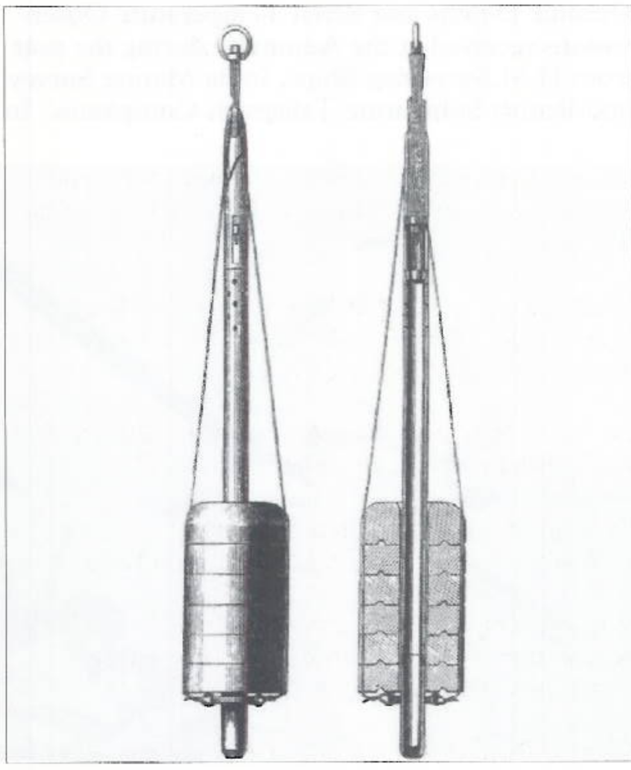


Fig. 8. Baillie Sounder

by a number of notable marine scientists, including Otto Pettersson, the Swedish inventor of a water bottle capable of retrieving samples from ocean depths whilst maintaining *in situ* temperatures; Fridtjof Nansen, the Norwegian who had mounted and taken part in the drift of the *Fram* across the Arctic 1893-96; Sir John Murray who, having sailed on the British 'Challenger Expedition' of 1872-76, had then recently completed the *Challenger Reports* which include details of many deep-sea soundings; Prince Albert of Monaco who since 1885 had been engaged in voyages of oceanographic investigation in the Mediterranean and the Atlantic in his yachts *Hirondelle* and *Princesse-Alice*.

The Congress nominated an international Commission to prepare the nomenclature for sub-bottom features, whilst charging the Commission also to instigate and prepare for publication a bathymetric map of the oceans by the time of the following (eighth) Congress in 1904.

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2- The Origin and Early History of 'la Carte générale bathymétrique des océans'

Jacqueline Carpine-Lancre

(translated by: Maya Whitmarsh)

THE BERLIN CONGRESS

Before the Berlin Congress

The nineteenth century witnessed the confirmation and acceleration of a trend to organise scientific research and to make it more professional. Meetings and discussions between specialists from different nations became more frequent. International congresses covering an increasing number of areas of human knowledge began to be convened for this purpose. In the field of geography the first meeting took place in Antwerp in 1871; the Sixth International Geographical Congress took place in London from 26 July to 3 August 1895.

As regards the marine sciences, the latter meeting was of particular importance. For the first time sessions were devoted to Oceanography, proving that this field and its given name were gaining an increasingly large audience, even though the discipline was still considered to be a subdivision of physical geography. The authors of the papers were personalities with an established reputation, for instance John Young Buchanan [1844-1925], Prince Albert I of Monaco [1848-1922], Julien Thoulet [1843-1936], a Professor at the University of Nancy, and the Swede Otto Pettersson [1848-1941].

The sectional meeting devoted to Oceanography was chaired by Dr. John Murray [1841-1914] on 31 July. This responsibility was a further mark of admiration and gratitude, among the many he received during 1895, for having brought to fruition the publication of the Challenger Reports, a task which was to secure his reputation for ever. Such a triumph was well earned since, during the preceding twenty years, he had succeeded in overcoming all kinds of obstacles: scientific, technical, diplomatic and economic.

Among the decisions taken by the London Congress, three need to be mentioned. In future the Bureau of each congress was to ensure that the adopted resolutions were implemented and reported on during the next congress. "The Congress also recognised the importance of recent Research in the Baltic, North Sea, and Atlantic, and expressed its opinion that the work should be extended on the lines proposed by Professor Pettersson" (*The international* ... 1895 : 476). Lastly, Berlin was chosen to host the next Congress.

Nomenclature and Terminology

The aims of international congresses were not only to allow participants to meet their foreign colleagues formally and informally, to hear and to make presentations on fundamental or current topics, to learn about the state of research and to identify problems yet to be solved. They were also intended to improve communication between specialists in a given field. This aim was not concerned with language as such, although the nineteenth century was compelled to decide how to replace the Latin language, which had ceased to be the "medium" between scholars and for which international artificial languages such as Esperanto or Ido had not managed to become a substitute.

In order to be able to establish and to codify universally adopted and applied principles, it was necessary to resort to two complementary but quite distinct approaches: nomenclature and terminology. In the maritime domain, the first in-depth study was made by Charles-Pierre Claret de Fleurieu [1738-1810], the best geographer-hydrographer of his generation. In 1799 he wrote the "*Observations sur la division hydrographique du globe, et changemens proposés dans la Nomenclature générale et particulière de l'hydrographie*". Fleurieu proposed limits and names for the division and subdivision of the World Ocean, as well as for sections of continental coastline. With regard to these questions of nomenclature he established the absolute principle that the name given by the first discoverer must be respected. He then dealt with terminology and gave a definition, usually accompanied by the equivalent English term, for the words which could suitably be adopted to designate the various forms of coastal relief.

Half a century later, the question of nomenclature relating to the oceans was again raised by a British committee appointed by the Royal Geographical Society, which met only once on 27

January 1845, under the chairmanship of Roderick I. Murchison [1792-1871]; however, the Minutes of this meeting were not published until 1893! As was the case with Claret de Fleurieu's *Observations*, only the surface of the oceans and the coastline were taken into consideration. Soon afterwards, the impetus provided by the research, soon to be called oceanographic, and the surveys connected with the laying of submarine telegraph cables, was to alter the situation radically. From then on submarine topographic features, their position, depth, and sedimentological and geomorphological characteristics were to be established and their forms, whether concave or convex, were to be given precise names.

Bathymetry

Clear and generally recognised principles dealing with the nomenclature and terminology of the submerged parts of the globe were all the more necessary, since the use of isobaths (bathymetric contours) had become more customary and bathymetric charts more numerous in the middle of the nineteenth century. From the end of the sixteenth century, soundings were beginning to be shown regularly on charts produced in Europe, in the form of a given number at a precise point. At the same time a chart was produced of a river in the Netherlands, on which lines linked points of identical depth. As has already been stressed, it was in the aquatic domain that the principle of expressing relief as contour lines was first applied, and not in the domain of the land surface. These lines of equal depth, or isobaths, can be found on a few rare charts of the seventeenth and eighteenth centuries: off the coast of Nova Scotia in 1715, and in the Mediterranean, as mentioned in *Histoire physique de la mer* by Luigi-Ferdinando Marsigli [1658-1730], printed in 1725. Two remarkable charts on which isobaths were marked every ten fathoms – one of the English Channel, the other of the waters around Fernando de Noronha Island – were drawn in 1737. Despite their well-known author, Philippe Buache [1700-1773], "first geographer to the King", and the series in which the chart of the Channel was printed, namely the *Histoire de l'Académie royale des sciences [de Paris]*, the use of bathymetric charts did not become customary until a century later.

In the fifth edition of *Explanations and Sailing Directions to accompany the Wind and Current Charts* by Matthew Fontaine Maury [1806-1873], printed in 1853, Plate 14 represents the *Basin of the North Atlantic Ocean*. The areas between the shore line and 1000 fathoms (1853 metres), 1000 to 2000, 2000 to 3000, and 3000 to 4000 fathoms were differentiated by increasingly lighter shades of grey as the depth increased. The sketch of 1853, with the addition of sounding points, was redrawn with greater care and made more easily readable for the sixth edition of *Explanations and Sailing Directions* (1854). This revised version was again included in the seventh edition (1855) and slightly altered in the eighth edition (1858-1859) of the book. In the meantime Maury had published *The Physical Geography of the Sea* which, from 1855 onwards, appeared in many editions, in English as well as in several other languages. It was without doubt the success of this work which resulted in the rapid and definitive adoption of bathymetric data in all categories of cartographic material: charts, atlases and globes. A bathymetric chart in relief was prepared by the U.S. Hydrographic Office for the Cincinnati Exhibition of 1888. On a gigantic terrestrial globe at a scale of one-to-one-million, which became one of the curiosities of the Paris Universal Exhibition of 1889, the varying depth of the sea was indicated by graduated colours. Quite quickly treatises and geographical handbooks as well as more general books began to include bathymetric charts.

As the general public grew more familiar with these charts, they also became a necessary complement to reports of oceanographic expeditions. The expeditions either covered only a limited area (*Vøringen*, *Travailleur* and *Talisman*, *Blake*, *Wild Duck*, *Pola*) or all the oceans (*Challenger*). In addition to isobaths and soundings, their markings also included areas of colour or grey shading (in the opposite sense to Maury's charts) which increased in intensity with increasing depth. In order to facilitate the reading of the chart, the area nearest to the shore was usually white. Sometimes lithological data were added to bathymetry. Other charts, which were not linked to a particular expedition, began to appear in the early 1880s, dedicated to one of the three oceans or to the World Ocean. Two countries were particularly active. In Germany the *Deutsche Seewarte* of Hamburg and the *Reichs-Marine Amt* benefited from the help given by Otto Krümmel [1854-1912], Professor at Kiel, and Alexander Supan [1847-1920], Professor at Gotha. In Great Britain Murray became the principal expert in this type of document, in association with the publisher Bartholomew of Edinburgh.

Soundings undertaken by hydrographic vessels, research ships and cable-laying ships were daily adding further details to the characteristics of submarine relief. Names were attributed to the depressions, banks and sills revealed in this way. As there was no international agreement, the naming was done in an anarchical fashion. It therefore became evident that a study should be carried out urgently in order to establish some principles of nomenclature and terminology relating to the oceanic zones.

As had been the case when the charts were produced, one of the two protagonists of the initiative was British: Hugh Robert Mill [1861-1951], the other German, Otto Krümmel. Both had a sound university education and knowledge of oceanographic operations which the former had undertaken in Scotland and the latter during the *Plankton-Expedition* on board the *National*. Furthermore, they had an exceptionally wide knowledge of the works and publications devoted to the sciences of the sea. Mill was Librarian at the Royal Geographical Society and in charge of the *Geographical literature of the month*, published in the *Geographical Journal*. As to Krümmel, he launched a biennial review in 1887, in the *Geographisches Jahrbuch*, in which he analysed and synthesised the oceanographic publications which had appeared during the preceding two years.

For many months prior to the Berlin Congress the two scientists had established a list of proposed terms to describe the forms of submarine relief. They consulted the best qualified specialists, in particular Admiral Sir William Wharton [1843-1905], Sir John Murray, Prince Albert I of Monaco, Admiral Stepan Ossipovitch Makaroff [1849-1904], and Professor Thoulet. They were of the opinion that it was imperative for a Commission to examine the subject at the Congress. Mill therefore presented a summary of the situation to the Geographical Section of the British Association for the Advancement of Science at a meeting held in Dover in mid-September 1899. "The Royal Geographical Society is at present engaged in the investigation of the whole great subject of the terminology of geography, and at the approaching International Geographical Congress at Berlin the question of the terminology and nomenclature of the forms of the floor of the ocean is to be discussed by representatives of different countries. The fact that the forms of the ocean floor cannot be seen, but only felt out by soundings, makes their study one of peculiar difficulty. Some distinguished authorities believe that our present knowledge of the deep sea is too slight to justify any systematic nomenclature. Meanwhile each investigator introduces a set of names of his own, for the most part based on analogies with land forms visible to the eye " (Mill 1900 : 810).

During the Berlin Congress

The Seventh International Geographical Congress, which took place in Germany for the first time, brought together a large number of participants who were received with pomp and efficiency. Germany wanted to convey to these important visitors an indisputable image of its talent for precision and organisation, and of the dynamism of its scientific and economic efforts which continued the successes of its recent territorial and colonial conquests. The smallest details bore signs of this striving for perfection: programmes and agendas were printed in several languages, abstracts of the papers were distributed before each session. The intellectual quality of the congress members was very high as testified by one of the participants: "The subjects dealt with by each group were equally captivating. Above all, the discussions were particularly stimulating and fruitful as they were led methodically and with the discipline dear to professors. Professors, in fact, formed the majority of the congress members" (Auerbach 1900 : 9). A special effort was made to transcribe these discussions, judging by the texts published in the Proceedings of the Congress, texts which were so detailed that one must assume that the session rapporteurs were assisted by stenographers and interpreters.

From the very opening, on 28 September 1899, particular importance was accorded to the sciences of the sea. The first plenary session was reserved for a presentation by Carl Chun [1852-1914] of the preliminary results of the *Deutsche Tiefsee-Expedition*, carried out between August 1898 and May 1899 on board the *Valdivia*, followed by a talk by Prince Albert I of Monaco "*Sur les animaux bathypélagiques obtenus par la capture des Cétacés*". The plenary session on the following day was assigned to the drafting of resolutions. Professor Hermann Wagner [1840-1929] from Göttingen and Professor Krümmel proposed that an international commission should be formed for the study of sub-oceanic nomenclature and that a corrected general chart of oceanic depths should be published prior to the next Congress (*Antrag* ... 1901).

The Session of 30 September 1899

The first of the three sessions devoted to oceanology was held on 30 September under the chairmanship of Pettersson. The second part of this session, "Adoption of a systematic nomenclature for basins and oceanic depths" consisted of three statements: one each by Wagner, Krümmel and Mill.

Wagner dealt with the nomenclature of marine spaces and their relationship to geographical nomenclature as a whole in a very theoretical way; he insisted that the final aim was to name without ambiguity. It was therefore absolutely necessary to proscribe the allocation of multiple names to one and the same topographic feature, whether terrestrial or marine, as well as any changes of names which could have trouble-some results, in particular in the didactic domain. In view of the rapid rate of development of oceanographic research, it was becoming urgent to obtain an international agreement which would serve as a basis for the names to be used in future for the ocean and its divisions.

The paper by Krümmel started with supplementary arguments in support of Wagner's statements; he supplied a whole series of examples of submarine features which had been given multiple names. He underlined the difference between British practice, which was to chose names on a whim, often bearing no relationship to the vessels or the scientists who had discovered these features, and the German method which took care to associate new names with geographical and topographical facts. He insisted that, from then on, the major forms of submarine relief should be named exclusively after their geographical location. Krümmel then dealt with the question of terminology; since 1881, he had been proposing a definition and a classification of the shapes of submarine topographic features for which the morphological criteria were, and ought to remain, determining.

Mill was in full agreement with the statements made by Wagner and Krümmel and commented and enlarged on their proposals. He stressed the particular characteristics which differentiate the purposes of terminology from those of nomenclature. "Terminology has to do with the description of typical forms which may occur in different places, nomenclature with the names of individual forms or particular places." The first proposal related to nomenclature: "The greater inequalities of the ocean-floor are to be named exclusively from their geographical situation." The second proposal concerned terminology and was worded as follows: "So far as the available soundings admit of the exact determination of a submarine form, the nomenclature is to be carried out systematically with reference to certain definite morphological categories." The third proposition concerned nomenclature as well as terminology. "There are certain important points in the relief of the ocean floor (e.g. the deepest single soundings and the shallowest part of a submarine elevation) which it is desirable to designate by names, and for these the names of persons or of ships are freely admissible" (Mill 1901 : 389, 390, 391). In conclusion, he recommended, as Wagner and Krümmel had already done, that a special commission should be formed to deal with all these questions.

Formation of the Commission on Sub-oceanic Nomenclature

A very animated discussion ensued (*Sonnabend* ... 1901). As had already happened frequently during international meetings where questions of nomenclature had been addressed, the Germans showed themselves to be pugnacious almost to the point of intransigence and rigorous if not dogmatic. As to Murray, he displayed an intractable attitude; his reticence towards the efforts made by Mill and Krümmel prior to the Congress made his behaviour predictable. Furthermore, Murray's interest in the sea floor had concentrated on, and was to remain concentrated on, two aspects: on the one hand marine deposits, the theme of a much noticed lecture he had given the day before, on the other hand areas deeper than three thousand fathoms, which he called "deeps". He considered that these aspects were, in some way, his "exclusive domain" in which he intended to preserve complete freedom of action and denomination. The rivalry between the British and the Germans was amplified by the simultaneous presentation of two general bathymetric charts, printed at the time of the Congress. The *Tiefenkarte des Weltmeeres* by Supan (fig.14) had accompanied an article written by him which had appeared in August in *Dr. A. Petermanns Mitteilungen*; the *Bathymetrical chart of the oceans showing the "deeps"* by Murray (fig.15) had completed an address that he had delivered in September during the BAAS meeting in Dover. In addition there were points of friction, of much greater seriousness, between the two nations. Krümmel had given some evidence of this in 1895 during a meeting of German geographers in Bremen while evaluating nautical institutes from the point of view of geography. He stated in the report which he presented there that "one must above all emphasise the role of the *Deutsche Seewarte* which to him appeared to be the most flourishing institute of its kind in Europe, and he took the opportunity to complain about the disdain with which most British people seemed to treat German hydrographic work. Ever since the *Challenger* expedition the British appeared to be under the impression that oceanography was a purely British science. [He] attempted to destroy this prejudice by giving details of the *Deutsche Seewarte*" (Zimmermann 1896 : 48). These examples illustrate the increasingly bitter struggle between Great Britain and Germany for maritime predominance, whether naval or scientific, especially since the advent of William II [1859-1941]. Eventually, the events in South Africa further added to the disapproval manifested against the British by Continental Europeans most of whom were siding with the Boers.

The discussion began with an intervention by Krümmel, in response to William Morris Davis [1850-1934], Professor at Harvard, regarding the use of the words *Thal* and *valley* for submarine relief. Prince Albert I spoke afterwards. At first he expressed his disagreement with Krümmel as to whether the name Monaco Deep, ascribed by Murray, was justified since the Prince had led the research in that sector for fifteen years. On the other hand, he fully agreed that the markings on the charts should be more clear and trustworthy. A hydrographic survey carried out in Red Bay, during a cruise which he had just finished in Spitzbergen, had overturned previously accepted data.

Murray then increased his arguments and counter-proposals in order to challenge the formation of a commission. He considered that once a submarine depression had been discovered it should be given a name straight away and that its description was more important than its name. The question of nomenclature did not only concern geographers but also geologists; the question could therefore be submitted to the next International Geological Congress. In any case, he had no intention of waiting for a unified nomenclature to be established before allocating names to the "deeps" indicated on the chart he had just produced.

Wagner replied to Murray's objections by recalling that the aim of the commission would be to give a precise and unique name to a given location and to define the forms of submarine relief, independently of their depth.

Pettersson, who was chairing the session, brought the debate back to the fundamental point: should a commission be formed or not? After further exchanges of arguments between Murray and the Germans, a decision was made in favour of forming a commission. Members were then proposed; the name of Sir John Murray was put forward first to the applause of the audience; the other names chosen were those of Mill, Thoulet, Otto Irminger[1] [1836-1923], Krümmel, Supan, Josef Luksch[2] [1836-1901] and, at the suggestion of Murray, Prince Albert I of Monaco.

The resolution reached after these intense discussions was submitted to the closing plenary session on 4 October and was adopted after it had been specified that the elected members would have the opportunity to co-opt new members. The title of the English version of this resolution, without doubt influenced by Mill, reflected more closely than did the German or French versions, the tasks assigned to the new commission "Terminology and nomenclature of sub-oceanic Relief. The Congress nominates an international committee on the nomenclature of sub-oceanic relief, charged with instigating the preparation and publication of a bathymetrical map of the oceans before the time of the meeting of the next Congress" (*Verhandlungen* ... 1901, 1 : 314).

After the Berlin Congress

The sessions of the Congress, as well as the excursions which preceded it and the visit to Hamburg afterwards, were a real success. The reports, often detailed, were published not only by the very many geographical societies of the period and in specialised periodicals, but also in the daily press and in reviews of scientific and general cultural information. A large proportion of the general public therefore learned about the formation of the Commission and the project of a general bathymetrical chart.

However well the composition and the tasks of the Commission on sub-oceanic nomenclature may have been defined in Berlin, neither its organisation nor the responsibilities of each member had been specified. For more than a year there was no trace of any sort of activity whatsoever. It was at the beginning of 1901 that Thoulet published a study entitled "*Projet d'une carte générale des grandes profondeurs océaniques*" in the *Bulletin de la Société de géographie de l'Est.*

Professor Julien Thoulet

The major role which Thoulet played in the conception and realisation of the Chart justifies giving full details of his education, activities and achievements up till then (Carpine 2002). He was born in Algiers in 1843, completed his secondary education in Paris and attempted twice, in vain, to enter the *École polytechnique*. It has not been possible so far to establish with certainty whether he pursued his education in another engineering college or whether he acquired practical experience. Whatever happened, it is evident that he was attracted by geography and topography. As early as 1867 he was admitted to the *Société de géographie* in Paris where he became a very active member, and where he gave many lectures and took on some functions within the Central Commission. The following year he presented the first research note on gnomonic projections, and in 1869 he gave a paper at the *Académie des sciences* entitled "*Sur les formules et les calculs qui ont servi à construire la grande carte gnomonique de l'Europe et des contrées adjacentes*". He then left for the United States where he spent two years as First Engineering Assistant attached to preliminary studies of the route of the Northern Pacific Railroad. During his stay in America he published an article "Applications of the pentagonal symmetry of the terrestrial globe" in The Engineering and Mining Journal of New York. Back in France he started his university education: a degree in physical sciences at the *Faculté des sciences* in Paris and a doctorate in science prepared at the *Collège de France*. He continued to present research notes, either at the *Société de géographie* or at the *Académie des sciences*, on various methods of cartographic projection: gnomonic, orthographic, stereographic, cylindrical or Mercator. In 1880 he was appointed to the Faculty of Montpellier, then in 1882 to the Faculty of Nancy where he held a chair in mineralogy until his retirement in 1913.

In 1886 Thoulet arranged to spend six months on board *Clorinde*, a stationary vessel of the French National Navy in Newfoundland. Was this decision inspired by his childhood memories of time spent on the shores of the Mediterranean or did he want to choose a scientific speciality which none of his university colleagues had so far adopted and which did not seem to attract either naval officers or hydrographic engineers? In his application for the mission he stated that "[he] felt the need to gain practical knowledge of the very special working methods employed on a vessel and in conditions so different from those of our laboratories[3]." This work in Newfoundland was to be very important to Thoulet's career; it made him decide to devote himself in future to "pure" (i.e. physical) oceanography, a field of research which he helped to make known and to develop in France through his own work, his numerous lectures, and the courses he taught at Nancy, in Paris and at the *École des hautes études maritimes*. The results of his research in Newfoundland were presented in ten research notes, the most important of which "*Considérations sur la structure et la genèse des bancs de Terre-Neuve*" was accompanied by several bathymetric charts. From then on he never ceased to stress the importance of isobaths in providing a clear image of submarine relief, the necessity of increasing the number of bathymetric charts and the urgency of publishing a general chart of the oceans.

After the Fifth International Congress for Geographical Sciences in Berne, Thoulet was a member of a commission, formed by the *Société de géographie de l'Est*, which prepared an excellent report on a project for an International Map of the World on the millionth scale, which was presented by Professor Albrecht Penck [1858-1945]. In 1894 Thoulet started work on a *Carte lithologique sous-marine des côtes de France*; its twenty-two map sheets were printed in colour between 1899 and 1902. In 1899, with the support of Prince Albert I of Monaco, he published a *Carte bathymétrique des îles Açores*. In the meantime he continued his study trips, especially in Scotland where he met Murray. He took part in research cruises: in 1891 on the first voyage of Prince Albert's yacht, the *Princesse-Alice*; in 1895 on board the *Caudan* in the Bay of Biscay; in 1897 and in 1899 on the *Laborieux*, a ship used by French hydrographic engineers while working off the coast of Brittany.

In this way Thoulet acquired wide-ranging experience of both laboratory techniques and working at sea; he had a very sound theoretical and practical knowledge of hydrography and of cartography; he was a skilful draughtsman. He knew English and German well, which allowed him to read the increasingly numerous oceanographic publications and to remain in contact through copious correspondence with his colleagues abroad. In this respect it must be pointed out that since the Franco-Prussian war of 1870 and the annexation of Alsace-Lorraine, Nancy University, where he was a Professor, was the university closest to the German frontier and had therefore become a seat of French Nationalism. This reinforced Thoulet's wish to give French oceanography a level of activity and quality comparable to that attained by the United States, Great Britain, the Scandinavian countries and Germany.

Although he had registered for the Berlin Congress, Thoulet did not take part and his paper on the "*Classification des fonds sous-marins et considérations relatives à la construction d'une carte lithologique des côtes de France*" was read by his colleague from Nancy, Bertrand Auerbach [1856-1942]. But, despite his absence, his name was immediately put forward and accepted for the Commission on sub-oceanic nomenclature.

It is certain that Baron Ferdinand von Richthofen [1833-1905], President of the Berlin Congress and as such President of the Executive Committee charged with supervising the implementation of the resolutions, informed him of his nomination. Perhaps he asked Thoulet to establish under what conditions the chart could be prepared. In any case, Thoulet had already been in a constant working relationship with Prince Albert I for fifteen years or so; it is possible that the Prince may have suggested to him that he could make this preliminary study in order to prevent any tension in the event of the initiative coming from either the British or the Germans. Or Thoulet could have taken the decision by himself, compelled by his perpetual urge to be active.

The First Memorandum by Thoulet

In his research paper on a general chart of oceanic depths, which was published in 1901, Thoulet was starting to point out the scientific and practical interest of such a general chart which would be more detailed than the charts published previously by Murray and the Germans, but more generalised than the hydrographic charts designed for navigation. The first stage should be limited to topography; the time was not yet ripe for including lithological details. He then "examined successively the various requirements such a chart must meet, the dimensions it should have, its mode of projection and, lastly, the way in which it should be updated with new discoveries as and when they were made" (Thoulet 1901b : 8).

In order to conform with Mill's proposal "On the adoption of the metric system of units in all scientific geographical work", adopted during the Berlin Congress, as well as with the recommendations made during the International Conference for the Study of the Sea, held in Stockholm, the chart was to use metres instead of fathoms. The Greenwich meridian was chosen as the zero degree meridian.

"The chart will use the cylindrical Mercator projection at a scale of 1:10,000,000 for that portion of the earth's surface on either side of the equator between latitude 0° and latitude 72° north and south. In view of the importance which polar exploration was assuming and in order to avoid the enormous spacings which higher latitudes demand, the earth's caps between 72° latitude and the poles would be projected gnomonically on the circular base of the cylinder of projection, cutting the lateral surface along the 72nd parallel of latitude" (Thoulet 1901b : 20). "The projection to be adopted is evidently the cylindrical Mercator projection. It is familiar to mariners, the calculations for establishing it are very simple, the drawing of the grid is quick and precise, and lastly – and this is the most important advantage – the fixing of a position by the intersection of two orthogonal straight lines is also very easy and precise" (Thoulet 1901b : 10). The limits of the sheets using the Mercator projection were to be the 0°, 90°, 180° and 270° lines of longitude and the 45°, 64° and 72° lines of latitude, north and south. Thus, the chart would consist of thirty-two sheets; twenty-four rectangular and eight quadrantal polar sheets.

As to the spacing of the isobaths, one hundred metres would be excessive, five hundred or one thousand metres would be insufficient; consequently a spacing of two hundred metres was proposed. Depending on the density of the available soundings, the isobaths were to be drawn as discontinuous, dotted or continuous lines. Where the density appeared to be acceptable, the areas between isobaths were to be coloured blue, increasing in intensity with depth. The sounding locations were to be indicated by a dot or a cross, accompanied by the depth in numbers.

The degree of confidence which one can place in the first bathymetric chart of the oceans at this scale must not be overestimated. In effect, the position of the ship while taking a sounding on the open sea, established by astronomical observation, was within a radius of 3 arc minutes, that is 3 nautical miles.

A card-index was to be kept up to date carefully in order to be able to identify without hesitation or error the origin of each sounding used in the making of the chart; each index card would carry the geographical co-ordinates of the sounding, its depth and a reference to the publication in which the details had been published. Thoulet stated the sources which could conveniently be used: the atlases of the *Deutsche Seewarte* for the three oceans, the chart of the Arctic ocean drawn after the *Vøringen* expedition and the atlases of the *Pola* for the Eastern Mediterranean and the Red Sea, not forgetting Murray's chart. The majority of the soundings carried out by naval staff (with the exception of cable-laying ships) were being included in increasingly abundant publications, which were subsequently used for the initial drawing of the chart as well as for updating it, an indispensable task which took many years.

All the aspects studied by Thoulet gave rise to long explanations, sometimes accompanied by mathematical formulae, calculations or drawings. The only exception was the final paragraph devoted to nomenclature and terminology. Thoulet limited himself to generalities; he did not take sides with regard to the tendencies manifested during the Congress. He concluded that "the best one will be the one which happens to become compulsory for all oceanographers" (Thoulet 1901b : 22).

In his experience, based in particular on the *Carte lithologique sous-marine des côtes de France*, Thoulet considered that the realisation of the bathymetric chart would not present any major problems and would not require any considerable staff or expenditure. Two or three full-time employees should be able to complete the chart within three or four years. Afterwards, to incorporate the three thousand soundings carried out each year, one single person should easily be sufficient to deal with the continuous updating.

During the three years following the Berlin Congress, Thoulet's research paper was the only contribution by a member of the Commission on sub-oceanic nomenclature towards furthering the project. Nevertheless, bathymetric work did not slow down. In 1901 Murray, in collaboration with the engineer who had worked on the *Britannia*, published the results of the cruise which had taken deep soundings in the North Atlantic in 1899; the study was accompanied by a map of marine deposits on which the isobaths were marked in fathoms. The following year he produced a bathymetric chart, together with Alexander Agassiz [1835-1910], based on the *Albatross* expedition in the tropical Pacific in 1899-1900. The question of nomenclature was referred to in the text; the divergence between the "German School", represented in particular by Supan, and the "Anglo-Saxon School" in which Agassiz manifestly supported Murray, was described in detail. The arguments put forward were the following: the rule of priority, the respect due to those who, often under difficult conditions, had made discoveries to which their names deserved to be attached and, finally, the impossibility of completely eliminating any names not conforming with the principles which Supan wanted to impose (Deacon 1997 : 392).

The *Deutsche Seewarte* also published a second edition of the atlas of the Atlantic Ocean in 1902, the first chart of which represented submarine topography. Bathymetric charts of the better surveyed sectors of all the oceans began to appear more frequently in books as well as in specialised articles.

THE FIRST EDITION

The Commission on Sub-oceanic Nomenclature

The practically total inactivity of the Commission on Sub-oceanic Nomenclature over a period of three years finally began to preoccupy Richthofen. On 23 October 1902 he sent out a circular letter as a reminder that the depth chart had to be prepared before the next Congress. He asked the members of the Commission to get together for a special debate to which they should bring all the material they had prepared so far. The meeting was to address the following points: to define the principles of sub-oceanic nomenclature; to share out the work among the members; to establish a future programme of work; to take the necessary steps to produce and publish the chart.

Richthofen recommended a central venue for the meeting: Brussels or Wiesbaden, and the date of 13 April. The members of the Commission were asked to let him have their views on the venue and the date of the meeting and to send in suggestions for the agenda. Furthermore, one or several names were to be proposed as a replacement for Professor Luksch who had died since the Berlin Congress.

In his reply Prince Albert I agreed to the proposed date of the meeting and chose Wiesbaden as the venue. He suggested that the agenda should include a discussion of a project to produce a chart at a scale of one-to-ten-million, in accordance with a memorandum from Thoulet, and recommended Admiral Makaroff as a new member.

In order to complete his documentation on the question of nomenclature, he asked his principal scientific collaborator, Dr. Jules Richard [1863-1945], for a synthesis which became a model of clarity and level-headedness. By analogy with the rules adopted in zoology and botany, the "specific" names – in this instance the denomination of a precise submarine feature – were to be subjected to the rule of priority and could not be modified. As to "generic" names, that is the terms designating the forms of the submarine relief, these had to be defined and agreed on internationally; they could therefore evolve if definitions or data were to change.

For Krümmel's part, he formulated four proposals relating to terminology and nomenclature which should be linked to the geographical position of submarine features, in accordance with the chart published by Supan in 1899.

Thoulet Revises his Memorandum

At the beginning of November 1902, Thoulet went to Paris to consider the question of the depth chart with Prince Albert's new collaborator, Enseigne de vaisseau Charles Sauerwein [1876-1913], a young officer in the French Navy. His grades on entering and leaving *École navale* were mediocre; the comments of his teachers, and later of his superiors, veered on the whole towards the negative: "varied but superficial knowledge; open-minded but showy rather than solid and correct." Until then he had only taken part in two cruises in the Far East, which had been interrupted due to ill health and were followed by long periods of convalescence. One wonders what circumstances, and what recommendations, had allowed Sauerwein to be appointed "*Officier d'ordonnance*" to Prince Albert in July 1902? Neither his very limited naval experience nor any form of scientific education could have justified his appointment. In order to remedy this absence of qualifications, he spent ten days in Nancy so that Thoulet could instil in him the first notions of oceanographic methods. During the summer of 1902 he took part in a cruise on the second *Princesse-Alice*, during which numerous soundings were taken in the areas around the Azores, as well as over the Princesse-Alice, Gorringe and Josephine Banks.

After working with Sauerwein for two days in Paris, Thoulet sent him a grid of the one-to-ten-million global chart and two types of map sheet, to be submitted to Prince Albert: a lateral (rectangular) sheet and a polar (quadrantal) sheet. He later sent him a revised version of his memorandum published the year before in the *Bulletin de la Société de géographie de l'Est*. He kept the same scale, the two modes of projection and the division into thirty-two sheets. He added details to the system of notation of the sheets which were to be designated by capital letters and Roman numerals at the one-to-ten-million scale: A.I, B.IV ... Letters and numerals were to be symmetrical in the two hemispheres separated by the equator; in the southern hemisphere the letters would be differentiated by the addition of a prime sign: A'.I, B'.IV (fig.9). Thoulet stressed that, on the basis of this chart, it would be easy to produce sheets at a scale that was ten or a hundred times larger. The systematic notation of the sheets would then be completed by the addition of lower case letters and Arabic numbers, followed by Greek letters combined with Arabic numbers: B.IV.c.7.δ.3. The revised memorandum ended with three proposals relating to terminology and nomenclature. Thoulet declared himself in favour of respecting the priority and total liberty of the "inventor" of a submarine topographical feature; however, this liberty was always to be subject to fixing the feature's position "by at least three non-collinear soundings, spaced less than 1 degree of latitude and of longitude apart" (Thoulet 1902 : 28).

While he was making these preparations directly related to the meeting which was to be held in Wiesbaden, Thoulet was actively preparing a new edition of his *Carte bathymétrique des Açores*. He wanted to update it with data obtained by the cable-laying ship *Britannia*, which had already been published by Murray, and the recent soundings carried out on the *Princesse-Alice*. But above all, having produced this one-to-one-million chart, he wanted to prove that a general one-to-ten-million chart would be capable of generating charts of a larger scale with extreme facility, thanks to the system of tenfold scale increase. Furthermore, this chart of the Azores would constitute the first step, for an oceanic area, towards the production of the International Map of the World on the millionth scale which all the geographical congresses had been discussing since the initial proposal by Penck in 1891. At the end of March Thoulet wrote to Sauerwein: "I am preparing for my journey to Wiesbaden; I have completely changed my atlas project; I am establishing a generic design of map[4]." To which aspects did the modifications planned by Thoulet apply? There is no document or other evidence to supply further details.

Meeting of the Commission in Wiesbaden

Richthofen organised the last few details of the meeting: it was to take place in Wiesbaden on 15 and 16 April 1903. The Commission – of which he was neither chairman nor a member – was to consist of nine members. Six of them had been chosen at the Berlin Congress: Prince Albert, Krümmel, Mill, Murray, Supan and Thoulet. As Luksch had died and Irminger had resigned, no doubt for reasons of ill health, they were replaced by Pettersson, Makaroff and Fridtjof Nansen [1861-1930]. The latter two, as well as Murray, apologised for not being able to participate in the work "for professional reasons". Prince Albert was accompanied by Sauerwein who was to carry out the function of session rapporteur. Neither the Minutes, which Sauerwein must have written, nor the report which Mill sent to the Council of the Royal

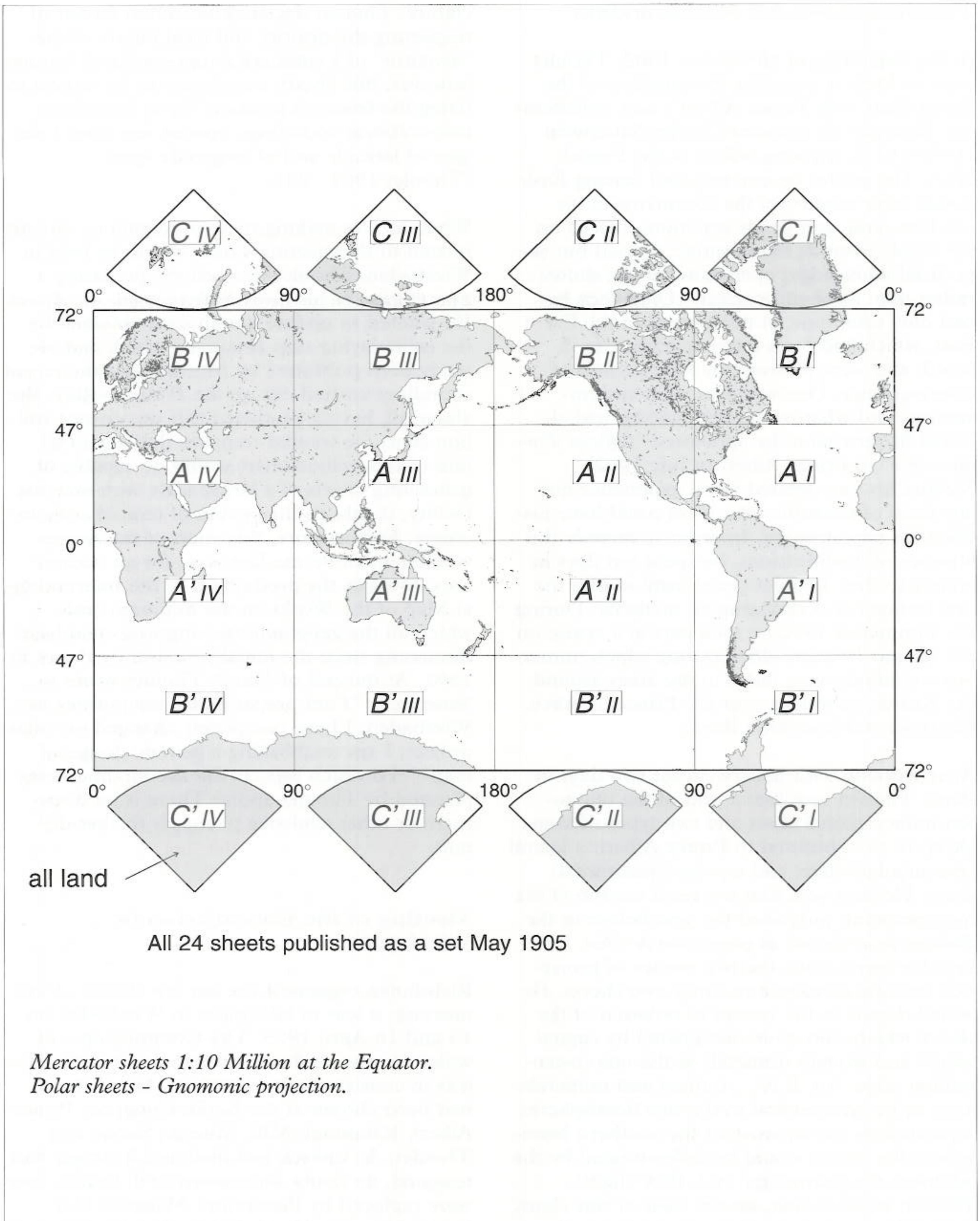

Fig. 9. Assembly diagram for GEBCO sheets (1st Edition)

Geographical Society, have been found. The progress of the work has therefore had to be put together on the basis of reports published in various periodicals.

Having elected the Prince as Chairman of the Commission, the members listened to Thoulet's account of his proposals, supported by his charts: the A.I sheet of the Atlantic Ocean at a scale of one-to-ten-million, the chart of the Azores at a scale of one-to-one-million, corrected and updated, and a diagram showing the relative positions of all the charts. A long discussion ensued and dealt mostly with questions of scale and projection. Had Thoulet already planned a reduction in the number of sheets prior to the meeting or was this a result of the discussion? The area between 72° N and 72° S was no longer to be divided into six but into only four "rows" of four sheets each; each polar cap was to correspond to four sheets. Consequently, the chart would consist of a total of twenty-four instead of thirty-two map sheets. Agreement was reached on the scale of one-to-ten-million and on two modes of projection: "From 72° S. to 72° N. the chart would be on Mercator's projection [...] From 72° to the poles the gnomonic projection would be employed [...]. All soundings of greater depth than 1000 metres would be entered upon the chart, and isobathic lines drawn so far as the data warranted. The unexplored part of the oceans would be left without isobathic lines" (Mill 1903 : 192). The depths indicated by the isobaths were to be: 200, 500, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, and 9000 metres. The areas between isobaths were to be coloured blue, increasing in intensity with increasing depth. The zero degree meridian was to be Greenwich.

At Pettersson's suggestion it was recommended "that the data of the new map should be published on an equivalent area projection on a smaller scale, suitable for the use of oceanographers in plotting various distributions for the purpose of measuring areas" (Mill 1903 : 192). As to Thoulet, he asked that local enlargements of particularly interesting areas, in which a large number of soundings had been taken, should be published in accordance with the principle of tenfold scale increase and using the sheet notation which he had proposed.

Krümmel then read out a letter received from Richthofen, containing a reminder that the responsibility of the Commission was limited to the preparation of the work which would form the basis of a proposal to the next geographical Congress. The Berlin Congress had not made any financial provisions for the production of the Chart and the Executive Committee, chaired by Richthofen, was not in a position to pay for a publication of this size. The role of the Commission therefore seems to have been reduced to a "purely academic discussion" (Sauerwein 1903a : 444). Prince Albert proposed that he should take on the cost of producing the Chart if the Commission could agree on its specification.

The Commission then tackled questions of nomenclature and terminology. As regards nomenclature, it was decided that it should respect the principles adopted for the general chart published by Supan in 1899 and that the rule of priority should be followed. As to the naming of forms of submarine relief, the German members were asked to choose about fifteen terms to designate the most important forms and to give them a precise and succinct definition. These terms and their definitions would then be translated into various languages, starting with English and French. In the paper which he had read in Berlin in 1899 Mill had justly commented: "The German language [...] by the facility of its word-groupings, forming new expression by linking together old ones, offers a direct encouragement to the recognition of minute differences and transitional forms in Nature; perhaps even to the search for them, French at the opposite extreme encourages, by the difficulty of coining compound words, the recognition and discussion of sharply defined categories and distinct groups. English is intermediate between the two as regards word-linking; it lacks the flexibility of German and the precision of French; but we can claim for it certain compensating advantages which permit it to share many of the good qualities of both the others" (Mill 1901 : 387).

The last session was devoted to an examination of the proposal made the day before by Prince Albert. A motion prepared by Mill was unanimously adopted: the responsibility for producing the Chart was to be handed over to the Prince, to whom the members of the Commission expressed their deep gratitude (*Réunion* ... 1903).

Preparation of the Chart

The decisions taken in Wiesbaden had an immediate effect. As had been requested, Supan prepared a list of terms and wrote the definitions of first order forms of submarine relief.

Towards the end of May he conveyed it to Thoulet who transmitted it to Prince Albert, accompanied by a French translation. The German text appeared in the July 1903 issue of *Dr. A. Petermanns Mitteilungen*; the English translation was done by Mill and was published in the August number of the *Geographical Journal*. The French translation took somewhat longer. Thoulet recognised with lucidity: "I have no right to decide on the question myself nor do I wish to[5]." He enlisted his colleague in Nancy, the geographer Auerbach, to provide linguistic as well as technical assistance. But he suggested to the Prince that he should appeal to "a French commission to choose the definitive terms to be adopted[6]." These questions were perhaps discussed during the *Princesse-Alice II* cruise in the summer of 1903, a cruise in which both Thoulet and Sauerwein participated. The French translation appeared, at the year end, in the *Bulletin de la Société de géographie de l'Est* (Supan 1903b) and in *La géographie, bulletin de la Société de géographie de Paris* (Sauerwein 1903b).

For the preparation of the Chart, Sauerwein was appointed as *Chef du Service de la Carte générale des océans*. The "official" address of the Service was the *Musée océanographique* in Monaco. But for practical reasons the work was carried out in Paris, in Prince Albert's own hotel, 10 avenue du Trocadéro, where a proper drawing office was set up. Nevertheless, there were well-established links between Paris and Monaco, particularly regarding access to indispensable documents. In effect, the Museum library, which opened soon after 1900 contained works, periodicals and reports of oceanographic expeditions which could only be consulted in Paris with difficulty, if at all.

In the spring of 1903 work started on assembling the data necessary to draw the chart. The hydrographic services of all maritime nations were invited to provide any data they had available in the form of charts or as lists. The contributions made by the British Admiralty, the Ministry of the Imperial Navy in Berlin, the Coast and Geodetic Survey of the United States, the French Hydrographic Service, and various companies involved in laying submarine cables were particularly appreciated.

The supervision of the technical side of the cartographic work was entrusted to a long-standing collaborator of Prince Albert, Alphonse Tollemer [1850-1919]. After obtaining a Diploma from the *École d'arts et métiers* of Angers, he was a student, then teacher at the *École des mécaniciens de la Flotte*; he then left the French National Navy to enter the French Hydrographic Service as a draughtsman-calculator. In 1888 the French Minister for the Navy recommended him to Prince Albert who was looking for a draughtsman capable of interpreting and translating on to a chart the results from floats launched by the *Hirondelle* between 1885 and 1887. From then on, Tollemer devoted a considerable amount of time, alongside his work for the Hydrographic Service, to the numerous charts which the Prince had drawn up as a result of his oceanographic activities and those of his collaborators. He drew the definitive version of Thoulet's *Carte bathymétrique des Açores*; he prepared a chart of Red Bay whose hydrography had been surveyed during a cruise off Spitzbergen in 1899 and which included isobaths, as well as soundings. He was also responsible for checking the accuracy and consistency of the list of stations effected during the cruises.

For the Chart of the oceans Tollemer was assisted by one of his colleagues from the Hydrographic Service, Jean Morelli [1859-1934], and another draughtsman, Bataille. The latter, appointed to work in New Caledonia, was replaced by an employee from the cartographic section of the Hachette publishing house, René Bolzé [1867-after 1910]. Finally, three other draughtsmen, Jacques Lebas [1868-after 1925], René Lévêque [1870-after 1932] and Achille Normand [1870-after 1934], contributed their labour part-time. This whole group of specialists began to make a draft of the soundings, the validity of which was examined and whose provenance was noted with care. "The charts that had already been published [were] mostly put to one side as it would not always have been possible to check all their measurements. The work therefore really used data obtained at first-hand" (Thoulet 1905 : 441). Through his activities Tollemer had access to the charts of the French Hydrographic Service and the lists of soundings published in the *Annales hydrographiques*. Among some of the other sources used were some charts from the British Admiralty and the *List of Oceanic Depths* which required conversion from fathoms to metres. The Annalen der Hydrographie and the *Dr. A. Petermanns Mitteilungen* yielded abundant documentation, as did the French, British and American *Notices to Mariners*. Reports of oceanographic expeditions were particularly appreciated since their first volumes were usually devoted to a list of the stations occupied and their depths; the majority of the reports gave details of recent observations which were being obtained with increasingly efficient and accurate equipment.

By mid-November 1903, the gathering of soundings for the first five sheets was already complete and, in a quite symbolic act, Sauerwein drew the first isobaths. In fact, his functions as *Officier d'ordonnance*, then from December onwards as the Prince's Aide-de-Camp, forced him to be away frequently and left him hardly any time for other activities. As to Thoulet, he was as usual overwhelmed with work. Apart from teaching his courses at Nancy, he gave lectures in Paris as part of a series organised by Prince Albert, as well as in Nancy for the *Sociéte de géographie de l'Est*. He analysed sea water samples and marine deposits collected during cruises on the *Princesse-Alice*. In addition to numerous publications and a synthesis volume he completed his *Carte bathymétrique des Açores* with a series of charts concerned with various observations: temperature on the sea floor and at a depth of one thousand metres, the distribution of calcium carbonate on the sea bed, and the distribution of total ammonia in the sediments.

