MAPPING AUSTRALIA'S CONTINENTAL SHELF

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After serving articles with the firm of Foster and Foster in Levin, New Zealand, Mr. Turner obtained registration in 1953. Following a period of appointments with the Condominium of New Hebrides, the Northern Territory Administration and a private uranium company in the Northern Territory he returned to New Zealand joining Shell, BP and Todd on oil exploration surveys there. In 1958, Mr. Turner was posted to the expatriate staff of the Royal Dutch/Shell Group and carried out exploration surveys in Dutch New Guinea and hydrographic surveys in the Niger Delta.

Returning to Australia in 1961, he joined the Division of National Mapping in Melbourne where he played a major part in the introduction of Aerodist for control surveys. In 1970, Mr. Turner moved to Canberra to form the Bathymetric Mapping Branch and is responsible for carrying out the program described in his paper.

INTRODUCTION

For centuries man has been involved with the area of the sea adjoining the shores of his natural habitat. Undoubtedly his first interest stemmed from the sustenance, and in many areas the balance of diet, afforded by the multitude of seafood to be found in its waters.

Apart from the influence that the seabed played on the location of fishing grounds and the hazards it caused to navigation, little was known of the submerged areas we now call the continental shelves, as the technology and the need for further knowledge did not develop until the 20th century when submarine navigation and the search for new sources of natural resources turned attention to these unexplored regions.

This attention became focused after the second world war when countries with advanced technology began to move out into the oceans with their research and equipment to gradually extract or harvest resources which had previously been inaccessible.

As an outcome of the expansion of activity, international considerations were taken up by the United Nations which convened an International Conference in Geneva in 1958. This resulted in the Conventions on the Territorial Sea and the Contiguous Zone and on the Continental Shelf. Australia became a signatory to these Conventions in 1963, and in so doing undertook to learn as much as possible of the nature and extent of its own continental shelf needed for the understanding, delineation and controlled exploitation of this area. Of course, even before this time, the newer forms of exploitation of the shelf, oil and heavy minerals, as opposed to the traditional fishing industries, had already made their presence felt and the need for a better knowledge of the shelf was generated by this without the incentive created by ratification by the Geneva Convention.

THE CONTINENTAL SHELF

The continental shelves of the world have been estimated to occupy 7.5% of the oceans, which is roughly equivalent to 18% of the total land mass. They form the upper part of the continental blocks on which the continents are formed and are generally described as the area of nearly flat or gently sloping surface of the sea floor that borders the continents.

The inner edge of the shelf is the shore line while the outer edge is usually recognised by a marked increase in slope (eg, from 0.1^{o} to around 6^{o}) which can occur at anything from a few metres to 1200 kilometres from the shoreline. Around Australia the width of the shelf varies from about 16 kilometres near Port Macquarie, NSW, to something in excess of 300 kilometres on the north west shelf.

The average depth of the edge of the continental shelf over the world is about 130 metres but conventionally it is taken as 100 fathoms or 200 metres (probably an inheritance from the time when navigation charts only showed the 10, 100 and 1000 fathom contours) and this has been recognised by the United Nations Convention on the Continental Shelf in defining the shelf as:

". . . . . the seabed and subsoil of the submarine areas adjacent to the coast but outside the area of the territorial sea, to a depth of 200 metres or, beyond that limit, to where the depth of the superadjacent waters admits of the exploitation of the natural resources of the said area . . . . ."

The significance of the extention beyond the 200 metre limit will be mentioned later in this paper.

THE ROLE OF THE DIVISION OF NATIONAL MAPPING

Australia accepted responsibility for the hydrographic charting of its waters from the United Kingdom in 1922. Since that time, and even before, emphasis was naturally placed on the examination of shipping channels and port entrances to ensure that navigation would be made safe and adequate charts were available to provide the mariner with the information he required to bring his ship safely into port on time.

This requirement is a never ending one as new ports are developed and more detailed hydrographic surveys are required as ships with deeper and deeper draughts enter and leave the ports around the extensive coasts of Australia.

The Royal Australian Navy Hydrographic Service is currently engaged on a five year programme known as Hydroscheme 70 which is directed towards carrying out hydrographic surveys requested by various government, local authority and shipping agencies on an agreed priority basis. The Hydrographic Service completed more than 40,000 line miles of sounding in various areas during 1972 using its two survey vessels with assistance from three patrol boats for part of the year and a further patrol boat for a harbour approach survey.

With the increase in interests other than maritime, it was evident that insufficient was known of the vast areas outside the shipping channels which would become of importance in the search for natural resources and the detailed knowledge of our continental shelf required by modern technology and international obligations. A basic requirement for any study such as this is a set of maps to depict the topographic relief of the area. These maps are then used as a base on which other resource information can be portrayed.