Under these conditions it was not surprising that the preparation of the Chart was in fact directed by Tollemer. Because he had committed himself to it, beyond his competence, he gave the enterprise all his care and goodwill. He was well supported by his colleagues and he managed, at the beginning of 1904, to produce drafts of the twenty-four sheets, with data updated to July 1903.

Presentation of the Chart to the Académie des sciences

On 11 January 1904, at a session of the *Académie des sciences de Paris*, the Prince presented the whole set of these drafts and enlarged on a short note signed by Thoulet and Sauerwein. This presentation was widely commented on in the French press and abroad. These reports were echoed not only in the periodicals covering scientific subjects, which were in the habit of reporting on the sessions of the *Académie*, but also in geographical reviews. The important newspapers in Paris: *Le Temps*, *Le Figaro*, the *Journal des débats* and the foreign press as far afield as the United States published more or less detailed statements, inspired by Sauerwein who had manifestly benefited from the advice and help given him by his journalist brother, Jules Sauerwein [1880-1967].

The work of the cartographers continued without respite: as soon as the preliminary drafts were finished, work started on the neat copies of the documents which were to be presented in the United States at the International Geographic Congress. New data, obtained up to 1 July 1904, continued to be integrated.

Approval of the Chart

Thoulet was "delegated to represent H.S.H. the Prince at the International Geographic Congress", by a sovereign ordinance issued on 25 June 1904. The Eighth International Geographic Congress was held in the United States, as a roving congress; in effect the work sessions, interspersed with excursions and visits, took place successively in several cities. The opening session took place on 8 September in Washington, D.C. The Congress then moved to Philadelphia, New York, Niagara Falls, Chicago and St. Louis.

Marine sciences occupied a place of honour in New York on 13 September. During the morning plenary session Murray gave a lecture devoted to deep sea deposits. In the afternoon, during a sectional meeting, Thoulet presented an account of the "*Carte bathymétrique générale des océans*"; after tracing the history of the enterprise, he stated the characteristics of the Chart, presented the drafts which he had brought with him and sought the approval of the Congress. The same evening a session was set aside for the examination of the report written by Richthofen on behalf of the Executive Committee elected at the Berlin Congress. The passage relating to the resolution which had been adopted for sub-oceanic nomenclature ended with a *satisfecit*: the Commission formed in Berlin had carried out the task with which it had been entrusted. A resolution was then proposed in the following terms: "Nomenclature of the ocean bottom. – Effective action has been taken on this subject by a committee appointed for the purpose, and the results have been published. The committee was also instructed to promote the preparation and publication of a map of the deep oceans. Professor Thoulet reports on behalf of the Prince of Monaco concerning the progress of this map. It is recommended that the thanks of the congress be voted to the committee for the effective labors, and to the Prince of Monaco for the publication of the map sheets now issued, and that the committee be continued" (*Report* ... 1905 : 61). During the discussion of the project that ensued "Professor Libbey was of the opinion that there was no necessity of continuing the committee. Dr. Thoulet agreed with Professor Libbey. The part of the paragraph calling for the continuance of the committee was accordingly rejected" (*Report* ... 1905 : 63).

When the resolutions which had been definitively adopted by the Congress had been put to the vote, the approval of the Chart was worded as follows: "The Eighth International Geographic Congress expresses its thanks to His Serene Highness the Prince of Monaco for having executed the map of the ocean, the preparation of which was desired by the congress of Berlin, and expresses especially its agreement with the scale and projection chosen, with the adoption of the initial meridian of Greenwich, with the adoption of the meter for indication of the depths, and with the system of international submarine terminology used" *Report...* 1905 : 108).

On a much less solemn note Thoulet sent Sauerwein a veritable paean of victory on 14 September: "The chart was a real success. Yesterday I presented my paper concerning the work of the Prince and related the history of the making of the chart. Professor Penck then immediately asked to speak and he himself presented the following proposal, only the gist of which I will give you as I do not yet have the exact text – 'congratulations to the Prince and to the Committee, approval of the mode of projection, of the choice of Greenwich as the zero degree meridian, the adoption of the metre, the terminology used – the commission was discharged of its functions which were considered to have been accomplished.' In summary, a complete success. I have just shown the chart in greater detail to a few people, among them Murray, Hugh Robert Mill, etc. Murray is furious that he has failed totally regarding the metre but he twice repeated that 'it is wonderful work! but it should be in fathoms. As long as there is a seaman left in England, he will not adopt the metre!'[7]"

Murray's reaction was also noticed by others attending the Congress and was mentioned in the reports which they wrote about the Congress. Perhaps his reaction was all the more violent as he himself had no doubt intended to publish such a chart, but with the depths given in fathoms. At least that is what two allusions in letters sent by Richard to Sauerwein in September and October 1904 lead one to suppose: "I am very happy that the metre has been adopted for the general chart of the oceans![8]" and "It is very fortunate that the chart in metres has arrived before the one in fathoms[9]."

On his return to France, at the beginning of October, Thoulet was received by Prince Albert in his Château de Marchais; he reported to the Prince on his trip to the United States and told him of the approval of the Congress, the definitive text of which was sent to the Prince by the General Secretary on 22 October. It was now necessary to get the printing done as quickly as possible, for it had been announced that the Chart would come off the press during the following spring.

Printing of the Chart

From the end of the year 1903 Tollemer had been asking *Vieillemard fils & Cie* in Paris, who had printed all the Prince's charts since the beginning of the 1890s, to provide a preliminary estimate of the costs involved in printing 500 copies of the Chart in six colours. In June 1904 *Vieillemard* were asked for a new quotation for the printing, as was the firm of *Rollet*, another supplier used by the Prince for engravings. Just before the *Princesse-Alice II* was fitted out for her summer cruise, Sauerwein for his part made contact with another printer in the Paris area, *Millet fils* in Asnières, who suggested the use of photo-lithographic reproduction. Supan was also asked to find out whether the prestigious firm of geographical editions in Gotha, *Justus Perthes*, would be willing to carry out the work; Supan reported that they agreed in principle but could not specify the exact cost or delivery time without seeing the original documents. A last call for quotations was made as soon as Thoulet returned from the United States. A proposal submitted by the *Établissement géographique Erhard frères* in Paris was accepted for a total of 27,635 francs (which represented the equivalent of about three years of Richard's salary as Director of the *Musée océanographique*, or five years of Thoulet's pay as University Professor!). This sum covered the stone engraving, the supply of stone and paper, the supply of proofs and the printing of five hundred "black and white" copies and five hundred copies "in colour". The printer committed himself to carrying out the work, the printing and the engraving, within "five and a half months from the day of the handing over of the master chart[10]." The first few sheets came off the press in the middle of February 1905; the printing was completed on 15 May 1905, one month later than initially planned.

In the meantime two complementary documents were published. First, an Introduction to the Chart which Thoulet had been working on since November 1903 and which he completed on his return from America. It comprised a historical account – from the Berlin Congress to the Congress in the United States – of a "*Projet d'une Carte bathymétrique générale de l'Océan*" in the form in which it had been adopted in Wiesbaden, a table for the "*Distances croissantes mesurées à partir de l'Équateur vers les pôles, en projection de Mercator, pour une carte au 1/10 000 000*" and a second table for the "*Rayons en cm des circonférences-latitudes pour les feuilles polaires au 1/10 000 000 (projection gnomonique)*", and finally a French translation of the "*Terminologie des principales formes du relief sous-marin par le Prof. Dr. A. Supan*". The text was accompanied by a diagram showing the relative positions of the sheets at a greatly reduced scale. Publication was initially planned for an instalment of "*Mémoires océanographiques*" by Thoulet within the *Résultats des campagnes scientifiques accomplies sur son yacht par Albert Ier, Prince Souverain de Monaco*. But Richard, who was responsible for the series, considered that the Chart did not bear any direct relationship to the Prince's cruises and that the Introduction would be more suitable for publication elsewhere. The *Bulletin du Musée océanographique de Monaco*, launched at the beginning of 1904, offered a solution with which Thoulet agreed. The document appeared in Number 21 of that *Bulletin* on 25 December 1904.

The second document was a "prospectus", prepared by Sauerwein. A brief history was followed by a few words of explanation regarding the data recorded on the sheets. He quoted the complete text of the approval by the Eighth International Geographic Congress, after which he referred to recent international geographical and oceanographic Congresses (London, 1895; Stockholm and Berlin, 1899; Kristiania (Oslo), 1901) during which it had been recommended that Greenwich should be the zero degree meridian and the metre should be used as the unit of depth. Finally, the terms of ordering the Chart were specified: the edition in colour would be sold for one hundred francs, the black and white edition at fifty francs. There was no plan to sell the sheets separately. The document included a "*Bulletin de souscription*", to be detached and sent to the *Musée océanographique*. The price included the cost of postage and packing, for which a number of solutions had been considered; in the end the charts were sent in strong cardboard tubes. The cost of postage and packing amounted to four francs per copy.

Description of the Chart

The *Carte générale bathymétrique des océans* consisted of twenty-six sheets: a title page, a title sheet with a key diagram showing the relative positions of the sheets and the twenty-four map sheets making up the actual Chart. The sheets were in "double-elephant" paper size (73 x 113 cm); the paper had been selected with care for Tollemer knew how much importance Prince Albert attached to this aspect. The printing was done by the lithographic process.

The title page was worded as follows: CARTE GÉNÉRALE BATHYMÉTRIQUE DES OCÉANS / DRESSÉE PAR ORDRE DE S.A.S. LE PRINCE DE MONACO / d'après le mémoire de M. le Professeur THOULET / adopté par la Commission de nomenclature Sub-océanique / et par le Congrès international de Géographie de Washington (8 septembre 1904) / sous la direction de M. CHARLES SAUERWEIN, Enseigne de Vaisseau / par M. TOLLEMER / avec la collaboration de MM. BATAILLE, BOLZÉ, LEBAS, LÉVÊQUE, MORELLI, NORMAND. This title was followed by the scale and the following details: Les Sondes sont exprimées en Mètres. – *Les Longitudes sont rapportées au méridien de Greenwich*. The abbreviations used for designating the nature of the sea floor (clay, shingle, *globigerina ooze*, mud etc.) were then listed. The legend finished with the key for isobaths of 200, 500, and 1000 to 10,000 metres.

Beneath the title: "CARTE GÉNÉRALE BATHYMÉTRIQUE DES OCÉANS / Feuille d'assemblage", a diagram represented, from top to bottom, the four sheets of the northern polar cap, the sixteen sheets from 72° N to 72° S, and the four sheets of the southern polar cap. The reference allocated to each sheet (AI, AII... C'IV) made it easy to locate each sheet. For the sheets which were displayed in Mercator projection, the labelled meridians were spaced thirty degrees apart; the boundaries of each sheet were indicated by a thicker line for the Greenwich meridian, for 90°E and W and for 180°. Apart from the equator, lines of latitude were indicated for 30° and 60° N and S, as well as for the boundaries of the sheets: 47° and 72° N and S. For the polar caps lines of latitude were drawn every degree, from 72° to the pole. The surface of the continents was coloured a uniform buff colour; the oceans bore no labelling at all. The only geographical names mentioned were those of the North pole and the South pole.

The borders of the sixteen sheets in the Mercator projection measured: 59 x 100 cm; the straight sides of the quadrants on the polar sheets measured 63.7 cm. On the twenty-four sheets the two-line title was printed at the top, outside the borders, and centre justified: CARTE GÉNÉRALE BATHYMÉTRIQUE DES OCÉANS / Feuille AI [AII, AIII..]. Whatever the mode of projection, the lines of longitude and latitude were spaced one degree apart; the lines were bolder every five degrees. The lines of longitude and latitude were also annotated outside the borders every five degrees. On most sheets the letters E. Gr. et W. Gr. were printed either side of the central meridian of the sheet. The figures used were of a particular design, so as not to give rise to any reading error: 0, 1 and 2 were small in size; 3, 5, 6 and 8 were almost twice as high; 4, 7 and 9 were subscript numbers. They were straight stick characters ("antique").

At the bottom left and outside the border (with the exception of sheets CII and CIV, where it was at the top left) the name of the printer is given in italics, in the following form: *Gravé et Imprimé par Erhard F^{res} 35 bis, Rue Denfert-Rochereau. Paris.*

The continents in both the "black and white" and the "coloured" editions were printed in a flat buff colour. They bore no indications of physical geography (mountains or rivers), human geography (towns) or political geography (frontiers). A few rare numbers were given for hill tops near coastlines, which no doubt navigators would have been in the habit of referring to while making landfall. The only names mentioned were those of continents, sub-continents, the principal nations, archipelagos and the most important islands.

In the maritime part, the soundings were indicated in accordance with the following principles: from 0 to 500 metres, only some of the validated sounding points were indicated, but all of them were used for drawing the isobaths; below 500 metres, all the accepted soundings were indicated on the charts. Their location was marked by a black dot, accompanied to the right by the depth in metres of that particular sounding. These figures were, if applicable, accompanied by one or several letters specifying the nature of the sea floor. Numbers and letters were written in italics.

The 200 metre isobath was indicated by a dotted line, the 500 metre one by a dashed line; the 1000 to 10,000 metre isobaths were drawn as continuous lines, regardless of the degree of confidence with regard to the density of the soundings (contrary to what Thoulet had planned in the first version of his memorandum). Here and there the values of the isobaths were indicated to make viewing easier. On the "coloured" edition the area from 0 to 200 metres was left blank; from 200 metres onwards eleven areas between adjacent isobaths had a blue-green tint which increased in intensity as the depth increased. In the "black and white" edition the maritime part showed only the sounding points and the isobaths, but no coloured areas. This form of presentation – which had perhaps been inspired by Pettersson's request in Wiesbaden and by the complementary chart projects of the Azores archipelago by Thoulet – was to allow scientists and mariners to note down personal observations and notations.

The names of the oceans, their sub-divisions and the seas were of course indicated. As to the features of the submarine relief, whether convex or concave, the rules established in Wiesbaden were scrupulously respected: the nomenclature was that of the *Tiefenkarte des Weltmeeres* by Supan; the generic names were the terms chosen by Supan and translated by Thoulet: *bassin, vallée, ravin, golfe, seuil, crête* and *plateau* (basin, trough, trench, embayment, rise, ridge and plateau). All the inscriptions: titles and feature names, were in French which was to remain the sole language of the Chart up to and including the fourth edition.

A further detail which reflected the lively interest shown at that time in polar exploration: the furthermost points reached in the Arctic and Antarctic regions were marked with the names of the explorers and the dates.

Reception of the Chart

On 19 May 1905 the first copy of the Chart was handed to Prince Albert. To express his satisfaction with the work accomplished, he awarded a first class gold medal of honour to Tollemer and a second class silver medal to his two principal collaborators: Morelli and Bolzé.

Despatching began on 20 May; the Chart was sent to Thoulet and the other members of the Wiesbaden Commission, to Richard, to the people and organisations who had subscribed to it, as well as to the *Bibliothèque nationale* in Paris, for the legal deposit. During their session of 5 June Prince Albert honoured the *Académie des sciences de Paris* with a copy in colour, destined for the library of the *Institut de France*. The press announced the publication, as did those responsible for compiling geographical bibliographies, in particular the Royal Geographical Society in London. In its September issue, under the column headed *Geographical literature of the month*, a reference to the Chart was accompanied by the following sentence:

"This important chart will be specially noticed in the *Geographical Journal*". The announced commentaries never actually appeared. In effect, although everything seemed to be proceeding auspiciously, shortcomings, imperfections and errors were revealed by an impartial analysis of the Chart and published in the most important French geographical periodical of the period, the *Annales de géographie*.

Intervention of Emmanuel de Margerie

Its author, Emmanuel de Margerie [1862-1953], was to play an important role in the field of Earth sciences for three-quarters of a century, in France as well as at an international level. He was gifted with a lively intelligence, an infallible memory, a rare capacity for work and had started to take an interest in geology at the age of 15. In 1878 he participated in the First International Geological Congress. From then on, helped by his extensive knowledge of several foreign languages, particularly English and German which he mastered perfectly, he participated in almost all the International Geographical and Geological Congresses and took on positions of responsibility during these meetings and within numerous learned societies and international associations. He made a notable contribution within the most varied fields: terminology, cartography, bibliography and critical analysis, field research, original publications and writing syntheses.

On 7 June 1905 he wrote a long letter to Thoulet and to Sauerwein in which, after the usual compliments, he started by deploring the absence of an index of the soundings which would give the necessary details of their provenance; he suggested that such an index should be published in the *Annales de géographie*. He went on to list the shortcomings and errors of the Chart over more than four pages. He attributed most of them to the fact that the draughtsmen had no knowledge of German or any scientific competence; because of this they had blindly copied errors which appeared on Supan's *Tiefenkarte des Weltmeeres*. Furthermore, the translation used for an identical form of submarine feature was not always the same on two different sheets. "All of this basically concerns details of pure form, attributable solely to the lack of intelligence of the draughtsmen in charge of transcribing names; although it is to be regretted that none of the many people mentioned on the title page was charged with the small task – so easily carried out – of checking the spelling and the language. However, the nomenclature adopted on the Chart raises two questions of principle [...]. The first one concerns Monsieur Supan alone since, on that point, the Prince and his collaborators have done nothing but follow his example: is it acceptable that one changes, at the present time, the names of seas universally known and used, such as: Golfe du Mexique (replaced with Bassin mexicain), Mer des Antilles (replaced with: Bassin de Puerto Rico) [...]. It seems strange, at least to French eyes, to see these words: Mer du Nord, written where the Mer de Norvège or océan Arctique (BIV) should be but absent between Holland and Great Britain [...]. The second question – but here I am impinging on territory which is no longer mine, since it has been decided on by vote – relates to the equivalence of the generic terms used by Supan and the French terms adopted by the Commission on Submarine Nomenclature. [...] As to the individual names given to these oceanic 'troughs' or 'trenches', I really do not see why the commission has, as a matter of principle, rejected those which had taken their names from a ship or a person's name – when that ship or that person had taken part in the discovery or the definition of the features [...]. I understand that one may have wished to avoid sprinkling the surface of the seas arbitrarily with a lot of names of naturalists or geographers, chosen at random [...] but has this reaction not surpassed its aim?[11]"

This letter which was worded courteously, immediately evinced a lively reaction on the part of Sauerwein as well as Thoulet. At the end of 1904 the latter had already written in a letter to Richard that he considered that "For the Chart project until after Wiesbaden, I have done everything and the others nothing; towards its execution the others have done everything and I have done nothing. May each one keep to his responsibilities[12]." From the moment that Sauerwein was appointed *Chef du Service de la Carte générale des océans*, Thoulet was no longer consulted; on the occasion of his rare and brief visits to Paris Thoulet was able to do no more than cast a glance at the work in progress. It was not until the beginning of 1905 that specimens of three sheets were submitted to him; after a careful examination he wrote to Sauerwein in order to point out "two serious deviations from the project approved in Wiesbaden.

"1. The cutting of the cylindrical charts was done at 47° precisely instead of halfway between the equator and 72° lat. N. and S., which falsifies the dimensions height-wise, [...] thus rendering illusory the uniformity and the notation of the sheets as they had been planned in the memorandum.

"2. The inclusion of the lithological nature of the sea floor, for which I could not at any price agree to either the principle or the nomenclature[13]."

In his reply Sauerwein played down the importance of the "material errors". "In a piece of work of such large scope, executed so rapidly, it was impossible to strive for perfection at the first attempt[14]." As to the most important remarks made by E. de Margerie, Sauerwein countered them with arguments which were not very convincing; in fact, he tried to evade all responsibility by taking refuge behind the authority of the Prince who would have considered Thoulet's observation as a "disguised reproach". He had used a similar "strategy" two years previously, after the printing of the second edition of the *Carte bathymétrique des Açores*; he had then assured Thoulet that if the corrections Thoulet had requested had not been made, it was because it was the Prince's wish. Of course, Thoulet had not been able to risk verifying with the Prince whether this assertion was well founded.

The "epistolary duel" continued until the end of June. In the end the Prince, a convinced believer in arbitration in any situation, brought Thoulet, Sauerwein and Margerie together at his residence on 14 July. How did this session proceed? There is no written testimony; it is likely that the topics discussed were those which Thoulet raised again in his last letter to Sauerwein, three months later. It is undeniable that the proofs of the charts were never submitted to any of the members of the Wiesbaden Commission to be verified before printing. The printing had already started when Thoulet at last had a chance to examine a few sheets and to convey his remarks. Yet it was he, alone, who suffered from the consequences of the imperfections of the Chart. His responsibility for the lectures and the physical oceanography courses which he had been organising for the past two years under the auspices of the Prince of Monaco, was withdrawn and handed over to Alphonse Berget [1860-1933]. Sauerwein seemed to retain all the confidence and esteem of Prince Albert; but no doubt he had realised that he was not made for a scientific career. Thanks to contacts he had built up during his years of service with the Prince, he managed to obtain an important post with one of the large Parisian newspapers and henceforth devoted himself to business and journalism. The Prince's goodwill towards him manifested itself once more, at the time of his "resignation for personal reasons" at the beginning of January 1906, when he made him a Knight of the Order of St. Charles.

So it was in the issue of the *Annales de géographie*, dated 15 November 1905, of which he was a director, that Margerie published his study on "*La carte bathymétrique des océans et l'œuvre de la Commission internationale de Wiesbaden*". It was remarkable for the minutiae of its detail and its erudition. In a tone which was much more balanced than he had used in his letters to Thoulet and Sauerwein, Margerie stressed that the majority of the faults of the Chart were the result of insufficient rigour in the execution for which Sauerwein had assumed full responsibility. The most serious errors: faulty division of the sheets using Mercator projection and the presence of lithological markings were attributable to a disregard of Thoulet's memorandum. Throughout his analysis, Margerie kept referring to this memorandum which, as the fruit of the experience and considerations of a specialist, and approved by an International Commission, ought to have been followed in the minutest details. Finally, Margerie deplored the approval given in Wiesbaden and underlined the extreme positions which Supan had taken with regard to the nomenclature and some of the terminology.

THE SECOND EDITION

A New Edition?

Due to their extent and pertinence, Margerie's comments could not fail to discredit the enterprise. However, it was undeniable that there had been an evident need for a general chart at that scale; the principles underlying the publication had been sound, and the graphic and aesthetic qualities, as well as the care taken over the printing, had been remarkable. Was it in order to compensate for this semi-failure that Prince Albert began to develop his oceanographic activities in a new direction? On 14 April 1906 he signed a legal document in Monaco by which he created a private foundation, the *Institut océanographique*. The new organisation was to include an Institute in Paris, which would be its registered office and with which the *Musée océanographique* in Monaco would be associated. The latter had been built and fitted out over the last eight years. The prime objective for this foundation was to formalise the teaching of oceanography, which had been taking place since January 1903 in the form of courses and lectures, under the direction of the Prince. Three academic chairs were created within the Paris establishment; the one in physical oceanography was granted to Berget: further confirmation of Thoulet's disgrace!

The inauguration of the building of the new Institute did not take place until 23 January 1911, but its statutes were approved by the French Government as early as 16 May 1906. As Chairman of the Scientific Advisory Board and of the Board of Trustees of the Foundation, the Prince owed it to himself to respect these statutes. In order to be able to arrange oceanographic enterprises outside this strict framework, he decided to put in place another, more flexible, structure over which he would have sole control: on 19 February 1907 a sovereign ordinance created a '*Cabinet scientifique*' (Scientific Office), with Dr. Richard as Director, Henry Bourée [1873-1940] as Head and Alphonse Tollemer as one of two Attachés.

On 1 May 1906 Bourée replaced Sauerwein as Aide-de-Camp to the Prince. In his capacity as a Lieutenant de vaisseau in the French National Navy, he soon proved himself to be a well-chosen collaborator. He had perfect command of navigational matters. He had a passion for the most up to date techniques, which had led him to spend a part of his naval career on board a submarine. He was a photographer and a cinematographer without equal. His inventive spirit and his manual dexterity made him a born inventor who was to create several items of valuable oceanographic equipment. He knew how to assume the responsibilities entrusted to him with seriousness and competence.

Also in the spring of 1906, the scientific world was informed about an International Oceanographic Congress which the Prince planned to host in Monaco, to coincide with the opening of the *Musée océanographique*. Although there were a very large number of positive responses to the circular letter announcing the project, the Congress was postponed from year to year until 1910, and never actually took place. There are several reasons which could explain this cancellation: the time of year may have been a bad choice for university people, the likely number of participants was insufficient, or it may have been because the attitude of the two major figures in oceanography, Alexander Agassiz and Sir John Murray, was more than reserved (Carpine-Lancre 1980).

Neither the pursuit of cruises, nor the planned congress, nor the changes made to the conditions under which the Prince's oceanographic work was carried out, made him lose sight of the *Carte générale bathymétrique des océans*. It occupied an important place in the Monaco section of the *Palais de la mer*, which housed the *Section internationale d'océanographie, des pêches maritimes et des produits de la mer*, during the 1906 *Exposition coloniale* in Marseille. Nevertheless, its distribution remained limited: by 1 January 1907 only fifty-four copies (six of them black and white) had been sold and twenty (one of them black and white) had been sent out free of charge, that is less than eight percent of the quantity printed!

In 1907 Richard summed up the situation perfectly in the following terms: "This considerable piece of work which has seen the light of day thanks to the love of science and the generosity of Prince Albert of Monaco, [...] marks an important event in the history of Oceanography; such a piece of work cannot be expected to achieve the desired state of perfection at the first attempt, but since it has to be continuously updated on the basis of the endless research carried out by marine explorers, it is easy to improve it gradually, and the second edition, which is in preparation, will mark a very great improvement over the first" (Richard 1907 : 48).

In effect, even though the first edition had not yet come off the press, Tollemer continued updating the draft without respite. Because of his work in the Hydrographic Service, he was familiar with the procedure. For his part, Thoulet never stopped saying and writing that frequent new editions would be necessary, in phase with the rhythm with which new data became available. The soundings taken by *HMS Discovery* supplied an excellent example of this. A preliminary chart had been published in the *Geographical Journal* in July 1903 to accompany an article by Sir Clements Markham [1830-1916] "*The first year's work of the National Antarctic Expedition*". The ship of Captain Robert F. Scott [1868-1912], on her return journey from the Antarctic, had put into port in the Azores at the same time as the *Princesse-Alice II*; but, supposing that the British would have been willing to share their data with Prince Albert in the course of their conversations, it would have been too late to include it in the first edition updated to the previous 1 July. Before long, when the German vessel *Planet*, designed to explore the three oceans, was put into service, the volume of new information was to increase to an even greater extent.

Was it possible not to be convinced that new data would always entail progress and, above all, amendments to what was known about submarine relief? Murray did not seem to share this opinion; on 25 January 1905, during a meeting of the Challenger Society, he affirmed that "recent expeditions had made only inconsiderable alterations in the contour lines of the sea-bottom published in the *Challenger* Reports; [...] no great changes were likely to be made by the soundings of future expeditions" (*The relation* ... 1905 : 158).

For his part, Prince Albert does not seem to have hesitated for one moment before starting to plan a new edition of the Chart. First of all, errors and omissions had to be corrected; to those pointed out by Margerie, had been added new ones in written reports published by Krümmel, Gerhard Schott [1866-1961] of the *Deutsche Seewarte*, and the *Scottish Geographical Magazine*. The interest in the Chart could be raised by following one of the suggestions made by Margerie: the bathymetry of the oceanic areas should be complemented by the hypsometry (heights above sea-level) of the continents. This addition would reveal the continuity or contrast between the land and the submarine relief. At the end of the 1860s a remarkable chart using this method of representation had been produced by the French mining engineer Achille Delesse [1817-1881]. Margerie's request seemed modest: "We are only asking for a few lines and a few reference points; and the existing atlases would amply suffice to supply them" (Margerie 1905 : 397). After Sauerwein's departure, Tollemer regularly reported to Richard on his work; throughout 1906, apart from corrections and updating, he mentioned his documentary research on hypsometry and rivers, and the transfer of these data to the Chart.

Three collaborators of the Prince were responsible for different aspects of the Chart: Richard, Bourée and Tollemer. They examined the problems to be solved and came to the following conclusions. First of all, the printing of the corrected Chart should not be rushed; it would be sufficient to have it available in time for the International Oceanographic Congress and would therefore be perfectly up to date when it was presented to the assembled specialists. Furthermore, it was advisable to take all possible precautions in order to avoid the criticism which the first edition had attracted; the sheets would have to be examined with perfect rigour, for example by members of the Wiesbaden Commission. Finally, the financial aspects would have to be considered, in particular with regard to the number of copies to be printed, taking into account the modest distribution of the first edition. The cost of engraving and printing had, in the end, amounted to 29,135 francs in 1905, that is five percent more than the initial estimate. For the revised edition, the printer had increased the cost to 45,000 francs, still for an issue of one thousand copies; Richard was all the more surprised as it would not be necessary to buy new stones or to re-do all the engraving. It seemed, therefore, that it was the addition of hypsometry which caused this considerable increase.

A Further Memorandum by Thoulet

The preparation of the second edition demanded all the more attention since, at the beginning of 1907, Thoulet published a new study devoted to the *Carte générale bathymétrique des océans* in the *Bulletin de la Société de géographie de l'Est*. With understandable tenacity, he wanted his "magnum opus" to be created in accordance with his wishes and his considerations. Fired by a certain amount of optimism, he attempted to prove that the "defects" of the first edition could easily be put right and without great expense. The elimination of lithological data and the correction of material errors would not pose any problems. The faulty division of the sheets, halfway between the equator and the 72° N and S lines of latitude would be rectified. It would be sufficient to transfer the area between 46°40' and 47°, incorrectly included on the sheets of the A and A' series, to the sheets of the B and B' series. He thought that "this work would not be difficult". A general catalogue of the soundings and of other documents used would be prepared. The date of publication of each sheet, as well as that of previous editions, would in future be mentioned. An international commission, to be appointed by the next International Geographical Congress which was to be held in Geneva in 1908, would examine the pending problems: nomenclature and terminology, the creation of bathymetric charts at one-to-one-million scale and the publication of specialised oceanographic charts, starting with temperature measurements. Thoulet considered that it would also be good to involve the permanent International Council for the Exploration of the Sea.

Despite the fact that Thoulet's study was unfortunately littered with numerous errors (of dates and calculations), it could not help attracting attention, particularly that of Bourée who sought his advice with regard to furthering the project of the new edition. The letters which they exchanged during the autumn of 1907 are of great interest. In reply to Bourée's question regarding a possible change in the use of white for the first (0-200 metres) area between isobaths, Thoulet replied[15]: "I do not share your opinion. This first white area decreases the number of colours needed – hence it saves money and increases the clarity and ease of reading the chart by emphasising the different appearance of the ocean and the continents." With regard to the use of a graduated brown colour for indicating the topography of the continents, Thoulet was categorical: "My opinion is frankly the opposite of yours. The chart is oceanographic, not geographical, the only beauty it should possess is that of simplicity and clarity. Why not indicate railway lines, the borders of countries, the areas where icebergs are encountered, etc. etc., all excellent information in itself, but unnecessary, even detrimental in the present instance. Only the separation between land and sea matters, and, very correctly, on all the hydrographic charts, French or foreign, the continents are shown only in a uniform colour. If you include continental topography, 1) you increase expenditure without gaining anything, 2) you diminish clarity, 3) you expose yourself freely to criticism in the event of uncertainties, and 4) for reasons of symmetry and balance, you would have to make as many colour gradations over the continents as you have made bathymetric ones. All of this would lead you vastly astray." Likewise, Thoulet considered it to be useless to add the lines of rivers and a certain number of "landmarks", or to indicate in the margin the range of colours used, which were graduated rather than a group of distinctly different colours as they were on geological or lithological maps.

Concerning the disputed question of the division of the "cylindrical" sheets, Bourée suggested maintaining the division used for the first edition, in order to avoid the considerable cost of completely remaking the sixteen corresponding sheets; a dotted line would be added at the place where the division should have been made. Thoulet devoted a long explanation to this problem and ended with the following conclusions: "In trying to remedy the error by adding a dotted line, one would only emphasise it further. I conclude that it would be even better, while acknowledging that the division was done badly, to leave things as they are, without adding a dotted line, to explain in a note included with each copy that the tenfold increase in scale should only be carried out in accordance with the table of my calculations, which would also be included with each copy [...] I confess that I regret to have to give you this advice, [...] in the hope that this measure will be but transitory and that, sometime in the future, when anticipated progress in oceanographic research will make it necessary to remake a single cylindrical sheet or if a new sheet has to be prepared, the correct division will be established."

As to quoting the sources used, rather than publishing a catalogue, Thoulet thought it would be sufficient to list them "at the bottom of each sheet or, better still, on a small loose note accompanying each sheet. This had been done in a number of atlases." He considered that stating the date of issue was quite indispensable. As to the terminology, he would accept "whatever was decided, provided that the terms used for naming the same type of submarine topographical feature were absolutely synonymous in the different languages."

He replied to the question, as to whether he would agree to check the proofs of the future edition, in a very intelligible and rather abrupt manner: "I will agree to it, on the clear condition that I will be an official member of a special commission formed for this purpose, which will function regularly and in the Minutes of which I could, in case of disagreement, record my opinion so that I would only ever have my personal share of responsibility to bear and could always preserve my entire freedom of appraisal."

The letter ended with some recommendations which future events proved to have been well founded. "Wherever possible, refer back to the chart at the stage before your predecessor was, unfortunately, able to exert his disastrous influence on it; carry it out as he should have done, based on information of which not a line – written or unwritten – has not been the subject of long reflections; confine yourself to choosing the best documents for the drawing of the isobaths, to the extent of supervising their transfer, their grouping on the new chart, but do not change any of the general arrangements. The new edition on which you are about to start is, and I repeat it, a piece of work which is neither difficult, nor costly, nor lengthy. For the sake of science, I hope that all the same the desire to do things differently from the way that I have indicated, will not lead to alterations which would very probably be regretted later; in wishing to do better, one greatly risks doing less well."

When, a few days later, Bourée submitted to him a specimen of a sheet destined for the new edition, Thoulet returned to the formal and international nature of the steps which had preceded the publication of the first edition and which Sauerwein had not respected. Thoulet specified his requirements if he were to be a member of a possible commission: "I must be given, beforehand, an official title specifying the precise and clearly defined limits of my responsibilities, large or small, as should any author or co-worker of any scientific work whatsoever, and most particularly when an enterprise is as formal as the one we have in mind[16]."

Under these circumstances, it was not surprising that Bourée wrote to Richard "I am wondering what your advice would be regarding the bathymetric Chart. I confess that I find the prospect of tackling it rather tiresome, given the restricted number of people who will be interested in it but who, nevertheless, will shout about it as a matter of principle[17]."

Formation of a New Commission

The Ninth International Geographical Congress was held in Geneva from 27 July to 6 August 1908. Thoulet was mentioned as one of the delegates, representing the *Société de géographie de l'Est*; however, the Proceedings do not include any communication or intervention on his part, either in the cartography or the oceanography sections. It would seem, therefore, that he had ceased to solicit the Congress about a new edition of the *Carte générale bathymétrique des océans*. The oceanographers present agreed to formulate two resolutions which the Congress adopted: two commissions were formed for the purpose of scientific exploration, the first one for the Atlantic Ocean, the second one for the Mediterranean Sea. Prince Albert was proposed as Chairman of these new commissions.

The following year, during Regatta Week in Kiel, which Prince Albert had attended almost every year since 1898, he had a long conversation with Krümmel. After discussing the commissions which had been formed in Geneva, they broached the question of the Chart and the Prince stated that the preparation of the new edition was almost finished.

From 1908, in addition to the continuous updating of the various sheets, Tollemer took on two considerable tasks. First of all, he made a summary of all the corrections and additions made to the Chart since its publication. Then he prepared a general list of the documents used. In the initial version (1901) of his memorandum about the Chart, Thoulet had planned a very detailed index which would allow one to identify the characteristics and the origin of all the soundings used. Was this index ever prepared and realised? It has not been found and there is no publication about it. A supplement attached to the presentation Thoulet gave in New York in 1904 had included a brief list of the documents that had been used, where concise references had been grouped together for each sheet.

The volume prepared by Tollemer was organised in the following way: each sheet (series A, B and C, then A', B' and C') was the subject of three lists:

1) A "*Liste des autorités consultées pour l'établissement de la première édition*". This started by mentioning the charts and their dates of publication; this was followed by the names of the vessels whose soundings had been used; the type of vessel (warship, cable-laying ship...), its nationality, the dates on which the work had been carried out and, if applicable, the name of the oceanographic or polar expedition was added.
2) A "*Liste des corrections à effectuer à la première édition*". This referred to errors of position and depth, and to faulty names in the nomenclature.
3) A "*Liste des nouveaux sondages communiqués par diverses autorités depuis l'établissement de la première édition*". This list was presented in the form of a table which specified the sources, the dates, the geographical co-ordinates, the depths (in metres) and possible observations. This volume, which consisted of more than three hundred pages, was printed in March 1910.

Preparation of the Meeting in Monaco

At the beginning of January 1910, Bourée sent a letter of invitation to the people who had been members of the former Commission[18], as well as to Margerie and Schott, the principle passages of which read as follows[19]:

"H.S.H. the Prince has decided that it would be right to produce a second edition of the 'Carte générale bathymétrique des océans' as soon as possible.

"However, this new task could not be usefully accomplished without the assistance of the scholars who, during a first meeting, have already put in place the basis of the enterprise or who, in their subsequent observations, have expressed their interest in such a publication.

"His Serene Highness has suggested that, on the occasion of the inauguration of the Musée océanographique in Monaco, which will take place on 29 March 1910, a new Commission could meet in order to examine under what conditions the second edition should be produced [...]

"By order of H.S.H. the Prince, I have the honour of asking you in this letter whether you wish, once again, to lend Him the support of your experience by agreeing to be a member of this new Commission.

"I should be obliged if you would let me have your answer as soon as possible, so that His Highness may know which collaborators He may count on.

"As soon as acceptances have been received, each member of the Commission will receive a report summarising the various criticisms which have already been made and the desiderata which have been expressed with a view to new improvements.

"This work will be followed by a schedule, established by order of His Most Serene Highness, which summarises the main points that will need to be discussed."

Krümmel, Margerie, Mill, Pettersson, Schott, Supan and Thoulet accepted this invitation. Murray had been planning to participate, together with Johan Hjort [1869-1948], in a long cruise on the *Michael Sars* in the Atlantic; he could not therefore be in Monaco a few days before the ship sailed. Nansen also excused himself for not coming.

Meeting of the Commission in Monaco

The ceremonies organised for the inauguration of the *Musée océanographique* in Monaco went on from 29 March until 1 April 1910. There was a succession of festivities (a gala at the Opera, a banquet, a water festival with fireworks and a reception at the Palace) and there were working sessions. One after the other, the Atlantic Commission, the Mediterranean Commission and the Scientific Advisory Board of the *Institut océanographique* met under the chairmanship of Prince Albert. Finally, during the afternoon of 1 April, the session of the Commission for the Bathymetric Chart took place.

In accordance with the procedure announced by Bourée, the members of the new Commission had received, beforehand, a synthesis of the criticisms formulated by Thoulet, Margerie, Krümmel and Schott. Discussions could therefore begin in accordance with the agenda:

1) Division of the sheets.
2) Colour to be adopted for the area between 0 and 200 metres depth.
3) Addition of rudimentary hypsometry to the continents; addition of important rivers and lakes, as well as a few names as points of reference.
4) Addition of a key to the colours, with a legend, in the margin.
5) Removal of abbreviations indicating the nature of the sea floor.
6) Indication of date of completion of each sheet and list of the authorities consulted for its realisation.
7) Conventions to be used for single soundings.
8) Examination of the catalogue of soundings.
9) Terminology to be used.
10) Appeal to members of the Commission to verify the sheets prior to printing.
11) Eventual tenfold increase of, or working at, a larger scale.
12) Any Other Business.

Apart from Prince Albert, who was in the chair, and the members of the Commission, Bourée, who acted as rapporteur, and Tollemer took part in the working session.

With regard to the first item, everyone deplored the errors which had occurred in 1905; however, after a vote, the majority decided not to re-engrave the stones but to point out the problems which this would present for any eventual tenfold increase in scale. The second item was left to cartographers to decide. The third item gave rise to a long discussion. Thoulet, supported by Supan, repeated his opposition to the introduction of hypsometry; in response, Pettersson was of the opinion that the indication of terrestrial relief would facilitate meteorological studies relating to oceanography. In accordance with the majority of votes, the drawing of rudimentary hypsometry was decided on. The Commission agreed, without any difficulty, to print a colour key for bathymetry and hypsometry in the margin, to eliminate lithological markings, to quote the sources consulted for each sheet and the date of its completion. As to Schott's proposal, it was agreed that, if they were interesting, the soundings which had not touched bottom would nevertheless be mentioned, inscribed below a line. The catalogue of soundings was approved and would be regularly updated by further volumes. The terminology in French, which was not very satisfactory, was to be reviewed by a sub-commission. The correction of the sheets prior to final printing would be entrusted to Schott for bathymetry, to Margerie for hypsometry and to Supan for nomenclature; other members would also be asked to help with the checking.

Under Any Other Business, Margerie raised the question of a mural chart for educational purposes. Together with Thoulet, he requested that a number of copies in "black and white" should be printed, as had been done previously. Thoulet was of the opinion that the sheets should be distributed through booksellers and be available as single copies. Finally, Pettersson expressed his possible interest in producing a globe at a scale of one-to-twenty-million, showing terrestrial and submarine relief.

The Minutes of the meeting, written by Bourée[20], were submitted to each participant who was asked to let him have his observations or, if there were none, to return the approved text, duly signed. After various amendments, the text was generally approved. It was included, together with a synthesis of the criticisms formulated before the meeting and a list of the points discussed, in an issue of the *Bulletin de l'Institut océanographique* of Monaco, dated 10 July 1910.

As planned, a sub-commission, "charged with revising the French language nomenclature of the ocean floor", met in Paris on 27 April 1910. It was chaired by Margerie and included Thoulet, the hydrographic engineer Joseph Renaud [1854-1921] and the geographer Emmanuel de Martonne [1873-1955]. The questions which they discussed were really related to terminology; each term in German was examined, as well as the translations initially proposed by Thoulet; the conditions for the use of these terms, or other terms if they seemed preferable, were defined. The subject of nomenclature only appeared in the request which ended the sub-commission's report: "The systematic proscription in submarine nomenclature of the names of persons and vessels should be revoked[21]."

Prince Albert had reason to hope that from then on all difficulties would be removed, all problems solved and every precaution taken so that the second edition could appear as quickly as possible and without giving rise to any criticisms. In fact, barely three weeks after the meeting of the new Commission the first omen appeared of the difficulties and crises which were to jeopardise the entire history of the second edition.

Margerie informed Bourée[22] that, for the hypsometry "with which H.S.H. the Prince of Monaco had been good enough to entrust him", he would seek the help of two draughtsmen who usually worked for him; they would draw the contours of the terrestrial relief under his sole direction and would transfer them directly on to the stones of the Chart at the printers, with whom they "were constantly in touch regarding research and business matters". This step proved that Margerie did not know anything about the way Prince Albert organised the scientific work which he directed. He employed neither sub-contractors nor consultants; he personally supervised all the printing done in connection with his activities; he insisted on correcting the proofs himself and to give the go-ahead for the printing of all the documents. The solution proposed by Margerie was never mentioned again, but it was a significant indication of the fact that Margerie wanted to be in charge of the enterprise.

Furthermore, before long "the rudimentary hypsometry", for which the then current atlases had been thought to be adequate, took on increasingly important proportions. Margerie listed references to an increasing number of documents which, logically, were not to be found in the library of the *Musée océanographique*; they therefore had to be purchased or consulted in the libraries of the *Société de géographie*, the *Société géologique* or *Bibliothèque nationale*.

Finally, Margerie decided that his collaboration was worth a very high price. A few days after the inauguration of the *Institut océanographique* in Paris, he sent a long letter to the Prince. In it he set out in detail a plan, "particularly dear to him", for a Geographical Institute, which he encouraged the Prince to set up in Paris – at the latter's cost of course!

Revision of the Nomenclature

In accordance with the procedure established by the Prince, the production of the definitive draft of the second edition was prepared by Tollemer, within the ambit of the *Cabinet scientifique*, under the supervision of Bourée. At the beginning of June 1911, photographs of the drafts for sheets AI and AII were sent to the members of the new Commission. Schott returned them with some corrections which proved how carefully he had examined them and, at the same time, how perfect was his knowledge of soundings and their interpretation. Throughout the publication of the second edition his collaboration in matters of bathymetry was to remain equally precise and punctual.

The printing of these first two sheets was planned for the month of December, when the reaction of "certain members" with regard to the changes introduced by Bourée to the nomenclature, raised new difficulties. Supan wrote to Bourée: "as to the nomenclature, our opinions on the point of principle are totally opposite.

"1) You are taking the position of priority, where the name already given has to be retained.

"2) I take the position of geographical nomenclature [...]

"The principle of depths and the principle of reliefs are leading us to completely different results. [...]

"Let the Commission take a stand, its decision will of course be adopted for the Chart and will be authoritative. As to myself, if the principle of priority were to be accepted, the decisions of the former Commission would be rescinded; there would then be no reason for me to collaborate with this new chart. In fact I ought not do so since, on this chart, I only take care of the names and because I wish to remain free to criticise in future[23]."

The printing of the two sheets was suspended. On 15 January 1912 Bourée sent the members of the Commission a detailed, carefully considered circular letter, in which the examples quoted were diplomatically chosen and the arguments presented in a manner designed to influence the responses. Bourée communicated the decisions taken by the sub-commission charged with the terminology in French; we should remember that, as for the previous edition, French was the sole language of the new one. He had applied these decisions and had, furthermore, taken into account the final vote regarding nomenclature, which demanded that the names of persons and vessels should be preserved, "on the basis of the right, generally acknowledged in the field of geography, of whoever makes a discovery, to give it a name". He added: "I believe that I must put in a reminder that the Monaco Commission has agreed that the new bathymetric Chart should be conceived, not only as a scientific enterprise useful to technicians, but also as a useful tool for all those who take an interest, in various capacities, in matters relating to the sea, and to pupils in schools.

"This is why it has been decided to increase the number of names serving as reference points, to facilitate the understanding of the Chart.

"Under these conditions, to eliminate well-known names, such as Red Sea and Black Sea, and to replace them with others, seems to me to go against the resolutions which were adopted in Monaco. One might perhaps add Erythrea Basin beneath the name of Red Sea, in a different script, and so on in other cases, in order to satisfy our eminent collaborator.

"To summarise, we are in the presence of two quite distinct opinions:

"1. To eliminate all the proper names, except for small (?) features, and to give the large features the names of adjoining countries.

"2. To keep the names given to the features by those who discovered them and to keep the names of seas, gulfs etc., generally accepted in all the atlases, but adding subsidiary qualifying names if necessary[24]."

The opinions solicited on this problem were provided by all the members (except Nansen). Bourée summarised the essential points in a new circular letter on 8 April[25]. Krümmel, who was ill (he died six months later), was unable to consider the question in depth but aligned himself with Supan's opinion. Schott considered himself to be a "moderate Supanist"; agreeing with the basic principles, but rejecting "certain modifications to names of seas sanctified through usage[26]." Pettersson thought that "the proposal of Prof. Supan to suppress all proper names except for the minor forms of the sea bottom in the chart to be a too radical reform to be introduced in the present publication[27]." Murray specified "I have never made use of the geographical names for the deeps and I do not think it wise to change the names of seas or 'deeps' which have already been published. Priority is in my view the only principle involved in this matter[28]." Mill did not reject Supan's principles completely but varied them slightly; he "should be inclined to consider that (as four plates of the map had already been completed before Professor Supan's objection was made known) the best course would be to waive a theoretical objection in face of the importance of having the work carried through without loss of time[29]." Margerie's and Thoulet's opinions had already been expressed in the vote taken by the sub-commission.

Consequently, Bourée concluded: "I therefore find myself clearly authorised by an indisputable majority to continue working on the publication of the bathymetric chart, referring to the report issued by the sub-commission over questions of nomenclature and terminology.

"I therefore submit wholly to the clearly expressed wish of the majority."

As had been foreseeable, Supan informed Prince Albert that, since he was in the minority, his "participation would not only be superfluous but might prejudice the pursuit of the work[30]." In response to the specific points which the Prince addressed to him, he confirmed that his dispute with Bourée was over a question of principle. "In the scientific domain there is no compromise[31]." Thus Supan vanished from this collective enterprise.

The printing

In early June 1912, the first two sheets of the new edition, AI and AII, were finally printed. On 10 June, during a session of the *Académie des sciences de Paris*, Prince Albert commented on this new edition and the decisions taken by the Commission which had met in Monaco two years previously. Two copies of sheet AI were presented, one in colour, and one in black and white "to serve as a working chart for those who wanted to add new information." The Prince also announced the publication of an "Index of new soundings [...] communicated by various Navies, explorers, etc." He specified that the second brochure, published a few weeks earlier, "also lists the authorities which have been consulted for details of hypsometry, and the newly adopted terminology". He also explained the arrangements for the completion of the work: "sheet A.I, presented today, is the first of a series of 24 which will appear successively, so that the work will be completed in about 18 months" (Albert I of Monaco 1912).

The schedule thus announced, which envisaged the printing of four sheets every three months, was far from being respected. Repeated interventions by Margerie were the main reason for the delays. During the summer of 1912 he went as far as requesting that the printing of a particular sheet should be stopped because "indispensable corrections [have not] yet been made[32]."

Schott checked the bathymetry in minutest detail; he pointed out all the errors and omissions to Bourée and Tollemer. His information was all the more trustworthy and complete since he had just published a *Geographie des Atlantischen Ozeans* which included a bathymetric chart of that ocean, in colour, at a scale of one-to-thirty-million. Moreover, Max Groll [1876-1916] in July of the same year (1912), published a study entitled "*Tiefenkarten der Ozeane mit Erläuterungen*" in the *Veröffentlichungen des Instituts für Meereskunde an der Universität Berlin*. It was accompanied by three bathymetric charts, in colour, at a scale of one-to-forty-million, whose scientific interest was immediately recognised. Still in 1912, Murray, together with Hjort, supervised a synthesis of the results of the cruise undertaken by the *Michael Sars*. The volume, entitled *The Depths of the Ocean*, immediately became a "classic" of oceanographic literature. The illustrations included, in particular, a *Bathymetrical chart of the oceans showing the "deeps" according to Sir John Murray*, and another chart devoted to the *Depths of the North Atlantic compiled from the latest sources 1911*.

The project of the *Carte du monde au millionième*, which had been planned for more than twenty years, came closer to being realised as a result of a first International Conference held in London in 1909, and a second one in Paris in December 1913. The work then proceeded within commissions and sub-commissions, one of which was charged with examining the bathymetry. It was chaired by Professor Penck, and included among its members Berget, who was attending as the Prince's delegate; and Margerie as rapporteur. There was no need to demonstrate the importance of the oceanic areas since, out of a total of 2642 sheets, 1786 covered the oceans. For these oceanic sheets the Conference re-used some of the principal arrangements made for the *Carte générale bathymétrique des océans*: the choice of isobaths (with the addition of a contour for 100 metres and the possibility of adding subsidiary contours, particularly for the shallower seas where they were economically important), and the choice of colours for the spaces between isobaths. As Berget had been authorised to propose, Prince Albert was to take on the responsibility for producing some of the oceanic sheets of the *Carte du Monde au millionième*.

The printing of the *Carte générale bathymétrique des océans* proceeded less rapidly than planned, but with a certain regularity. After the four sheets of the A series and those of the A' series, three sheets of the B' series were ready by the beginning of summer 1914. A further instalment appeared in March 1914. It included a list of the documents which had been consulted to establish the bathymetry of all the sheets, with the exception of that of the austral polar sheet C'IV, which contained no ocean at all, and the hypsometry of all the sheets, with the exception of sheets C'I, C'II and C'IV. The new soundings submitted since 1912 were indicated on sixteen out of the twenty-four sheets.

The War and Its Consequences

The outbreak of war in August 1914 brought with it a total halt of the publication of the Chart. Richard, Tollemer and Morelli were too old to be mobilised. Bourée had to resume his service in the French Navy; the director and most of the employees of the Erhard printing establishment departed for the Front. Raw materials, especially paper, became scarce. Monaco, as a neutral country, was sheltered from hostilities but was hit hard by the economic consequences of the conflict. The release of further soundings was suspended; in any case, the exchange of scientific and technical documents suffered from the repercussions of the war. Despite these circumstances, Groll managed to publish a mural version of his bathymetric charts at a scale of one-to-twenty-million, in 1915; the soundings on it were less numerous than on the previous version but the names of submarine features had been added.

Prince Albert, who was an ardent pacifist, had done everything in his power, particularly through his relationship with William II, to try and prevent the war. Once it had started, he began to concentrate his efforts on what needed to be rebuilt once peace had been re-established. When, in 1918, the second German offensive on the Marne seemed to be threatening Paris, he moved what he considered to be most precious to a secure place in the country, including the documentation relating to the *Carte générale bathymétrique des océans*.

Once peace had returned, the Prince and Richard could not help noticing that technology, which they had always been very aware of, especially with regard to the resources it offered to oceanographic instrumentation, had made enormous progress during – and because of – the war. Improvements had been made, over the past century, to sounding apparatus, sounding machines, and to the wires and cables with which these were equipped (Carpine 1996). Nevertheless, the ships which were carrying out the soundings had to interrupt their progress for several minutes, if not hours. Attempts had been made to establish depths using various methods other than by direct measurement. In his book, *L'océanographie*, Richard gave a remarkable recapitulation of these trials; the measurement of depth using a propeller, by water pressure, by the study of the compression of sea water, by sound propagation and by variations in gravity. He himself had carried out very extensive research into the latter technique, devising a bathometer which had not given satisfactory results (Carpine 2002). Methods based on the propagation of sound had become more numerous from the beginning of the twentieth century: Berggraf, Behm and Fessenden had built equipment of various kinds before 1914. The position finding and navigation of submarines accelerated the development of techniques and instruments in all the belligerent countries. The Prince and Richard were particularly well informed about the work of the French hydrographic engineer, Pierre Marti [1891-1938], whose sounding apparatus using sound enabled lines of soundings to be taken without the ship having to slow down. This technique, as well as the use of ultrasound, which was being investigated by Paul Langevin [1872-1946] in particular, came to revolutionise the field of bathymetry. From then on, with a speed and a precision which it had been impossible to achieve previously, the number of soundings began to multiply to an extent which would have been unforeseeable a few years earlier.

Another technique, that of wireless telegraphy, came into operation during the last few years of the nineteenth century. Its usefulness in calculating the positions of ships was very quickly recognised. In 1908 the French hydrographer Anatole Bouquet de la Grye [1827-1909] gave a presentation at the *Académie des sciences de Paris* on the "*Détermination de l'heure, sur terre et sur mer, à l'aide de la télégraphie sans fil*". Experiments in transmission made from the top of the Eiffel Tower, on the initiative of Gustave Ferrié [1868-1932], confirmed that the regular emission of time signals by wireless telegraphy would be perfectly feasible in future.

The improvements thus obtained, both in the field of soundings and of positioning, made the completion of the Chart more urgent than ever. Morelli took over the responsibility for the cartographic work after the death of Tollemer, in 1919, whose assistant he had been for nearly twenty years. During a conversation with Pettersson in November 1920, the Prince confirmed to him that he was placing the publication of the last few sheets of the Chart at the top of his priorities; but he was worried about the enormous increase in printing costs. A fourth and last instalment of the documents consulted and of the new soundings was published in 1920. The last sheet of the B' series appeared a few months before the death of the Prince on 26 June 1922.

The Death of Prince Albert

In his will, Prince Albert had made the necessary arrangements to ensure that his scientific work would survive him and that the work in progress would be completed. Richard was appointed as the first of four executors of his will. In one of the articles of this will, the Prince had specified "I give and bequeath to Dr. Jules Richard [...] the total sum of seven hundred thousand francs, of which [...] six hundred thousand francs are intended to complete the scientific and literary work which I leave unfinished, of which he will be the judge, including however the large scientific publication containing the results of my oceanographic cruises and the bathymetric chart of the oceans."

Despite these provisions, the last few sheets were having to be prepared and published under increasingly difficult conditions. From the moment of his accession, the only son and successor to Prince Albert, Prince Louis II [1870-1949], decided to sell the hotel in which the drawing office had been established. Morelli had to move his materials, his archives and his documents to the *Institut océanographique* in Paris, without delay.

The Erhard printing establishment had a new director and a new name; it was now the *Institut cartographique*. The economic and social upheavals which the war had caused, and the development of printing techniques which used lithography less and less, made their effects felt. There was no official act to close down the Prince's *Cabinet scientifique*; but it no longer appeared in the *Annuaire officiel de la Principauté*, which was tantamount to its dissolution. Richard found himself to be solely responsible for the tasks with which Prince Albert had entrusted him in his will. He was obliged to remain in Monaco in order to direct the *Musée océanographique* and went to Paris only very rarely; it was therefore practically impossible for him to supervise the printing of the Chart. The correspondence which he conducted with Morelli reveals why it took nearly ten years to finish the publication of the last eleven sheets. Lack of personnel, lack of materials and repeated strikes were some of the reasons given by the printers to justify the delays which occurred at every stage of the engraving, the corrections and the printing. Having been assured that Richard would not entrust the work to another supplier, the *Institut cartographique* gave priority to other customers who were financially more interesting or to work which was technically less demanding. Morelli himself found it increasingly difficult to carry out his work, for reasons of ill health, which eventually forced him to resort to an assistant when he was having severe eye problems.

Once the war was over, Schott again lent his support, as efficiently as always, to the bathymetry. In doing this, he demonstrated great generosity, for his help was given free of charge at a time when Germany was experiencing disastrous economic conditions.

In addition to the many difficulties caused by the printers, Margerie's attitude constantly provoked delays. The Chart was only one of his innumerable responsibilities: directing the *Service géologique d'Alsace et de Lorraine* and the publication of the *Carte géologique murale de l'Alsace et de la Lorraine*, running the Secretariat of the *Carte géologique internationale de l'Afrique*, a long stay in the United States as Visiting Professor at seven universities. He never ceased to ask for the drafts or engraving to be completed, or even remade, or to ask for the printing of the sheets to be halted. Morelli did not succeed in getting him to return the proofs or in obtaining his agreement to go ahead with the printing. He countered all the increasingly abrupt remarks which Richard sent him with the same argument: out of respect for the memory of Prince Albert one must not hesitate to sacrifice a few weeks, if necessary a few months, in order to achieve the same standard of perfection for the last few sheets of the Chart that the Prince would have wanted.

Richard had planned that the Chart should be finished in 1925 at the latest. The repeated delays continuously fuelled his dissatisfaction. "The money left by the Prince at his death in 1922 [...] having suffered the same fate as the franc in 1926", he was alarmed that the expenditure for the Chart was growing to the detriment of what he considered to be the major oceanographic work of the Prince, the *Résultats des campagnes scientifiques*. These financial problems made him decide not to pursue the recommendation adopted, at Margerie's request, by the International Geographical Congress in Cairo in 1925: the publication of a fifth and last instalment of the lists of soundings. In addition, he took steps to transfer the responsibility for, hence the survival of, the Chart to other competent organisations, once he had completed the task entrusted to him by the Prince, which was to see the current edition through to its completion. His irritation reached a climax in 1930 when he had to resort to sending registered letters to Margerie.

Was it unwittingly, or to justify himself, that the latter declared he was busy "activating" the publication of the Chart? Everything in the exchange of letters between the two men contradicted Margerie when he affirmed that "with the agreement of Dr. J. Richard, Director of the Scientific Office of the Prince, I have had total responsibility for the last few sheets, notably for those which represent the two polar caps" (Margerie 1946 : 668).

Thoulet had been only too good a prophet when he opposed the addition of hypsometry. This decision largely contributed to the delays in publishing the Chart. Over ten years, an increasing number of regional bathymetric charts had been published with the aid of new techniques, in Europe and in the United States. By the time the last few sheets appeared, the Chart was completely obsolete. This fact was stated quite bluntly at the International Congress of Oceanography, Marine Hydrography and Continental Hydrology, held in Seville in May 1929.

Description of the Second Edition

Like the previous Chart, the second edition of the *Carte générale bathymétrique des océans* consisted of twenty-six sheets, its format was identical and the printing was also done by the lithographic process (fig.10).

The title sheet was worded as follows: CARTE GÉNÉRALE BATHYMÉTRIQUE DES OCÉANS / DRESSÉE PAR ORDRE DU PRINCE ALBERT I^er DE MONACO / d'après le Mémoire de M. le Professeur THOULET / adopté par la Commission de Nomenclature Sub-océanique / et par le Congrès International de géographie de Washington (8 septembre 1904) / Deuxième édition (1912-1930) / sous la direction de M^r HENRI BOURÉE, Lieutenant de Vaisseau, / de M^r le Prof. EMM. DE MARGERIE (Hypsométrie) et de M^r le Prof. G. SCHOTT (Bathymétrie) / par M^r J. MORELLI. This title was followed by the scale and the explanation: *Les Sondes sont exprimées en Mètres. – Les Longitudes sont rapportées au méridien de Greenwich*. This was followed by a key to the depth and height contours, and by two further lines of information: La 1^ère édition (1903-1904) a été faite sous la direction de M. CH. SAUERWEIN par M. TOLLEMER, and *En vente au Musée océanographique de Monaco*.

The two-line title of the twenty-four sheets of the Chart was at the top, outside the border, and centre justified: CARTE GÉNÉRALE BATHYMÉTRIQUE DES OCÉANS / PUBLIÉE PAR LE CABINET SCIENTIFIQUE DE S.A.S. LE PRINCE DE MONACO. On the left, just above the border, the words: Date de la mise à jour de cette feuille (Date of production of this sheet) were followed by the actual date (variable depending on the sheet). On the right, the reference of that particular sheet was indicated.

The sources consulted for bathymetry and hypsometry, as well as the key to the colours for the depths and the relief of the land surface were printed at the bottom of the sheets, outside the border.

The projections had not been modified. The division of the sheets in the Mercator projection was kept to 0°, 90° W and E, and 180° lines of longitude. In the end the division along the lines of latitude was rectified and carried out as planned by Thoulet, that is at 46°40' instead of 47°. The grid was similar to that of the first edition. The numbers used for labelling the lines of longitude and latitude were of a regular design and identical in height; the font of the numbers used for the soundings were identical to those of the first edition.

The name of the printers was omitted from three sheets. It usually appeared at the bottom left, outside the border. It appeared in various formats. On nine of the sheets published first, the text was as follows: *Gravé et Imp. par Erhard F^res Paris*. On the next three sheets, it changed to: *Gravé et Imprimé à l'Institut Cartographique de Paris*. On the last nine sheets it read: *Imp. de l'Institut Cartographique de Paris*.

The relief of the continents was expressed by contours whose values were similar to those of the isobaths: 200, 500, 1000, 2000 ... 8000 metres. The buff colour became darker with increasing height. Apart from the relief, rivers and the characteristics of glaciers were indicated; the number of place-names had increased considerably.

For the maritime part, the more numerous soundings were always indicated by a point, accompanied by the depth in metres. The labelling of the nature of the sea floor had disappeared. The shades of blue used in the key to the depths were slightly different from that of the first edition.

At first five hundred copies "in colour" and two hundred copies in "black and white" were printed. For obvious reasons of economy, Richard reduced the number of printed copies of the last three sheets (CI, CII and CIV) to 400 in colour and 100 in black and white. Between 1912 and 1921, the price of the coloured sheets

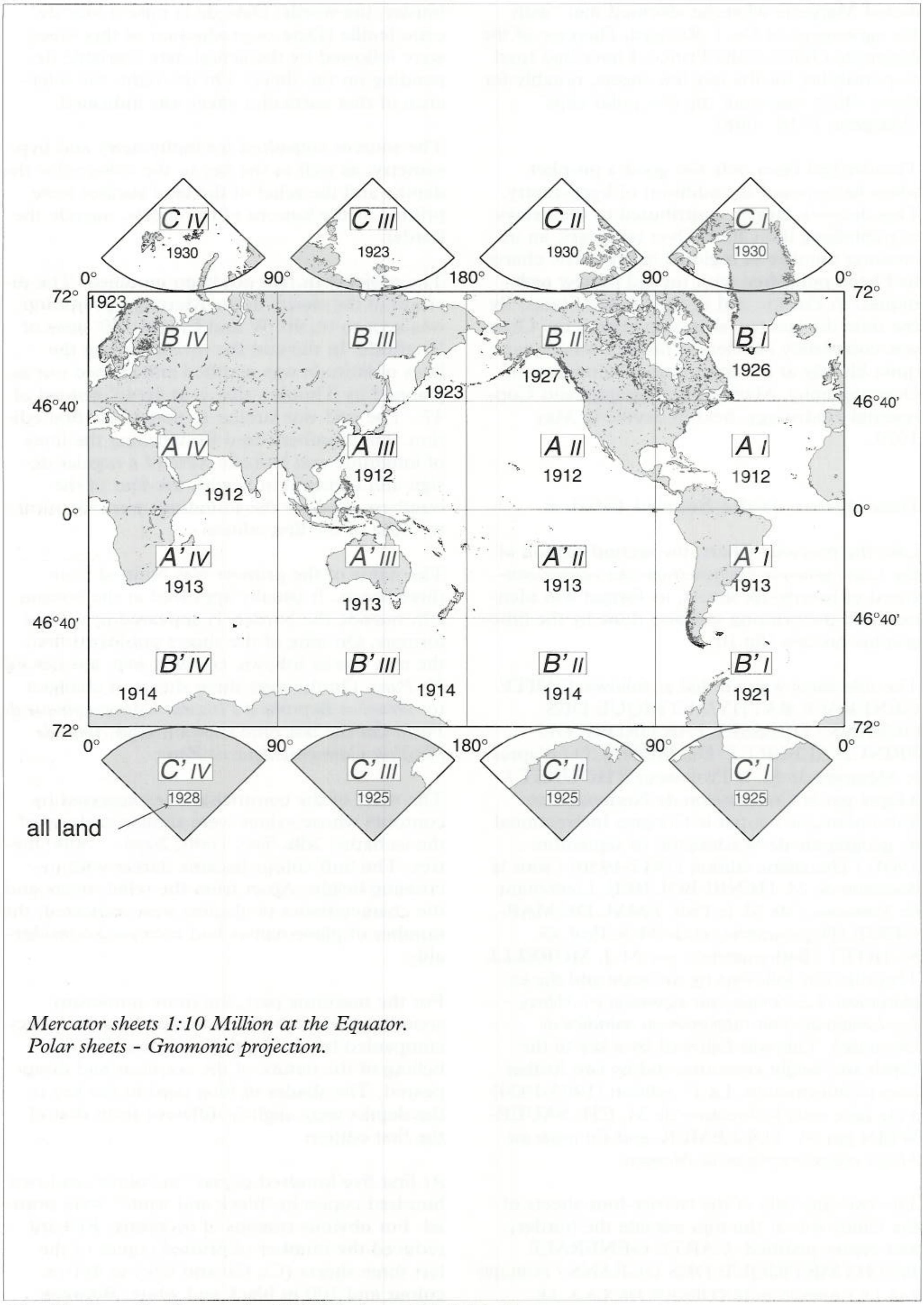

Fig. 10. Assembly diagram for GEBCO sheets (2nd Edition)

was 10 francs and that of the black and white sheets 5 francs; in October 1921 these prices were increased threefold. The price of the volumes was increased from 7 to 10 francs. Between 1912 and 1921, the distribution was handled by the *Musée océanographique* in Monaco and in Paris by Challamel, a bookseller-publisher specialising in maritime and colonial subjects. For a few years the firm of Andriveau-Goujon Henry Barrère also sold the Chart in Paris.

In 1920 the printer asked to be relieved of the stocks of the first edition and of the sheets of the second edition already printed. Bourée sold the damaged copies; the remainder were sent to the *Musée océanographique*. It was decided that the sheets which had already appeared in a second edition should be cut up into index cards.

From 1922 onwards, publicity for the Chart appeared regularly in the *Bulletin de l'Institut océanographique*. Nevertheless, although a shade less so than the first edition, the second one was a commercial failure. When publication ceased, only one hundred and forty-eight complete sets had been sold. About fifty, sent out free of charge, went to collaborators, to people responsible for bibliographies, to some university libraries and geographical societies, to hydrographic services and to naval ministries. The sale of single sheets never exceeded thirty or forty copies per year.

The Transfer of Responsibility

As a distant reverberation of the international conferences and congress held in Washington (1889) and St. Petersburg (1908 and 1912), an International Hydrographic Conference was organised in London in 1919. The war had proved to hydrographers that it was necessary to intensify their contacts, to reconcile their working methods and to standardise their cartographic products. Twenty-four States were represented at the meeting, one of which was Monaco; Prince Albert had chosen to be represented by Berget who took a copy of the *Carte générale bathymétrique des océans* with him. At the suggestion of the French delegation, it was decided to form an International Hydrographic Bureau. A Committee was entrusted with studying the details of its organisation and location, and as they were anxious to establish the Bureau in a neutral country, near the sea, Monaco was chosen. Prince Albert's reputation also influenced their choice. The Sovereign of Monaco, for his part, as an advocate of international co-operation (Albert I of Monaco 1998), could only be in favour of establishing the Bureau in his Principality.

The Bureau was established in Monaco in 1921, one year before the passing of Prince Albert. It would seem that cordial links between the *Musée océanographique* and the Bureau were soon formed; the two organisations, both looking to the sea, had clearly distinct but complementary functions. Aware of the privileged position which the Bureau occupied at the centre of the network of hydrographic services, Richard requested its assistance, in 1924, in obtaining the latest data, needed to complete several of the Chart sheets. He could not have failed to be sensitive to the quality and the seriousness of the Bureau's publications. The subjects dealt with in the *Review*, the *Special Publications* and the *Bulletin* often had some link with bathymetry, whether it was a question of sounding techniques or cartographic problems. It is obvious that the studies conducted by the Bureau were based on sources that were international, abundant and carefully kept up to date.

On 6 January 1928, Richard addressed a long letter to Rear Admiral Albert Niblack [1859-1929], Chairman of the Steering Committee; in it he stated that "The Second Edition of the *Carte générale bathymétrique des océans* is nearing completion [...] It is much to be desired that the bathymetric chart [...] should keep up with the progress of science. In my opinion this can be done only by an international organisation and the International Hydrographic Bureau seems to me to be the most suitable[33]." On 12 January, Commander Geoffrey Spicer-Simson [1876-1947], the Secretary-General, sent the following reply: "The Bureau cannot take on the responsibility for the day-to-day upkeep of this chart without having, beforehand, consulted its member States. The Steering Committee will study this question in order to be able to make an informed report, enabling these States to take a decision[34]." Pierre de Vanssay de Blavous [1869-1947], a member of the Steering Committee, wrote a note which Richard acknowledged on 23 February: "I am fully confident that the States [the member States of the International Hydrographic Bureau], once they have read your very clear report, will wish to honour the work and the memory of Prince Albert by agreeing to keep up to date the Chart of the Oceans, which he was generous enough to instigate at his own personal expense in order to respond to the repeated wishes of the International Congresses[35]."

The question was put on the agenda of the First Extraordinary International Hydrographic Conference, held in Monaco between 9 and 20 April 1929. On 26 April, Richard was officially informed, through Spicer-Simson, that "The International Hydrographic Conference of Monaco has just authorised the International Hydrographic Bureau to keep the General Bathymetric Chart of the Oceans up to date in future, in place of the Scientific Office of Prince Albert of Monaco which has been in charge of this until now. Consequently, the Steering Committee has asked me to inform you that it has accepted the proposal formulated in your letter of 6 January 1928[36]."

Epilogue

The change-over was complete. Richard had every right to consider that he had found the best solution to ensure the perpetuity of an enterprise to which Prince Albert had attached so much importance.

It is incontestable that, without the unwavering will, the scientific competence, the financial contribution and the considerable technical means provided by the Prince, the Chart would never have been published. Without doubt he was particularly aware of the highly international character of the enterprise. The commission nominated in Berlin, and those convened in Wiesbaden and in Monaco, had gathered representatives from eight nations. The provenance of the data used to draw the sheets was even broader. The level-headedness of Mill and Krümmel, Pettersson's broad-mindedness and the competence and devotion of Thoulet, Richard, Bourée, Schott, Tollemer and Morelli deserve to be underlined. These positive aspects compensated for the difficulties encountered while bringing to fruition a task of such proportion: Sauerwein's shortcomings, Supan's intransigence, Margerie's unreasonableness and the direct and indirect consequences of the war. It is likely that the Prince may have regretted the persistent reserve of Sir John Murray who never explicitly referred to the *Carte générale bathymétrique des océans*, restricting himself to writing in a small popular science book: "The Prince of Monaco, the Berlin Institut für Meereskunde, and the writer have published maps showing practically all the deep-sea soundings known up to the present time" (Murray 1913 : 25). It is true that another member of the *Challenger* expedition, Buchanan, made one of the most positive judgements of the Chart: "The Museum at Monaco bears testimony at every turn to the great lines on which the Prince has himself worked, and in which his work is fundamental. Thus, in the purely hydrographical department, we see his bathymetrical chart of the world, on which all the trustworthy deep soundings are entered. This great document may be said to be the foundation-stone of oceanographical work" (Buchanan 1910 : 7).

As to the Prince himself, he was able to express his own sentiments when he went to the United States to receive the Agassiz medal. He made a speech before the National Academy of Sciences in Washington, on 25 April 1921, which in some way was his scientific testament. He did not fail to include the *Carte générale bathymétrique des océans* in the summary of his oceanographic achievements (Albert I of Monaco 1921 : 184): "I shall close my all too brief survey of the mighty domain created by the science of oceanography by speaking to this distinguished assembly of the bathymetric chart of all the seas of the globe the preparation of which I undertook at the time of the International Congress at Berlin in 1899. I realized then that this task was necessary as a basis and a program for the great work to which I have consecrated my life."

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NOTES

1 Naval Officer, Secretary of the Royal Danish Geographical Society.

2 Professor at the Naval Academy of Fiume; he took an active part in the cruises of the *Pola*.

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4 J. Thoulet to C. Sauerwein; Nancy, 30 April [*error pro* March] 1903 (AMOM = Archives of the Oceanographic Museum of Monaco).

5 J. Thoulet to C. Sauerwein; Nancy, 10 June 1903 (AMOM).

6 J. Thoulet to C. Sauerwein; Nancy, 28 May 1903 (AMOM).

7 J. Thoulet to C. Sauerwein; New York, 14 September 1904 (AMOM).

8 J. Richard to C. Sauerwein; Monaco, 25 September 1904 (AMOM).

9 J. Richard to C. Sauerwein; Monaco, 19 October 1904 (AMOM).

10 Erhard to A. Tollemer; Paris, 18 October 1904 (AMOM).

11 E. de Margerie to C. Sauerwein; Paris, 7 June 1905 (AMOM).

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[31] A. Supan to Prince Albert I of Monaco; Breslau, 18 May 1912 (APM, C.800 bis 5).
[32] E. de Margerie to H. Bourée; Agay, 18 September 1912 (APM, C.800 bis 4).
[33] J. Richard to A. Niblack; Monaco, 6 January 1928 (AMOM).
[34] G. Spicer-Simson to J. Richard; Monaco, 12 January 1928 (AMOM).
[35] J. Richard to P. de Vanssay; Monaco, 23 February 1928 (AMOM).
[36] G. Spicer-Simson to J. Richard; Monaco, 26 April 1929 (AMOM).

The archives consulted and used in the preparation of this work are too numerous to be quoted here as references; only documents from which extracts have been cited are included in these notes. Additional information will be included in a study, currently in preparation, which will be devoted to *Le Prince Albert 1er de Monaco et la cartographie.*

The majority of the above archives belong to the *Musée océanographique* in Monaco. Other documents used are held by the archives of the *Palais princier* in Monaco, the *Archives nationales* (France) and the archives of the *Académie des sciences de Paris*, the *Service historique de la Marine* in Vincennes, the archives of the Royal Geographical Society in London, the *Riksarkivet* in Copenhagen and the Nansen Foundation in Oslo, as well as in two private archives.

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I would like to express my deep gratitude to all those, too numerous to be mentioned here by name, who, whether in charge of archives, libraries and map libraries, or as historians, geographers, cartographers, oceanographers and hydrographers have helped me during the long period of preparation of this work. I am particularly grateful to Maya Whitmarsh for her quite remarkable translation.

3- The International Hydrographic Bureau Period

(3rd & 4th Editions)

Adam J Kerr

The Third Edition

Dr Jules Richard, previously Director of the Cabinet Scientifique of HSH Prince Albert I of Monaco, in a letter dated 6 January 1928, noted the near completion of the Second Edition of the General Bathymetric Chart of the Oceans and set in motion the preparation of the Third Edition. He mentioned that there were three North Polar charts to be finished and then the work entrusted to him by Prince Albert would be completed. He invited the International Hydrographic Bureau to undertake to keep the General Bathymetric Chart of the Oceans up to date with the progress of science[1]. He noted that only an international organisation was capable of the work and that the International Hydrographic Bureau seemed the most suitable. He further noted that if the Bureau agreed to his proposal he would gratuitously hand over the lithographic stones of the chart, which were then at the *Institut cartographique de Paris*. He commented that the cost of printing the sheets was small compared with that of preparing the stones.

The Directing Committee of the IHB, under the Presidency of Rear Admiral A.P.Niblack, decided to refer the offer to the Member States at the next International Hydrographic Conference (First Supplementary I.H.Conference) in 1929. In an article in the International Hydrographic Bulletin, March 1928, the changing state of knowledge of ocean bathymetry was recognised in the following quote: "But the methods of echo sounding which are coming more into use in all countries will shortly introduce great improvements in our knowledge and it is already reasonable to suspect that the topography of the bottom of the sea is hardly less complicated than the relief of the continents. Thus a third edition of the General Bathymetric Chart of the Oceans will become imperative at a date, which doubtless is not far off, and it is essential for the general study of the Oceans...".

In the same article, it was stated that the Third Edition would be work of truly international character and interest and can be undertaken by the IHB, the organisation of which makes it easy to collect the necessary information. It was also noted that it would entail fairly considerable expenditure and the need to increase the present staff of the Bureau by obtaining the services of a professional draughtsman[2]. However, it was believed that the work could be undertaken without increasing contributions. The Directing Committee also felt that there would be greater demand for the product in a few years and that some cost recovery could be expected. An interesting comment, in view of later developments concerning toponomy, was that it would be expedient for the International Hydrographic Bureau to publish an edition with English nomenclature in accordance with article 21(a) of the Statutes; this could be done quite easily but would entail a relatively small increase of expenditures.

Although the Third Edition has been criticised by some writers[3], it undoubtedly had to cope with a huge array of problems, not the least of which was finance, as the previous remarks correctly prophesied. The serious limitation of resources resulted in a very extended period between conception and completion. During the period 1935-1955, which included the major disruptions caused by the Second World War, there were major advances in hydrographic and oceanographic technology. These included the advent of the continuous profiling echo sounder and electronic positioning and resulted in a very significant increase in the amount of data collected, and in the need to develop new organisational and technical methods to manage it. Although the major criticism levelled against those responsible for producing the Third Edition, their inability to apply modern cartographic and geological knowledge and principles, was undoubtedly correct, the producers were clearly faced with a variety of overwhelming problems. Nevertheless, they did succeed in developing organisational procedures, which developed international co-operation, some of which endured successfully, at least until the age of digital data and modern communication.

The requirement for a Third Edition does not appear to have been explicitly agreed at the 1929 I.H. Conference. Instead, an agreement was reached in more general terms, namely as stated in Resolution No. 23: "That the Bureau be charged with keeping up to date the General Bathymetric Chart of the Oceans of which the 'Cabinet scientifique du Prince Albert de Monaco' has just drawn up the Second Edition, it being understood that this be done as a special case and not to be regarded as a precedent for future work of a similar nature". It was also decided that an English version of the chart was not considered necessary[4]. This set the tone for organisational measures to be put in place. In 1930, Ingénieur hydrographe général Pierre de Vanssay de Blavous, President of the Directing Committee of the IHB, presented a report concerning Bathymetric Soundings of the Oceans to the Fourth General Assembly of the International Union of Geodesy and Geophysics (IUGG) in Stockholm[5,6].

In this paper we read of plans to collect ocean soundings on 1:1 million collector sheets. Other matters such as the method of correcting soundings, whether to use the Mercator projection and the method of deciding the priority of publishing sheets were raised. An appeal was made to receive advice from learned oceanographers, to help the Bureau solve these questions. Vanssay de Blavous proposed that a consultative committee be constituted, with meetings at Monaco. In view of the criticisms that were later made by scientists the following questions raised by him at this meeting are most relevant :

a. Do you consider that the "Carte générale bathymétrique des océans" fulfils the requirements of Oceanographers in so far as its scale, its type of projection and its present division are concerned and that it should be kept up to date by the issue of new editions? If so, by the issue of the new edition of which sheet do you consider that commencement should be made?
b. If the reply to the above question is in the negative, what do you consider should be done to fulfil the requirements of Oceanographers? Which organisation could undertake a publication on a new basis?

Subsequently, a number of oceanographic scholars wrote letters to the Bureau, expressing their opinions on the technical structure of the Third Edition. The concept of 1:1 million scale collector sheets was adopted and from 1931 the Bureau collated on these sheets all the soundings that it had been possible to obtain. These were plotted by the Bureau's own draughtsmen.

In a Circular Letter, dated 5 December 1932[7], the Bureau instructed Member States on the information required concerning all oceanic soundings. This included: 1. Position; 2. Depths obtained; 3. Method of sounding; 4. Nature of bottom; and 5. Whether depth given is corrected or not. If the depths were not corrected they were asked to provide in addition: 6. The slope of the wire; or 6(a). Velocity of sound used; and 6(b). Any observations taken of salinity, temperature, etc. at various depths.

Plotting sheets at approximately 1:1 million scale on the Mercator Projection, were provided gratuitously by the Hydrographic Office of the Imperial Japanese Navy. It was noted[8] that the scale of these plotting sheets was amply sufficient for the insertion, with adequate accuracy, of the details of the oceanic soundings. One thousand of those sheets were needed to provide world coverage and constitute the collecting sheets for all oceanic soundings; the Bureau would maintain them.

An organisational feature was the publication of pamphlets to accompany each sheet. Originally there were four pamphlets describing all sheets of the edition, but by now there was a pamphlet for each sheet. These contained specific references to the sources and to all the hydrographic charts used and listed the position of new soundings by latitude and longitude, with details of their origin from scientific cruises of research and survey vessels. Such details were available from the "List of Oceanic Soundings" published by the British Admiralty. The French "Annales Hydrographiques" and the German "Annalen der Hydrographie" also provided sources, as did the pamphlets published by the Hydrographic Office of the USA. In attempting to make comparisons between existing and new data it was necessary to scale soundings from the 1:10 million scale sheets of the Second Edition. However, it was noted that successive compilations by reduction or increase of scale caused accumulation of positional errors that amounted to as much as ten sea miles[9].

Attention was now being given to the reduction of echo soundings in terms of the speed of sound through seawater. Echo soundings, in depths greater than 1,000 metres, were corrected for the local velocity of sound whenever the data supplied allowed. Initially these corrections were provided by the IHB itself from various tables combined, but later Matthews Tables[10] were used. All remaining soundings were corrected to a standard velocity of 1,500 m/s.

In the period from 1929 until the Second World War, there was considerable scientific activity at sea and a number of major oceanographic cruises took place. These resulted in the production of numerous national bathymetric charts which were listed in a detailed paper by Bencker[11] on the preparation of the Third Edition of GEBCO. Data from these national efforts found their way to the IHB and led to a steady increase in the total amount of data handled. Bencker[12] notes that the First Edition showed 18,400 soundings and the Second Edition about 30,000 soundings. By the time, the Third Edition was nearing completion, in 1952, there were over ten times that amount, with about 358,700 soundings plotted by the Bureau.

The cartographic design of the published sheets of the Third Edition followed the model used in the previous editions, except that the projection for the area north and south of 72° latitude was changed from Gnomonic to Polar Stereographic[13]. Twenty-four sheets were planned. Sixteen of these were on the Mercator Projection at scale 1:10 million at the equator between latitudes 72° North and 72° South. In the Polar regions there were to be eight sheets on Polar Stereographic projection (fig.11).

With an increasing amount of data it was now possible to be selective in the number of soundings that were to appear without overlap on the published sheets. Bencker[14] has produced statistics which show the percentage of soundings that were selected. As the amount of data available varied greatly between sheets in the low latitudes, it is difficult to derive any trend in these statistics, except to note that somewhat less than 20% of the original soundings appeared on the published sheets. Monahan[15] has been critical of the selection and treatment of the soundings, noting that echo sounding profiles were not treated as profiles but broken into discrete "soundings". Furthermore, he states that almost without exception the shallowest points of the profiles were selected. This, in fact, was in accordance with the navigational chart cartographer's principle to exaggerate potential dangers to the navigator. Unfortunately for the purpose of portraying the true geomorphological form of the ocean floor this was unsatisfactory and led to obscuring many of its more important features, in particular some geologically interesting trenches and submarine valleys. However, not only was the sounding selection questionable in the eyes of the scientists but the accuracy of positioning individual soundings sometimes left much to be desired. Bencker writes "New soundings, inserted after the others, are frequently only indirectly connected to the preceding systems; successive compilations by reduction or increase of scale have caused an accumulation of errors. Even on the 1:10,000,000 chart we have found errors attaining 10 sea miles."[16]

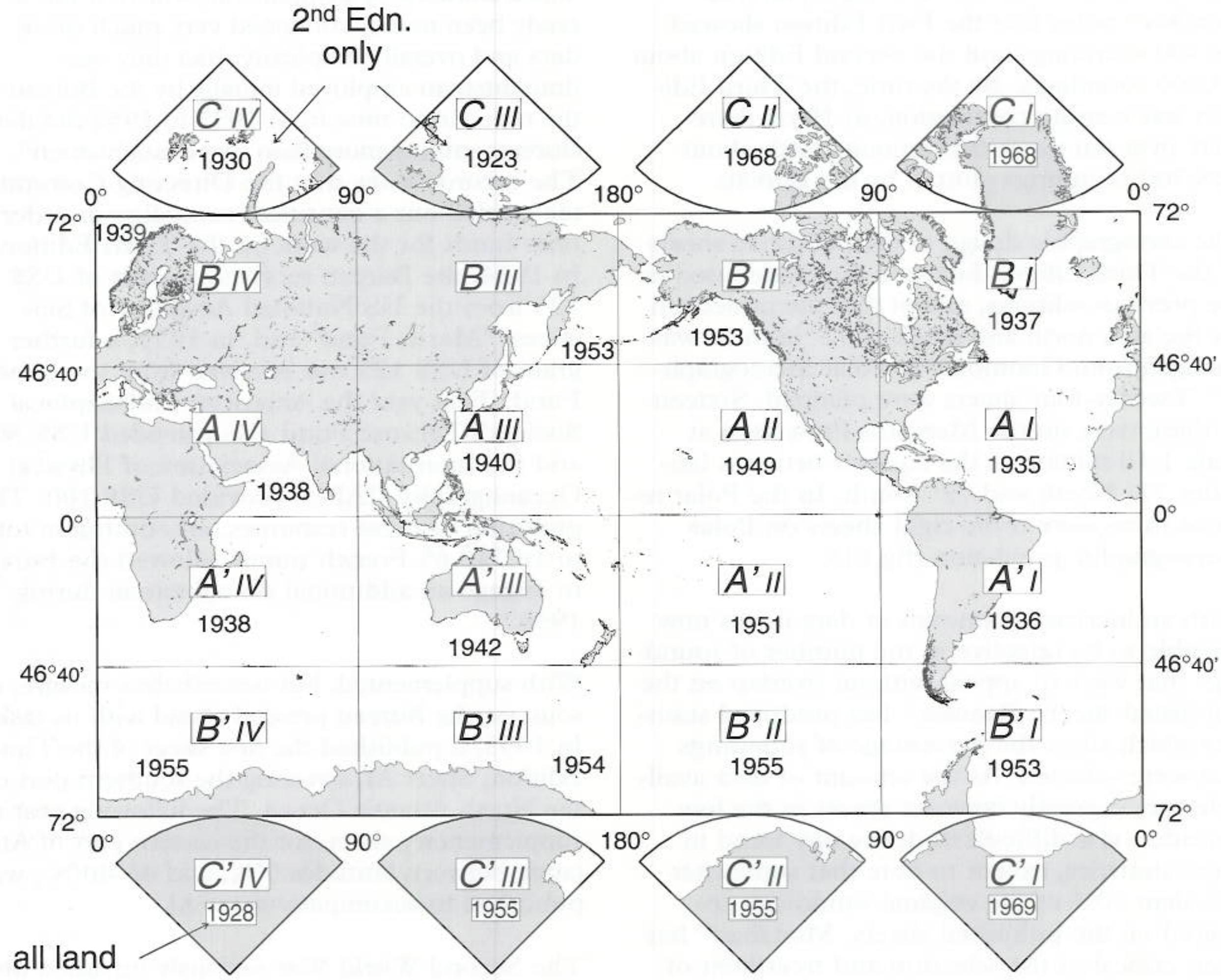
While it is reported that the First Edition had enjoyed the services of seven draughtsmen, the Third Edition, by comparison, which, it has already been noted, contained very much more data and overall complexity, had only one draughtsman employed initially by the Bureau for the task. At no time from 1933 to 1952 did the Bureau employ more than two draughtsmen[17]. The records show that the Directing Committee carried out a continual campaign in order to raise funds for the work on the Third Edition. In 1934, the Bureau received a grant of US$ 125 from the US National Academy of Sciences' "Marsh Fund" and, in 1935, a further grant of US$ 125 was received from the same Fund. That year the American Philosophical Society's Penrose Fund also provided US$ 500 and the International Association of Physical Oceanography (IAPO) provided US$ 100. The provision of these resources, amounting in total to 18,740.65 French francs, allowed the Bureau to engage an additional draughtsman during 1936[18].

With supplemented, but nevertheless meagre, resources, the Bureau pressed ahead with its task. In 1935, it published the first sheet of the Third Edition, Sheet AI, covering the southern part of the North Atlantic Ocean. The following year a supplementary sheet, for the eastern part of Atlantic between latitudes 5°N. and 46°40'N., was published to accompany sheet AI.

The Second World War seriously intruded on the programme although some compilation work appears to have continued. Following the war the Bureau began to look for more economical procedures for the production of the sheets. This led, in 1949, the French *Institut géographique national* (IGN), in Paris, to offer to print the Third Edition of sheet A II, on terms very favourable to the Bureau[19].

The Bureau continued over a period of some twenty years with a steady, albeit slow, publication of sheets, according to the schedule in the table on page 57.

In the period from 1951 onwards the Bureau received funds from various sources for the work on GEBCO. These included the US National Academy of Sciences, the *Office scientifique des recherches coloniales* (France), the International Council of Scientific Unions (ICSU) and the Challenger Society.



Mercator sheets 1:10 Million at the Equator.
Polar sheets - Polar Stereographic projection.

Fig. 11. Assembly diagram for GEBCO sheets (3rd Edition)

GEBCO Third Edition		
Sheet	**Date**	**Printers**
AI	April 1935	Institut cartographique de Paris
AII	1 May 1949	Institut géographique national
AIII	1 February 1940	GAILLAC MONROCQ et Cie, Paris
AIV	1 February 1938	GAILLAC MONROCQ et Cie, Paris
A'I	January 1936	Institut géographique national
A'II	1 January 1951	Institut géographique national
A'III	May 1942	GAILLAC MONROCQ et Cie., Paris
A'IV	1 July 1938	GAILLAC MONROCQ et Cie., Paris
BI	1 June 1937	Institut cartographique de Paris
BII	1 February 1953	MICHARD, Paris
BIII	1 February 1953	MICHARD, Paris
BIV	1 February 1939	GAILLAC MONROCQ et Cie., Paris
B'I	1 October 1952	Anc. Ets. Dufrency, Paris
B'II	1 March 1955	Anc. Ets. Dufrency, Paris
B'III	1 March 1954	MICHARD, Paris
B'IV	1 March 1954	MICHARD, Paris
CI	1 October 1968	Institut géographique national
CII	1 October 1968	Institut géographique national
CIII	Not published	
C IV	Not published	
C'I	1 June 1969	Institut géographique national
C'II	1 March 1955	Institut géographique national
C'III	1 March 1955	Institut géographique national
C'IV	Not published	

Table compiled by Antoine Ferrero-Regis (IHB)

In 1953, Vice Admiral J.D.Nares, then President of the Directing Committee of the IHB, read a paper at the International Joint Commission on Oceanography's meeting in Liverpool, in which he outlined the financial situation of preparing the Third Edition. In this paper[20], while recognising the contribution made already by several organisations, he noted that the Bureau, with its present budget, could only produce one sheet per year. This amounted to a cycle of 20 years per edition, which was too long a period for the charts to be of real scientific value. He proposed that a five-year cycle was essential, with an ability to produce four sheets per year. This would require an additional US$ 7,500 per annum to meet publication costs. He then proposed several measures to obtain these funds, including asking ICSU to make an annual grant of US$ 2,500 that would cover the cost of one more sheet per year. Dr. Ronald Fraser, liaison officer between ICSU and UNESCO, undertook the investigation of financial support. On a visit to the Bureau, it was noted that it had sufficient funds to pay for three new sheets B'I, BII and BIII, anticipated to be issued in 1953. Dr Fraser, following an investigation, stated that an allocation of US$ 2,000 for the year 1954 had been recommended to the Executive Board of ICSU and he confidently expected formal approval by the Board. With this promise in hand Admiral Nares then proposed a schedule for work in the period 1954-56, with the Bureau meeting the ICSU grant to make a total of US$ 4,000 a year available in the first two years and US$ 4,500 available in the last year. In addition to the funds promised by ICSU, Admiral Nares noted some ongoing grants that appear to have been received annually from the US National Academy of Sciences, the Challenger Society and the *Office de la recherche scientifique et technique d'outre-mer*, France.

During its last years, work progressed in compiling and publishing the final sheets of the Third Edition. Some additional funds were received, as already discussed, but the staff of the Bureau remained at the same level. Unfortunately, as observed by Monahan[21]: "The Third Edition was out of date long before 1955, when the edition was declared finished, despite the fact that three Polar sheets were published later (1968-9) and three others remained untouched." Sadly, although the Directing Committee and staff of the Bureau had worked long and hard in the face of both funding shortages and major changes in technology, they had failed to align themselves with the current needs of their main customers, the marine scientists.

The Fourth Edition

David Monahan[22], writing in 1977, said "If the Third Edition was out of date, the Fourth was a veritable anachronism, since profiles were still broken into discrete soundings and interpretation performed by untrained people." However, he noted that changes had taken place in the production procedures, with the introduction of the Volunteering Hydrographic Offices (VHOs), which undertook the preparation of the 1:1 million scale collector sheets for specific parts of the world. In 1958, the Bureau had requested certain Hydrographic Offices to volunteer for the preparation of the plotting sheets of GEBCO in order to distribute this task on a regional basis. These sheets were submitted to the IHB for review and then forwarded to the *Institut géographique national* (IGN) for drawing of contours and the preparation of the final 1:10 million scale sheets.

In his 1953 paper presented to the International Joint Commission on Oceanography[23], Admiral Nares had also mentioned how difficult it was for the IHB to present bathymetry in a form that will fully satisfy the various scientists who they hoped would use the charts. He stated that different types of scientists had different ideas of how the depth contours should be drawn. He welcomed suggestions from scientists on how the IHB could improve the sheets before the final printing. He also suggested that the IJCO could possibly name a scientific expert who could review each sheet objectively.

At the General Assembly of the International Association of Physical Oceanography in 1957 a committee was formed on the General Bathymetric Chart of the Oceans, with the mandate "to promote the preparation of an up-to-date chart of the bottom topography of the Oceans in liaison with the International Hydrographic Bureau and the International Council of Scientific Unions"[24]. The committee was comprised of the following persons:
Dr. G.Böhnecke (Chairman) (Germany)
Dr. Ronald Fraser (Secretary) (ICSU)
Mr. A.Atherton (UKHO)
Dr. P.L.Bezrukov (Academy of Sciences, USSR)
Dr. Bruce C.Heezen (Lamont Geological Observatory, USA)
Dr. H.F.P.Herdman (National Institute of Oceanography, UK)
Dr. H.W. Menard (Scripps Institution of Oceanography, USA)
Dr. K.Suda (Hydrographic Office, Japan)
RAdm A.Viglieri (IHB, Monaco).

The following year (1958), a small round table meeting took place at the Bureau on 3-4 June. This meeting was attended by Dr. G.Böhnecke, Dr. Ronald Fraser (ICSU) and members of the Bureau's Directing Committee. Recommendations were adopted concerning the distribution of the work of preparation and publication of the GEBCO among the various organisations concerned[25]. Official agreement by the IHB to the future action on GEBCO can be found in Resolution P.73 - Bathymetric Chart[26] of the VII[th] International Hydrographic Conference. As it provides a useful reference it will be quoted in full:

"P. 73 – Bathymetric Chart

It was decided that the following resolution be added as paragraph IV to item No 37, page 129 of the Repertory:
IV. The Conference arrived at the following conclusions:-

1. That the General Bathymetric Chart of the Oceans is primarily intended for use in oceanography and other branches of science..
2. That the work involved in producing a general bathymetric chart is in urgent need of continuation.
3. That a proposal concerning the possibility of financial support of a general bathymetric chart, over a period extending from November 1, 1958 to at least the date of the XIIIth International Hydrographic Conference in 1962, was communicated to an observer for the International Council of Scientific Unions, on behalf of ICSU and of UNESCO; of the order of $ 10,000 per annum from UNESCO and of $ 5,000 from ICSU, such amounts being subject to the formal approval of the General Conference of UNESCO on the one hand, and of the Executive Board of ICSU on the other.
4. That charts should be produced at such a rate that complete editions every few years may be envisaged.
5. That it seems impractical for the International Hydrographic Bureau to perform all the work at the required rate.
6. That it appears to be desirable to spread the work out between the International Hydrographic Bureau, a central organisation concerned with the topography and morphology of the ocean floor under ICSU, and certain Hydrographic Offices on a regional basis.

7. That the Directing Committee consult with ICSU as to the means whereby the above arrangement may be made.
8. That the central organisation concerned with the topography and morphology of the Ocean referred to above might well be a permanent service in the Federation of Astronomical and Geophysical Services (FAGS), whose finances would be the responsibility of the Federation.
9. That pending this arrangement, the International Hydrographic Bureau should continue as hithertofore but should not increase its expenditure until it receives further directives in this direction.
10. That in any new arrangement that might be made, there should be very close cooperation between the International Hydrographic Bureau and the proposed permanent service.
11. That the wishes of His Serene Highness Prince Rainier III, who has been informed of the proposed alterations, which are believed to be in full accord with the objectives of the distinguished Ruler, Navigator and Oceanographer Prince Albert I, shall be fully considered in any revised arrangements that are made."

On 7 July 1958, the Bureau sent a Circular Letter to its members concerning future plans for the GEBCO[27]. Besides quoting the I.H. Conference Resolution P. 73, the Directing Committee informed Member States that there had also been the XI[th] General Assembly of the IUGG at which GEBCO matters had been discussed. An *ad hoc* committee was formed with Dr. Böhnecke as Chairman, but apart from him and Dr Fraser, there were different members from the committee formed earlier. It is unclear how these two committees officially interacted. Nevertheless this *ad hoc* committee appears to have endorsed the main points of the earlier IHO resolution, namely the adoption of the 1:1 million scale plotting sheets and the regionalisation of the work. This led to the identification of certain Volunteering Hydrographic Offices (VHOs) to take on some of the work. These countries were initially identified as Canada, France, Germany, Great Britain and Japan.

The main committee appears to have met infrequently, due possibly to funding shortages, with the records showing a meeting taking place 17-19 March 1959 at the IHB[28]. At that meeting the following co-opted members joined the Committee:

- RAdm. K. St. B.Collins (UK)
- Dr. Per Olof Fagerholm (Sweden)
- Mr. H.Ermel (Germany).

Recommendations and statements were recorded at the meeting. Some of these concerned refinements to the system of utilising Volunteering Hydrographic Offices and some concerned basic issues on the design of the charts in the future. The Committee recommended that all Member States be invited to participate and that there was a need for detailed guidance to be given to these VHOs. Expressing its views on the final charts, there were recommendations on such matters as projection, scale and representation of the morphology of the sea bottom. It was suggested that an editorial board under ICSU (FAGS or SCOR) be set up for reviewing the contours and that members of this board should do the contouring themselves before the GEBCO charts were issued. This board should consist of geophysicists and others primarily interested in GEBCO.

The discussions that had gone on between the Bureau and the Member States over several years were brought to some conclusion at the VIII[th] International Hydrographic Conference in 1962 with a decision to add paragraph VI to Technical Resolution K 27[29]. As this amendment would set the tone for the data compilation for the 4[th] Edition of the GEBCO, it will be quoted in full:

"VI a. It is recommended that Member States be asked to give further consideration to accepting the work of preparation of the 1:1,000,000 plotting sheets so that world coverage may be obtained.

b. It is resolved that the work on the compilation of the GEBCO sheets be performed under the auspices of the IHB with the assistance of States Members and other international organisations which have primary interests in oceanic soundings.

c. It is resolved that the necessary financial provisions to cover the cost of compilation and printing shall be met with IHB funds with such assistance as may be received from interested scientific organisations. It is resolved that for this purpose, a sum of 50,000 gold francs per year or 250,000 gold francs over five years shall be set aside for use by the IHB in developing the GEBCO programme as quickly as possible."

In 1964, the first meeting of a re-constituted committee took place at Monaco, under the chairmanship of Ingénieur hydrographe général

A.Gougenheim (retired French Hydrographer). The meeting considered the nomenclature and production of GEBCO and came up with five recommendations[30]. Of these recommendations, the fourth is particularly significant. It suggested that an editorial board be established to review the contours before the GEBCO was issued, and that the board should consist of the chief of the office volunteering to publish the new editions of the GEBCO sheets at 1:10 million, together with geophysicists and others primarily interested in the GEBCO. Another interesting recommendation was to create a GEBCO sub-committee to study the standardisation of proper geographical names for ocean bottom features, to serve as a guide for future GEBCO sheets.

Just prior to the above meeting, a matter had been raised in 1963 that was to cause considerable debate within the IHB. Through discussions at the Intergovernmental Oceanographic Commission (IOC), the Head Department of Navigation and Oceanography (GUNIO) of the USSR stated that it was prepared to assume the task of compiling and publishing, at its own expense, the 1:10 million sheets, on condition that it was provided with copies of all the plotting sheets[31]. In the I.H.Bulletin the following year, the IHB announced that the majority of its Members had authorised it to negotiate with the IOC and GUNIO. It noted that the negotiations would be fairly lengthy[32]. This was formalised when on 10 March 1964 the Bureau issued a Circular Letter[33] summing up the Member States' responses to the USSR proposal. Twenty-five of the forty-one Member States were in favour of the IHB entering into negotiations with the IOC on the offer made by the USSR. On a second question of whether the Member States would assume the task of publishing the GEBCO themselves, thirty-seven replied negatively and none responded positively.

In spite of France having been included in the above list of negative replies, we read that in August 1964 "The Bureau had received a follow-up letter containing further details of the offer made by the "*Institut géographique national*," Paris, to compile and publish the new edition of GEBCO, in co-operation with the French *Service hydrographique de la marine* (SHM)."[34] This clearly introduced a dilemma for the Bureau, with two generous offers on its hands. Later that year, the President of the IHB Directing Committee informed IHO Member States of the Directing Committee's decision to choose the French offer. In explaining this choice, he noted that the IGN had already published sheets AI and A'I and gave other administrative reasons for the choice[35]. The correspondence sought Member States' approval of the decision. This approval was announced in 1965[36]. The GEBCO programme was firmly announced to consist of three primary steps:

Part I - Compilation of the 1:1 million plotting sheets by the Volunteering Hydrographic Offices.

Part II - Final processing of the 1:1 million plotting sheets by the IGN with the technical co-operation of the *Service hydrographique de la marine*.

Part III - Assembling the final overlays and printing of the 1:10 million sheets by the IGN.

On 9 April 1965, an agreement was signed between the French *Institut géographique national* (IGN) and the *Service hydrographique de la marine* (SHM), as one party and the International Hydrographic Bureau as the second party, concerning the publication of the 1:10 million GEBCO sheets. Contained in this agreement was an article 4, stating that SHM would verify the selected soundings and draw the bathymetric contours. IGN would fix the final and corrected soundings in metres and plot them on the plotting sheets. Another article 10 stated that the IGN undertook to publish each sheet within 12 months of receiving all the plotting sheets[37].

With the administrative arrangements in place, work was able to proceed in earnest on the preparation of further sheets. A questionnaire was sent out to the VHOs to ascertain the progress of the 1:1 million sheets and from this to predict the delivery of the 1:10 million sheets by IGN. The situation on 1 January 1966 was summed up as follows:
Completed plotting sheets sent to IGN in respect to the following sheets:

BIV June 1965
BI September 1965
B'IV September 1965

Completed sheets expected to be sent to IGN in the period February 1966 to April 1967:

B'I, C'I, A'IV, AIV, CII, A'I, CI

The following sheets to be completed between July 1967 and the end of 1969:

AI, BIII, AII.

Details concerning progress on other sheets were also noted in this report[38]. A year later a further report on the preparation of plotting sheets was issued showing some minor slippage but the work generally proceeding to plan[39].

During 1967 a meeting of the GEBCO Committee was convened at Zurich, under the chairmanship of Ingénieur hydrographe général

A.Gougenheim[40]. It may be noted that the membership of the original committee had changed significantly, with the following persons participating:
A.Gougenheim (Chairman) (France)
F.M.Edvalson (USA)
B.C.Heezen (USA)
A.S.Laughton (UK)
A.G.Segre (Italy)
G.B.Udintsev (USSR)
G.Chatel (IHB)
F.Mayet (IGN)
D.W.Newson (UK)
A.H.Cooper (Australia).

At this meeting the work of the Nomenclature Sub-Committee and of the Editorial Committee were discussed. Although the former appeared to be proceeding well, the latter seemed to be having some problems. From the recommendations of the former body it may be noted that French was still to be the sole language used in the publication. Although the Editorial Committee paid tribute to the work of the VHOs, it is clear that there was considerable concern about the quality of the work and according to some members soundings shown on 1:1 million sheets, drawn up by the seventeen VHOs, were between 50% and 80% erroneous and that information from seismic, geologic and sedimentary sources would often lead to a more accurate knowledge of the bathymetry. It was suggested to the IHB that it "might exhort Hydrographic Offices to exercise greater circumspection and to be prepared to reduce the number of soundings on the plotting sheets rather than take the risk of including erroneous soundings among them." There was considerable debate on how depth curves were drawn and proposals that the responsibility of the Editorial Committee be based on geological and geophysical data to guide the experts. During the meeting the IHB representative also voiced concern on the slowness of production, stating that it was essential that new editions of the GEBCO sheets should be issued rapidly to make up for the fact that they were long overdue in comparison with previous editions. However it was noted that due to the organisation of the work set up by the IHB, GEBCO was now to be published on a regular basis.

Another event taking place in 1967 was the IXth International Hydrographic Conference. Discussions on GEBCO appear to have been limited but of interest is a proposal presented by Canada that Technical Resolution K 26.1 be amended to state that an English version of GEBCO was desirable. This proposal, after some debate, was however rejected[41].

Yet another event that took place during 1967 was an announcement that the Bureau would no longer be responsible for the distribution and sale of the GEBCO and Special Publication No.30 concerning GEBCO. This responsibility was passed to the *Institut géographique national*[42].

During the period from 1967 to 1970 the GEBCO programme continued but at an increasingly slower rate in the face of criticism and production difficulties. In 1968, it is recorded that the Chairman of the GEBCO Committee, Ingénieur hydrographe général Gougenheim, received some criticisms of sheet B'I, formulated by experts on marine geology. As these criticisms appeared justified and could give rise to some doubts in the minds of users as regards the reliability of the GEBCO, it was decided to postpone temporarily the sale of the sheet. In 1969, as a result of numerous shortcomings noted on the Plotting Sheets and the GEBCO sheets already published or in the course of preparation, the Directing Committee decided to slow up the publishing of the sheets. Again in 1972, in order to provide time for the Volunteering Hydrographic Offices to improve the quality of their contributions, the publication of the 1:10 million sheets was slowed down.

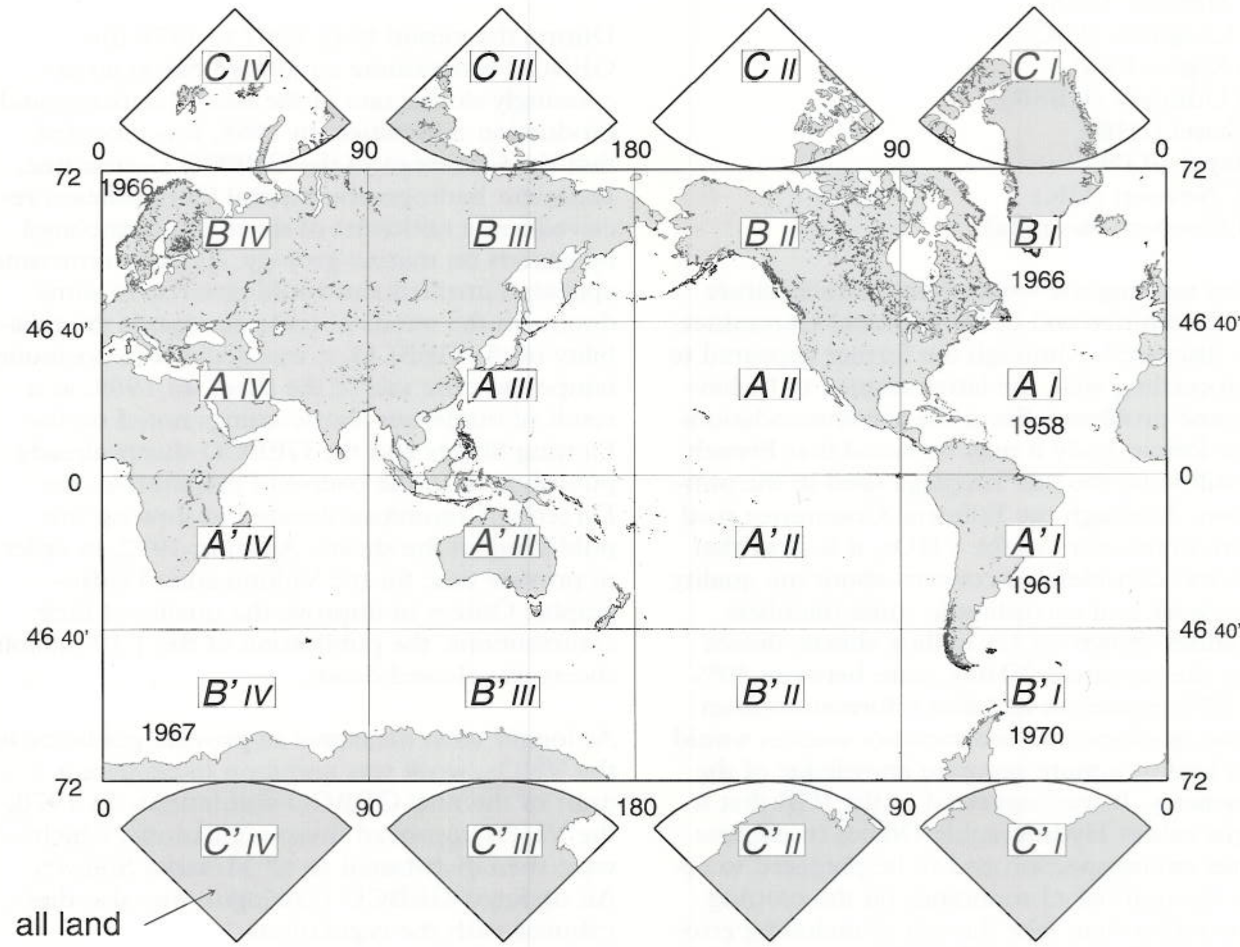
As longer term measures to provide guidance to the VHOs, work was going on to prepare a draft of the new GEBCO regulations. In 1970, the VHOs approved these regulations, which were then distributed to all Member States[43]. An updated GEBCO Catalogue was also distributed with the regulations.

The Fourth Edition was never completed. The list below records the dates and publishers of the six sheets that were published (fig.12):

GEBCO Fourth Edition

Sheet	Date	Printers
AI	1 January 1958	Institut géographique national
A'I	July 1961	Institut géographique national
BI	1 December 1966	Institut géographique national
BIV	1 December 1966	Institut géographique national
B'I	1 October 1970	Institut géographique national
B'IV	1 February 1967	Institut géographique national

Information compiled by Antoine Ferrero-Regis (IHB)



Mercator sheets 1:10 Million at the Equator.

Fig. 12. Assembly diagram for GEBCO sheets (4th Edition)

The end of the Fourth Edition

In 1970, the Intergovernmental Oceanographic Commission (IOC) of UNESCO, following approval by the United Nations General Assembly of its Long-term and Expanded Programme of Oceanic exploration and Research (LEPOR), set up a Group of Experts on Long Term Scientific Policy and Planning. Amongst other matters it examined morphological charting of the sea floor and recommended that the Commission participate in the production of a world bathymetric map, bearing in mind that the IHB was the most experienced body in this field. Following a request from IOC to its Scientific Advisory Body, the Scientific Committee on Oceanic Research (SCOR), SCOR Working Group 41 was established to consider the matter further[44]. As a result, during 1973, the voices of scientists that had already existed for some time, were officially noted by the Working Group, under the chairmanship of Dr. A. S.Laughton, who was also a member of the GEBCO Committee[45].

The Working Group met in the United Kingdom on 2-3 April 1973 and made a number of recommendations on the future of GEBCO (see Part 5 below). These were considered at a meeting of the GEBCO Committee, held at Monaco 5-6 June 1973, under the Chairmanship of Ingénieur hydrographe général Marc Eyries[46]. Two main issues were discussed: i) the possible replacement of the GEBCO Committee by some other group; and ii) the replacement of the present type of GEBCO chart at 1:10 million by another at the same scale. It was agreed that the present committee needed to be re-structured as a GEBCO Guiding Committee and that there were scientific shortcomings in the present 1:10 million sheets. It was further questioned if it was worthwhile for the IGN to complete the Fourth Edition, as it was contracted to do. The Committee recommended to the IHB that the work on the 1:10 million series in its present form be suspended and that IHO be invited to terminate its contract with the IGN for the Fourth Edition. However, the GEBCO 1:1 million plotting sheets should continue to be updated. Finally there was general agreement with the fifteen recommendations of SCOR WG41. This set the tone for future action on the Fifth Edition.

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GEBCO 1999 Meetings

June 22-30, 1999
Bedford Institute of Oceanography, Dartmouth NS, Canada

1 Robert FISHER
2 Gleb UDINTSEV
3 Lucas de CAMPOS COSTA
4 YASHIMA Kunio
5 Patrick SOUQUIERE
6 Michael CARRON
7 John WOODWARD
8 Meirion T. JONES
9 Michel HUET
10 William RANKIN
11 Norman Z. CHERKIS
12 John K. HALL
13 Alexis HADJIANTONIOU
14 Michael LOUGHRIDGE
15 Hans Werner SCHENKE
16 David MONAHAN
17 Arne NIELSEN
18 Bernard COAKLEY
19 Andrew GOODWILLIE
20 Peter HUNTER
21 Tony PHARAOH
22 Pauline WEATHERALL
23 Larry MAYER
24 Brian HARPER
25 Marcus ALLSUP
26 Anthony LAUGHTON
27 Walter SMITH
28 Lois VARNADO
29 Richard A. MARTINO
30 Margaret HARRIS
31 Martin JAKOBSSON
32 Neil GUY
33 Trent PALMER
34 Marco Antonio CARVALHO Oliveira
35 Ron MACNAB
36 Desmond SCOTT

Fig. 13

Fig. 14. Tiefenkarte des Weltmeeres by Professor Alexander Supan, 1899.

Published in Dr A. Petermanns Geogr. Mitteilungen, Heft VIII

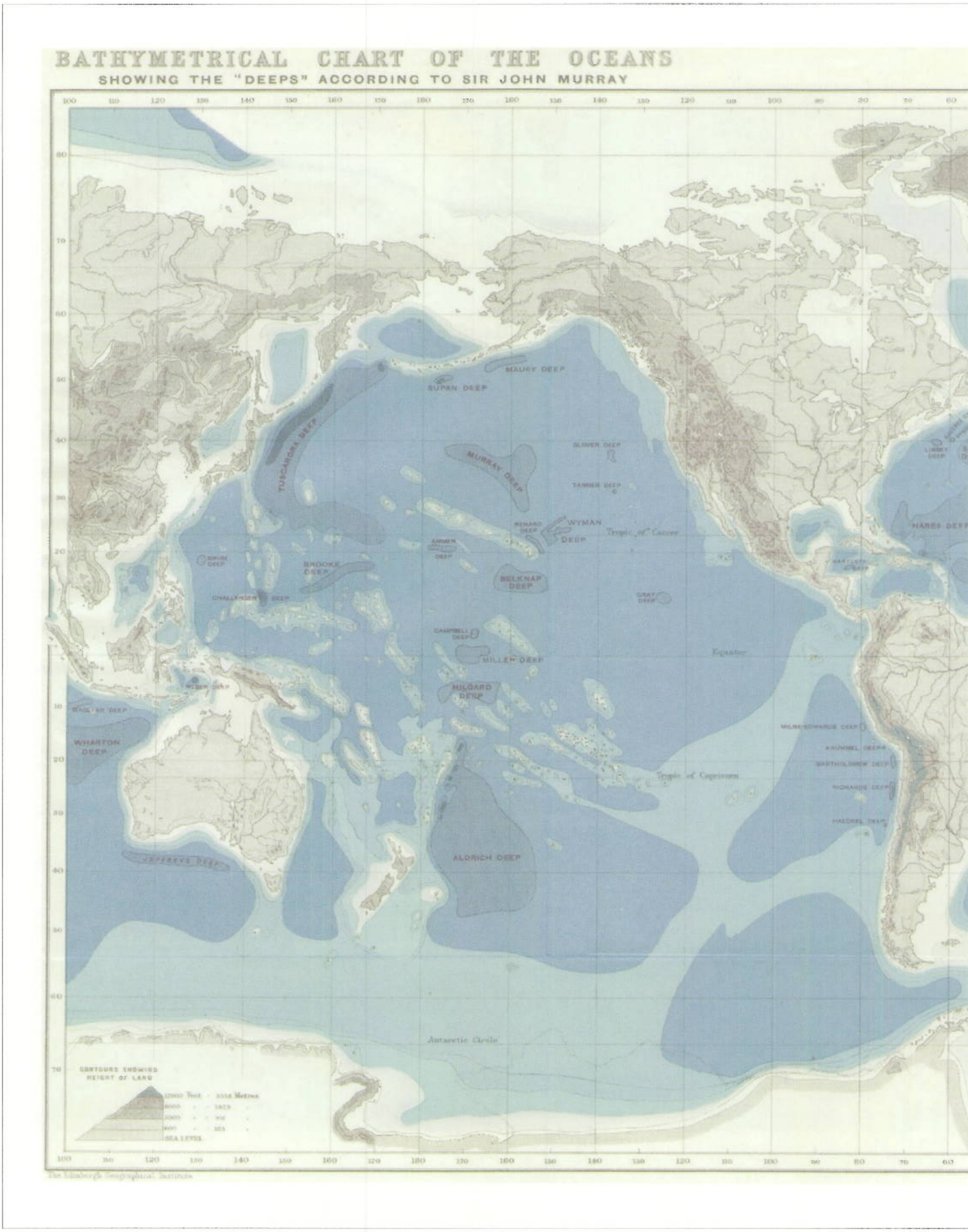

Fig. 15. Bathymetrical Chart of the Oceans showing the "deeps" according to Sir John Murray, 1899.

Published in The Scottish Geographical Magazine, Vol. XV, No. 10

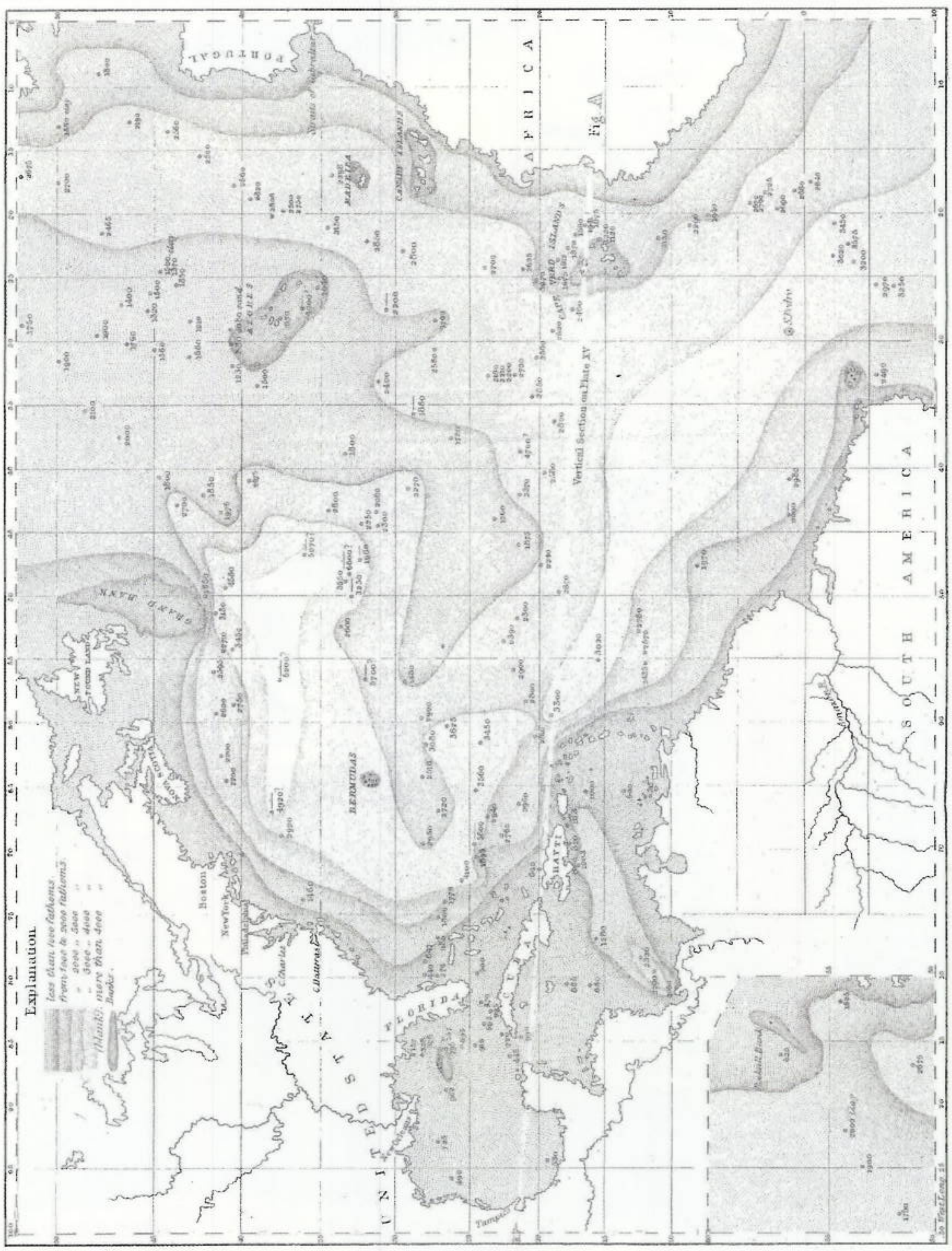

Fig. 16. Contour chart of the basin of the North Atlantic Ocean published by M.F. Maury in 1861 in "Physical Geography of the Sea". This was one of the earliest contour charts of a whole ocean basin. Note: The faint line running across the centre of the chart is the location of a profile of the seafloor shown in the original publication

Fig. 17. Sheet B1 - 1st Edition (1903)

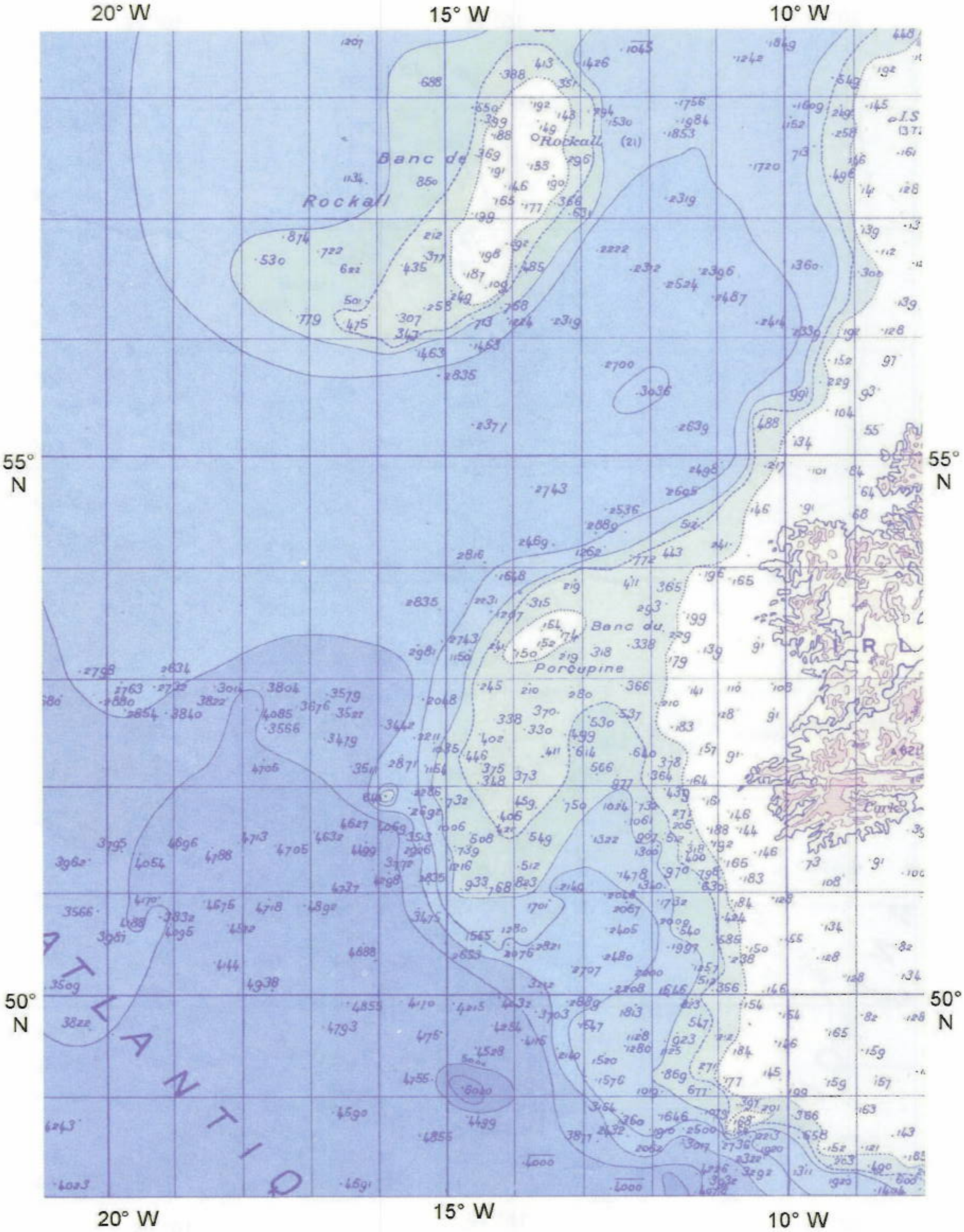

Fig. 18. Sheet B1 - 2nd Edition (1926)

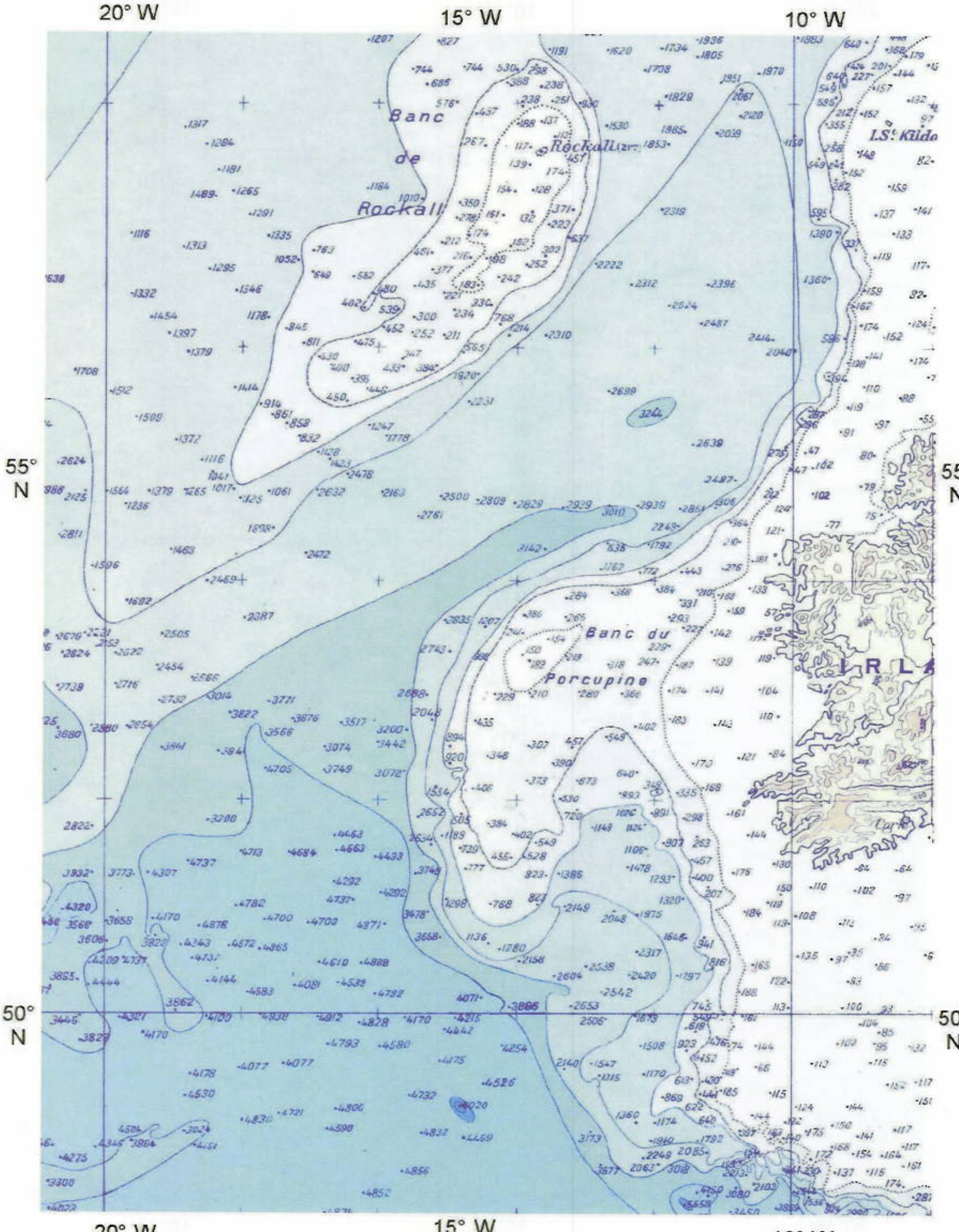

Fig. 19. Sheet B1 - 3rd Edition (1937)

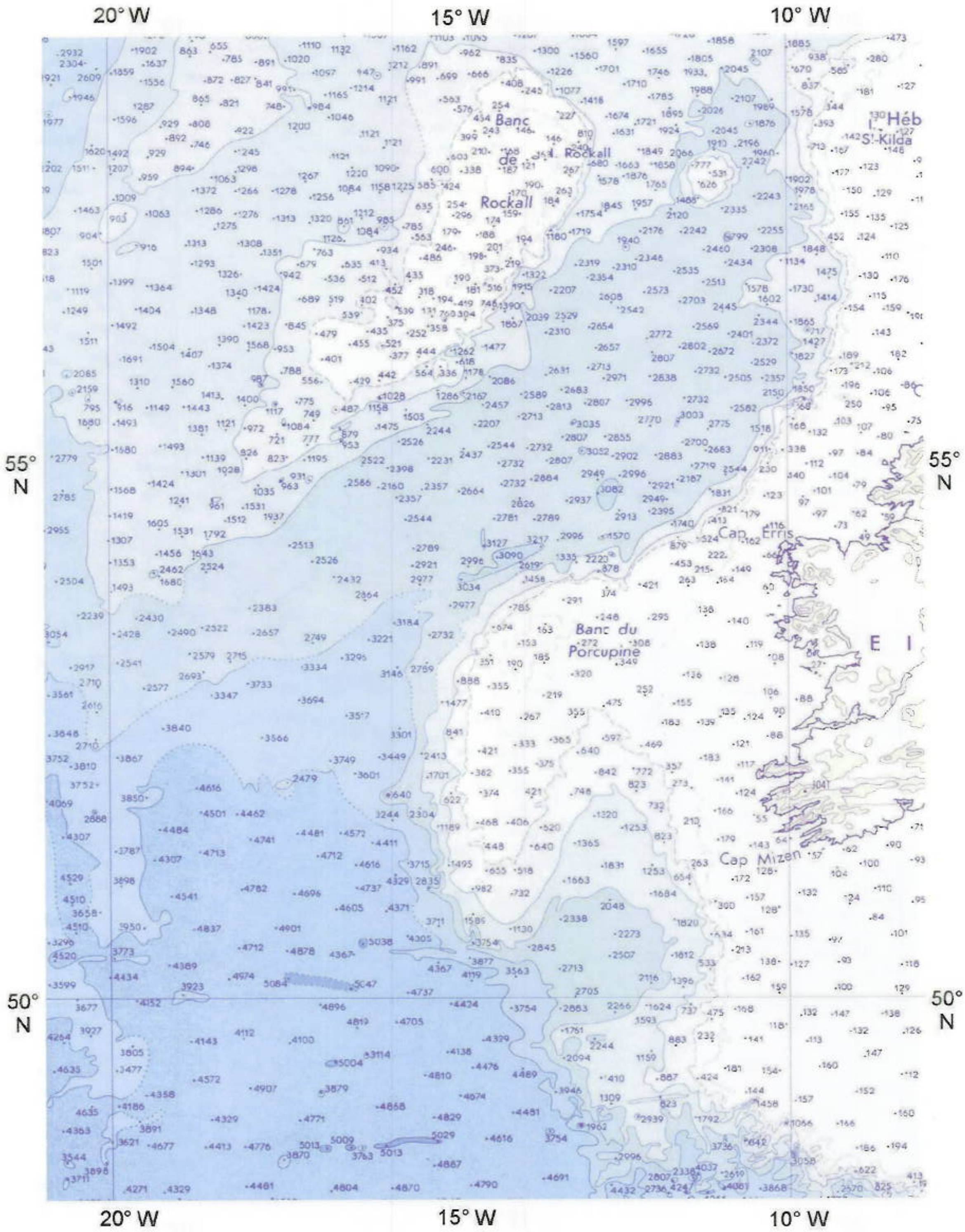

Fig. 20. Sheet B1 - 4th Edition (1966)

Fig. 21. Sheet 5.04 - 5th Edition (1978)

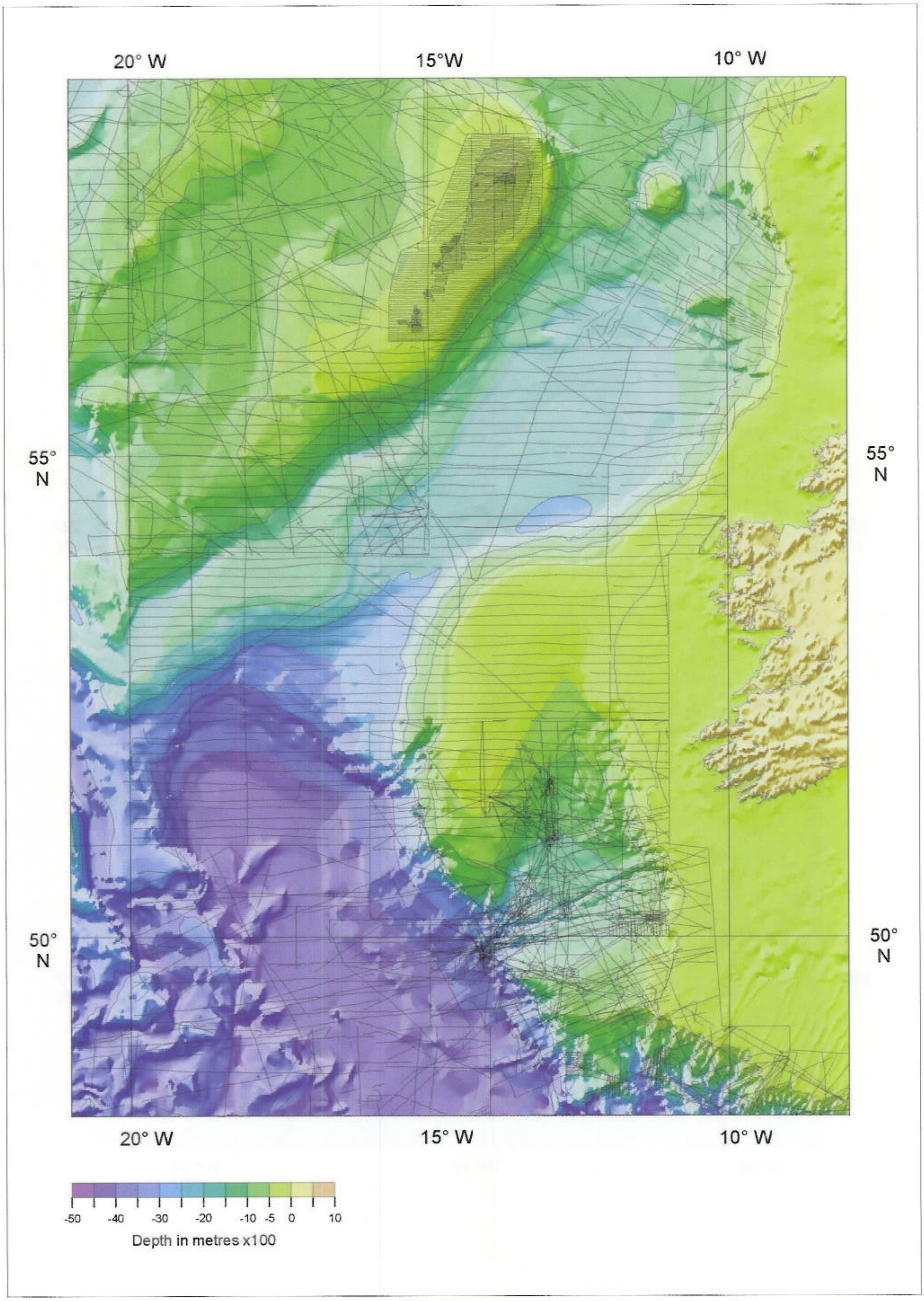

Fig. 22. North-east Atlantic - GDA Version (2002)

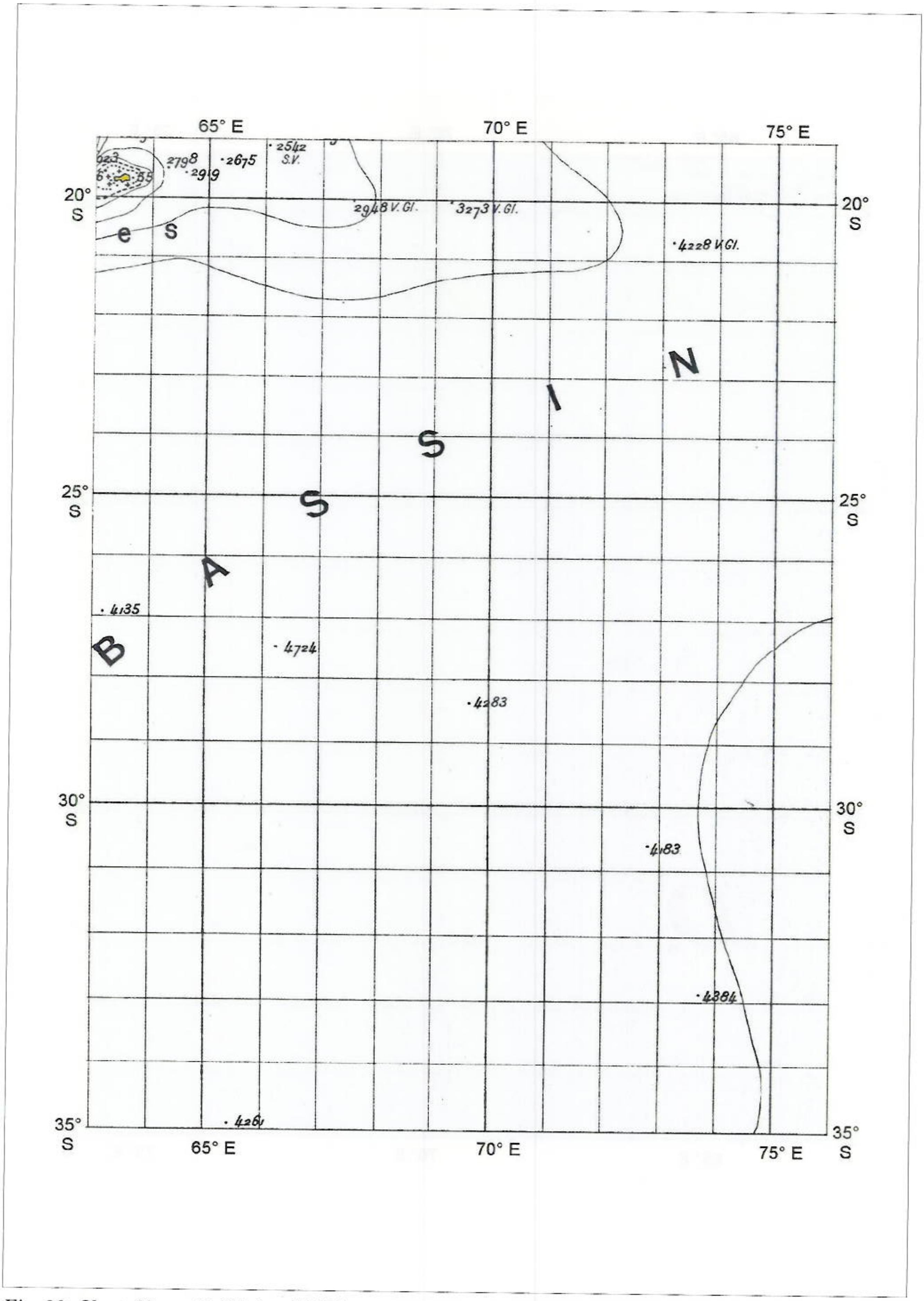

Fig. 23. Sheet A' IV - 1st Edition (1903)

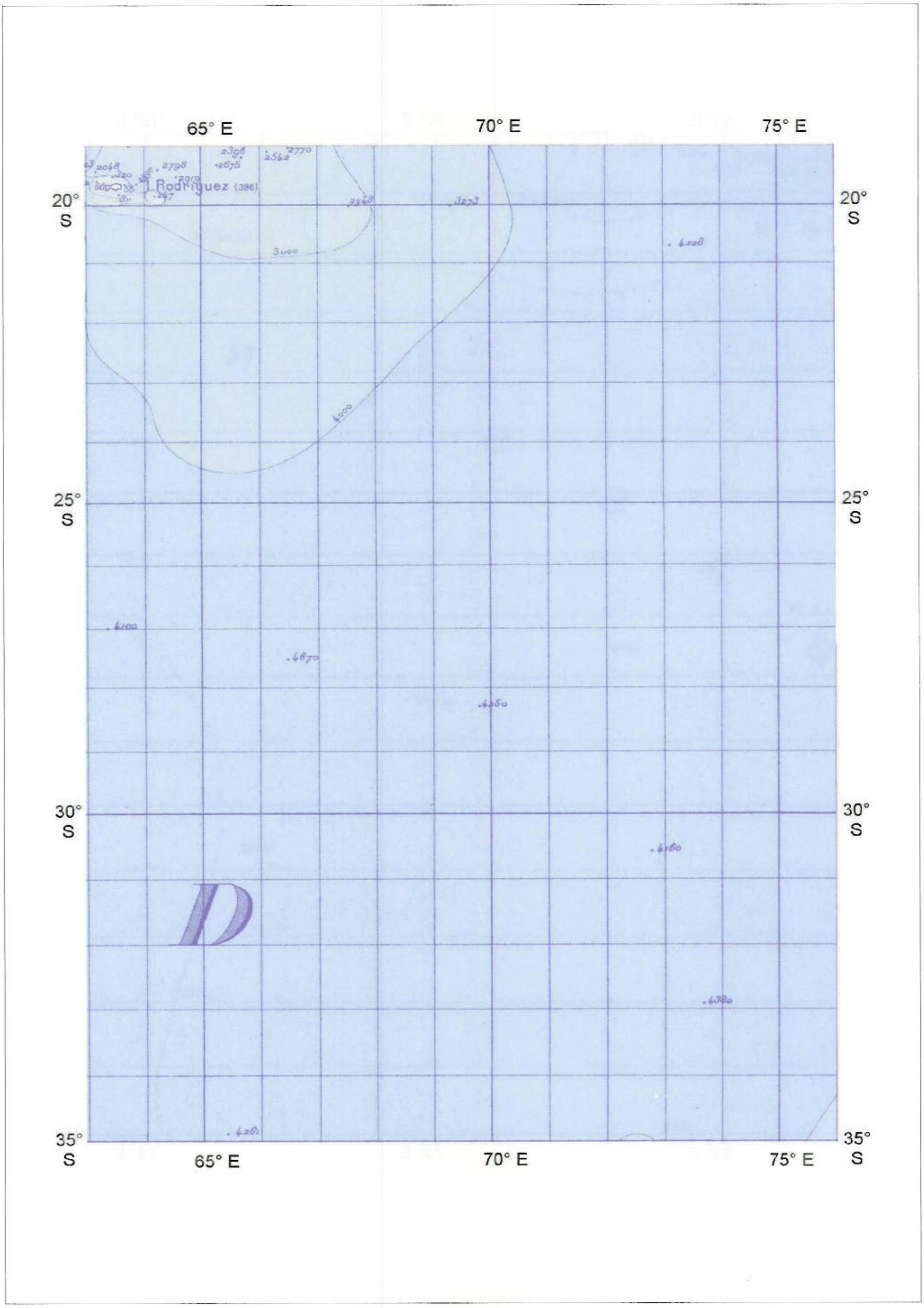

Fig. 24. Sheet A' IV - 2nd Edition (1913)

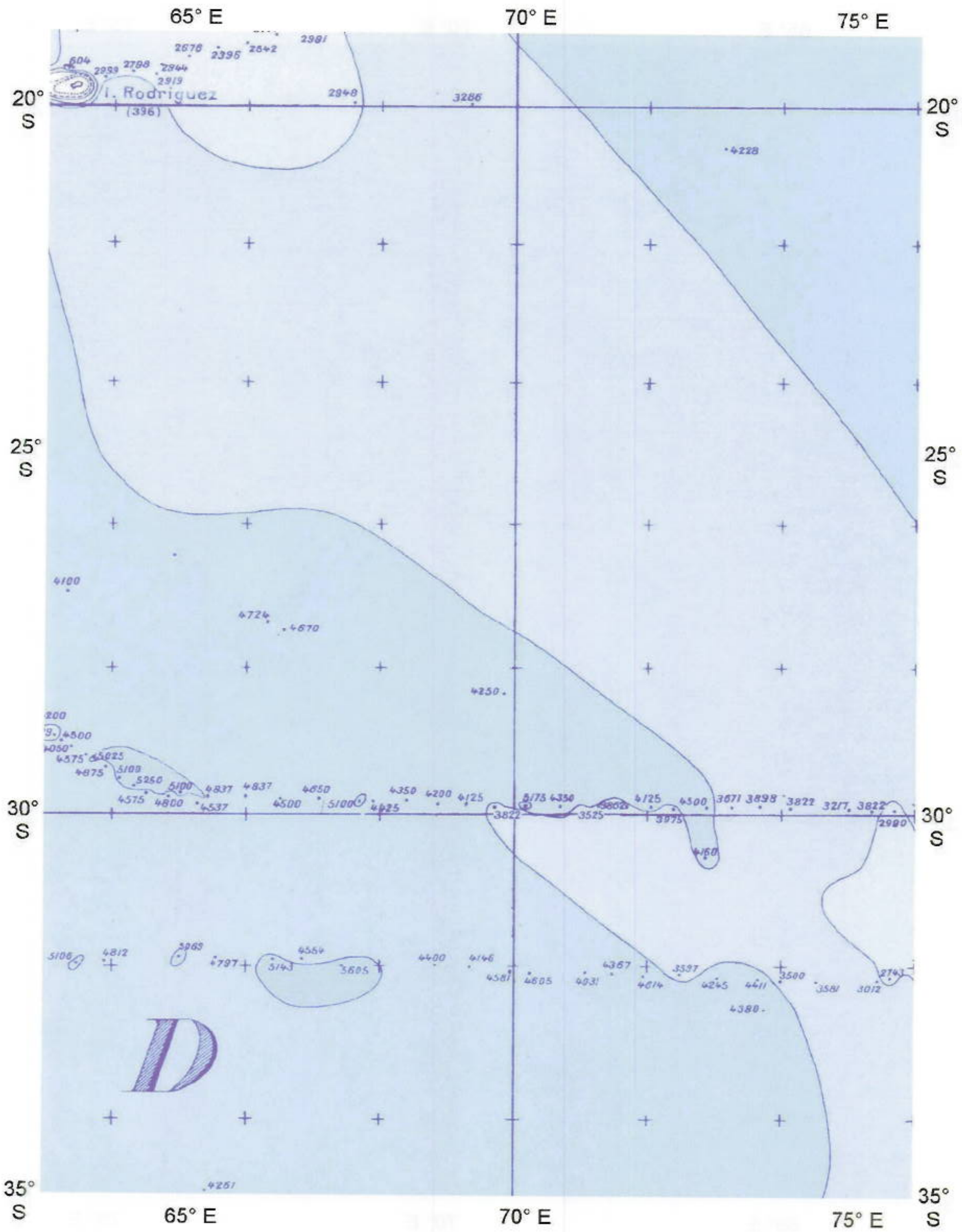

Fig. 25. Sheet A' IV - 3rd Edition (1938)

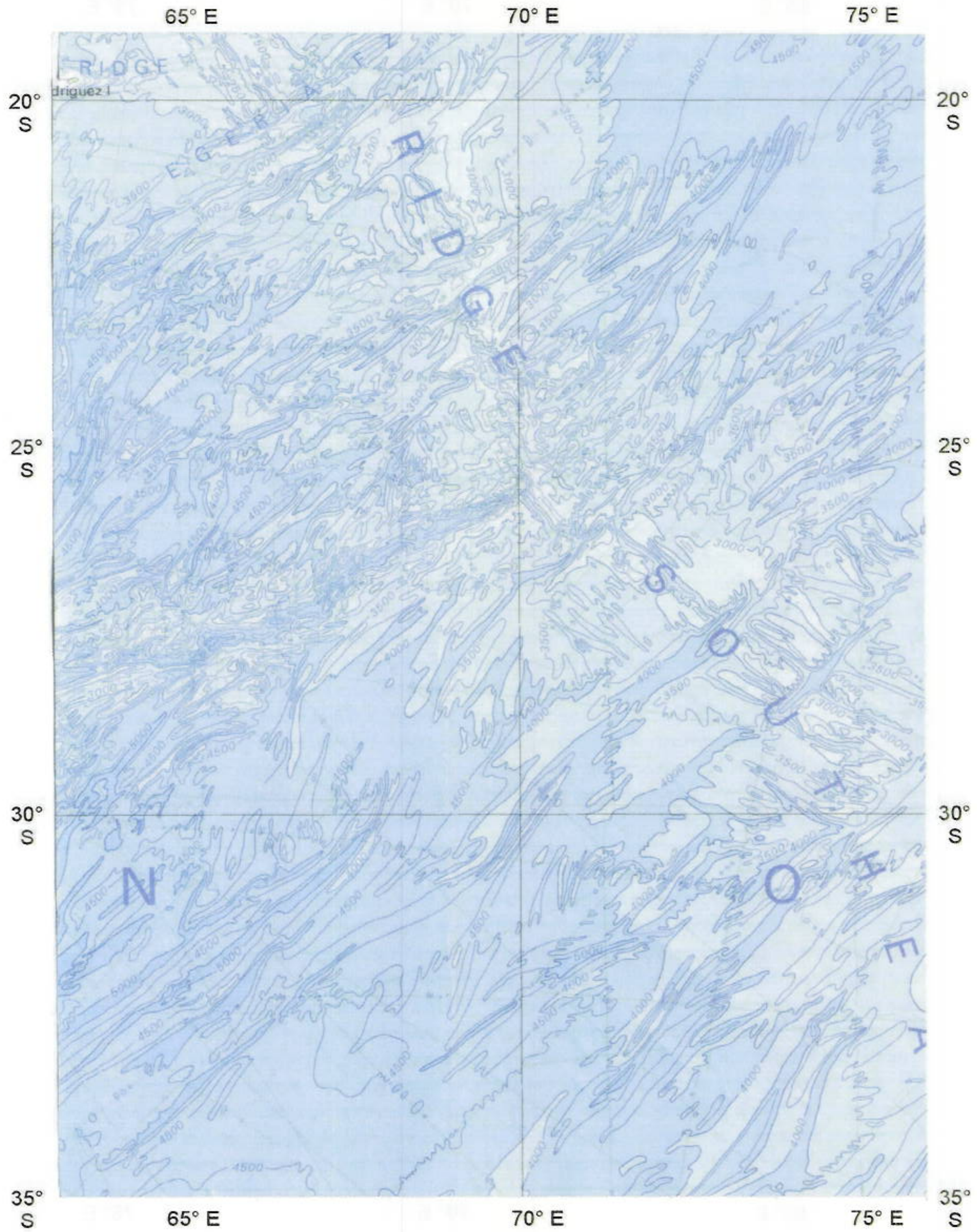

Fig. 26. Sheet 5.09 - 5th Edition (1982)

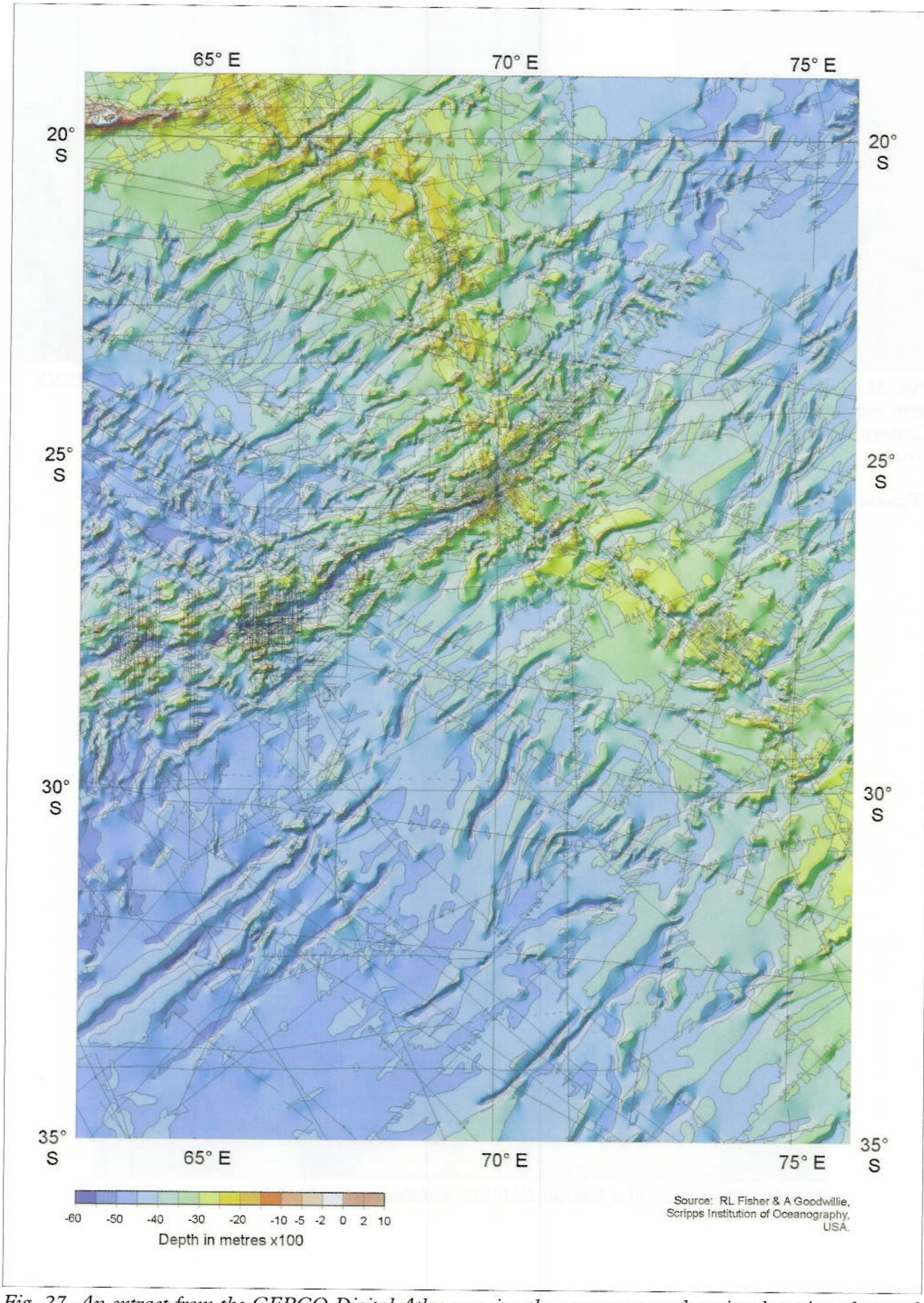

Fig. 27. An extract from the GEBCO Digital Atlas covering the same area as the printed version of part of Sheet 5.09 (figure 26)

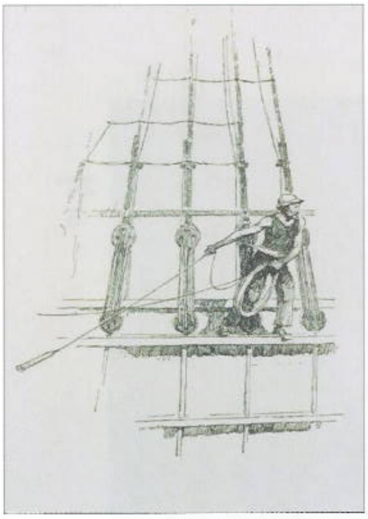

Fig. 28. Sailor sounding from merchantman - 19th Century sketch by Gordon Grant

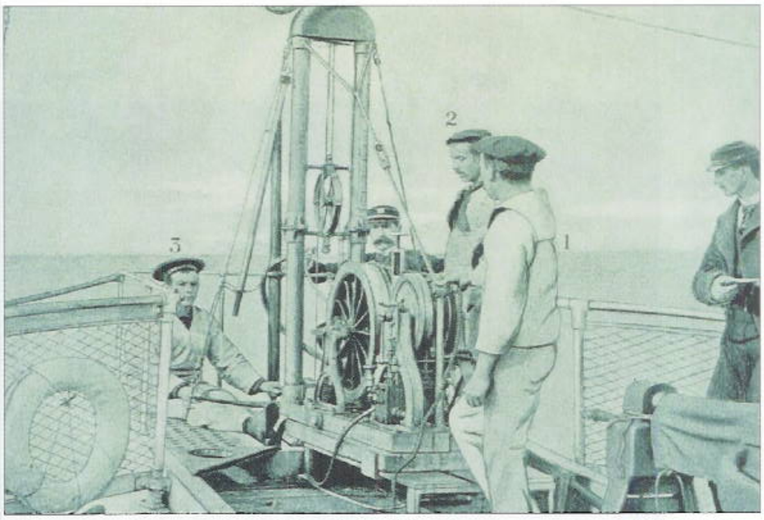

Fig. 29. Sigsbee Sounding Machine in use on board USNS Albatross

(Figures 28 & 29 are reproduced by courtesy of the NOAA Central Library, USA)

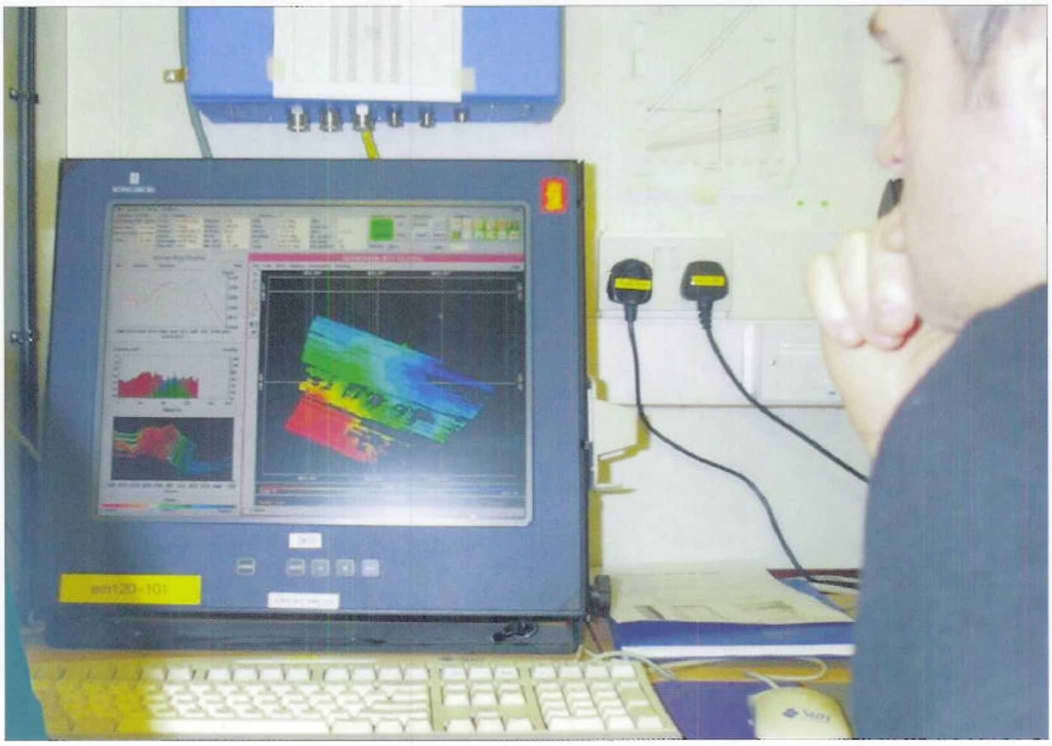

Fig. 30. The display of a Simrad EM-120 multibeam echo-sounder

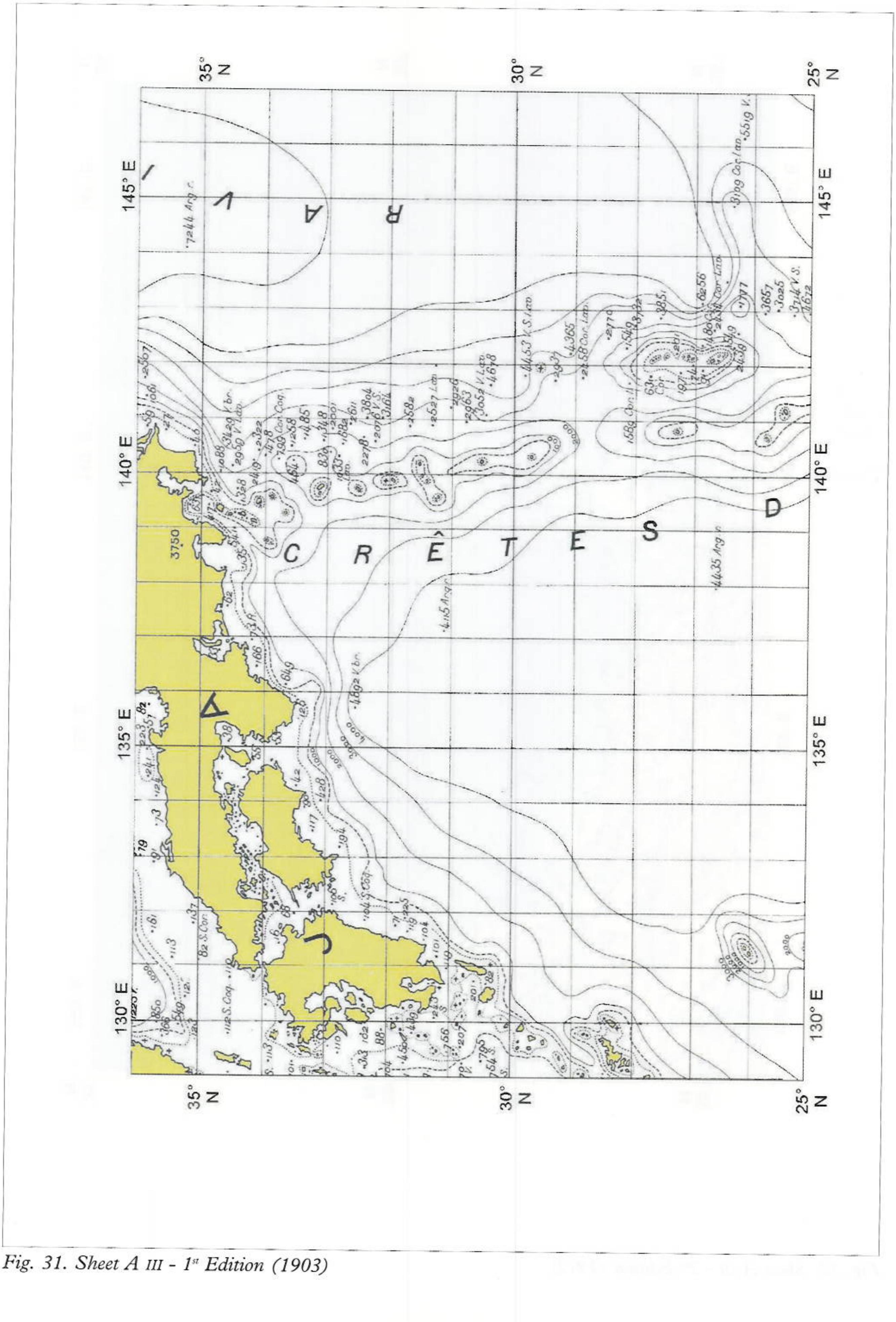

Fig. 31. Sheet A III *- 1st Edition (1903)*

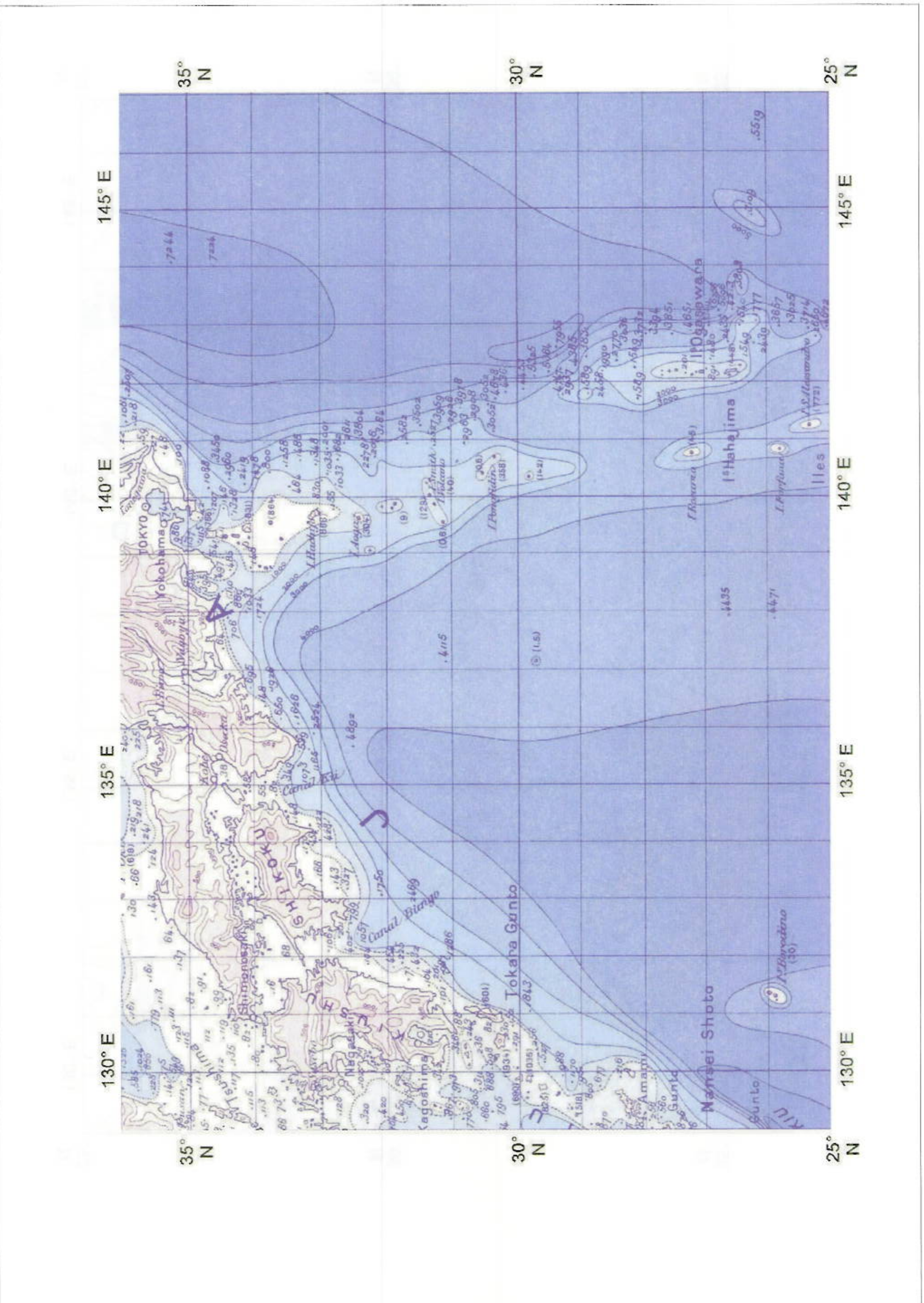

Fig. 32. Sheet A III *- 2nd Edition (1912)*

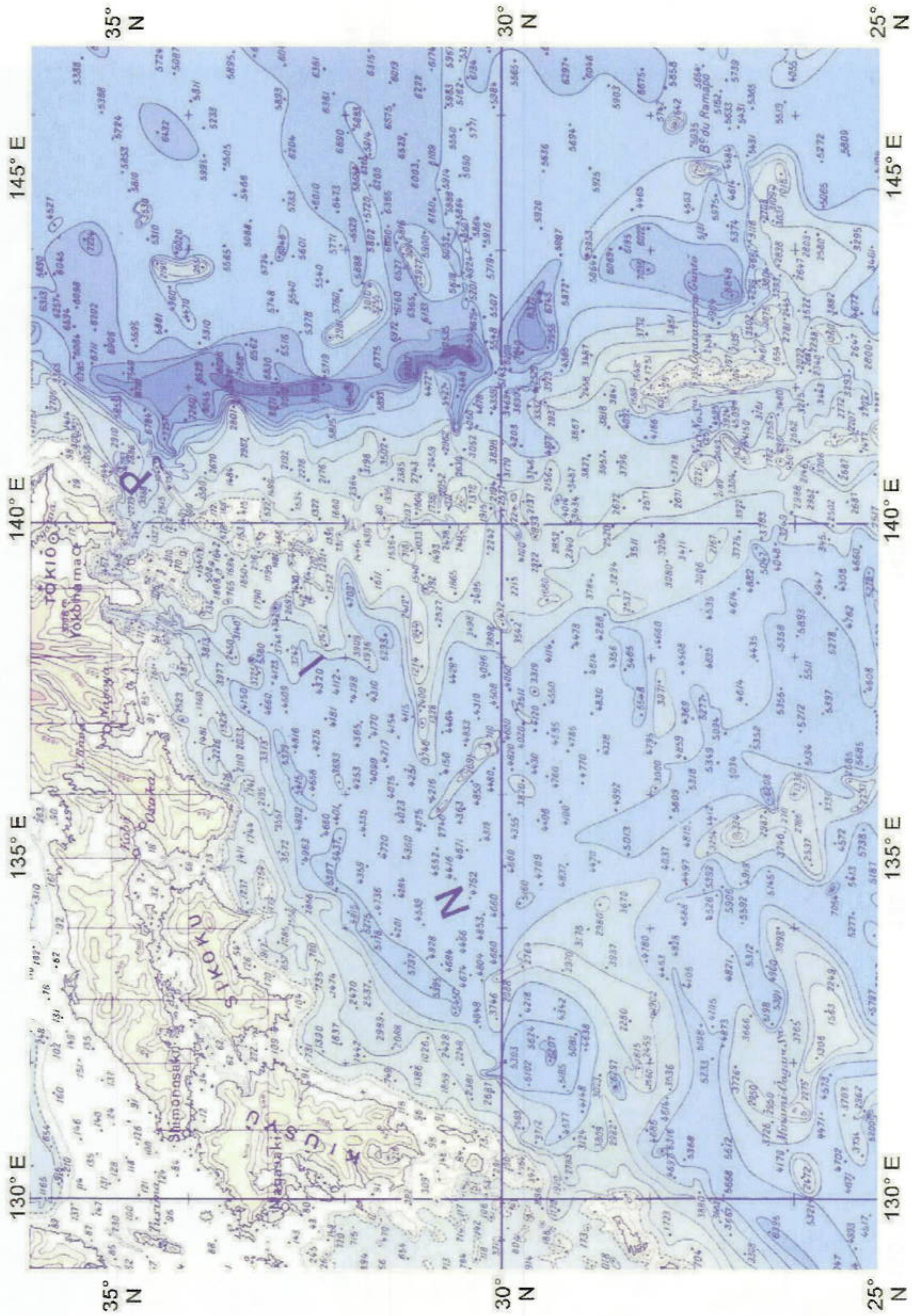

Fig. 33. Sheet A III - 3rd Edition (1940)

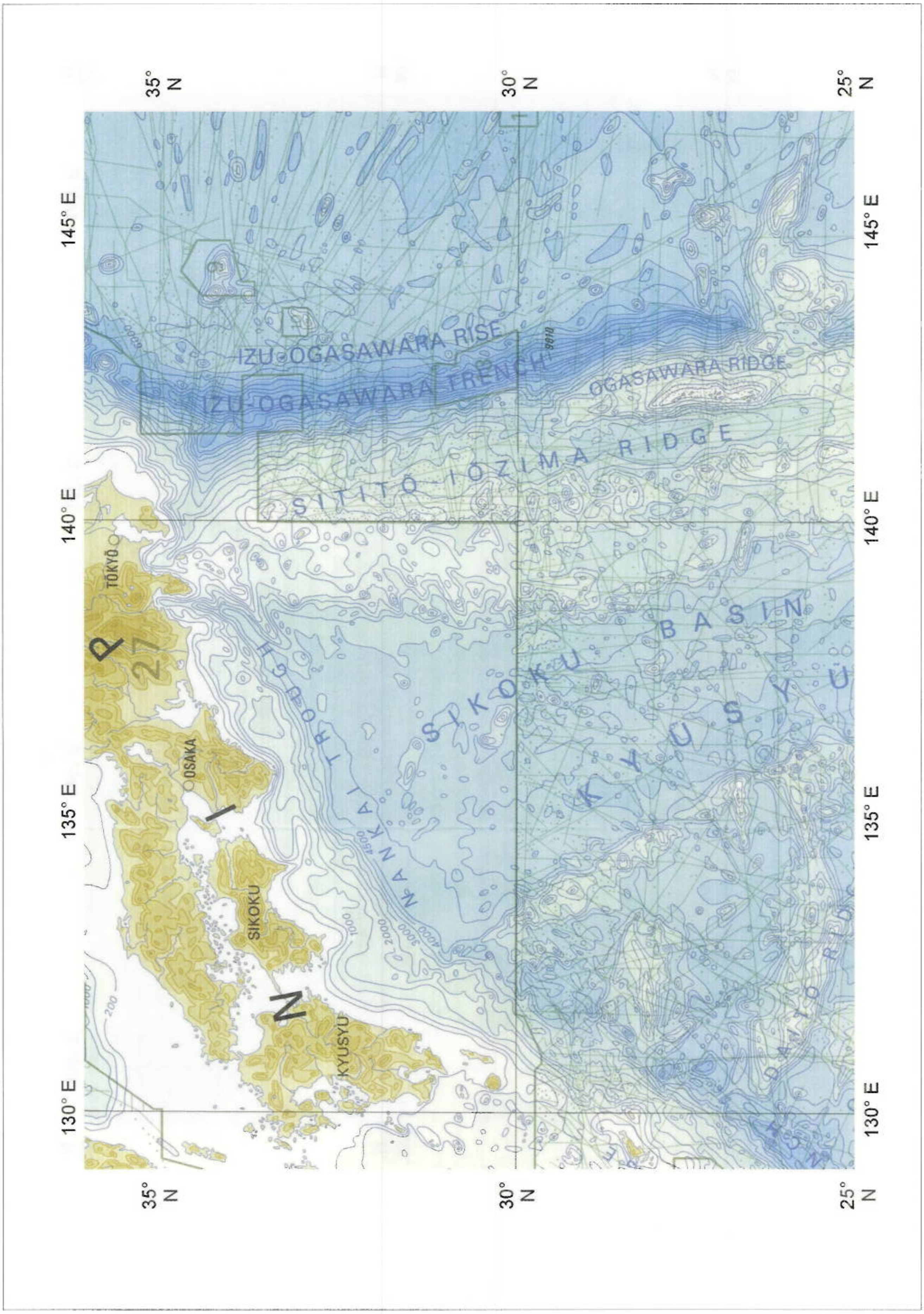

Fig. 34. Sheet 5.06 - 5th Edition (1979)

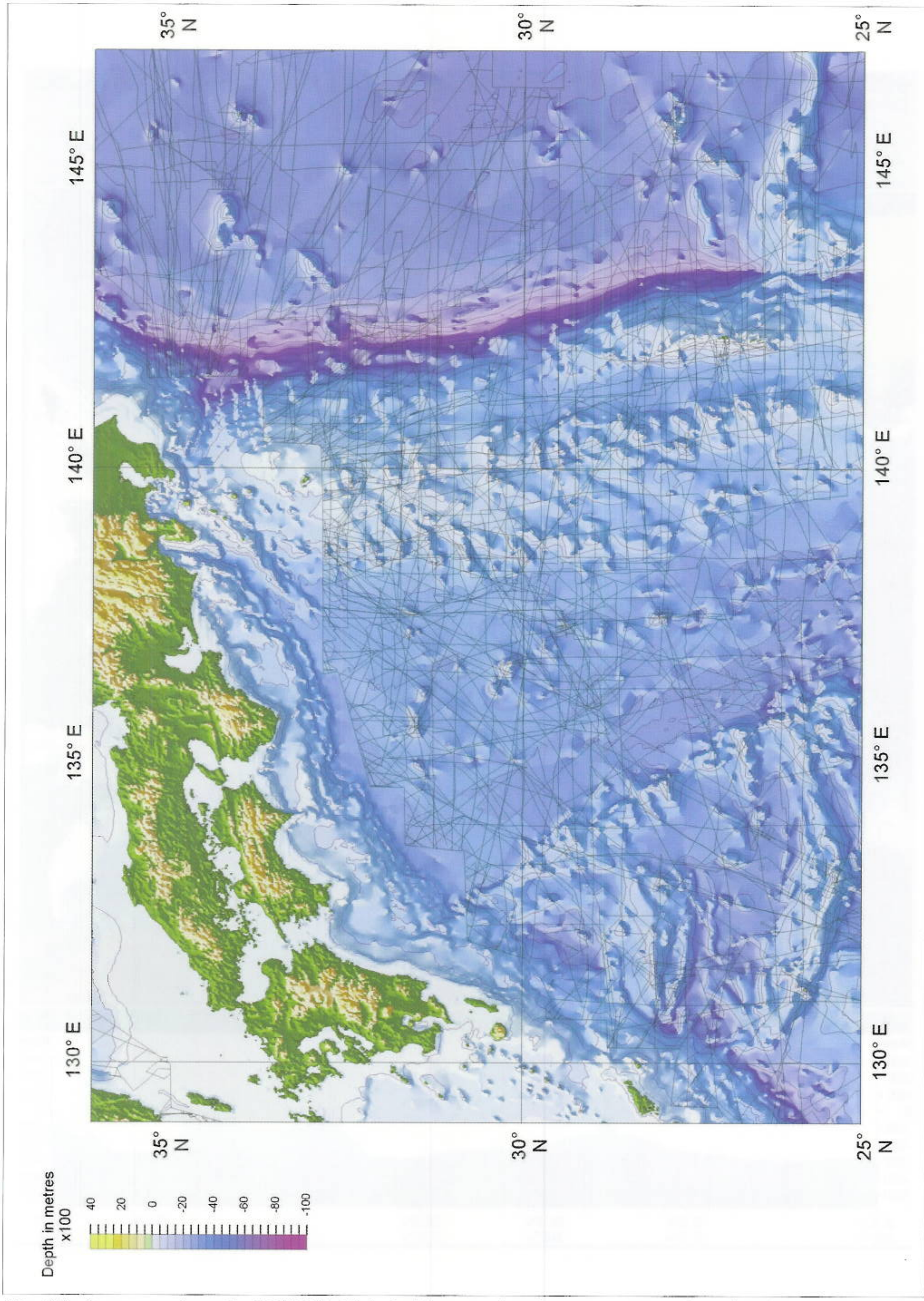

Fig. 35. An extract from the GEBCO Digital Atlas covering the same area as the printed version of part of Sheet 5.06 (figure 34)

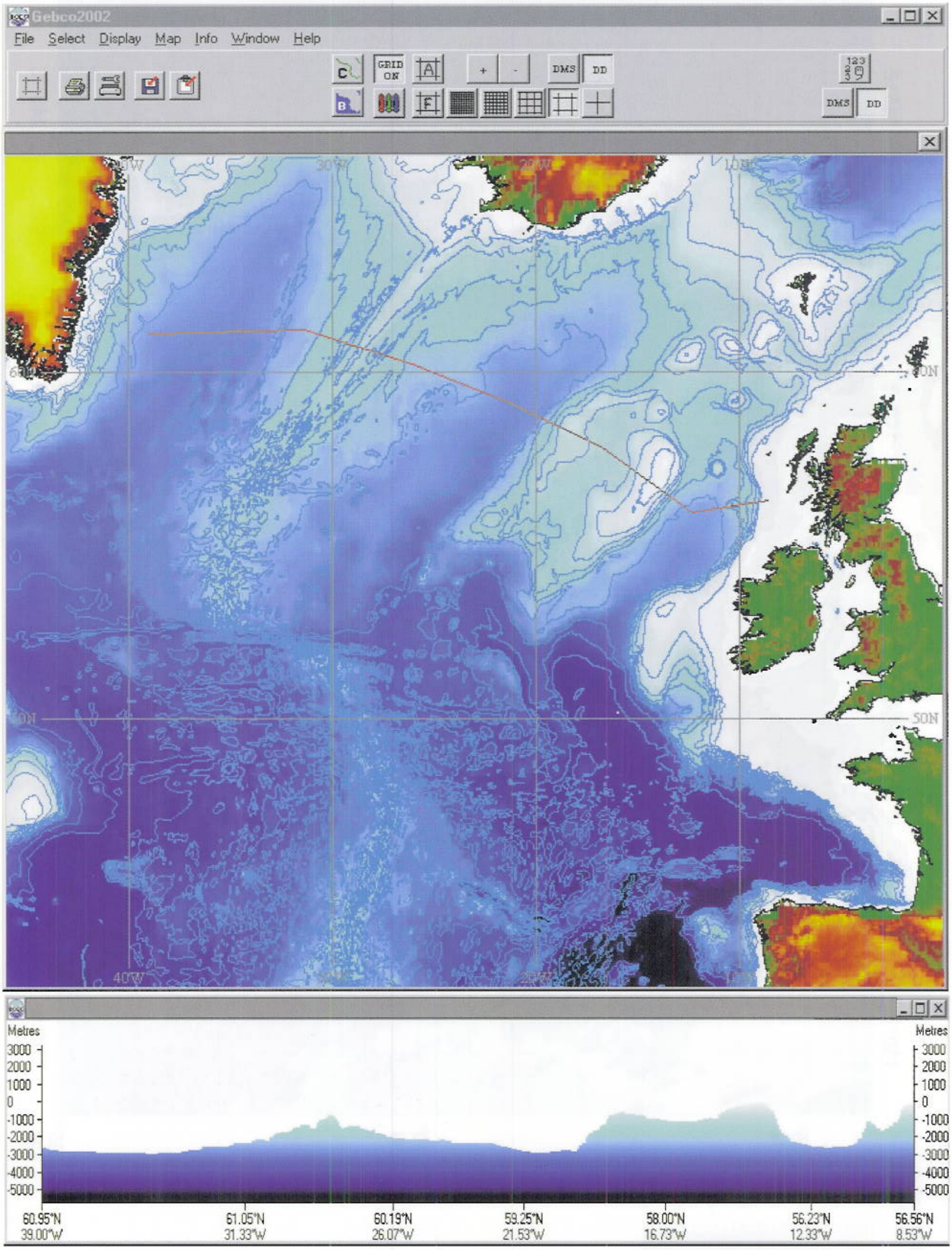

Fig. 36. Computer-based image illustrating the facilities of the Centenary Edition of the GEBCO Digital Atlas (pre-release version using a provisional bathymetric grid)

4- The Intergovernmental Oceanographic Commission (IOC)

Foundation

The Intergovernmental Oceanographic Commission (IOC) of Unesco was founded, following recommendations from an Intergovernmental Conference on Oceanographic Research convened by Unesco[1], in March 1960. These arrangements were approved by the Unesco General Conference in November 1960 and the first session of the IOC was held in October 1961. The Summary Report of that session[2] (item 6) records:
'It was recognized that immediate exchange of oceanographic data in accordance with the Data Centre's Manual of the International Geophysical Year (IGY) should be started for such programmes commencing from 1 January 1960. Ways and means of exchange of bathymetric data were also discussed at length. The problem of publishing a new General Bathymetric Chart of the Oceans was raised several times and the opinion was expressed that Unesco might assist financially in this matter. However no specific recommendation was made in this connexion in view of the forthcoming International Hydrographic Conference in May 1962.'

The 'new GEBCO' to which this refers was the 4[th] Edition, as the structure for this edition was then being developed by the International Hydrographic Bureau (IHB), the International Association of Physical Oceanography (IAPO) and the International Council of Scientific Unions (ICSU), following the strong scientific need which had been identified during the International Geophysical Year (see 3- The IHB Period above).

Long-term and Expanded Programme of Oceanic exploration and Research

By 1968 IOC was developing its Long-term and Expanded Programme of Oceanic exploration and Research (LEPOR) and the IOC was asked by the United Nations General Assembly (resolution 2467D/XXIII) to co-operate with the Secretary-General in the preparation of "the comprehensive outline of the scope of the long-term programme of oceanographic research"[3]. In December 1968, the United Nations General Assembly adopted a resolution[4] which contained the following request:
(The United Nations General Assembly) requests the United Nations Educational, Scientific and Cultural Organization that its Intergovernmental Oceanographic Commission:
'intensify its activities in the scientific field, within its terms of reference and in co-operation with other interested agencies, in particular with regard to co-ordinating the scientific aspects of a long-term and expanded programme of world-wide exploration of the oceans and their resources of which the International Decade of Ocean Exploration[5] will be an important element, including international agency programmes, and expanded international exchange of data from national programmes, and international efforts to strengthen the research capabilities of all interested nations with particular regard to the needs of developing countries.'

This comprehensive 'expanded programme' was divided into six parts:
1. Problems of Ocean-Atmosphere Interaction, Ocean Circulation, Variability and Tsunamis;
2. Living Resources and their relations with the Marine Environment;
3. Marine Pollution;
4. Geology, Geophysics and Mineral Resources beneath the Sea;
5. The Integrated Global Ocean Station System (IGOSS);
6. Specific International Regional Investigations.

It was clear from the start that only a very limited number of the proposed projects could be handled by the IOC with its existing staff and budget, and Unesco proved unwilling to increase its size and funding commensurate with the task foreseen as needed by the United Nations General Assembly. The 'expanded programme' became the basis for the Commission's programmes over many years, but these only covered a number of selected projects. In addition, many of the other projects were undertaken outside the aegis of the IOC. One of the 'Research programmes proposed to solve the principal scientific problems' was:

Morphological charting of the sea floor[6]

Scientific aspects: *Geological investigations require bathymetric charts at appropriate scales as base maps. Other marine disciplines use reconnaissance or detailed charts of sea-floor morphology in aspects of their research.*
Practical aspects: *Base maps for off-shore exploration for minerals and fuels; for bottom fisheries; or for engineering purposes. Bathymetric charts at appropriate scales are required for all aspects of mineral exploitation, fisheries, engineering construction, and other operations on or above the sea floor.*
Scales: *1:1,000,000 for reconnaissance purposes. Preliminary charts for many regions, both shelf and deep ocean, can be made from available data. More precise charts at this scale will be required for deep ocean areas with spacing of 5-15km between lines depending on complexity of the bottom morphology and on the nature and detail of the geological programme in the area. Scales of 1:250,000 or larger scale will be required in critical areas (where land-sea geological and geophysical transects are to be made).*
Thus the way was clear for the IOC to become fully involved, with the International Hydrographic Organization (IHO), in the production of a new edition (by now the 5th) of the General Bathymetric Chart of the Oceans (GEBCO).

Scientific Advice from the Scientific Committee on Oceanic Research (SCOR)

From its foundation IOC's main (non-governmental) Scientific Advisory body was the Scientific Committee on Oceanic Research (SCOR) of the International Council of Scientific Unions (ICSU), so the Commission now turned to SCOR for advice on the scientific aspects of this programme. SCOR responded by forming a Working Group to handle this request; this was initially under the Chairmanship of Dr Johannes Ulrich of Germany but he was followed after the first meeting by Dr A S Laughton (United Kingdom). Details of the task undertaken by SCOR Working Group 41, and its recommendations follow (5- Scientific Committee on Oceanic Research (SCOR) Working Group 41- Morphological Mapping of the Ocean Floor).

References

1. A Preparatory Conference was convened by Unesco, in Paris, 21-26 March 1960 (doc. UNESCO/NS/163, Paris, 13 May 1960). This was followed by the full Conference, held in Copenhagen, 11-16 July 1960 (doc. UNESCO/NS/167, Paris, 7 October 1960).
2. Report of the First Session of the Intergovernmental Oceanographic Commission, Unesco, Paris, 19-27 October 1961 (doc. UNESCO/NS/176, Paris, 1 February 1962.
3. Summary Report of the Sixth Session of the Intergovernmental Oceanographic Commission (Unesco doc. SC/MD/19, Paris, 1 June 1970), Annex X 'Comments on Development of the Expanded Programme, submitted by the Scientific Committee on Oceanic Research (SCOR) of ICSU, and the Advisory Committee on Marine Resources Research (ACMRR) of FAO'.
4. United Nations General Assembly Resolution 2467 (XXIII), December 1968, as quoted in the Summary Report of the Sixth Session of the Intergovernmental Oceanographic Commission (Unesco doc. SC/MD/19, Paris, 1 June 1970), Annex IV 'Comprehensive Outline of the Scope of the Long-term and Expanded Programme of Oceanic exploration and Research (LEPOR)', Introduction.
5. The International Decade of Ocean Exploration (1971-1980). Ref: IOC Resolution VII/7 (Unesco doc. SC/MD/29, Paris, 30 October 1972), Annex VII.
6. Summary Report of the Sixth Session of the Intergovernmental Oceanographic Commission (Unesco doc. SC/MD/19, Paris, 1 June 1970), Annex IV 'Comprehensive Outline of the Scope of the Long-term and Expanded Programme of Oceanic exploration and Research (LEPOR)', Part 4 Geology, Geophysics and Mineral Resources beneath the Sea, Principal programme I.

5- Scientific Committee on Oceanic Research (SCOR)

Working Group 41 – Morphological Mapping of the Ocean Floor

Sir Anthony Laughton PhD FRS

Formation of Working Group

SCOR responded to a request from IOC by forming Working Group 41 'Morphological Mapping of the Ocean Floor', under the Chairmanship of Professor Dr Johannes Ulrich of Germany "to determine a rational scheme for reduction and presentation of sounding data that would constitute a framework in which the international mapping of the sea floor could proceed" (Report to SCOR from the International Workshop on Marine Science, Honolulu, September, 1971). Regrettably, Dr Ulrich was unable through illness to participate in much of the Working Group's activities and Dr Anthony Laughton was appointed as Acting Chairman for the first meeting and subsequently became Chairman.

Oceanographers had become increasingly dissatisfied with the GEBCO charts for a variety of reasons in spite of the support for GEBCO by Derek Newson published in the Cartographic Journal[1]. Active workers found that the charts were too out of date, did not reflect current thinking about the sea bed and the processes operating there and that the interpretations of areas where there were no soundings were inadequate. As a result, the sales of the Third and Fourth edition (currently being prepared) were dwindling so that the *Institut géographique national* in Paris, which was compiling them, was asking for financial assistance.

Several laboratories had initiated and maintained their own bathymetric charts for their own research purposes, but these varied greatly and in no way constituted a global set. Amongst these Dr Laughton, of the National Institute of Oceanography (NIO) in the UK, had maintained a series of BM charts of the North Atlantic and of the NW Indian Ocean, and Dr Bob Fisher had worked extensively on the morphology of the Central Indian Ocean[2]. The International Indian Ocean Expedition (1959–1967) resulted in a Geological-Geophysical Atlas of the Indian Ocean in which Laughton and Fisher contributed much of the bathymetry.

Two meetings in Canada in autumn 1972 addressed the problems of ocean mapping. The first meeting of SCOR WG 41 was held on 21st August immediately prior to the XXIVth meeting of the International Geological Congress in Montreal. Almost simultaneously the Sixth International Cartographic Conference of the International Cartographic Association (ICA) met in Ottawa to discuss, amongst other items, ocean floor mapping.

Laughton, Roberts and Graves[3] of the National Institute of Oceanography, United Kingdom, had written a paper for the ICA conference on "Deep Ocean Floor Mapping for Scientific Purposes and the Application of Automatic Cartography" in which they detailed the need for improved charts, reviewed a comprehensive list of currently published charts, including the GEBCO Third and Fourth Editions, and set out ideas on how global charts could be improved.

This paper was written in response to an article on the need for world bathymetric charts by L.N.Pascoe[4]. Pascoe had proposed that the needs of oceanographers could be met by the publication of contours already being drawn for the 1 to 3.5 million scale International Series of Navigation Charts. This concept was rejected by Laughton *et al.*

At the first meeting of WG 41, attended by only four members, the paper of Laughton *et al* was discussed in considerable detail and it was concluded that a critical appraisal of the charts listed there should be carried out by members of the group in their own laboratories, that a questionaire should be circulated to obtain a wide range of views from active marine scientists and that the next meeting should prepare a document analysing their merits and demerits and make recommendations. It discussed the desirable specifications for a world series.

Some aspects of automatic cartography had been developed in the UK by David Bickmore of the Experimental Cartography Unit of the Royal College of Art, and he had worked closely with the NIO group in various trial areas. The Working Group discussed many of these ideas, which initiated the concepts of digital handling of bathymetry that would not be implemented effectively in GEBCO for another twenty years.

Immediately following the WG 41 meeting, the ICA discussed these ideas and set up a Working Group on Oceanic Cartography under the Chairmanship of Adam Kerr of the Marine Sciences Directorate of Environment, Canada. The two working groups had some common membership and it was planned that they should work in parallel. However the ICA Working Group had little influence on the future of the GEBCO which was largely determined by SCOR WG 41.

Dr Fisher had attended the Ottawa meeting of the ICA and subsequently reported, in a typically vigorous letter to Dr Baker, Executive Secretary of ICSU, his extreme concerns about the different approaches used to produce bathymetric charts by the professional hydrographers of the ICA and the oceanographers of SCOR.

A second meeting of SCOR WG 41 was held at NIO, Wormley, UK, on 2nd and 3rd April 1973 and was attended by most of the members of the WG and by many observers. The following membership attended:
J Ulrich (Germany) Chairman
A.S.Laughton (UK) Acting Chairman
D.C.Kapoor (IHB)
D.Newson (UK)
T.Sato (Japan).
E.Uchupi (USA), A.V.Ilyin (USSR) and V.Kanaev (USSR) were unable to attend but sent very useful contributions.

Several observers were present and contributed to the discussions:
F.W.G.Baker (Executive Secretary ICSU and Secretary GEBCO)
D.P.Bickmore (Experimental Cartography Unit, UK)
A.Ferrero (IHB)
A.J.Kerr (ICA WG on Oceanic Cartography)
G.Kredel (Fed. Rep. Germany)
D.G.Roberts (NIO) Acting Secretary
D.P.D.Scott (Secretary IOC)

All members had been circulated with the questionnaire in order to evaluate bathymetric charts within the scale ranges of 1:12 to1:6 million, 1:5 to 1:2 million and 1:1 million to 1:400 thousand. The GEBCO charts fell in the first range. During the meeting most of these charts were displayed and reviewed.
The WG also reviewed the organisation of bathymetric data exchange and compilation, generated ideal specifications for a new world chart series, discussed the future of GEBCO, the relationship of the WG with the ICA WG and proposed a series of recommendations to its parent body SCOR.

Prior to the meeting, an informal meeting had been held at UNESCO between RAdm. G.S.Ritchie, (President of IHO), F.W.G.Baker (ICSU and GEBCO) and D.P.D.Scott (IOC) about the future of GEBCO and this was reported to the WG 41 meeting. They noted that the IGN had only poor sales, that the sheets failed to meet the needs of the scientific community, that there was inadequate funding, but that the data collection method was generally satisfactory. Amongst the proposals put to the Working Group were firstly that the 1:10 million GEBCO sheets should be abandoned as a scientific global base chart of the oceans and secondly that the structure of the GEBCO Committee be changed, to become a joint IOC/IHO body on which both oceanographers and hydrographers should be represented. These proposals were put to SCOR WG 41.

Recommendations

After vigorous and constructive debate, the Working Group made the following recommendations, as recorded in the Minutes of the Second Meeting.
"SCOR WG 41:
(1) advises that the IHO continue its role as the specialised world data centre for oceanic soundings, recommends the continuing collection of soundings on a 1 in 1 million scale and welcomes the large contribution made through the Volunteering Hydrographic Offices,
(2) recommends the 1 in 1 million plotting sheets should show sources and precise limits of available high quality bathymetric surveys made at larger scales,
(3) recommends that IOC should attempt to locate data sources not at present routinely transmitting soundings to the IHO and to find ways and means of including such soundings in the world 1 in 1 million collector series,
(4) recommends that the IHO (in conjunction with the IOC, CMG and SCOR) should implement a study of future methods of automatic data storage, retrieval and transmittal based on standard data formats in parallel with, and as a future extension of, the 1 in 1 million sounding

collection system,

(5) recognises the need in the scientific community for a Mercator world bathymetric chart in colour on an approximate scale of 1 in 10 million. Such a chart must be derived from the larger scale charts prepared or approved by marine scientists employing current geological and geophysical knowledge,

(6) notes that wide discussions with colleagues have shown that the 1 in 10 million GEBCO series of bathymetric charts as prepared under the present system does not fulfil the needs of marine scientists because the contouring of the collected soundings has not responded to advances in earth science. Therefore the chart does not portray the closest approximation to the true shape of the seafloor that might be obtained from bathymetric data so interpreted. Additionally, the present series has deficiencies in presentation and is mostly out of date,

(7) recommends that it be recognised that the world bathymetric chart must be compiled from the best available bathymetric charts, published or unpublished, supplemented by contoured soundings collected on the 1 in 1 million scale,

(8) believes that a new system of production is imperative and recommends that a guiding committee for the preparation of the world chart be set up with nominations from IOC/SCOR/CMG/IHO. This advisory group should be composed of active marine scientists and hydrographers and its activities would replace those of the present GEBCO committee,

(9) recommends a small, full-time geoscience unit consisting of two experienced marine geologists or geophysicists with a draughtsman and secretarial support be set up to handle the task of preparing an acceptable final compilation of bathymetry for subsequent cartographic drawing, printing and distribution,

(10) recommends that this core unit should be internationally funded and based at a centrally located oceanographic institution with an active group in oceanic geology where good map collections and library facilities would also be available,

(11) recommends that, where appropriate, *ad hoc* consultant groups of marine scientists knowledgeable in particular areas, should be set up to assist the core unit and guiding committee,

(12) recognises that the task of drafting for reproduction and printing will need to be considered as a separate stage in the publication of the world chart. We appreciate that funds have been previously made available by the Monegasque government at the comparable stage of the GEBCO 1 in 10 million series, but understand that considerable additional funding will be required to implement this new project,

(13) notes the long association of the world bathymetric chart with the IHO and wishes to continue the association of the final product with the IHO,

(14) recommends that rapid publication is essential and that revision should be undertaken at frequent intervals on a continuing basis; intervals of revision of any particular chart would be determined by the acquisition or generation of significant quantities of new soundings,

(15) recommends that wide publicity be given to the new charts produced under the proposed system."

The report with its recommendations was endorsed by the SCOR Executive at its meeting in Texel in May 1973 and transmitted to the GEBCO committee and to IOC for their consideration.

Conclusion

The GEBCO Committee, at its meeting in Monaco in June 1973, reviewed its own questionnaire, that the committee had circulated, regarding the usefulness of the current GEBCO charts and also discussed the proposals from SCOR WG 41. There was general support for these recommendations and they were endorsed by the committee.

It was recommended to IHB that work on the 1:1 million series in its present form be suspended and that the contract with the IGN for the Fourth Edition be terminated, but that the plotting sheets of collected soundings be continued as the basis for the new global charts. The old GEBCO Committee was finally wound up with a letter from the Secretary dated 5th March 1974.

In a Status Report to SCOR dated 3rd January 1974, the Chairman of WG 41 (by this time Dr Laughton had become Chairman) reported that the GEBCO committee had accepted all the recommendations and that a new Guiding Committee for GEBCO had been set up by IOC and IHO, after consultation with SCOR, IAPSO and CMG, which was due to meet in

February 1974. In a final Status Report to the SCOR meeting in Equador in October 1974, the Chairman noted that the IOC/IHO Guiding Committee had started work, even though no funds for the Geoscience Unit had been found, and that the Working Group considered that it had fulfilled its task of stimulating activity on Morphological Mapping of the Ocean Floor. It was disbanded on 4th November 1974.

There is no doubt that this Working Group provided the impetus for a regeneration of GEBCO after its slow decline in the Third and Fourth editions. The chart specifications discussed by the Working Group formed the basis for the new specifications developed by the Joint IOC/IHO Guiding Committee for GEBCO and the charts of the Western Indian Ocean prepared for the IIOE Geological-Geophysical Atlas were to form the first of the new Fifth Edition of GEBCO.

There were many in the scientific community who felt passionately about the need for better global charts of the bottom of the oceans and they effectively exerted pressure through the analysis and discussion provided by SCOR Working Group 41.

References

1. Newson, D.W. (1971). "The General Bathymetric Chart of the Oceans – Seventy Years of International Cartographic Co-operation", Cartographic Journal, June 1971, 39-47.
2. Fisher, R.L., Johnson,G.L. and Heezen,B.C. (1967). "Mascarene Plateau, Western Indian Ocean." Geol. Soc. Amer. Bull. 78, 1247-1266.
3. Laughton, A.S., Roberts,D.G. and Graves, R. (1973). "Deep Ocean Floor Mapping for Scientific Purposes and the Application of Automatic Cartography". International Hydro. Rev., 50 (1), 125-148.
4. Pascoe, L.N., (1972). "World Bathymetric Charts". International Hydro. Rev. 49 (1),153-160.

6- A Change of Direction

(5th Edition)

Desmond P D Scott

Establishment of the Joint IOC-IHO Guiding Committee for the General Bathymetric Chart of the Oceans (GEBCO)

On receipt of the report, with its recommendations, of SCOR Working Group 41, the IOC Assembly[1] and the IHO approved, in November 1973, 'the formation of a joint IOC/IHO Guiding Committee for the (new) General Bathymetric Chart of the Oceans, after consultation with the SCOR, IAPSO (the International Association for the Physical Sciences of the Ocean) and CMG (the Commission for Marine Geology of IUGS), to replace the existing GEBCO Committee, for the purposes of:

(1) determining the needs of the scientific community, educational authorities, and other users of GEBCO charts;
(2) producing, based on these needs, new specifications for the preparation and production of the world bathymetric 1:10 million series charts, within the general guidelines recommended by SCOR Working Group 41.

Based on this decision, a Form of Understanding was reached between the IOC Secretariat and the International Hydrographic Bureau that membership of the Guiding Committee would be covered by the following Guidelines:
The Guiding Committee will consist of ten members, five of whom will be nominated by IHO and five by IOC. Of the IOC members, two will be selected by IOC, one by SCOR, one by IAPSO and one by CMG.

1 In close consultation, the co-sponsoring bodies will ensure that members of the Guiding Committee will be appointed on a wide geographical basis, and that no more than one member will be nominated from any one country.
2 Members of the Guiding Committee are experts acting in their personal capacity and shall not represent their government.

Inauguration

The 1st session of the Joint Guiding Committee was convened by the IOC Secretariat in Unesco, Paris, 25-26 April 1974[2]. Professor Eric S W Simpson, representing CMG, was elected as Chairman GEBCO and Mr Desmond P D Scott, Secretary IOC, was elected Permanent Secretary GEBCO.

At the opening meeting, the Guiding Committee received an Official Despatch from His Serene Highness Prince Rainier III of Monaco[3]:

On the occasion of the Joint IOC/IHO Guiding Committee's first session on the new Bathymetric Chart of the Oceans, I am glad to note the still lively interest for this chart, the drawing of which was initiated by my respected ancestor, Prince Albert I, and that the highest international authorities are working so closely together for the dual purpose of bringing it up to date and financing its publication. It is my pleasure to express my best wishes for the full success of your committee's work, and for the GEBCO programme. My sincere thanks to all those participating.

Rainier, Prince de Monaco.

The following reply was sent:

I acknowledge with gratitude your kind message on the occasion of the first session of the Joint IOC/IHO Guiding Committee for the (new) GEBCO. The Committee has requested me to reply informing Your Serene Highness of their appreciation of your continued interest in the GEBCO and to assure you that every endeavour is being made to continue the work started by your illustrious ancestor, Prince Albert I, by preparing and publishing an updated global series of bathymetric charts which will meet the needs of man in the modern world.

Harrison Unesco
Assistant Director General for Science

Specifications for the GEBCO (5th Edition)

The initial tasks of the Guiding Committee were then to finalise new 'Specifications for the GEBCO' and develop an Assembly Diagram for the new edition. It was decided that as the name *'Carte générale bathymétrique des océans'* ('General Bathymetric Chart of the Oceans') was a traditional name going back to the early years of the century and the reign of Prince Albert I of Monaco, and the connection was still strong, firstly with the ruling Grimaldi family as shown by the above exchange of cables, and secondly with the Monegasque Government which then provided the IHB with an annual grant of about FFr 50,000 (now, in 2002, EUR 7,400) in support of GEBCO data collection (at that time on 1:1 million series master sounding sheets).

This generous annual subsidy, which is still greatly appreciated, has proved to be an extremely valuable asset ensuring continuation of work on the GEBCO project over the years. The projection (Mercator) and scale (1:10 million at the equator) for the sixteen sheets between 72°N and 72°S were accepted but it was decided to modify the sheet limits and change the sheet numbering to a more logical system.

The first four editions had used the same layout and the peculiar sheet numbering system that had been adopted originally in 1903 for the 1st Edition. The numbering was improved and, following discussions during the next two sessions of the Guiding Committee, the Assembly Diagram (fig.37) was modified in three ways:

1. At the suggestion of Dr Takahiro Sato, then Director of Chart Division, Japan Hydrographic Department (but later to become Chief Hydrographer of Japan), the longitude limits of the eight southern hemisphere Mercator sheets were shifted 20° to the East to obtain improved coverage of the southern Atlantic, Indian and Pacific Oceans.
2. Taking this shift into account, Professor Bruce Heezen was invited to recommend overlaps between sheets to ensure that important ocean basins or seabed features were not cut by sheet limits but appeared in full on one sheet or another. These were accepted and also an overlap was agreed between sheets 5.15 and 5.16 for political reasons.
3. The Guiding Committee decided to have only two polar sheets, both on Polar Stereographic Projection on a scale of 1:6 million (at 75° latitude), instead of the eight in earlier editions, but having an overlap (64°-72°) with the Mercator sheets.

In fact this last decision came in for some criticism later, after publication, when it was pointed out that the Antarctic sheet (5.18) would have been of more use if it had been on a smaller scale allowing it to extend further north, possibly to 45°S. Much more recently the IOC and IHO have joined with the International Arctic Science Committee (IASC) to compile the International Bathymetric Chart of the Arctic Ocean (IBCAO)[4] in four sheets on a larger scale. These will then supersede the GEBCO Arctic sheet (5.17).

Using as a guide two sets of recommendations, those prepared by SCOR Working Group 41, and others prepared by the former GEBCO Committee at its final meeting (Monaco, 5-6 June 1973), the Guiding Committee drew up and adopted new 'Specifications for the GEBCO (5th Edition)'[5]. The Joint Guiding Committee also received useful turnover advice from the Chairman of the former GEBCO Committee, Ingénieur Général Marc Eyries. Whilst at that time it was inevitable that depths should be illustrated by means of contours, it had become increasingly clear, both from criticisms received and from a complete fall in sales reported by the IGN, that the traditional methods of contouring by linear interpolation between depths measured at discrete points by sounding machines and single-beam echo soundings was not depicting the true morphology of the sea floor. It had become clear that it was essential to combine these data with the results of other marine geophysical-geological studies. That this was the correct and necessary solution to the problem was shown by the sales figures which rocketed from very low figures with the 4th Edition to over 50,000 flat sheets and 900 Boxed Sets of the 5th Edition by 1996 (fig.38).

The new specifications, which were designed to improve presentation and quality control, included the following:

Soundings. In order to indicate contour reliability, all soundings used were to be shown as dots representing discrete soundings or lines representing continuously sounded traverses. Areas of detailed surveys where soundings are denser than can be conveniently shown could then be indicated by numbered boxes referenced in the margin. This can be seen clearly in the upper half of the 5th Edition version of the Porcupine Seabight region (fig.21).

Depth Contours. Contours were then to be derived from the best available larger scale charts which had been prepared or approved by marine scientists in the light of current geological and geophysical knowledge, or taken from surveys of such detail that there was no room for interpretation. Where such data were not available, contouring from soundings was to be undertaken by experienced geoscientists. Contours

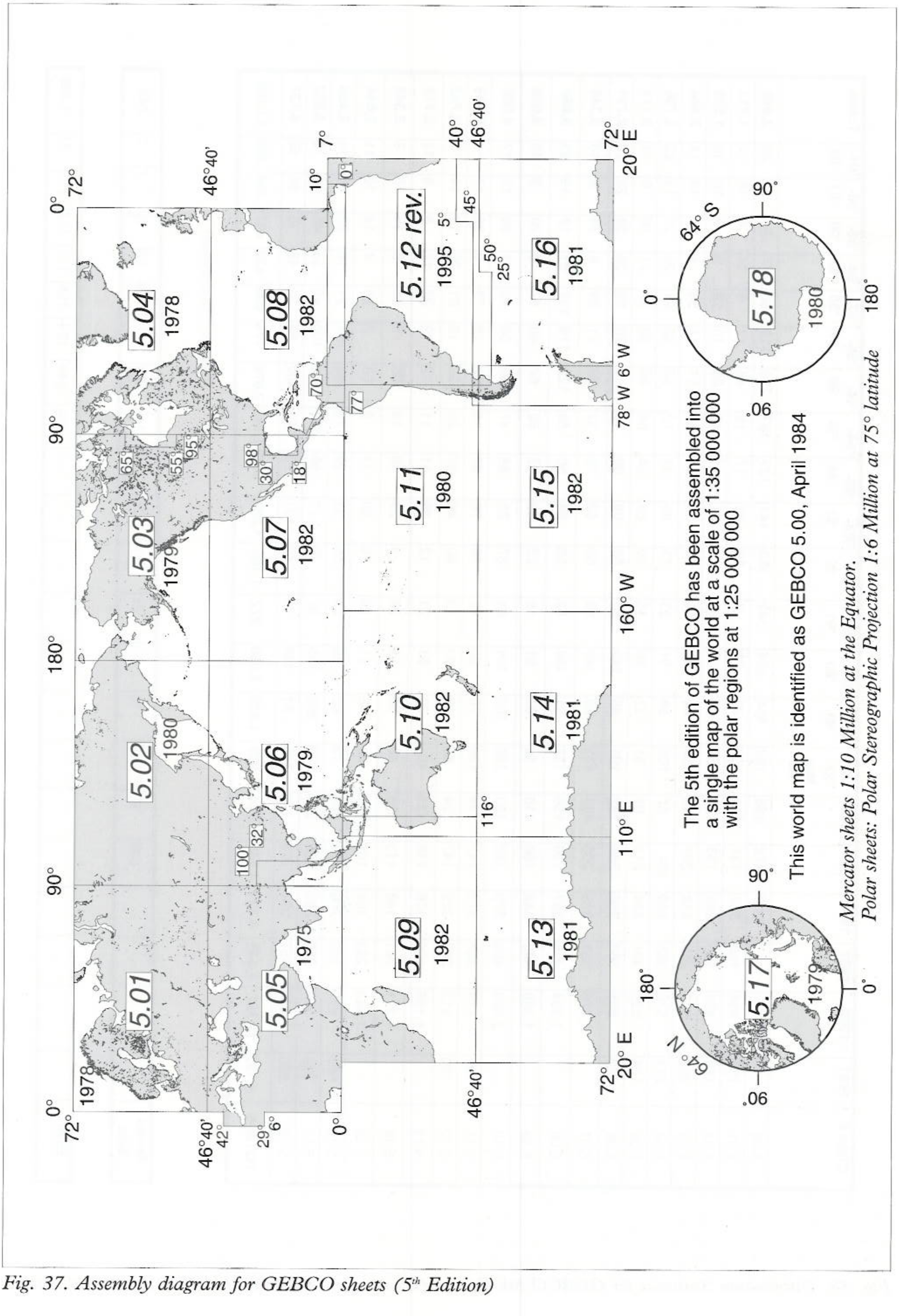

Fig. 37. Assembly diagram for GEBCO sheets (5th Edition)

Chart #	1981	1982	1983	1984	1985	1986	Jan '87- Mar '88	'88- '89	'89- '90	'90- '91	'91- '92	'92- '93	'93- '94	'94- '95	'95- '96	'96- '97	'97- '98	'98- '99	'99- '00	'00- '01	'01- '02	Totals
5.00	-	-	-	702	472	356	192	164	224	142	262	141	127	187	235	119	80	77	94	36	26	**3,636**
5.01	130	458	155	332	137	104	59	27	70	8	13	75	17	15	46	17	6	11	9	12	12	**1,713**
5.02	159	498	156	346	153	137	50	48	66	50	2	41	11	45	95	10	28	3	9	10	16	**1,933**
5.03	202	643	250	438	201	145	68	59	80	55	62	35	14	73	51	11	54	4	15	13	11	**2,484**
5.04	211	570	385	440	194	87	105	88	91	23	73	90	37	72	98	52	92	24	31	13	22	**2,798**
5.05	134	526	301	324	213	61	81	32	90	15	30	89	24	64	60	30	37	21	19	6	14	**2,171**
5.06	172	508	366	366	206	182	101	88	142	81	88	68	99	17	119	20	58	29	38	23	20	**2,791**
5.07	-	1,276	398	379	200	167	143	69	146	93	86	62	78	32	59	21	68	6	36	8	18	**3,345**
5.08	-	1,334	498	397	230	156	127	91	154	52	55	94	50	89	122	178	137	61	13	19	23	**3,880**
5.09	-	1,366	390	344	190	115	50	83	91	15	22	50	42	52	67	40	57	10	20	9	16	**3,029**
5.10	-	2,029	405	370	152	165	125	103	104	61	87	83	88	47	99	30	42	11	36	15	17	**4,069**
5.11	161	516	354	373	142	124	129	70	80	41	76	75	87	15	82	15	73	9	33	17	11	**2,483**
5.12	190	512	367	325	147	124	57	49	153	13	90	49	67	25	*426	18	81	26	12	14	17	**2,762**
5.13	-	1,106	198	128	116	131	104	32	51	21	12	38	11	11	72	19	22	12	8	9	12	**2,113**
5.14	-	1,271	241	148	113	128	68	38	56	26	9	23	16	14	106	9	35	9	14	10	8	**2,342**
5.15	-	1,043	233	167	105	113	51	48	51	29	16	30	11	8	68	7	25	4	14	10	11	**2,044**
5.16	603	577	206	206	133	146	73	62	86	25	58	33	28	73	58	14	21	18	22	10	14	**2,466**
5.17	262	524	285	285	308	201	230	203	155	97	77	77	96	181	111	106	49	55	45	97	78	**3,522**
5.18	968	570	257	257	773	122	116	81	168	75	42	131	73	121	102	59	31	42	19	68	52	**4,127**
TOTALS	**3,192**	**15,327**	**5,445**	**6,327**	**4,185**	**2,764**	**1,929**	**1,435**	**2,058**	**922**	**1,160**	**1,284**	**976**	**1,141**	**2,076**	**775**	**996**	**432**	**487**	**399**	**398**	**53,708**

* Sheet 5.12 (Revised)

Boxed Sets	-	-	-	-	530	86	59	18	53	31	31	30	15	14	29	11	9	17	2	7	6	**948**

GDA	-	-	-	-	-	-	-	-	-	-	-	-	-	376	248	124	155	112	112	112	81	**1,320**

Fig. 38. Distribution Statistics for GEBCO 5th Edition Charts, Boxed Sets & the GEBCO Digital Atlas

were normally to be drawn in at 500m intervals, but intervening contours could be added at 100m intervals where data permitted. Unlike the presentation on nautical charts, no need was seen for scattered soundings at intermediate depths; these depths were indicated by the contours. Spot values shown were therefore to be confined to highs and lows. The resultant patchiness of the final chart then reflected the quality and quantity of the input data and indicated the need for more surveys. It was stressed that no attempt was to be made to generalize down to the lowest quality data.

Correction of Echo Soundings. Depths, in metres, were to be corrected for the velocity of sound in sea water. The correction of soundings obtained by acoustic methods had been covered by resolutions of the IHB dating back to 1929 when it was decided to use 'Matthews Tables' published by the British Admiralty. Subsequently other tables for the correction of soundings came into use, notably those derived from Wilson's formula and the Kuwahara Tables. In 1975 the various methods of correction adopted by Member States of the IHO were listed in IHB Special Publication No.46. But in 1980 the British Admiralty published the Third Edition of 'Matthews Tables', now entitled 'Echo-Sounding Correction Tables (NP139)', but they have become generally known as 'Carter's Tables'.[6] A computerised version of the Tables enables echo-soundings to be corrected automatically, given the ship's position.[7]

Coastline and Land Topography. As a direct result of the close collaboration between the GEBCO and the French *Institut géographique national* (IGN), in particular with the 3rd and 4th Editions, it was agreed that the 5th Edition could use the coastline and land topography from the *'Carte générale du monde'* (CGM), but with the GEBCO code of colours. As the coastline and topography for the Antarctic continent does not appear on the CGM, the shoreline used on sheets 5.13, 5.14, 5.15, 5.16 and 5.18 was taken from the American Geographical Society Map of the Antarctic Region and the latest shoreline then available (1979) from the Scott Polar Research Institute, University of Cambridge, England.

Geographical Names and Nomenclature of Ocean Bottom Features. A small Sub-Committee was established under the Chairmanship of Mr Gerald N Ewing, Dominion Hydrographer, Canada, to replace the earlier Sub-Committee which had been created in 1964 under the former GEBCO Committee. This new Sub-Committee, which was entirely Canadian in membership (apart from its Secretary: RAdm D C Kapoor, Director IHO), provided day-to-day advice on Geographical Names and Nomenclature of Ocean Bottom Features to the CHS as the 5th Edition sheets were being compiled. On completion of that task, the Sub-Committee was placed in abeyance in August 1982 and then re-established with a completely new membership, under the chairmanship of Dr Robert L (Bob) Fisher, in May 1983.

Publication of the GEBCO (5th Edition)

At this time data from the International Indian Ocean Expedition (IIOE) were being worked up and 1:5 million proof sheets of the bathymetry of the northern Indian Ocean, which had been prepared for publication in the Geological-Geophysical Atlas of the Indian Ocean[8] under the editorship of Dr Gleb Udintsev, were already available. These, together with a chart of the Mediterranean Sea provided by the *Institut français des pétroles* (IFP), Soviet sheets of the Black and Caspian Seas, and the Gulf of Guinea from work undertaken by Professor Bruce Heezen, enabled the Canadian Hydrographic Service, working closely with the Scientific Co-ordinator for this sheet, Dr A S Laughton, the French *Institut géographique national* (for the base projection) and the GEBCO Sub-Committee on Geographical Names and Nomenclature of Ocean Bottom Features, to produce and publish the first sheet of the GEBCO (5th Edition) in time for assessment during the second session of the GEBCO Guiding Committee, 28-30 April 1975.

Furthermore the opportunity was taken to distribute 200 copies to delegates at the third session of the Third U.N.Conference on the Law of the Sea (17 March-10 May 1975). This sheet was also widely distributed to all members of the GEBCO community, all Member States of the IHO and to appropriate scientific organizations, with invitations for comments and constructive criticism. Taking into account comments and criticisms received, sheet 5.05 of the northern Indian Ocean and the Mediterranean Sea then became the model on which the remaining sheets of the series were based.

Unlike the production arrangements followed for the first four editions when compilation and publication of all the sheets of each edition were undertaken by the same production teams, for the 5th Edition compilers were recruited from marine scientists in different institutions worldwide, who were able and willing to carry out geomorphological contouring of their areas of interest. On many occasion these areas did not coincide with GEBCO sheet limits, so there could well be several compilers for a 5th edition sheet. Scientific Co-ordinators were therefore appointed for each sheet to ensure the smooth seamless nature of the dataset, both between areas of responsibility and also along GEBCO sheet limits (see Annex).

It was at this time that the decision was made to invite Dr Robert L (Bob) Fisher to act as Scientific Co-ordinator for the southern Indian Ocean (sheet 5.09), and from this small beginning, and the principle of mutual assistance, GEBCO has gained outstanding revised contouring of about a quarter of the world's oceans, which forms the basis of the gridded dataset in the latest release of the GEBCO Digital Atlas.

The Joint Guiding Committee had become increasingly concerned about the arrangements that would be needed to print and publish worldwide-cover of GEBCO sheets (16 on Mercator projection 72°N - 72°S, and two on Polar Stereographic Projection), even when compilation work had been completed.

The Canadian Hydrographic Service (CHS) had produced the first sheet (5.05) of the new edition and had offered to produce and publish three more Atlantic Ocean sheets (5.01, 5.04 and 5.12), but had then stated that responsibility for further sheets would depend on the formation of a GEBCO Geoscience Unit, and agreement to its being sited in Canada. Furthermore at that time an approach had been made by the Secretariat of the U.N.Conference on the Law of the Sea to the Secretary IOC and the Directing Committee IHO, inviting the two bodies 'to forward proposals for the development of training facilities and other assistance aimed at helping delegates to the Conference, appropriate national authorities and others to understand the technical regulations ... in order to interpret correctly the limits of the legal continental shelf.'[9]

The Guiding Committee therefore formed a Sub-Committee on Technical Problems relating to the Law of the Sea, under the Chairmanship of Dr A S Laughton, and prepared a detailed statement[10], but it was made clear that 'such tasks may be beyond the resources of the Guiding Committee' and this had to be conditional on the necessary additional funding being made available.

A report was then made by the Guiding Committee to its governing bodies, resulting in a positive response being made to the UN Secretariat by IOC and IHO[11]. In the view of the Guiding Committee, establishment of the GEBCO Geoscience Unit, if properly funded, would be the first step towards meeting this requirement. However although a considerable effort was made, including approaches to the World Bank and the United Nations Development Programme (UNDP), and with strong support from the UN Secretariat, as well as from Ambassador Arvid Pardo, the father of the Third UN Conference on the Law of the Sea, and Mr Bernardo Zuleta, the Special Representative of the United Nations Secretary-General to the Conference, the necessary funding was not forthcoming.

At this time, consideration was even given to the possibility that sheets would be printed by different agencies, usually those undertaking compilation work, but this was recognised as unsatisfactory. The breakthrough came when the Canadian government, realising that it would not be possible to establish a GEBCO Geoscience Unit within the timescale envisaged for production of the 5th Edition, offered in 1978 to print and publish the whole series, subject only to the condition that all income from sales would be credited to the Canadian Hydrographic Service. In expressing his thanks for this generous offer, the Chairman announced a goal, which was accepted by the representative of the CHS as feasible, of having the complete series of 18 sheets published in time for the XIIth International Hydrographic Conference in May 1982. This was achieved and in addition a World Sheet (5.00) was published in April 1984.

When the full series had been published, a decision was taken to issue all 19 sheets (folded), together with a Supporting Volume, as a Boxed Set[12] for use by libraries and individuals for reference purposes. It also proved useful for improving GEBCO publicity.

Besides a Preamble, Introduction, Brochures and a Catalogue of Bathymetric Plotting Sheets, the Supporting Volume[13] contains sections on the History of the GEBCO; Credits for each Sheet; References and Sources for each Sheet; Geographical Names and Nomenclature; Standardization of Undersea Feature Names; Role of the International Hydrographic Organization as the World Data Centre for Bathymetry; The Correction of Echo-Soundings; Copyright and Author Attribution; Sales Arrangements; and Terms of

Reference for the Joint IOC-IHO Guiding Committee for the GEBCO. In two Appendices are Specifications for the GEBCO (5th Edition); and GEBCO Personality Lists (1974-82).

In April 1987 it was learned that Mr Norman Cherkis, US Naval Research Laboratory (NRL), was preparing for publication a bathymetric chart of the South Atlantic. As the published sheet 5.12 was already considered to be out of date and did not justify the cost and effort of digitization, the Guiding Committee, acting on the advice of the GEBCO Sub-Committee on Digital Bathymetry, decided, subject to the agreement of Mr Cherkis (and his publishers, the Geological Society of America), to publish a revised version of this sheet in the GEBCO series, if all the associated problems could be overcome. This was achieved and a revised version of this sheet was published in May 1995.

Digitization

By the 4th Session of the Joint Guiding Committee in May 1977, it had become increasingly clear that a digitized dataset was needed in addition to the traditional paper chart series. Concern was being expressed that a great deal of bathymetric data was being collected and stored in digital form, and as a result was not getting into the archives of the IHB in its capacity as the World Data Centre for Bathymetry. With this in mind, the Guiding Committee appointed Dr Bosko D Loncarevic of the Atlantic Geoscience Center, Canada, as a one-man Sub-Committee on Digital Bathymetry to prepare a report on the question: 'Is there an advantage in having digital bathymetric data?' The Guiding Committee however instructed the Sub-Committee to distinguish between: (a) digitally acquired data; (b) digitized selected soundings; and (c) digitized contours. When received in October 1980, Dr Loncarevic's final report listed the advantages of a changeover to Digital Bathymetry and this was accepted by the Guiding Committee and the IHO to be highly desirable.

A new Sub-Committee on Digital Bathymetry was then formed under the Chairmanship of Mr Gerald N Ewing, and required to[14]:

1. Analyse and prepare a consolidated report on the responses to questionnaires sent out to IHO Volunteering Hydrographic Offices (VHOs) and to selected Oceanographic Institutions[15];
2. Study and report on the desirability and the ways and means of digitizing the contours of the GEBCO (5th Edition); and
3. Study and report on the desirability and the ways and means of achieving an international system of storage and retrieval by an automatic digital system of the data at present stored by the IHB (as the World Data Centre for Bathymetry) on 1/1 million scale plotting sheets, and any further data to be collected in the future. This sub-committee was active until Mr Ewing was elected Chairman of the GEBCO Guiding Committee in March 1982. It was then reorganised under the chairmanship of Dr Meirion T Jones, Director of the British Oceanographic Data Centre (BODC) - see Part 8 'GEBCO enters the Digital Era - the GEBCO Digital Atlas' which follows.

However, it should be recorded that these requirements, formulated in 1980, led eventually to:

1. the understanding that although some of the VHOs which had accepted responsibility for maintenance of 1/1 million plotting sheets were now digitizing the data shown on these sheets, other countries had no plans at that time to change over to such a system and would continue to maintain the plotting sheets. It was realised that the two systems would therefore have to co-exist for the foreseeable future. It was not until September 1991 that the IHO Working Group on Ocean Plotting Sheets, under the chairmanship of Mr Brian Harper, recommended that 'all remaining analogue Oceanic Plotting Sheets should be phased out by 1996.'[16]
2. an agreement being reached with the International Gravity Bureau in Toulouse, and by August 1982, Dr Georges Balmino was reporting that '(vector) digitization of the GEBCO bathymetric contours had now been started'[17]. However this initiative proved to be premature for technical reasons and it was not until 1992 that digitization of the GEBCO (5th Edition) contours was completed and, as an interim measure, distributed by the British Oceanographic Data Centre (BODC) on a single 6250bpi magnetic tape in GF3 format.[18] This was followed by the release of the GEBCO Digital Atlas (GEBCO 94) on CD-ROM in 1994. During this period the GEBCO Digital Atlas (GDA) concept was being developed, and in June 1991 the Guiding Committee developed and published[19] a GEBCO Structural Diagram, to illustrate the various components of the GEBCO system and its relationships to other data sources and other separate but related projects and products (fig.39).

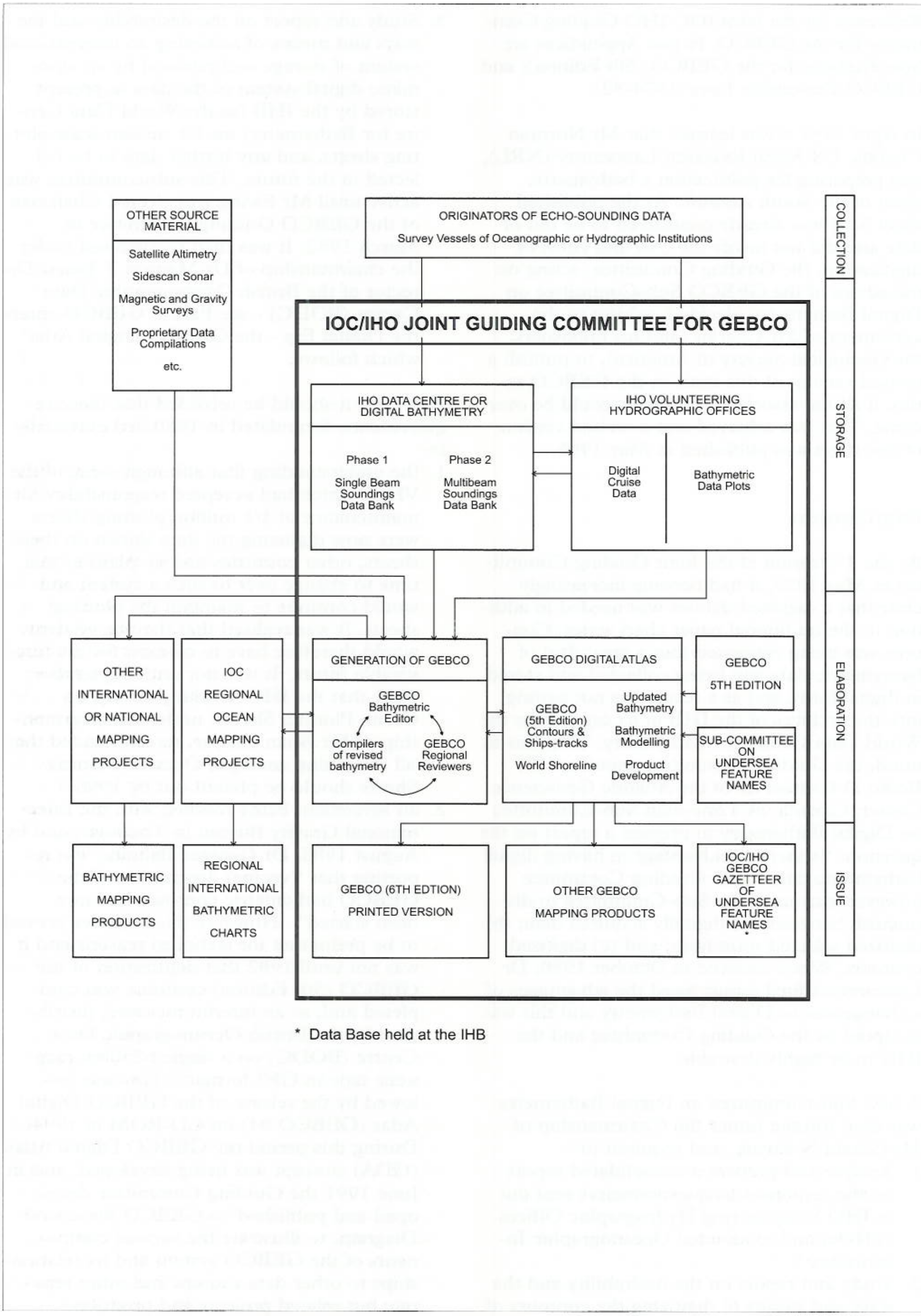

Fig. 39. GEBCO Structural Diagram

3. the establishment, as from 1 June 1990, of the IHO Data Centre for Digital Bathymetry (DCDB), operated by the U.S. National Geophysical Data Center (NGDC) in Boulder, Colorado, USA, on behalf of the IHO. Following some years of discussions and negotiations in the GEBCO Sub-Committee on Digital Bathymetry and the Joint Guiding Committee, a 'Proposal for Creating an IHO Center for Digital Bathymetry' dated May 1988 had been received by IHO from the U.S. National Geophysical Data Center,[20] and had been approved by IHO Member States.

Oceanic Plotting Sheets

Compilation and publication of the GEBCO (5th Edition) has coincided with the ever increasing speed of availability of new technologies. The traditional method of collecting soundings on hand-drawn master sounding sheets, which had sufficed for the first four editions, rapidly became out of date for the fifth. As the development of digital data technology gathered momentum, serious questions were being raised about the viability and continued use of the GEBCO plotting sheet system, and the roles of the Volunteering Hydrographic Offices (VHOs). So, in 1990, an IHO Working Group on Oceanic Plotting Sheets (WG/OPS), under the chairmanship of Mr Brian Harper (UKHO), was formed with the following terms of reference:

1. To investigate the ways in which VHOs could keep the GEBCO Oceanic Plotting Sheets (OPS) updated.
2. To investigate ways of ensuring that new bathymetric data are consistent with previous data of the same area or disprove earlier data.
3. To discuss the best way to exchange bathymetric data in order to ensure effective updating data procedures.
4. To investigate how a move towards digital data handling should proceed, and the problems involved.
5. To discuss progress in the change-over by the VHOs from OPS to digital data bases.
6. To define the future requirements for OPS and in particular:
   a) to recommend whether digital bathymetric data should be included on the OPS;
   b) to identify difficulties that may arise if OPS continue to be maintained following the establishment from 1st June 1990 of an IHO Data Centre for Digital Bathymetry;
   c) to identify the future role of the VHOs in maintaining OPS.'

The Working Group, composed of representatives from eight VHOs and one from IHB, made eighteen recommendations. The main points being summarised as:

- VHOs should fully embrace digital methods of data collection, storage and exchange.
- Manual plotting sheets to be phased out by 1996.
- Standard methods of quality control to be introduced and recommendations given on the standardised distribution of data to the IHO DCDB.
- Facilities to be introduced to advertise on a regular basis all data held in the DCDB for free access by HOs using MGD77 format.
- Procedures for identifying and flagging disproved data should be developed.
- Future impact of increased Multibeam data collections will require Part 4 of the GEBCO Guidelines[21] to be rewritten.

The report was submitted to the IHB in 1991 and presented at the International Hydrographic Conference (IHC-XIV) in May 1992[22]. Ten years later, all the VHOs have embraced digital data technology; however, in respect of sharing depth data, some of the goalposts have moved again. For numerous reasons Hydrographic Offices have chosen to operate different regimes with respect to the provision of raw data to the DCDB. These range from full compliance with the Working Group's recommendations to a policy of withholding access to raw depth data. Although some HOs have concentrated on building their own database, without passing data to the DCDB, they have all made gridded versions of such data freely available.

In April 1985 Mr Gerald N Ewing, who had by then been appointed Assistant Deputy Minister, Ocean Science and Surveys, Canada, retired and Sir Anthony Laughton PhD FRS (representing SCOR) was elected as Chairman, and Ingénieur Général André Roubertou as Vice Chairman. At the same session a small Task Team was formed under the chairmanship of Ing.Gén. Roubertou, to study the task involved in the preparation of the GEBCO (6th Edition), taking into account the new technology, as indicated in the Terms of Reference of the Guiding Committee, item 3, which reads: 'After analyzing the impact of the GEBCO (5th Edition) on the world community over a number of years after issue of full world cover, draw up plans for the next edition which should reflect the new technologies and data available ... etc.'[23]

The detailed, excellent and most useful Report of the Task Team was submitted to the Guiding Committee in April 1987[24] and its findings have formed the basis for later developments with the GEBCO Digital Atlas (GDA), now taken as the 6th Edition, but the Guiding Committee has taken note of, and is in full agreement with, the Task Team's statement that 'A large majority of users expressed the need for the usual paper chart, accompanied by the corresponding electronic chart'.

References

1. IOC Resolution VIII-3 General Bathymetric Chart of the Oceans (GEBCO), in Unesco document SC/MD/39 Annex II
2 Summary Report of the First session of the Joint IOC/IHO Guiding Committee for the General Bathymetric Chart of the Oceans (GEBCO) (doc. IOC-IHO/GEBCO-I/3)
3 Summary Report of the First session of the Joint IOC/IHO Guiding Committee for the General Bathymetric Chart of the Oceans (GEBCO) (doc. IOC-IHO/GEBCO-I/3) Annex IV
4. IBCAO Website: ww.ngdc.noaa.gov/mgg/bathymetry/arctic/arctic.html
5 IHO/IOC/CHS. 1984. GEBCO - General Bathymetric Chart of the Oceans (5th Edition), Ottawa, Canada, 74p. Appendix I
6 Echo-Sounding Correction Tables (NP139). These new tables were the culmination of many years' work extending back to even before the 10th International Hydrographic Conference in 1972 when the IHB was asked to investigate the possibility of having the existing tables revised for international use. The computation of the Tables was carried out by D J T Carter of the United Kingdom Institute of Oceanographic Sciences.
7 IHO/IOC/CHS. 1984. GEBCO - General Bathymetric Chart of the Oceans (5th Edition), Ottawa, Canada, 74p. Section 8
8 Geological-Geophysical Atlas of the Indian Ocean. Academy of Sciences of the USSR, and the Main Administration of Geodesy and Cartography under the Council of Ministers of the USSR, Moscow, 1975. This atlas formed part of the report on the Geological-Geophysical results of the International Indian Ocean Expedition, 1959-1965.
9 Short Summary Record of Discussion at the first Officers' Meeting (doc. IOC-IHO/GEBCO Officers-I/3), item 6
10 Summary Report of the seventh session of the GEBCO Guiding Committee (doc.IOC-IHO/GEBCO-VII/3), item 7
11 Summary Report of the fourteenth session of the IOC Executive Council (doc. IOC/EC-XIV/3), Annex II, Resolution EC-XIV.2 (reproduced in the Summary Report of the eighth session of the GEBCO Guiding Committee (doc. IOC-IHO/GEBCO-VIII/3), Annex IV)
12 GEBCO Boxed Set. Published by the Department of Fisheries and Oceans, Scientific Information and Publications Branch for the Canadian Hydrographic Service. Under the authority of the IHO and IOC (UNESCO). ISBN 0-660-52685-9
13 IHO/IOC/CHS. 1984. GEBCO - General Bathymetric Chart of the Oceans (5th Edition), Ottawa, Canada, 74p.
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15 IHO Circular Letter 4/1979 dated 15 February 1979.
16 Summary Report of the thirteenth session of the GEBCO Guiding Committee (doc. IOC-IHO/GEBCO-XIII/3), Annex V, item 2 (iii).
17 Short Summary Record of Discussion at the third Officers' Meeting (doc. IOC-IHO/GEBCO Officers-III/3), item 6
18 Summary Report of the ninth meeting of the GEBCO Sub-Committee on Digital Bathymetry (doc. IOC-IHO/GEBCO SCDB-IX/3), item 4.3
19 IHB publication B-7, September 1991 (with revisions to June 1993) GEBCO Guidelines for the General Bathymetric Chart of the Oceans. Paragraph 1.2.10.
20 Summary Report of the twelfth session of the GEBCO Guiding Committee (doc. IOC-IHO/GEBCO-XII/3), item 9; and Summary Report of the seventh meeting of the GEBCO Officers (doc. IOC-IHO/GEBCO Officers-VII/3), item 4 (former item 9).
21 IHB publication B-7, September 1991 (with revisions to June 1993) GEBCO Guidelines for the General Bathymetric Chart of the Oceans. Part 4 Digital Bathymetric Data (Multibeam Echo-Sounders) In press
22 Report of the IHO Working Group on Oceanic Plotting Sheets (WG/OPS). IHO publication P-6: Vol.2 of the Report of Proceedings of the XIVth International Hydrographic Conference, 4-15 May 1992, Monaco, pp.275-9.
23 Summary Report of the ninth session of the GEBCO Guiding Committee (doc. IOC-IHO/GEBCO-IX/3), Annex III.
24 Summary Report of the eleventh session of the GEBCO Guiding Committee (doc. IOC-IHO/GEBCO-XI/3), Annex V.

Annex

Credits for Each Sheet of the Series

Sheet 5.01

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Federal Republic of Germany

Sheet 5.02

Scientific Coordinator
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Institute of Physics of the Earth
Moscow, USSR

Sheet 5.03

Scientific Coordinators
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Office of Naval Research
Arlingon, USA
and
David Monahan
Canadian Hydrographic Service
Ottawa, Canada

Sheet 5.04

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Sheet 5.06

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Sheet 5.07

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and
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Sheet 5.08

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The cartography for the 18 sheets of the GEBCO fifth edition, was carried out between 1975 and 1982 by the Geoscience Mapping Unit of the Canadian Hydrographic Service.

7- GEBCO's Role in Seafloor Terminology

Dr Robert L Fisher

Formation of a standing Sub-Committee on Geographical Names and Nomenclature of Ocean Bottom Features (GEBCO-SCGN)

In 1974, in anticipation of a fifth edition of GEBCO, the first under the joint aegis of IOC and IHO, the IOC/IHO Guiding Committee authorised formation of a standing Sub-Committee (GEBCO-SCGN) to oversee the standardization of seafloor topographic usage on GEBCO charts. Such oversight groups were not new: earlier, panels had met at the International Hydrographic Bureau in 1952, 1954 and 1964, for example. One result had been a GEBCO list: 'Nomenclature of Ocean Bottom Features', published in the International Hydrographic Review.[1] Similarly, several nations, notably Canada and the United States (since 1960), have had panels to establish bathymetric nomenclature mandates for use by employees of those governments: the US's Advisory Committee on Undersea Features (ACUF) has ... since 1963 ... promulgated their rulings in a series of gazetteers.

GEBCO's Sub-Committee on Geographical Names and Nomenclature of Ocean Bottom Features was intended to be an internationally-recognized authority; its initial members were a Canadian, Dominion Hydrographer Gerald N Ewing as Chairman, French senior naval hydrographer André Roubertou, American marine geologist Bruce Heezen and, as Secretary, IHB Director RAdm D C Kapoor. The first meeting at Dartmouth, Nova Scotia, early in 1975, examined briefly the history of such efforts, recommended that hydrographic representation be sought from the United Nations Group of Experts on Geographical Names (UNGEGN), found that no prior published definition compilations seemed adequate for needs foreseen for the GEBCO (5th Edition), and agreed to consider as a tentative model a recent report from the Canadian Advisory Committee on Undersea Feature Names.[2] More lastingly, the panel established several general principles (taken as "ground rules") that have continued to govern the appearance, language and colour nuances of GEBCO sheets. Their sole hands-on activity was to review the imminent 5th Edition's only draft sheet, newly prepared by Dr A.S. Laughton, and modified to meet their newborn ground rules. By that action they established as GEBCO practice that for each sheet the scientific co-ordinator ('convenor') would forward a proposed list of seafloor feature generic/specific names consonant with the principles for GEBCO-SCGN review and approval, prior to printing.

Ground Rules

Almost immediately after that first (1975) meeting, the list of seafloor feature definitions, formulated by Canada's Advisory Committee and accepted by the Canadian Hydrographic Service, was circulated to the GEBCO Guiding Committee and GEBCO-SCGN members. It consisted of only 58 terms, each with a simple one or two sentence definition. These adhered to principles still fundamental in GEBCO lexicons:

> "the definitions are based on similarity of form, gradient, relative size and other physical characteristics and avoid, in so far as possible, the use of maxima and minima in physical measure."

In short, the criteria are primarily geomorphological. In all subsequent reviews and fine-tuning of the GEBCO name base, the avoidance of petrologic composition or implications of origin is continued. Only very recently - with the advent of micro-contoured multibeam-mapped elevations - has it been deemed advisable to maintain perspective by defining seamounts as major topographic entities 'at least a thousand metres in relief above the seafloor'.

One almost immediate reaction to the distribution in April 1975 of the 'Canadian list' was a detailed official response from the Executive Secretary of the U.S.Board of Geographic Names (USBGN), Richard Randall, who was then also Chairman of UNGEGN's Working Group on Undersea and Maritime Features. He pointed out that, as a non-national entity, the IHO could not be directly affiliated to UNGEGN but might be represented at sessions by observers, that the USBGN had already long been active with undersea feature name activity and many of the 'Canadian list' definitions 'did not coincide in all instances with those used by USBGN', and finally 'deplored that the United States was not represented on GEBCO-SCGN' and requested that USBGN 'have the opportunity to participate in future discussions on definitions'. (In point of fact, Bruce Heezen, a U.S. civilian professor, had from the beginning been a one-fourth part of the GEBCO-SCGN membership.) With time all these issues have been answered or ameliorated; today the Secretary of USBGN's Advisory Committee on Undersea Features (ACUF) attends GEBCO-SCGN/SCUFN meetings as a welcome expert voice and to ensure close liaison between the two groups.

By early 1976 the first and second U.N.Conferences on the Standardization of Geographic Names had adopted a resolution[3] (#8) recommending in part that the U.N. Permanent Committee of Experts on Geographical Names: (1) obtain from IHO, IOC and IAPSO the full results of their recent work on establishing definitions and terms for undersea nomenclature; (2) establish means for distribution of both a list of such internationally-standardized terms and definitions, and an initial list of recommended geographical names for features requiring names; and (3) develop procedures for international standardization of naming new undersea features as they are discovered, defined and identified in the future. UNGEGN was charged to continue to consult with, and use the facilities of IHO, IOC, IAPSO and other relevant bodies to further U.N. objectives in standardization. The Conference further resolved (#26) that, given the importance of international standardization of names of undersea features beyond areas of single sovereignty, the UNGEGN should co-operate, in particular with IHO, to draw up a system for naming such undersea features. These statements, clarified and ratified by the third such Conference (Athens, 1977), outline the basic mandates under which GEBCO-SCGN/SCUFN carries out its extra-national activities. As a practical matter, most of the solicitation/reception of names proposals, distribution of decisions and publication of the Gazetteer are now undertaken directly through IHO/IOC auspices and facilities.

Undersea Feature Terminology

Invoking such legitimacy, at its third meeting (Patricia Bay, British Columbia, Canada) in April 1978, GEBCO-SCGN was joined by Richard Randall, Convenor of the U.N's Working Group on Undersea and Maritime Feature Names, and Jack Pierce, a senior member of the USBGN. On the Sub-Committee's side, original member, Professor Bruce Heezen, had died at sea in June 1977; Dr Robert L. Fisher, deep-sea marine geologist of Scripps Institution of Oceanography (SIO), had been named to that vacancy. The principal business before the meeting was to develop .... collaboratively .... 'Guidelines for Standardization of Undersea Feature Names' and a joint list of terms and definitions. A list of 'Undersea Feature Terminology', recommended by the Sub-Committee for the GEBCO (5th Edition) as of late 1977, had already been published[4]. That list of 39 generic terms contained, accompanying each term's definition, a reference taken from ocean science literature in the English language that used the term in the sense there defined. A corresponding but separate list in French had been prepared by Ingénieur général André Roubertou, quoting citations originating in French language literature.

The session participants now closely compared the U.N., USBGN(ACUF) and IHO lists, containing a total of 46 terms: definitions of 14 were identical, others required compromise and revision. As a result, a joint list of agreed terms, 44 in all, was prepared and today serves almost unmodified as the foundation for terminology appearing in documents such as the IHO-IOC GEBCO Gazetteer (IHB publication B-8). Secondly, clear and applicable principles were then established for guidelines governing IHO/UN international usage in seafloor nomenclature decisions, of wording still in the introduction to 'Standardization of Undersea Feature Names' (IHB publication B-6). The chief architect of that joint UN-IHO text was BGN's Richard Randall. The Undersea Name Proposal Form, contained in publication B-6, has been translated into nearly a dozen languages. Lastly, the Sub-Committee reviewed four of the GEBCO (5th Edition) draft sheets, then undergoing final cartographic preparation at the Canadian Hydrographic Service (CHS) in Ottawa, finding unique problems and ambiguities inherent to each, a common condition but held to be solvable by cartographer-convenor correspondence.

By the early 1980s the Sub-Committee's duties, reviewing and approving the 5th Edition name portrayals had nearly ended, and its mandates and guidelines were in place. CHS's Gerald N.Ewing was followed as Chairman by a civilian academic, SIO's Robert L.Fisher. By 1983 items in hand included refining and amplifying .... inserting various indigenous citations .... revising the multi-language publication 'Standardization of Undersea Feature Names' (IHB publication B-6) and making formal and informal efforts to encourage academic organizations and individuals to interact with GEBCO entities, to employ .... or at least recognise .... its products, and to submit for pre-publication review (by GEBCO-SCGN) name proposals for features discovered or delineated during their research explorations. An invited editorial: 'A Proposal for Modesty' appeared in a geological journal[5]. Co-operation was established with the Editorial Board of the IOC's complex International Bathymetric Chart of the Mediterranean (IBCM), to review and ratify seafloor names, usage and terminology in this chart series, in this thus foreshadowing today's efforts to collaborate with six additional IBC regional Editorial Boards.

GEBCO Gazetteer

A major GEBCO-SCGN project, fundamental to wider community GEBCO acceptance, was initiated in 1985: the compilation of feature names/positions appearing on 5th Edition sheets and on small-scale (1:2 million and smaller) International (Nautical) Chart Series sheets. This was accomplished by the Secretariat of the Sub-Committee, at the International Hydrographic Bureau (IHB). The ongoing intent is the enlargement by accumulation and insertion of similar data acquired from approved name proposals resulting from agency cartographic products and academic research cruises. This facet, proposal review, has proved to be the key agenda item and major time-burner at all subsequent GEBCO-SCUFN biennial meetings. One obvious result is that the Sub-Committee's biennial Summary Reports of meetings have grown from 3-4 pages in the '70s to 20-30 pages in the early '90s, to more than 100 pages at the present time.

The first edition of the 'IHO-IOC Gazetteer' (IHB publication B-8) appeared in November 1988. Subsequent versions in an improved format were produced from 1997. The current Gazetteer is available from the GEBCO website (www.ngdc.noaa.gov/mgg/gebco/). This document has become scholarly and authoritative in application, now listing information as to history, e.g. reason for subject's commemoration and relation to locality, discovery date/ship/explorer, proposer and date of accreditation (if known). The Gazetteer database is maintained in digital form by IHB staff and hence is readily revised, augmented and consulted. Recognizable regional gaps have become areas for attention and solicitation to agencies and individuals.

Reorientation and Renaming of the Sub-Committee

With expectation of development of different methods appropriate to the construction and issuance of a 6th Edition of GEBCO - very likely primarily in the digital database and with questions of generic feature terminology largely settled - in 1993 the Guiding Committee approved new Terms of Reference for the Sub-Committee and changed its name to the Sub-Committee on Undersea Feature Names (SCUFN). Its Chairman and membership remained as before but duties became more activist, in recognition of broadening audience and wider product responsibilities. Currently SCUFN follows those 1993 Terms of Reference (Annex).

Rationale

The preceding text has traced the evolution of GEBCO's most durable and only instrument for definition, monitoring and dissemination of seafloor terminology. Even when the Sub-Committee is applying its sober guidelines, there are occasional instances of perplexity, acrimony and controversy. Given, the aims of the programme are to employ geographical, geomorphological and historical expertise, authorising names free of duplication and worthy of permanence. Demonstrated precedence is in principle compelling. Non-duplication in both specific and generic names is expected, at least for a given ocean. Candidates for commemoration favoured by the guidelines are those persons who have made major contributions to the marine sciences and/or exploration, and, in nearly every case, are no longer living.

Sub-Committee members serve as individuals with expertise, not as organization, agency or national representatives, except for the ex-officio member, an IHB Director. In making decisions, members are expected to be unbiased, apolitical, free of chauvinism, given to appreciate cleverness or appropriate humour, quick to deplore coarseness, sycophancy or nepotism. No such restrictions limit the proposers, often colourful seagoing scientists - authors impatient for recognition. One traditional perquisite of exploration and discovery is the 'right' to name the feature discovered. The maps of some remote land areas are replete with surviving personal legacies of nepotism, self-promotion or rough humour. So, in some sectors, is the seafloor; there, long usage frequently ensures retention. Political statements via the seafloor tend to be unsubtle and transitory; one cartographer's charismatic terrorist may become history's thug; a political prison's parolee can become President. In one instance, national sensibility forbade a sly juxtaposition of the names of long-dead military figures to dominate spatially their celebrated opponent. Such political issues by no means dominate SCUFN's agenda, however; a more balanced orientation is found in an invited lecture to maritime interpreters - lexicographers[6].

Philosophy

A question more fundamental than political is the evolution and proper application of the term 'seafloor topography', also known as 'bathymetry'. With seafloor shape determined from soundings, entities are identified by relief, measured in changes in distance to the seafloor. Hence topographic features deserving of names have been characterized and classified by that relief (e.g. 'seamount') or complete lack of it (e.g. 'abyssal plain'). Recent remote sensing methods (notably satellite altimetry) detect - by inequalities in the gravity field - the presence of differences areally in mass distribution. This is attributed to crustal compositional differences, or more frequently to feature shape or seafloor elevation or depression.

Such gravity field plots can reveal topographic entities but elevation parameters .... summit depth, relief, exact shape and dimensions .... are not definitively detectable. Frequently indications of obvious anomalies lie in regions known to be sedimented to near horizontality. GEBCO-SCUFN has avoided approving generic and specific names for such putative tectonic elements unless at least recognizable seafloor elevation difference has been indicated by existing soundings ('ground truth') and sometimes by magnetic anomaly patterns suggesting trends. In similar vein, SCUFN's seafloor terminology does not include entries for theoretical model elements, e.g. 'transform fault' vice 'fracture zone', 'inner high' vice 'seamount' at faults' intersection, or 'triple junction', 'propagating rift' or 'dueling ridges', for example.

Acknowledgments and Expectations

At this time of Centenary-and-celebration, one might close on a more personal note. In the nearly three decades since GEBCO-SCGN/SCUFN was created as a standing GEBCO Sub-Committee, seventeen individuals with twelve national origins have served as members. In that period, thirty others have attended its nominally biennial meetings as observers, agency confrères or invited specialists. Of the Sub-Committee members, at least four have made timely, differing ... but each very significant ... contributions. One founding member, Ingénieur général André Roubertou, has been a key player in assembling, simplifying and researching the now-succinct language and honed-down list of definitions and characteristics of seafloor topographic entities encountered in the ocean basins and on the continental boundaries. Agreements with similar and competing arbitration bodies were negotiated. He identified and submitted near-identical documentation in the French language, finding instances of like usage in the fertile marine literature. His enterprise helped produce the model for the dual-language series 'Standardization of Undersea Feature Names' (IHB publication B-6), published (with English) in five other languages. After twelve years and seven meetings, he made a change, becoming Chairman and Chief Editor of one of the IOC's regional chart series, the International Bathymetric Chart of the Central Eastern Atlantic (IBCEA). There, his experience with, and respect for, details of seafloor nomenclature and naming criteria has proved most constructive.

Another who has made a deep and unique contribution is Russian marine geomorphologist, Dr Galina Agapova, an academic expeditionary specialist. Her extensive shipboard experience, wide contacts in eastern Europe and valiant efforts under intense professional stresses have guided and educated the Sub-Committee. Specific areas include assembling, presenting and correcting the now-numerous Gazetteer entries derived from the Soviet Union's intensive and historic sub-polar exploration, modern fisheries' research surveys, and early eighteenth and nineteenth century Russian reconnaissance cruises. She has participated on-site in seven biennial meetings, six as a full member; her industry and initiative in maintaining intersessional activity has been outstanding.

A third contributor, only recently (1998) named a full member of GEBCO-SCUFN, has for seventeen years been an assiduous observer-counselor to the Sub-Committee. Desmond Scott, erstwhile Permanent Secretary GEBCO and Secretary IOC, was invited to attend eight biennial meetings and there functioned as meeting rapporteur, preparing the draft minutes that encapsulated most accurately the discussions and decisions, the reasoning and shades of meaning that made their way into the final

Summary Reports, together with tabulations of proposed actions.

Last of the quartet is the current Secretary of GEBCO-SCUFN, Ingénieur en chef Michel Huet, a staff member of the IHB at Monaco, who has served for eleven years and through six biennial meetings. His own SCUFN-related mandate is to act as primary contact/receptor for proposal submissions and archiving, to facilitate intersessional progress by active consultation with the Chairman of the Sub-Committee, to prepare and distribute biennial meeting Summary Reports and now principally to accumulate, correct, update and promulgate as a Gazetteer (IHB publication B-8) the IOC-IHO GEBCO digital database of names that have been proposed and approved for international use. This last-listed activity has become, and will increase as, the keystone element in the GEBCO-SCGN/SCUFN's 21st Century rationale.

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3. Second U.N. Conference on the Standardization of Geographic Names, Resolution *#8 Treatment of names of features beyond a single sovereignty*; and Resolution #26 *Standardization of names of undersea features beyond a single sovereignty*.
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Annex

GEBCO SUB-COMMITTEE ON UNDERSEA FEATURE NAMES (SCUFN) TERMS OF REFERENCE

(As approved by the GEBCO Guiding Committee, May 1993)

1. The Sub-Committee on Undersea Feature Names reports to the Guiding Committee, as its designated authory for all matters concerning undersea feature names.

2. It is the function of the Sub-Committee to select those names appropriate for use on GEBCO graphical and digital products, on the IHO small-scale INTernational chart series; and on the IOC regional International Bathymetric Chart series.

3. The Sub-Committee shall:

3.1 select undersea feature names on the basis of:

a) undersea feature names provided by national organizations concerned with nomenclature;

b) names submitted to the Sub-Committee by individuals, agencies and organizations involved in marine research, hydrography, etc.;

c) names appearing in scientific journals or on appropriate charts, with valid supporting evidence.

Such names will be reviewed before they are inputted into the gazetteer.

3.2 define when appropriate the extent of named features;

3.3 provide advice to individuals and appropriate authorities on the selection of undersea feature names in international waters and, on request, in waters under national jurisdiction;

3.4 encourage the establishment of national boards of geographic names and undersea features, and when such a board does not exist for a given coastal state, co-operate in the naming of seafloor features related to those national waters;

3.5 prepare and maintain international gazetteers and supplements of undersea feature names;

3.6 encourage the use of undersea features names used on GEBCO products on other maps, charts, scientific publications, and documents by promulgating them widely;

3.7 prepare and maintain internationally agreed guidelines for the standardization of undersea feature name and encourage their use;

3.8 review and assess the need for revised or additional terms and definitions for submarine topographic features;

3.9 maintain close liaison with the UN Group of Experts on Geographical Names and national authorities concerned with the naming of undersea features.

8- GEBCO enters the Digital Era – the GEBCO Digital Atlas

Dr. Meirion T. Jones

Founding Director (retired) of the British Oceanographic Data Centre and Chairman of the GEBCO Sub-Committee on Digital Bathymetry

For almost two decades (1984-2003), the technical focus for the development of GEBCO has been provided through its Sub-Committee on Digital Bathymetry (SCDB). During the period 1984-93, the Sub-Committee's activities were centred primarily on the digitization of the GEBCO 5th Edition and the establishment of an international database of digital echo-soundings. Thereafter, the focus switched to considering how digital techniques might be exploited to enhance and develop GEBCO, with particular attention being paid to the updating of the GEBCO contours and the creation of a GEBCO bathymetric grid.

From the outset, the SCDB rapidly established itself as an international forum for bathymetric mapping experts, from both the hydrographic and geoscientific communities, to meet and exchange ideas on an annual basis. It gave GEBCO a mechanism for keeping in touch with ongoing bathymetric mapping activities worldwide and enabled it to keep abreast of modern developments and technologies. In addition to bathymetrists, the SCDB has over the years attracted a wide range of experts in related fields such as marine geophysics, hydrography, satellite altimetry, geographic information systems, marine data management, and ocean mapping technology. These links proved invaluable in developing a broad-based vision for GEBCO's activities.

So as to promote the work of GEBCO and engage as wide a community as possible in its activities, the SCDB's annual meetings were held at a range of institutions worldwide including hydrographic offices, marine laboratories, data centres and university research centres. The list of venues for the annual meetings given below reflects the Sub-Committee's wide-reaching approach:

1984(5): US Naval Oceanographic Office, Bay St Louis, USA
1985(7): *Bureau gravimétrique international*, Toulouse, France
1986(8): Intergovernmental Oceanographic Commission, Paris, France
1987(12): National Geophysical Data Center, Boulder, Colorado, USA
1988(15): Institute of Oceanographic Sciences, Wormley, UK
1989(19): National Geophysical Data Center, Boulder, Colorado, USA
1990(16): *Alfred-Wegener-Institut für Polar- und Meeresforschung*, Bremerhaven, Germany
1991(25): Head Department of Navigation and Oceanography, St. Petersburg, Russia
1992(17): British Oceanographic Data Centre, Bidston, UK
1993(28): National Geophysical Data Center, Boulder, Colorado, USA
1994(16): University of New Brunswick, Fredericton, Canada
1995(21): SACLANT Undersea Research Centre, La Spezia, Italy
1996(20): East-West Centre, Honolulu, USA
1997(26): UK Hydrographic Office, Taunton, UK
1998(26): Institute of Geological and Nuclear Sciences, Wellington, New Zealand
1999(32): Geological Survey of Canada, Dartmouth, Canada
2000(27): Royal Danish Administration of Navigation & Hydrography, Copenhagen, Denmark
2001(21): Japan Hydrographic Department, Tokyo, Japan
2002(25): University of New Hampshire, Durham, USA

Numbers given in parenthesis above refer to the number of experts attending each meeting. Whereas the SCDB started off as a small group of experts working on a limited number of specific tasks, once progress had been demonstrated on these tasks the SCDB soon attracted a broad forum of experts keen to collaborate in the work of GEBCO. A photograph of the participants at the GEBCO-XVII and SCDB-XVI meetings at the Geological Survey of Canada in 1999 is shown in fig. 13.

Digitization of the GEBCO 5th Edition

At the outset, the SCDB was tasked with maintaining a watching brief on those agencies or institutes intending to digitize the 5th Edition and with investigating how digital techniques might be used to expedite production of the 6th Edition. In the event, it undertook the lead role in co-ordinating the digitization of the 18 sheets of the 5th Edition and in establishing what is now called the GEBCO Digital Atlas.

Digitization of the 5th Edition proved a major task and took the best part of ten years to complete (1984-1993). As usual, funding was a major problem and the provision of resources for the work was dependent on the foresight and goodwill of national agencies. The successful completion of the task relied heavily on the generous co-operation of two organisations in particular; the French *Institut géographique national* (IGN) through support given to the *Bureau gravimétrique international* (BGI) in Toulouse; and the UK Natural Environment Research Council (NERC) through its support of the British Oceanographic Data Centre (BODC).

The project was initiated by the BGI in 1983 but progress in digitizing was slow in the early years due to difficulties in developing the necessary software to undertake the work. The immensity of the task was well beyond what could be achieved using manual curve following techniques and the IGN undertook to raster scan the sheets. Although raster scanning technology was readily available in the early 1980s, the associated vectorizing software systems were not capable of dealing with the complexity and richness of information presented on the printed GEBCO sheets. An interactive system for editing and labelling contours was eventually developed at the BGI and work was soon completed in digitizing the contours of the circum-Antarctic sheets (5.13, 5.14, 5.15, 5.16 and 5.18 – see fig.37 for sheet numbering scheme). These data became available through BODC in 1987 and shortly thereafter work was completed on sheet 5.01. However, the sheets of the North Atlantic (5.04 and 5.08) took a further two years to complete due to their complexity and the labour intensive nature of the work. Work was also completed on the Arctic sheet 5.17. Unfortunately, in early 1989, BGI was forced to suspend further work on the digitization project due to lack of resources.

Recognising the importance of a high quality digital data set of global bathymetry for ocean modelling, the UK NERC agreed in 1990 to fund the completion of the digitization project and to provide a facility to support the future updating of the data set. This was achieved by establishing two fulltime posts; the post of GEBCO Digital Atlas Manager at BODC and the post of GEBCO Bathymetric Editor at the Institute of Oceanographic Sciences, which later was moved to Southampton as part of the Southampton Oceanography Centre. Significantly, NERC also provided BODC with specialist technical support from its research unit at the University of Reading, the NERC Unit for Thematic Information Systems (NUTIS). Gary Robinson at the Unit was instrumental in identifying and installing state of the art technology at BODC to support the project. This included the Laser-Scan VTRAK system which provided BODC with a highly effective facility for vectorizing, editing and labelling raster scanned contours and, for the past decade, this system has underpinned the digitization, manipulation and management of GEBCO data at BODC.

Prior to its installation at BODC, Gary Robinson successfully used the VTRAK system to digitize the contours of the Pacific sheets 5.03, 5.07, 5.10 and 5.11. In parallel with this, the IGN was able to provide BGI with further funding in 1990 which resulted in the digitization of the contours of the Indian Ocean sheets 5.05 and 5.09. Andrey Popov at the Head Department of Navigation and Oceanography at St Petersburg contributed by supplying digitized contours for sheet 5.02 in the Arctic and northeast Pacific, while BODC successfully compiled the data set for the Pacific sheet 5.06 using digital data provided by Shin Tani of the Japan Oceanographic Data Center.

Before the digitization of the 5th Edition was completed, the Guiding Committee decided that sheet 5.12 in the South Atlantic should be revised and that digital techniques should be used in the revision. The revised contouring of various sections of the sheet was carried out by scientists in the USA, Russia, New Zealand and the UK. Following review by two nominated GEBCO experts, the hand drawn contours were submitted to BODC for digitizing and compiling into a single seamless sheet. The contents of the digital file were then used by the Canadian Hydrographic Service as a base from which to print a revised version of sheet 5.12 in 1994.

Digitization of the 5th Edition at the various centres was carried out on stable base transparencies of the master bathymetric contour plates of the published sheets kindly provided by the Canadian Hydrographic Service. At each centre, the transparencies were raster scanned using laser scanning equipment and following vectorization, the contours were exhaustively checked and edited using interactive terminal displays. Gaps in contours, caused by labels on the published charts, were filled in digitally from the terminal. Each digitized contour stream was then manually assigned an appropriate bathymetric depth by cross reference to the contours on the printed sheets.

Prior to their release, the digitized contours for each sheet were reviewed in detail at BODC. This review involved plotting out the contour vectors on the same scale and projection as the published sheets, and checking out the registration and labelling of each vector – no mean feat considering that the 18 sheets of the 5th Edition produced some 95,000 contour segments. The registration checks confirmed that the techniques adopted at the participating centres were able to reproduce the 5th Edition contours to an accuracy comparable with the line thickness of the contours on the published sheets. BODC was also responsible for edge-matching the digitized contours between the various sheets so as to ensure that the resultant data set provided seamless bathymetry across the globe for the basic GEBCO contour depths i.e. at 0m, 200m, 500m, and at 500m intervals thereafter.

Recognising that the digitized contours would be of limited value without corresponding information on the distribution of soundings used in their original compilation, it was decided that the trackline control information should also be digitized from the 5th Edition sheets. Using almost identical techniques and procedures to those used in digitizing the bathymetric contours and coastlines, the tracklines were digitized on a sheet by sheet basis in a collaborative venture between three centres from 1990 to 1993. Thus, two sheets were digitized by the *Alfred-Wegener-Institut für Polar- und Meeresforschung*, Bremerhaven; three sheets by the Head Department of Navigation and Oceanography, St Petersburg; while the remaining 13 sheets were digitized by BODC. Quality control, final editing and reformatting of these data into a uniform data set were again performed at BODC.

The complete data set of the digital contours, coastlines and tracklines for the GEBCO 5th Edition was finalised in June 1993, thereby providing a high quality digital base from which future editions of GEBCO might evolve. The project was a major undertaking and more than 15 staff years of effort were involved in bringing it to a successful conclusion. The success of the project owed much to the painstaking work of two individuals in particular: Denis Toustou at BGI and Pauline Weatherall at BODC.

A digital coastline for GEBCO

Having converted the 5th Edition contours into digital form, the updating of GEBCO was no longer constrained by the 1:10 million scale of the printed chart and it was envisaged that future updates might well be prepared at scales of up to 1:500,000 (or even up to 1:250,000 in isolated cases) in certain regions. However, by its very nature, the digitized 5*th* Edition coastline, based primarily on the *Carte générale du monde of the Institut géographique national*, Paris, was suited only for use at scales of the order of 1:10 million.

In 1989, a search was instigated by SCDB for an alternative coastline satisfying the criteria that it should be: a) digital, b) suitable for scales of up to 1:250,000, c) global in coverage, d) of consistent accuracy across the globe and e) available for use in GEBCO. It was fortunate that, just at that time, the US Defense Mapping Agency (DMA) (subsequently to become the US National Imagery and Mapping Agency (NIMA)) released its World Vector Shoreline (WVS) – the only coastline able to approach the GEBCO criteria[1]. Acting on the advice of SCDB, the GEBCO Guiding Committee agreed in 1991 that WVS should be adopted as the standard coastline for use in the future updating of GEBCO and the DMA generously gave GEBCO permission for such use. The WVS is now also used as the standard coastline in most of the IOC's Regional Ocean Mapping Projects.

The WVS was developed by the DMA as a digital data file, at a nominal scale of 1:250,000. Worldwide coverage of the data set was completed in July 1989, working to a specification that 90% of all identifiable shoreline features should be located within 500 metres (i.e. 2mm at 1:250,000) of their true geographic position with respect to the World Geodetic System (WGS-84) datum.

The main source material for the WVS was DMA's Digital Landmass Blanking (DLMB) database which was derived primarily from the Joint Operations Graphics and coastal nautical charts produced by DMA. The DLMB data consisted of a land/water flag file on a 3 by 3 arc-second interval geographic grid. This raster database was converted into vector form to create WVS and explains the 3 arc-second stepping interval apparent in the coastline when plotted out at high scale. For areas of the world not covered by the DLMB database, the shoreline was taken from the best available hard copy sources at a preferred scale of 1:250,000.

The SCDB viewed WVS as an impressive product but was concerned that the target accuracy of 500m for WVS applied to only 90% of the world's shoreline and that no indication was given for the accuracy of the remaining 10% or where the areas with lesser accuracy occurred. It was anticipated that the main areas of reduced accuracy would probably occur around Antarctica and parts of the Arctic. Tests conducted on behalf of the SCDB confirmed the inaccuracies in WVS around the Antarctic continent and also identified the problem of defining a shoreline in the presence of ice in the coastal zone.

In non-polar regions of the world, the coastline is simply the boundary between the land and the sea. Being coincident with mean sea level, it also acts as the zero depth contour. However, in the Antarctic, the concept of a coastline is more complex and needs to represent the boundary between three domains *viz.* land, sea and ice shelf. The following types of coastline occur around Antarctica: ice coastline, rock coastline, grounding line, rock against ice shelf, iceberg tongue, floating glacier tongue and ice shelf front.

With the publication of the Scientific Committee on Antarctic Research (SCAR) Antarctic Digital Database[2] in 1993, a high quality seamless and coherent coastline of Antarctica became available for the first time. Not only was it in digital vector form but it also clearly codified the different types of coastline and included a far more comprehensive definition of ice shelf limits than had been available previously. Compiled from a combination of existing maps and satellite imagery, this new coastline was suitable for use at scales of up to 1:1 million.

For GEBCO purposes, it was decided in 1996 to standardise the coastline south of 60°S on the SCAR Coastline instead of WVS. As there are no coasts crossing the 60°S latitude boundary between the two data sets, there are no discontinuities of coastline. Furthermore, the SCAR Coastline is available at a range of scales compatible with those available in the WVS.

No attempt was made to match the 5th Edition bathymetric contours with the WVS/SCAR coastline and isolated occurrences inevitably arise where the WVS/SCAR coastline appears in conflict with the bathymetry e.g. around oceanic islands and where the coastline abuts a submarine scarp. Such mismatches are mainly a consequence of the different scale and resolution of the two data sets. However, as and when the GEBCO bathymetry is revised in various areas, the WVS/SCAR coastline is being phased in as a matter of routine and is checked for consistency with the bathymetry. This has already occurred for the area of revised sheet 5.12 and in all other areas where the bathymetry has been updated.

Although uncertainty has existed about the accuracy of WVS in the Arctic, it should be noted that the International Bathymetric Chart of the Arctic Ocean (IBCAO) project has adopted WVS for the Arctic in all areas except Greenland and northern Ellesmere Island, where an updated coastline was made available to the project by the Danish National Survey and Cadastre (KMS). In 2002, KMS kindly gave GEBCO permission to use its coastline in these areas and these have now been incorporated into GEBCO.

The GEBCO Digital Atlas (GDA)

The digitised contours, coastlines and tracklines of the 5th Edition were used to initialise what is now called the GEBCO Digital Atlas and which is maintained at BODC on behalf of the GEBCO community. The GDA now forms the base for the updating of the GEBCO contours. No longer constrained by the fixed scale and projection of the printed sheet, the GDA enables improved bathymetric compilations to be merged into GEBCO at scales ranging from 1:10 million up to 1:500,000 or better depending on the sounding density. New data can be readily "stitched in" so as to maintain a seamless data set.

Not only does the GDA provide a highly practical method for maintaining and updating GEBCO but it also forms the basis of a product in its own right, providing users with a digital source of data that can be readily manipulated and displayed according to their own particular needs. With this in mind, in 1992, the Guiding Committee invited BODC to prepare a PC-based product for disseminating the GDA data set to users according to specifications prepared by the SCDB.

The First Release of the GDA was published on CD-ROM by BODC in March 1994[3]. It was accompanied by a purpose-built PC software interface, providing the user with a powerful and user-friendly tool kit for selecting, interrogating, visualising, overlaying and exporting data from the GDA. The following digital data sets were included:

a) a complete set of bathymetric contours, coastlines and tracklines from the GEBCO 5th Edition
b) bathymetric contours and coastlines from the 1st Edition of the IOC International Bathymetric Chart of the Mediterranean (IBCM)
c) a set of digital global coastlines based on the World Vector Shoreline
d) a trackline inventory of the digital echo-sounding data held at the IHO Data Centre for Digital Bathymetry
e) a geographically referenced version of the IHO/IOC Gazetteer of Geographical Names of Undersea Features
f) a digital version of the Third Edition of the Echo-Sounding Correction Tables

A Second Release of the GDA was published on CD-ROM by BODC in March 1997 including revised bathymetry for the southern Indian Ocean, Weddell Sea and the north-east Atlantic off the British Isles[4]. In addition, it included the SCAR coastline of Antarctica. The published CD-ROMs are in use in over 1,000 institutions across the globe including research laboratories, hydrographic offices, universities, private companies and government departments. By 2002, BODC had distributed some 1,320 copies to users in 87 countries worldwide.

The updating of GEBCO using digital techniques effectively started with the revision of sheet 5.12 in 1993. Instead of digitizing the printed sheet at a scale of 1:10 million, the digitization was actually carried out prior to the printing process using base material prepared at a scale of 1:5 million. Furthermore, when the GDA was published in 1994 the GEBCO bathymetry for the Mediterranean was replaced by previously digitized contours taken from the 1:1million scale charts of the IBCM. These serve as the first examples of the GDA being updated at scales of better than 1:10 million. Indeed, much of the material used to update the GDA since 1994 has been digitised at scales of 1:1 million or larger.

In order to maintain the high quality and global nature of GEBCO, standards were established by the SCDB in 1994 for incorporating new material into the GDA[5]. Prior to their inclusion in the GDA, new updated bathymetric compilations in any given area are expected to conform to the following principles:
a) contours should be expressed in corrected metres.
b) as a minimum, the GEBCO basic contours of 200m, 500m, and at 500m intervals thereafter, should be included. Where appropriate, the inclusion of contours at 20m, 50m and 100m is to be encouraged. Where additional intermediate contours are included an interval of 100m is recommended.
c) the GEBCO basic contours should be continuous within the compilation area.
d) contours cutting the edge of the compilation area should be 'stitched in' to those in the surrounding area of the GDA – in general, the 'stitching in' should be from outside the compilation area rather from inside.
e) in coastal zones and around islands, the contours should be compatible with the World Vector Shoreline (or the SCAR Coastline).
f) compilations submitted should be accompanied by the ship tracks and survey boxes (annotated with their source) used in compiling the contours.
g) the updating material should normally consist of digitized contours – if submitted in hard copy form, sufficient graticule points should be included within and at the edges of the map to enable potential distortions to be checked through subsequent digitizing and if necessary corrected.
h) compilation methods should be fully described in supporting documentation, including details of the projection, ellipsoid and scale used, as well as information on any support material that might have been used e.g. magnetic surveys, sonar images, satellite altimetry, proprietary compilations; the names and affiliation of the authors of the map; the data sources used; and the date the map was compiled.
i) in international waters, the names of newly named undersea features should be submitted for approval to the GEBCO Sub-Committee on Undersea Feature Names, or to the appropriate national authority where they fall within territorial waters.
j) before release into the public domain, updated compilations and supporting material will be submitted for review by an approval panel of referees which will consist of the compiler and two independent experts. The review team will report back to the GEBCO Officers.

The GDA is updated and maintained at BODC by the GDA Manager, Pauline Weatherall, using proprietary Laser-Scan mapping and database software. As each new compilation is received, careful checks are made on the quality of digitization including contour labelling, geographic registration, and conformance with any hard copy charts that may have been published from the compilation. Checks are also made against the GEBCO shorelines and any necessary editing is carried out interactively. If material is received in hard copy form, it is raster scanned externally and then vectorized at BODC using the Laser-Scan VTRAK system. In merging new sheets into the GDA, careful attention is paid to edge-matching the basic GEBCO contours (i.e. 200m, 500m, and 500m intervals thereafter) across the boundaries of the sheets into the surrounding GDA bathymetry so as to maintain seamless bathymetry. Adjustments are made as necessary, taking due account of the underlying trackline control information. Intermediate contours are only edge-matched if present on both sides of the boundary. No attempt is made to edge-match tracklines crossing the boundaries – a mismatch of tracklines between sheets usually occurs when sheets compiled at different scales are joined and reflects differences in geographic registration accuracy.

In recent years, GEBCO has been able to benefit from outputs provided by a number of IOC Regional Mapping Projects in addition to the IBCM including the International Bathymetric Chart of the Caribbean Sea and Gulf of Mexico (IBCCA), the International Bathymetric Chart of the Central Eastern Atlantic (IBCEA) and the International Bathymetric Chart of the Arctic Ocean (IBCAO).

Since 1994, the bathymetry of about one third of the world's oceans has been revised and submitted to BODC for updating the GEBCO Digital Atlas. The geographic coverage of the revised material is shown in fig. 40 where the updated areas are numbered in the sequence G1 to G9. These comprise the following compilations:

G1: Arctic Ocean – the contours for this region were compiled from the gridded data set of the IBCAO and were prepared for GEBCO by Norman Cherkis (formerly of the Naval Research Laboratory, Washington) and Martin Jakobsson (University of New Hampshire, Durham). A striking feature of the IBCAO is that it was generated using state of the art computing technology with the source soundings maintained in digital form and with the use of gridding techniques to underpin the compilation of the Chart[6]. The techniques involved enable the chart (which is essentially a digital grid-based product) to be routinely updated as and when new sounding data become available.

G2, G4 and G5: North-east Atlantic – much of the work in compiling the contours in these areas was undertaken for GEBCO by Peter Hunter at the Southampton Oceanography Centre. Most of the work was carried out at scales of 1:1 million. Included in this data set are IBCEA Sheet 1.01 off Iberia prepared by the *Instituto Hydrográfico*, Lisbon; and a bathymetric map of the Bay of Biscay compiled by Jean-Claude Sibuet at the *Institut français de recherche pour l'exploitation de la mer* (IFREMER), Brest.

G3: Caribbean Sea and the Gulf of Mexico – two sets of updated bathymetry were submitted to GEBCO for this region: a) IBCCA Sheets 1.01 to 1.04 prepared by the National Geophysical Data Center, Boulder for the Northern Gulf of Mexico and the Atlantic Ocean east of Florida; and b) IBCCA Sheets 1.05 to 1.09 for the Southern Gulf of Mexico and the northern part of the Caribbean from José Frias Salazar at the *Instituto Nacional de Estadística, Geografía e Informática* (INEGI) in Mexico.

G6: Central Eastern Atlantic – updated bathymetry for this area comprises IBCEA Sheets 1.08 to 1.12 produced by the *Service hydrographique et océanographique de la marine* (SHOM), Brest, France, and delivered to GEBCO in digital form

G7: Weddell Sea – an updated bathymetric chart for the Weddell Sea was provided to GEBCO by Hans-Werner Schenke and his co-workers at the *Alfred-Wegener-Institut für Polar- und Meeresforschung* (AWI), Bremerhaven. The improvement of the bathymetry in this area owes much to the extensive multi-beam echo-sounding data collected by the AWI's ice breaking research vessel RV *Polarstern*[7, 8].

G8: Greater Indian Ocean – this is by far the largest contribution to the updating of GEBCO, covering almost a quarter of the world's oceans and extending out to 12°W in the Atlantic and to 170°E in the Pacific. It was compiled by Dr Robert L Fisher at the Scripps Institution of Oceanography, La Jolla, and represents a major personal achievement of considerable benefit to GEBCO and its user community. The contours were compiled on some 250 sheets at a scale of four inches per degree longitude (approximately 1:1 million) over a ten year period up to 2002. The hand drawn contour sheets, with accompanying trackline sheets, were digitised by Pauline Weatherall at BODC. In addition to the original 500 sheets (contours and tracklines), over 600 sec-

Fig. 40. Geographic coverage of sheet areas digitized to form the Centenary Edition of the GEBCO Digital Atlas

tions of update charts were delivered to BODC for digitising during the project. The work was completed in September 2002.

G9: Waters around New Zealand – the regional bathymetric map of New Zealand was delivered as a contribution to GEBCO by Ian Wright of the National Institute of Water and Atmospheric Research (NIWA) in Wellington. The data were submitted to BODC in digital form in 2000.

Work on incorporating these data into the GEBCO Digital Atlas was completed in October 2002. It will be noted that the new material is at a considerably larger scale than the 1:10 million scale of the GEBCO 5th Edition. This reflects the move of GEBCO away from the fixed scale paper chart and the ultimate goal of enhancing GEBCO with the best available bathymetry.

GEBCO Gridded Data Set

From the outset, the SCDB clearly recognised the importance of generating a gridded version of GEBCO on a uniform global grid. With modern computing technology, the gridded format offers far more flexibility than traditional contour vectors, particularly in modelling applications and in the visualisation and manipulation of data. The topic first arose in the context of applying Digital Terrain Modelling techniques to bathymetric mapping. Most of these efforts were concentrated on multi-beam survey data where the density of soundings was sufficient for the application of such techniques. For many years, the SCDB was kept abreast of developments in the field through the work of Hans-Werner Schenke and his colleagues at AWI, in the Weddell Sea. In 1988, a small Task Team was established under Dr Schenke to keep the SCDB informed.

In the period up to 1994, considerable discussion took place within the SCDB on possible ways and means of generating a GEBCO grid. The focus of attention at the time was on the generation of a grid based on the actual soundings rather than using the digitized contours. However, these efforts were compromised by the problems inherent in the available coverage of sounding data i.e. the inhomogeneous distribution of data at centres such as the IHO Data Centre for Digital Bathymetry and the fact that the data emanated from a wide diversity of sources with highly variable accuracy. Of particular concern were the navigation errors contained in much of the earlier data, an unknown level of dubious soundings and crossover errors between tracks. These problems were of course well familiar to the traditional bathymetrist forced to apply his own interpretive skills in order to generate a coherent set of contours.

With the publication of the First Edition of the GDA, the SCDB reinvigorated its attempts to generate a grid and a small Task Team was established in 1994 to research the issue under the leadership of Walter Smith of the US National Ocean Survey (now at the NOAA Laboratory for Satellite Altimetry). The digital contours from GEBCO sheet 5.12 (revised) were used as a test bed on which to evaluate the various gridding techniques available. Considerable experience was gained in the problems related to generating a GEBCO grid and the focus shifted back to using the GEBCO contours as the source data.

In 1997 a draft paper "On the preparation of a gridded data set from the GEBCO Digital Atlas contours" was prepared by the SCDB Task Team. It provided a comprehensive review of the problem including the needs of potential users, mathematical considerations, and the strengths and weaknesses of the various methods available to compile the grid. The conclusions of the review did not offer a simple solution for GEBCO and it was decided that a pragmatic approach was required. Mike Carron of the US Naval Oceanographic Office co-ordinated the next phase of the work which was to discover what was reasonably possible to achieve, given the time and resources available to GEBCO.

In the event, it was decided the GEBCO grid should be based on the most up to date version of the GDA contours and that computation of the grid should be carried out by a network of volunteering centres using common algorithms based on "rubber-sheeting" techniques[9]. Members of the network were well versed in the problems of gridding[10] and made extensive use of the widely-used GMT package of software programs[11]. Initially, the grid was to be produced at 2.5 minute intervals in geographic latitude and longitude but in early 2002 it was decided to create the grid at 1 minute intervals so as to better replicate the contours.

Two particular issues that needed addressing were: a) how to construct the grid in abyssal plain regions where the contours were widely spaced (this was addressed by including in the gridding process the data from high quality sounding tracks passing through these areas); and b) how to represent the bathymetry in shallow water areas not well represented by the GEBCO contours (following a circular letter from the IHB, many hydrographic offices assisted the project by volunteering more detailed contour information on the continental shelves).

In late 2002, a first version of the global grid was completed and made available for inclusion in the GDA. The work was co-ordinated by Mike Carron with major input provided by the gridding efforts of Bill Rankin and his co-workers at the U.S. Naval Oceanographic Office, Andrew Goodwillie at Scripps Institution of Oceanography and Peter Hunter at Southampton Oceanography Centre. Significant regional contributions were also provided by Martin Jakobsson, Hans-Werner Schenke, John Hall (Geological Survey of Israel) and Ian Wright (NIWA). Technical advice on algorithms was provided by Walter Smith.

IHO Data Centre for Digital Bathymetry

From its first meeting, the SCDB took a keen interest in the establishment of an international computer-based system for the management and dissemination of echo-sounding data. Previously, the international soundings data bank had been maintained in hard copy form on master sounding sheets. As mentioned earlier, this manual system originated with the compilation of the 1st Edition of GEBCO. Subsequently, the IHB was entrusted with the task in 1929 and a world series of plotting sheets was established, at a scale of 1:1 million on Mercator projection, on which to record and publish all sounding data outside the continental shelf. This task eventually became too great for the small staff of the Bureau and in 1962 the IHO Member States agreed to setting up a network involving the services of Volunteering Hydrographic Offices (VHOs) in 18 IHO Member States. Each of VHOs accepted responsibility for compiling bathymetric data in specific geographic areas and for periodically updating the 1:1 million Collected Soundings Sheets in their area of responsibility.

Individual Hydrographic Offices were charged with ensuring the regular supply of bathymetric data to the appropriate VHO, and the IHB in Monaco maintained a co-ordinating role in this scheme, issuing information on the status of the various sheets from time to time. Copies of the soundings sheets were available to the user community on direct application to the appropriate VHO – a nominal charge was usually made to cover the cost of copying. When the ICSU World Data Centre (WDC) system was established following the International Geophysical Year in the late 1950s, the IHO system became recognised as the World Data Centre for Bathymetry.

The Collected Soundings Sheets (also known as the Ocean Plotting Sheets) formed the base from which much of the contouring of the GEBCO 5th Edition was compiled. However, during the preparation of the 5th Edition in the early 1980s, it became apparent that a number of the GEBCO scientists responsible for undertaking the contouring had at their disposal considerably more data than appeared on the 1:1 million sheets maintained by the VHOs. The shortfall in data submission to the VHOs appeared closely related to the introduction of computer techniques for the handling of bathymetric data, particularly in the geoscience community. Since the late 1960s, geoscientists had been finding it far more convenient to store and exchange their data in computer files and to plot out data automatically as and when the need arose. Computer techniques also enabled far greater volumes (and densities) of echo-sounding data to be handled than could be readily hand scribed onto plotting sheets.

The SCDB reviewed this situation in 1986, recognising that a major part of the missing data might well be found in the underway marine geophysics database maintained by the US National Geophysical Data Center (NGDC) in Boulder, Colorado, USA. At that time, the Boulder centre held almost 2,000 cruises of bathymetric, magnetic and gravity data, primarily from US laboratories but also with contributions from Japan, France, Russia, UK, New Zealand, Canada, South Africa and China. The database already included over seven million nautical miles of digital echo-sounding data and had clearly demonstrated the practicality and value of computing techniques for managing such data.

The SCDB advised that, in pursuing its goal of maintaining a global collection of sounding data for the deep ocean, the IHO should seek to collaborate with the US NGDC in creating a digital database for sounding data. At its meeting in Paris in 1986, the SCDB drafted supporting documentation to facilitate such collaboration. In 1987, the US Government submitted a proposal based on the SCDB documentation to the XIII[th] International Hydrographic Conference for the establishment of an IHO Data Centre for Digital Bathymetry (DCDB) to be operated by the US NGDC on behalf of the IHO. In 1990, the IHO Member States agreed to this proposal and on 1[st] June 1990 the IHO DCDB was duly established, co-located with the US NGDC in Boulder.

The IHO database of digital, single beam echo-sounding data is co-held within NGDC's GEODAS (Geophysical Data System) database of worldwide underway geophysics data. When the IHO database was first established in 1990, the GEODAS database held over 18 million echo-soundings collected on more than 2,500 cruises/cruise legs and covering a track distance of 9.3 million nautical miles. By June 2002, the IHO DCDB had assimilated a further 23 million echo-sounding values covering 5.2 million nautical miles of track into the GEODAS database. In June 2002 the total GEODAS database contained some 41 million echo-soundings from 4,425 cruises/cruise legs covering a track distance of 14.5 million nautical miles.

The distribution of the digital echo-sounding data currently stored in the GEODAS system is shown in fig.41. It will be readily noticed that, although the international collection of sounding data has come a long way since the 18,000 soundings of the GEBCO 1st Edition were compiled in 1904, for many areas of the globe there are still large gaps in the data coverage. The distribution of data remains sparse and non-uniform – it is particularly sparse in the Southern Hemisphere and, even in the North Atlantic, trackline separation is typically of the order of 30km and up to 300km in places. Notwithstanding this, the establishment of the IHO DCDB at the US NGDC can be considered as a success story providing GEBCO with a major resource for updating its bathymetric products.

It is interesting to note the source of the data submitted to the IHO DCDB as summarised below, where an analysis is given of the data holdings by country of origin for January 1990 and June 2002. The analysis is given in terms of the number of cruise legs of bathymetric data assimilated into the database and the echo-sounding track distance covered by these cruise legs. Not surprisingly, the database is dominated by data from US institutions – amounting to three quarters of the holding in 1990 and two thirds in 2002. This reflects the highly successful role that the US NGDC performs at a national level. However, it is reassuring to note that the holding of data emanating from non-US sources, as measured in terms of track coverage, has more than doubled since the IHO DCDB was first established.

Source Country	**No of cruises /cruise legs**		**1000s of n.miles of bathymetry**	
	1990	**2002**	**1990**	**2002**
Argentina	0	5	0	17
Australia	3	20	21	99
Brazil	0	10	0	44
Canada	150	170	620	632
Chile	0	1	0	3
China	1	15	2	71
Cuba	0	5	0	33
Finland	0	1	0	6
France	183	255	429	671
India	0	13	0	9
Japan	135	287	664	1,098
Germany	1	55	8	186
Netherlands	2	9	10	28
New Zealand	15	24	26	54
Portugal	0	8	0	9
Russia	16	55	155	451
South Africa	18	21	46	67
Spain	0	1	0	3
United Kingdom	40	501	123	1,139
USA	1,953	2,969	7,153	9,862
TOTAL	**2,517**	**4,425**	**9,257**	**14,482**

Source of echo-sounding data stored in the GEODAS system in January 1990 and June 2002

The innovative use of computing techniques at NGDC has revolutionised user access to the worldwide collection of echo-sounding data. A major step forward was taken in March 1993, when NGDC released a two volume CD-ROM version of its complete GEODAS data holding. It contained all data assimilated up to the end of 1992 and was accompanied by a user friendly software interface providing the user with direct access to over 4 gigabytes of marine geophysical trackline data, including the complete holding of single beam echo-sounding data.

Following the success of the CD-ROM publication, NGDC released updated versions of the CD-ROM on an almost annual basis up to the end of 1998 thus ensuring that users were kept up-to-date with the holdings of the GEODAS database. Thereafter, NGDC adopted the methodology of posting updated data on the Internet as soon as they were assimilated into GEODAS thereby greatly minimising any delay in making newly submitted data (including the

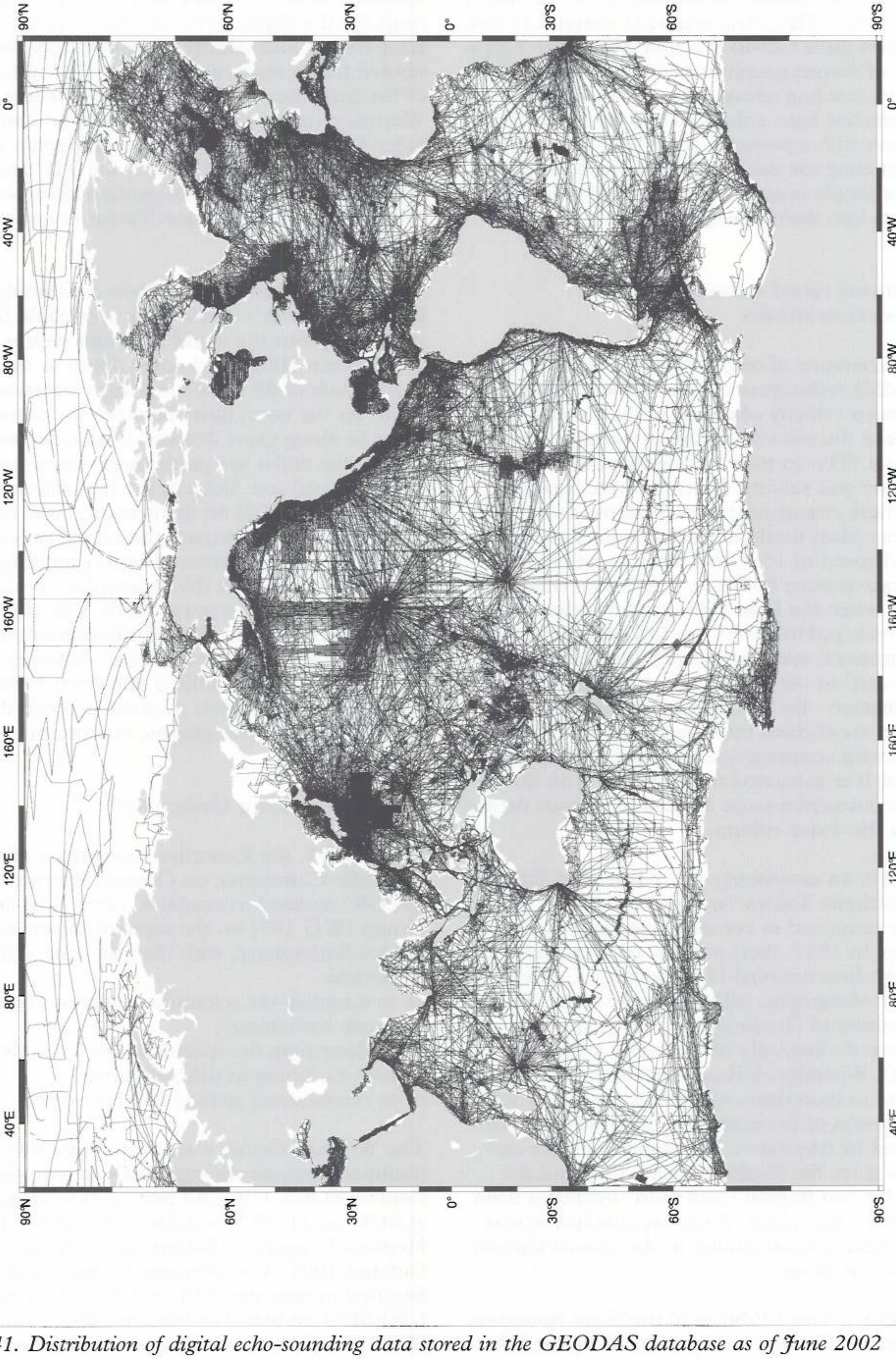

Fig. 41. Distribution of digital echo-sounding data stored in the GEODAS database as of June 2002

echo-sounding data submitted to the IHO DCDB) available to users. In June 2002, a new release of the GEODAS CD-ROM was issued including all updates assimilated up to the end of May 2002[12]. This latest release (Version 4.1) now occupies three CD-ROMs and offers over 7 gigabytes of marine geophysical trackline data. With each succeeding release, the software interface to the data has been enhanced and now provides the user with a powerful set of tools for selecting and plotting the data. It also provides the users with a simple interface for exporting user-selected data into their own applications.

Computerised echo-sounding correction tables

Measurements of seafloor depths using echo-sounding techniques depend on knowledge of the mean velocity of sound in the water column between the echo-sounding device and the seafloor. This in turn is dependent on the temperature and salinity down the water column and these characteristics vary across the world's oceans. Most modern echo-sounders assume a sound speed of 1500 m/s while some earlier versions assume 800 fm/s (1463m/s). Since 1927, when the First Edition of Matthews Tables[13] was published by the UK Hydrographic Department, standard correction tables have been used to correct for the true speed of sound in seawater – for this purpose the world's oceans are divided into discrete areas linking regions with common sound velocity profiles and a table is constructed for each area with the depth correction to be applied to various depths down the water column.

In 1939, an extensively revised Second Edition of Matthews Tables[14] was published and these tables remained in common use until the early 1980s. In 1947, their use was recommended by the Vth International Hydrographic Conference to all hydrographic offices. In 1964, the National Institute of Oceanography (subsequently to become the Institute of Oceanographic Sciences), Wormley, UK, undertook to make pilot studies to investigate whether there was a need for revision of the areas and depth corrections defined by Matthews. Investigations were carried out for the Mediterranean Sea[15] and the Gulf Stream Region[16] and both revealed a need to update the tables. A similar conclusion was also reached from studies in the area of Canadian data holdings[17].

In 1980, a Third Edition of the Echo-Sounding Correction Tables[18] was published by the UK Hydrographic Department. The tables were extensively revised to incorporate the large number of temperature and salinity measurements obtained since 1939 and used an improved formula for the dependence of sound velocity on temperature and salinity. Computations for the revised tables were carried out by David Carter of the Institute of Oceanographic Sciences, Wormley, using oceanographic station data provided by the US National Oceanographic Data Center, Washington. In 1982, the XIIth International Hydrographic Conference at Monaco adopted the Third Edition Tables to replace Matthews Tables.

The Third Edition Tables (now commonly known as Carter's Tables) are applicable for use throughout the world for water depths greater than 200m, and cover depth to the sea bed in each of 85 echo-sounding correction areas. As the boundaries between the correction areas lie along exact degrees of latitude and longitude, the tables are particularly suited for computerised use. Indeed, the first action undertaken by SCDB on its formation was to make available a computer based package for automatic determination of echo-sounding corrections given simply the geographic co-ordinates and the uncorrected depth. The package was prepared by the Data Banking Section of the UK Marine Information and Advisory Service (forerunner of BODC) and from 1984 onwards was made widely available to both the geoscience and hydrographic communities.

SCOR Working Group 107

In late 1995, the Executive Committee of the Scientific Committee on Oceanic Research (SCOR) decided to establish a new Working Group (WG 107) on the topic of Improved Global Bathymetry, with the following Terms of Reference:

a) to establish the scientific needs for improved ocean bathymetry;
b) to determine the specifications for accuracy and resolution in different areas;
c) to recommend actions and priorities.

The Working Group was chaired by Dr Colin Summerhayes, Southampton Oceanography Centre (SOC), UK, and met on two occasions; at SOC on 11-13 November 1996 and at Johns Hopkins University, Baltimore, USA, on 27-28 October 1997. The Working Group report was finalised in autumn 2001 and published by UNESCO on behalf of IOC in 2002[19].
WG 107 prepared a strong scientific case for

improving global bathymetry, identifying it as a prerequisite for progress in the scientific understanding of the different components of the earth's global systems, and for intelligent management of global resources. It recognised that data on the shape of the seabed are necessary in a great variety of applications e.g. to select sites for communications cables and fisheries; to make inferences about the geological history and energy and mineral resource potential of ocean floor structures; and to guide computer simulations of the behaviour of the oceans. These simulations are important in predictions of the hazards faced by coastal communities (e.g. approaching tsunamis) and in predictions of the future patterns of climate change on time scales of months to decades. Improved knowledge of the shape of the seabed is one of the factors required for success of the planetary scale global observing systems (GOOS, the Global Ocean Observing System, and GCOS, the Global Climate Observing System), the operations of which will help mankind to manage sustainably an increasingly crowded Earth.

Science topics requiring improved bathymetry

The Working Group identified the following topics for which there are scientific justifications for improvements in bathymetry (aspects for which the group considered that bathymetry is a key limiting factor in furthering understanding of ocean processes or applications are identified in parenthesis):

- ocean models (especially for steering of currents by straits and deep topography, and for sills controlling exchange of deep water, but also for much of the ocean floor)
- deep water circulation (channels/mudwaves; for controlling paths of bottom currents)
- tides (need detailed shelf edge and shelf bathymetry, and bathymetry of seamounts/ banks which dissipate tidal energy)
- tsunami forecasting (requires detailed bathymetry of continental shelves in areas of risk, and knowledge of continental slopes in areas prone to slumping such as trenches and volcanic slopes; requires knowledge of deep ocean bathymetry, because the wavelengths of tsunamis are so long that they 'feel' the bottom over most of their route and so can be influenced by deep ocean bathymetry)
- upwelling and fishing resources (need detailed knowledge of bathymetry of seamounts /banks)
- wave climate (detailed knowledge of coastal seas is needed for modelling storm surges with greater accuracy)
- coastal sediment transport (near-shore)
- continental shelf morphology (for geomorphological understanding, and tides and surges)
- environmental impact baselines (e.g. pre-disposition of waste)
- plate motions:
  a) tectonic fabric of ocean basins (for details of off-axis spreading history and for assessing back arc basin evolution)
  b) ridge dynamics (axial valleys; fracture zones etc. – altimetry can suggest other places and processes on the mid ocean ridge that need to be looked at to test hypotheses based on work already done)
  c) structural trends (for resource potential e.g. to measure plate buckling at trenches)
  d) mantle dynamics (age/depth relationships)
- seafloor fabric (detailed mapping and understanding evolution of abyssal hills)
- continental margin sediment thickness (oil and gas: for accurate prediction of subsurface structure)
- slope stability (islands and continents: slope gradient is a key factor)
- palaeoceanography (for channels on continental shelves)
- industrial needs:
  a) platform siting (on continental slopes and shelves)
  b) pipeline and cable siting (over entire length of pipeline or cable route)
  c) fisheries (to assess possible new fishing grounds)
  d) waste disposal and mineral extraction (to characterize possible sites)
- social needs
  a) delimiting juridical continental shelf to define EEZs (states with wide continental margins)
  b) education needs such as visualisation and awareness.

In reviewing the scientific needs, WG 107 also assessed the horizontal (H) and vertical (V) resolutions required of the improved bathymetric data in order to address the needs and concluded as follows:

i) in the open ocean seawards of the continental shelf and slope, the required resolutions are 5-10km(H) and 10-50m(V) over the open ocean; 1-5km(H) and 20m(V) over open ocean sills; 250m(H) and 10m(V) for abyssal hills; and 100m(H) and a few metres (V) in rift valleys

ii) on the continental slope, the requirement is for 1km(H) to 500m(H) over canyons and ridges

iii) on the continental shelf, the requirement progressively increases from 100-500m(H) in waters deeper than 10m, to 50m(H) in water less than 2.5m deep.

WG 107 Recommendations

The Working Group identified a clear scientific need for improving the coverage of bathymetric data worldwide, both in the open ocean and over the continental shelves, and came up with 34 recommendations for addressing the situation. These are listed below in the order in which they appear in the text of the Working Group's Report.

Rec.1: *research should be undertaken on sill flow, using high resolution modelling, nesting, and parameterisation, with the aim of finding an approach that can be successfully applied in climate and other models.*

Rec.2: *research should be undertaken on the sensitivity of numerically modelled sill flow to model resolution and topographic details, resolution and orientation.*

Rec.3: *efforts should be made to check the hypothesis suggested by altimetric data that seamounts cause much more dissipation of tidal energy in the ocean than had formerly been supposed.*

Rec.4: *collection of swath bathymetric data from continental shelves should be increased.*

Rec.5: *partnerships between academia, hydrographers, industry, NGOs, and navies should be created to develop regional international bathymetric charts as the basis for creating a gridded global bathymetric Digital Elevation Model or appropriate resolution (which could vary depending on water depth).*

<u>Key Issues – Data Gaps</u>

Rec.6: *NGDC(IHO DCDB) track charts (showing the coverage of NGDC's echo-sounding data holdings) should be placed on the Internet so as to encourage people to fill data gaps.*

Rec.7: *attempts should be made to get funds from agencies like the Defense Mapping Agency to fund echo-sounding on commercial transits.*

Rec.8: *Antarctic tourist cruise ships should be approached to provide data.*

Rec.9: *funding agencies should be asked to recognize the waste of resources involved, and to fund echo-sounding on transit on research vessels.*

Rec.10: *funding agencies should develop mechanisms for ensuring that data are digitised and sent with track data to NGDC (IHO DCDB).*

Rec.11: *at the very least, hydrographic ships and research vessels should keep their centre beams on at all times (reducing the requirement for data processing), and especially during transit.*

Rec.12: *consideration should be given to equipping floats (like Argo floats) with pingers to indicate water depth.*

Rec.13: *consideration should be given to making low cost bathymetric surveys using autonomous marine vehicle technology, which could be particularly effective under ice.*

Rec.14: *nations should be encouraged to add bathymetric data from EEZ surveys to the international pool of data (via NGDC(IHO DCDB)).*

Rec.15: *to ensure maximum benefit, the objectives of bathymetric compilations should include the publication of maps and the production of a digital data set that can be placed in the public domain for free and unrestricted use by the general community.*

<u>Key Issues – Data Policy</u>

Rec.16: *the issue of the substantial loss of internationally potentially valuable bathymetric data through a de facto policy of failure to collect them requires serious consideration by environmental science funding agencies, leading to corrective action in this matter.*

Rec.17: *published bathymetric maps should be released for incorporation into the GEBCO.*

Rec.18: *funding agencies should provide funds for the employment of people with appropriate expertise to compile and contour new bathymetric maps – particularly at regional scales.*

Rec.19: *agencies funding marine science topics should require that any proposals for scientific experiments should include provisions for site surveys and bathymetric maps, and that the bathymetry should be made available to GEBCO and the data sent to NGDC (IHO DCDB).*

Rec.20: *funding agencies should develop policies to review the locations of existing data, and require principal investigators to plan new surveys and pas-*

sage tracks to and from survey areas to occupy unsurveyed seafloor.

Key Issues – Digitizing Data

Rec.21: *all available data should be digitized.*

Key Issues – Getting Data into Data Centres

Rec.22: *funding agencies should support an appropriate number of centrally funded posts to ensure that the widest possible use is made of expensive-to-collect bathymetric data.*

Key Issues – Accessing already collected but 'unavailable' data

Rec.23: *major research institutions and funding agencies should take steps to identify material that has not yet been submitted to central archives (NGDC (IHO DCDB)), and provide funds to enable these data to be rescued.*

Rec.24: *Antarctic Treaty countries should be encouraged to release and exchange data.*

Rec.25: *navies should declassify and release bathymetric data to the scientific community, and that at the very least such data should be released in gridded fashion within a 0.5 minute (900m) grid.*

Rec.26: *money should be found to facilitate the digitising of Russian bathymetric data for wider release.*

Rec.27: *a more formal relationship is required between Hydrographic Offices and academic institutions that collect bathymetry throughout the world, so that notice is given to the Hydrographic Offices when bathymetry is to be acquired, some level of meta data are exchanged, and agreement is reached on when and under what conditions data will be made available.*

Rec.28: *academic institutions and Hydrographic Offices should work together to address the needs for original survey data and various types of gridded data.*

Rec.29: *bathymetry should be integrated to ECDIS for use with the ship's primary navigation system in offshore areas where navigation safety is not an issue.*

Rec.30: *geophysical survey companies should be approached (perhaps through joint industry groups such as the Western Frontiers Association) to determine their willingness to release bathymetric data.*

Rec.31: *an international scientific discussion meeting should be organised at which both industry and academic representation would present their interests and capabilities, with a view to forming a working plan and identifying a potential group of sponsors.*

Key Issues - Standards

Rec.32: *standards of measurement should be set for bathymetric data collected by research vessels, and a standard method should be used for computation of bathymetric grids.*

Key Issues – Education/Awareness

Rec.33: *bathymetric maps should be made available as educational tools on the Web and through media such as CD-ROM, as GEBCO is now doing.*

Rec.34: *articles should be written in popular science magazines (New Scientist, Scientific American) drawing the importance of mapping the surface of our planet to the attention of the wider (voting) public.*

Priority Actions identified by WG 107

The Working Group identified 6 priority actions for the near future and made 34 recommendations (listed above) as to how these priorities could be met and other issues addressed. Several recommendations relate to changes that are required in the policies of national funding agencies so as to facilitate the acquisition and availability of bathymetric data. Bearing in mind the constraints on funding, WG 107 decided that gathering additional data by ships equipped with swath bathymetry and side-scan sonar systems, though crucially important especially in data gaps, would not be the first priority. It recommended that much could be done by working more effectively and efficiently with what had already been collected, so the initial focus should be on getting more data into the system. Against this background, the Working Group concluded by recommending the following priority actions:

Priority 1: Turn equipment on to generate more data (all too often expensive echo-sounding equipment is not turned on, thus wasting the potential to acquire the data – a penny wise/pound foolish approach to scientific management).

Priority 2: Digitise the data that are presently available, and send new data au-

Thousands of nautical miles of echo-sounding data collected during specified five year periods

	Pre-1960	1960-64	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99
Argentina	---	---	---	---	---	---	1	8	8
Australia	---	---	---	---	---	17	12	40	30
Brazil	---	---	---	---	---	19	19	6	---
Canada	---	8	145	200	191	70	10	2	6
Chile	---	---	---	---	---	---	---	3	---
China	---	---	---	---	26	14	13	13	5
Cuba	---	---	---	33	---	---	---	---	---
Finland	---	---	---	---	---	---	---	---	6
France	---	---	37	142	94	195	164	29	10
India	---	---	---	---	---	7	2	---	---
Japan	---	12	164	146	230	141	223	176	6
Germany	4	---	25	13	24	8	68	36	6
Netherlands	---	---	---	1	6	---	21	---	---
New Zealand	---	---	---	---	13	11	---	24	6
Portugal	5	4	---	---	---	---	---	---	---
Russia	160	53	26	84	47	23	34	24	---
South Africa	---	---	---	12	37	10	---	8	---
Spain	---	---	---	---	---	---	---	3	---
United Kingdom	---	2	23	51	169	119	291	281	170
USA	82	853	1618	2495	1394	948	1047	937	457
TOTAL	251	932	2038	3177	2231	1582	1905	1590	710

Fig. 42. Distribution of digital echo-sounding data held at the IHO DCDB in June 2002 by country of origin and year of collection

tomatically and in digital form to data centres.

Priority 3: Begin serious investment in data rescue (data archaeology).

Priority 4: Encourage cruises to fill the substantial gaps that exist especially in the South Pacific, South Atlantic, Indian, Southern and Arctic Oceans, in the Arabian Sea, in the back-arc basins between China and Kamchatka, and in places in the North Atlantic and the North Pacific (e.g. between Hawaii and North America).

Priority 5: Use new technology (e.g. drifting floats and autonomous marine vehicles) to gather new data from large data gaps.

Priority 6: Investigate the possibility of acquiring data from commercial ships by voluntary means.

Discussion

SCOR WG 107 has clearly emphasised the need for improving the coverage of bathymetric data whether by improving the management of data already collected or by encouraging the collection of new data particularly in data gaps. The former is a combination both of developing, resourcing and implementing national policies to ensure the timely delivery of quality data to the IHO DCDB and of rescuing data at risk. In this context, it is interesting to analyse the distribution of data currently held at the IHO DCDB by date of collection and by country of origin. The above table (fig.42) summarises the volumes (expressed in terms of thousands of nautical miles of track) of digital echo-sounding data held in the GEODAS database by source country and by year of collection.

A number of observations may be made from this table:

a) the database contains very little pre-1960 data – it is presumed that much of the pre-1960 data are to be found on the Ocean Plotting Sheets;
b) the database is dominated by US data, reflecting not only the high activity of US ships but also the effectiveness of US national archiving at NGDC;
c) only two non-US countries appear to routinely submit their data to the IHO DCDB viz.

Japan and the UK – the former reflects strong bilateral arrangements between Japan and the US; the latter is due primarily to the allocation of staff resources at SOC to ensure the submission of UK bathymetry to NGDC;

d) there are commonly delays of the order of five years or more before data are submitted.

Despite the successes at NGDC in assembling a global database of digital echo-soundings, much work remains to be done to maximise the submission of data and to ensure a routine flow of data from all quarters of the globe. National commitments are required to ensure the searching out and delivery of data. In the pre-digital era, Hydrographic Offices were responsible for ensuring the input of national data to the Ocean Plotting Sheets and the VHOs took responsibility for assembling and searching out data in their respective geographic regions. Analogous but updated networking mechanisms are now required to support the activities of the IHO DCDB. In addition, resources need to be found to rescue and digitise data that currently reside in analogue form.

In the context of the above, it is interesting to note the successes achieved by Dr Fisher in searching out and assembling data for his compilation of the bathymetry of the greater Indian Ocean and by the IBCAO team in assembling data for the Arctic Ocean. Fig.43 shows the trackline distribution of echo-sounding data that were used in the compilation of the 5th Edition sheets in the area of Dr Fisher's recent compilation. Most of these sheets were printed in 1981/82 except for the area north of the Equator which was printed in 1975, and the area north of 40°S in the Atlantic which was published in revised form in 1994. By comparison, fig.44 shows the trackline distribution of echo-sounding data assembled by Dr Fisher in preparation for his recent contribution to the GEBCO Digital Atlas and includes data collected up to 2002. This shows more than a twofold increase in data coverage over a period of two decades and reflects not only an increase in data collected but also Dr Fisher's painstaking efforts to seek out data from both the scientific and hydrographic communities. In soliciting data, Dr Fisher stipulated that he would only use the data for compiling his contours and would not pass the data to third parties. It is interesting to conjecture what might have been the effect on data submission if this stipulation had not been made.

Similar successes in data assembly were achieved by the IBCAO project where a pooling of echo-sounding data was effected between the coastal states bordering the Arctic Ocean (Canada, Denmark, Norway, Russia and the US) and including the involvement of Iceland, Germany and Sweden. The team has a close involvement with the geoscience programmes active in the region, including the US Scientific Ice Exercise (SCICEX) project, and is able to attract sounding data into its database within a year or so of their collection. Availability of the IBCAO data to the wider community is effected through the release of a bathymetric data grid rather than through the release of the source data.

The defence interests of several countries have led to large areas of high quality bathymetric survey being classified. Some of these areas have since been declassified and made available to GEBCO, but many more remain and could provide extremely valuable additional data for GEBCO. Thus, for example, the IBCAO project and GEBCO have benefited greatly from the release of bathymetric data collected by the US Navy – and, to a lesser extent, by the British Royal Navy – during patrols beneath the permanent ice cover of the Arctic Ocean between 1957 and 1988.

In addition to the issue of data flow into the IHO DCDB, there is also a problem with the rate at which echo-sounding data are being collected across the world's oceans. Analysis of the data held at Boulder by year of collection shows a strong peak of around 800,000 nautical miles of track bathymetry per annum collected in the early 1970s compared with an average of 350,000 nautical miles per annum through the 1980s and into the early 1990s. To a large extent, the peak of 1971 reflects the widespread interest in deep sea bathymetry following acceptance of the theory of plate tectonics. It also reflects an era of block funding to oceanographic institutions which permitted the operation of ships worldwide without concern for the costs of individual surveys. Unfortunately, in recent years, it has become common practice on a number of research vessels to turn off their echo-sounders when not engaged in specific survey or science activities (e.g. on transit), thereby missing a golden opportunity to obtain valuable new data in data gaps. This point is strongly addressed in the SCOR WG 107 recommendations.

Unless major new initiatives such as the proposed Global Ocean Mapping Project, GOMaP,[20] come to fruition, it is likely for the foreseeable future that the mapping of the deep ocean will continue to rely to a large extent on the data already collected over the past one hundred years. In this context, the bathymetrist

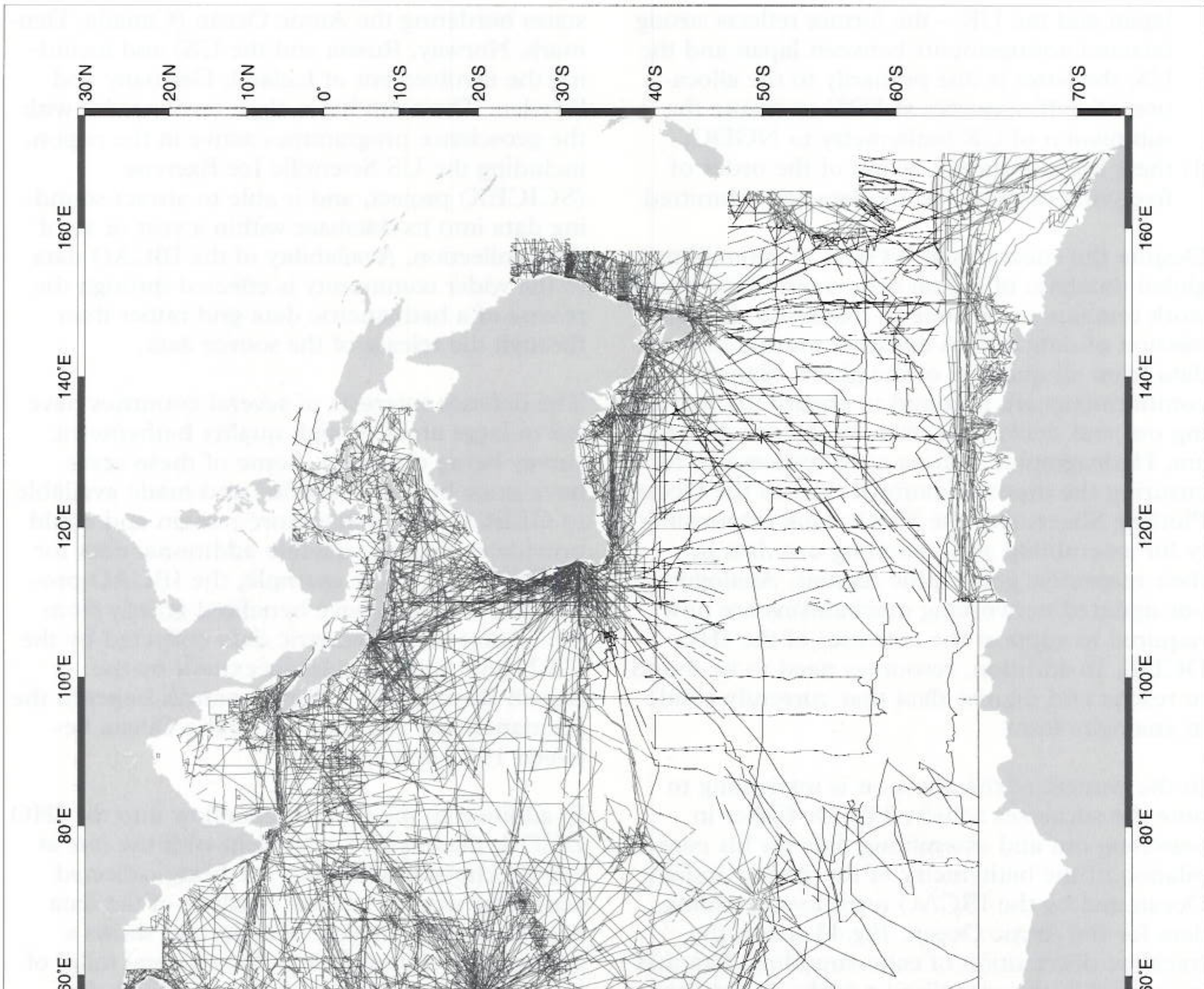

Fig. 43. Distribution of echo-sounding data used in the compilation of the GEBCO 5th Edition for the bathymetry of the greater Indian Ocean

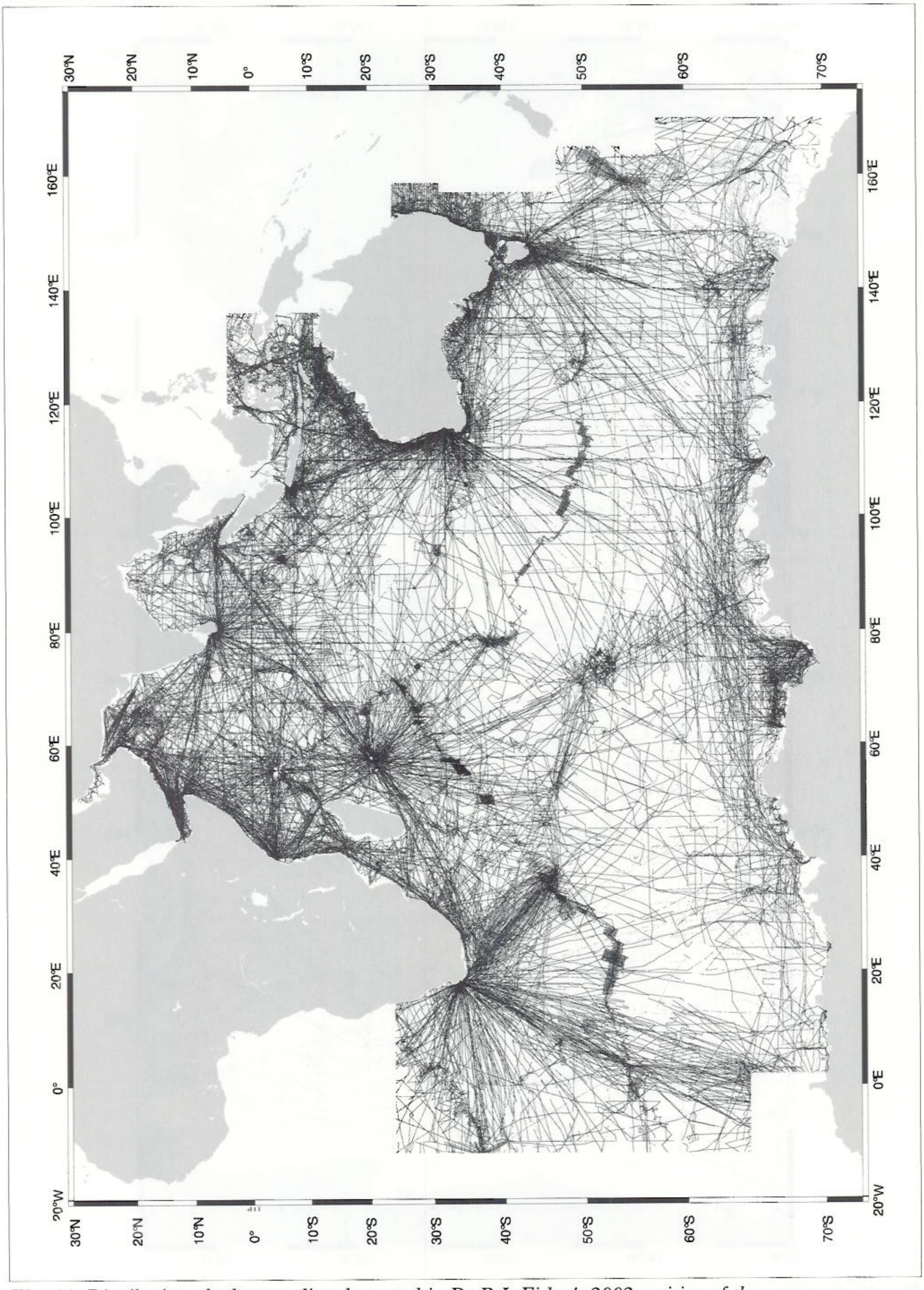

Fig. 44. Distribution of echo-sounding data used in Dr R.L.Fisher's 2002 revision of the same area as shown in fig.43

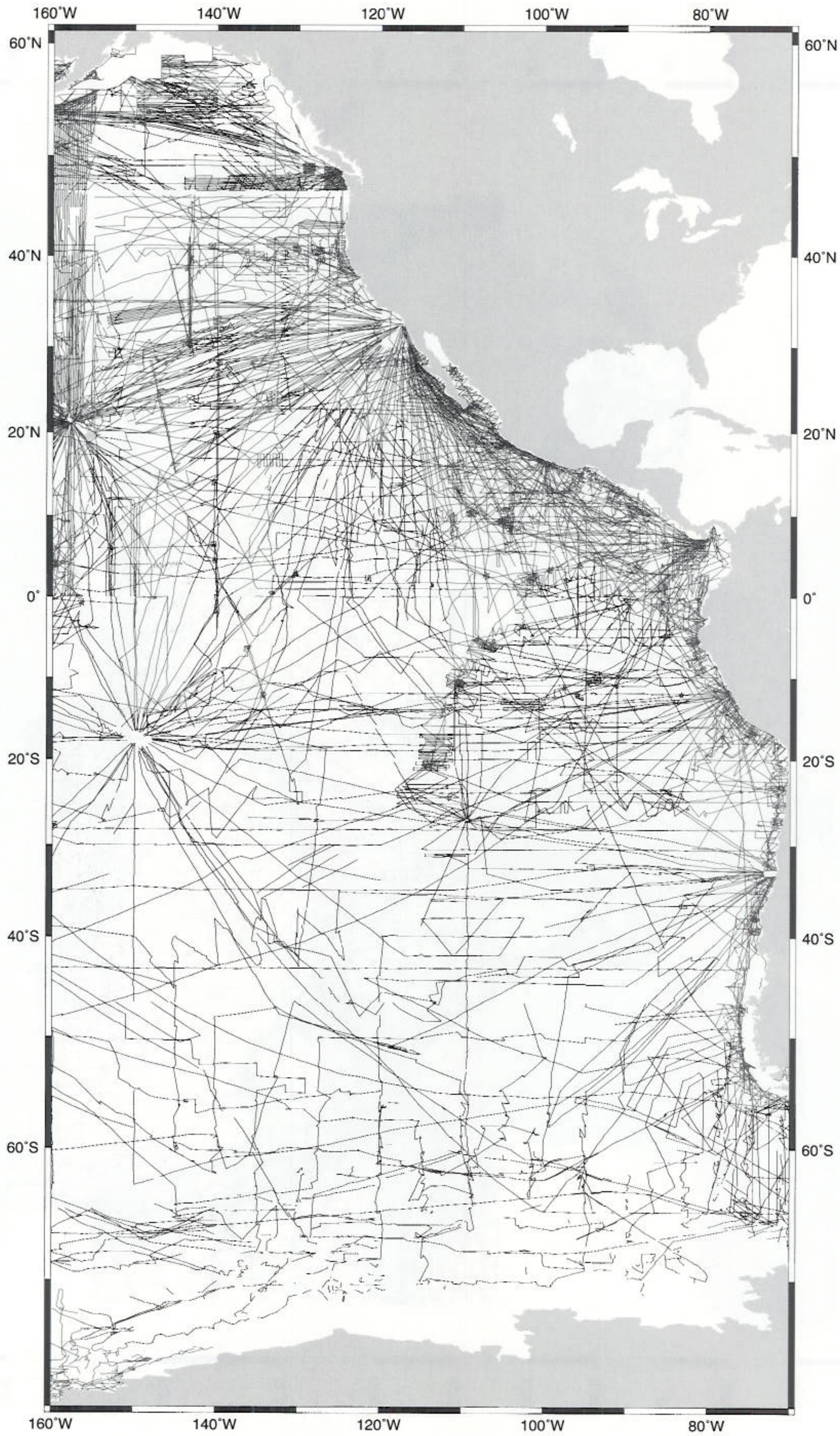

Fig. 45. Distribution of echo-sounding data used in the compilation of the GEBCO 5th Edition for the area of the Pacific Ocean east of 160°W

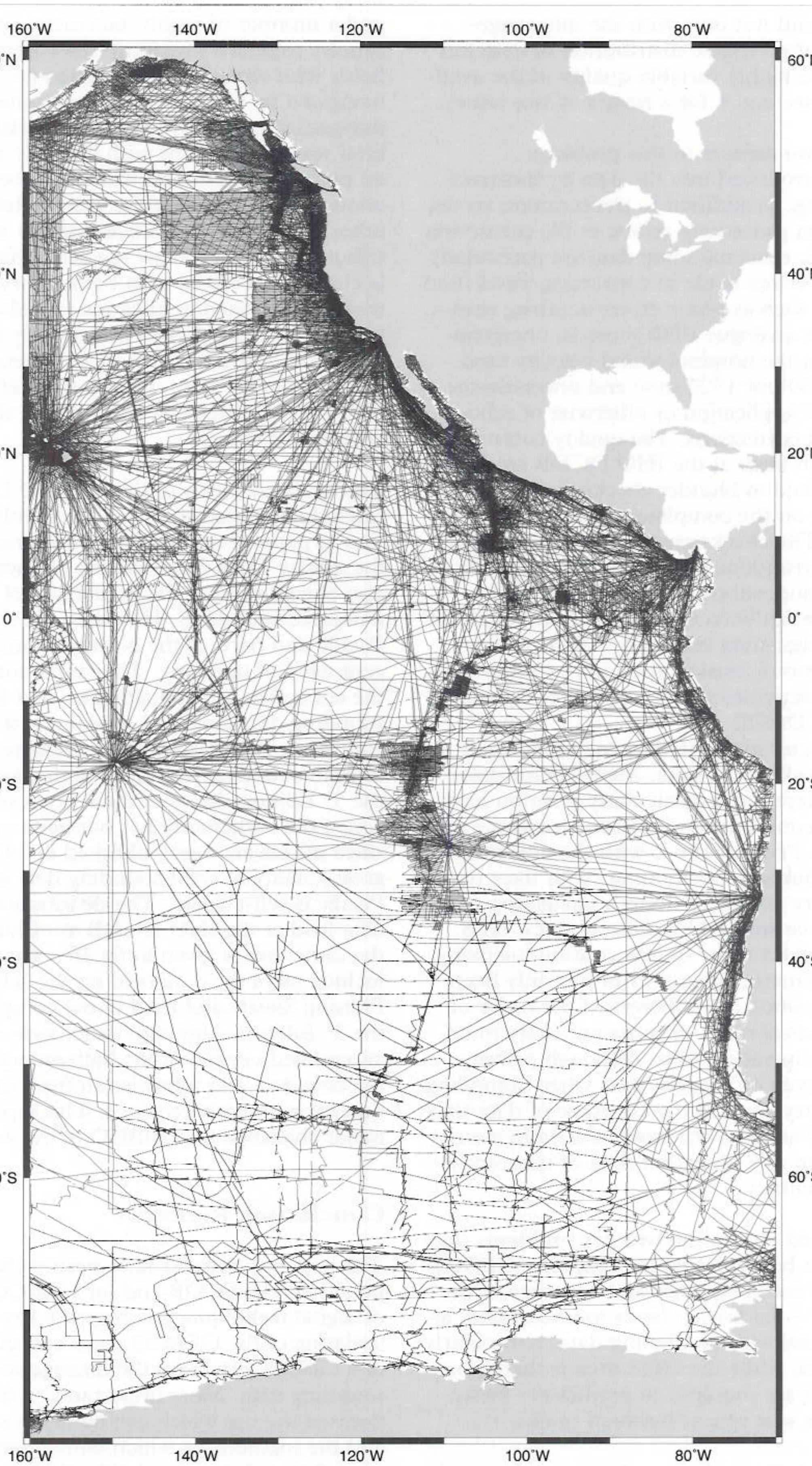

Fig. 46. Distribution of digital echo-sounding data held at the IHO DCDB as of June 2002 for the same area as shown in fig.45

has to contend not only with the inhomogeneous and often sparse distribution of data but also with the highly variable quality of the available data. (see e.g. [21] for a review of this issue).

There are two aspects to this problem:

a) Errors introduced into the data by incorrect processing. In addition to transcription errors, navigation processing errors, or file corruption problems, echo-sounding data are particularly prone to errors made in converting travel time to depth such as phase errors in taking readings from analogue PDR records, uncertainties about the nominal sound velocity used (1463, 1500 or 1520 m/s) and uncertainties about the application or otherwise of echo-sounding corrections. The quality control procedures in force at the IHO DCDB are essentially limited to blunder checking and checking on the completeness of data labelling. The checks are capable of detecting major corruptions in the data but fail to identify the more subtle errors that arise if the data have not been systematically checked out by the originating institution. This issue requires serious consideration in any future networking activities set up to support the role of the IHO DCDB.
b) Inaccuracies in the underlying techniques used to collect the data. Methods for determining depth and particularly position have evolved considerably in recent decades. (see e.g. [22-25]). Prior to 1967, with the advent of Transit Satellite positioning (with fixes typically every couple of hours), navigation tended to be controlled by celestial fixes. GPS now provides more or less continuous fixing with sub-metre accuracy but has only been available since 1986. Errors of the order of 1-10 nautical miles or more are likely to be apparent in earlier data. Although priority can be given to modern data when compiling bathymetry, such is the coverage of data that for many areas of the world the bathymetrist still has to rely on earlier data of inherently lower accuracy.

As mentioned above, the two key problems that confront the bathymetrist in compiling GEBCO scale charts are the quality and coverage of the source data – the former leads to uncertainty as to how to deal with conflicting data, particularly at crossovers, while the latter means that interpretive skills are required to predict the bathymetry in the vast spaces between tracks.

Two technological advances have greatly eased these problems over the past two decades; the advent of the Global Positioning System (GPS) and a number of highly successful satellite altimetry missions providing sea-surface gravity fields with virtually global coverage. With tracks navigated by GPS (and its forerunner satellite navigation systems), the bathymetrist is delivered sounding depths with virtually no associated positional error and which can be used as control data. The satellite gravity fields on the other hand provide unique insights into the distribution of mass below the sea surface (which is closely associated with bathymetry) – although of limited application in sedimented areas, they nevertheless provide key information on trends and structures in sediment free areas. They have also been used to good effect to predict the bathymetry in areas where the sounding coverage is sparse[26].

The updated sheets of the GEBCO Digital Atlas (including revised sheet 5.12 but with the exception of parts of the Arctic) have all made use of the gravity fields from satellite altimetry and have also benefited from the availability of satellite navigated soundings. However, the sheets in the Pacific and parts of the North Atlantic are in urgent need of updating. They were compiled in the era before satellite altimetry and lack all sounding data collected over the past 20 years and more. Fig.45 shows the trackline distribution of echo-sounding data used in the compilation of the 5th Edition sheets in those areas of the Pacific where the bathymetry has not been updated since the sheets were published in 1979/82. The great paucity of echo-sounding data in the South Pacific is self-evident. The distribution of digital data held at the IHO DCDB as of June 2002 for the same area is given in fig.46 – this does not include all of the data held on the IHO Ocean Plotting Sheets and used in the compilation of the 5th Edition. Although major gaps still remain, an updated version of the bathymetry incorporating new data and information from satellite altimetry is urgently required. This represents a major challenge for GEBCO in the years ahead.

Concluding Remarks

The past two decades have been a challenging period for the SCDB and for GEBCO. The use of digital techniques has played a key role in the updating of the GEBCO contours, the creation of a GEBCO grid and the management of echo-sounding data. More importantly it has revolutionised the use which can be made of GEBCO and the methods by which bathymetry can be compiled and processed. The SCDB has had many stimulating discussions on the relative merits of contouring and gridding data, on the role of automatic techniques in generating GEBCO's products and on the application of satellite altimetry to the prediction of bathymetry. These discussions will continue well into GEBCO's second century as techniques are sought and developed in support of the goals of GEBCO.

In order to coincide with the centenary celebrations of the GEBCO project, a Centenary Edition of the GDA is to be released in April 2003. It will contain a full release of the GEBCO contours, including the updates shown in fig.40 thereby providing completely new bathymetry for the Arctic and Indian Oceans as well as significant updates for areas of the North Atlantic, the Weddell Sea and the area around New Zealand. Just as importantly, the Centenary Edition will also include the first release of the GEBCO Bathymetric Grid, providing bathymetric data on a one minute global grid.

The Centenary Edition will be delivered as a set of CD-ROMs and will be set in the environment of a MicroSoft Windows based software interface developed by BODC's software engineer, Ray Cramer. The interface will enable the GEBCO bathymetry to be viewed in a variety of forms and projections and enable the user to select and download contour vectors and gridded data for use in their own applications. Fig. 36 provides an example of the type of output that can be generated using the facilities of the software interface.

One important aspect of GEBCO, which is continued in the Centenary Edition of the GDA, is the inclusion of trackline information highlighting the coverage of data used in its compilation. This is intended to act as a continual reminder to users that the world's oceans have not been systematically surveyed and that, for virtually all areas of the oceans, the mapping is based on the interpretation of random tracklines of data from a multitude of sources and with highly variable data quality and coverage. SCOR WG 107 has delivered a clear message about the urgent need to improve the coverage of bathymetric data in the world's oceans.

In presenting the 1st Edition of GEBCO to the Paris Academy of Sciences in January 1904, Professor Julien Thoulet remarked ".... Here then is everything that is known today about the relief of the ocean floor. For many years to come, mariners, telegraphists, engineers, oceanographers, and scientists will continue their soundings, for now we must proceed to fill in the details; no point of any sea on the globe will escape our investigations ...."

Nearly one hundred years on, Professor Thoulet's remarks appear equally applicable on the release of the Centenary Edition of the GDA. It is salutary to note that, whereas in the meantime high resolution topographic maps have been produced for Mars, Venus and the far side of the Moon, the mapping of the world's oceans will continue well into the foreseeable future. Moreover, it seems likely that it will depend, as in the past, on a small band of enthusiastic scientists across the world who are prepared to volunteer and apply their skills and energies to this challenging endeavour. It is the aim of GEBCO to encourage and facilitate these efforts and to strive continually to ensure that GEBCO can deliver the best available bathymetry of the world's oceans, following in the footsteps of those enlightened individuals who initiated the project a century ago.

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