The traditional hydrographic chart does not lend itself to this purpose as it is designed to portray matters relating to navigation and provide a plot sheet on which the navigator can plan his route and plot his progress. Hydrographic surveys place emphasis on examining an area to ensure that no reefs, shoals or pinnacles exist which may constitute a hazard to shipping or, where these do exist, to show their relationship to landmarks or navigation aids. The vertical datum to which depths are reduced is usually related to the level of the lowest tide expected in the area. In open waters, deeper than the draught of vessels likely to sail there, a general indication of water depth is usually all that is shown. The scales of charts are dependent on the complexity of the area and range from larger than 1:25,000 in confined areas to as small as 1:8,000,000 for intercontinental navigation charts.

Bathymetric maps, on the other hand, are designed to portray sea bed relief by contours at a common scale and on one horizontal and vertical datum. These are closely related to topographic maps and play a similar role in development of the areas they cover.

A committee of interested Commonwealth Departments was formed in the late 1960's to consider these requirements and its report resulted in 1970 in a Cabinet Decision which made the Division of National Mapping responsible for a programme to map the continental shelf of Australia at a scale of 1:250,000.

SURVEYING METHODS

The essentials of hydrographic surveying are simply the simultaneous observation of position and water depth.

The basic tools of the Hydrographer one hundred years ago were the compass, sextant and lead line. With these relatively simple but efficient pieces of equipment much work of surprising accuracy and detail was performed. In fact it is a tribute to the enterprise of early navigators and hydrographic surveyors that their work is still retained on modern hydrographic charts (albeit in hairline type) and in some areas even today constitutes the only knowledge of the seabed.

Two major innovations transformed the methods of hydrographic surveying in the first half of this century. The advent of the echosounder, a development of wartime necessity, and the later development of radio positioning devices provided the capacity for increased accuracy and the achievement of that accuracy at much greater ranges than ever before possible.

The echosounder measures the depth of water by timing a low frequency pulse reflected off the seabed and recording this either as a continuous trace on chart paper or, more recently, by digital display. To achieve survey accuracy, the equipment must be carefully calibrated and checks are made at frequent intervals by measuring echosounder depths to a bar lowered from the vessel to known depths. In this way the echosounder can be adjusted and with the proviso that depth measurement is affected by water temperature and salinity, accuracy is maintained throughout the survey. The application of corrections for tidal variations from the selected datum provides the required final value of depth of water. A sample of an echosounder trace is shown at Annex A.

The interval at which position is recorded during the sounding operation varies according to the nature of the survey but as continuous observation of position is usually possible with modern positioning systems there are no restrictions on the interval which may be selected.

Basically, radio positioning equipments rely on the phase comparison of signals transmitted from known stations on shore and interpreted at the receiver as lane counts, each lane representing a division of the frequency of transmission. These equipments, such as Decca Hi-Fix or Raydist, can be used either in the direct range/range mode from two transmitting stations or by a hyperbolic lattice of lanes from a combination of three interrelated transmissions suitably placed to cover the survey area. (See Annex B.)

A further development, made possible by the modern portability of accurate timing devices during the late 1960's, enabled position to be determined by measurement of distance from the time taken for a pulse to travel over the intervening distances between transmitters and receivers eg. Loran C, Toran O. Accuracy of this form of positioning is troubled by the deviations of the ray path from transmitter to receiver caused by the variations in the height of the atmospheric layer from which it is reflected, but has enabled ranges to be increased to an extent by which worldwide coverage of navigational accuracy can be achieved by the Omega system from only 8 transmitting stations throughout the world with a relatively simple receiver on board the vessel.

This method of position fixing is likely to increase in accuracy with innovations currently being developed but its role has now been rather overshadowed by the developments of the sixties in satellite doppler positioning.

Satellite doppler positioning developed from the observations of change in frequency of an orbiting satellite, as it passed over a receiver, which were originally used to track the orbit of the satellite. Using the reverse procedure it was realised that if the orbit of the satellite was known, the same doppler shift of transmitted radio frequency could be used to determine the position of the receiver. This principle has been developed by the Applied Physics Laboratory of the Johns Hopkins University for the United States Navy to provide an all weather world-wide position fixing system known as the Navy Navigation Satellite System (NNSS).

The system consists at present of five satellites in circular polar orbits at a nominal altitude of 1000 kilometres giving an orbit period of about 108 minutes. The satellites are tracked by fixed receiving stations which obtain data on the satellite orbits. This information is used to compute predicted orbital data which is injected into the satellites and transmitted by them as part of the message used to compute a position at mobile receivers.

The receiver system consists of an omnidirectional antenna, radio receiver, precise frequency standard and a small (4K) computer with teletypewriter. The doppler shift in frequency of the satellite transmission is measured against the frequency standard over successive two minute periods. The slant ranges derived from these provide the basic data to compute the position in terms of the Applied Physics Laboratory (APL) datum which is based on the centre of gravity of the earth.

The approximate geographical co-ordinates of the ship's position and an accurate estimate of the course and speed maintained throughout the period of measurement (up to 8 two-minute intervals) is entered through the teletypewriter enabling the computer to provide an unambiguous position related to a known instant during the observation. This position is transformed to the Australian Geodetic Datum using corrections derived from a number of comparisons at fixed positions throughout Australia.

The accuracy of a satellite fix at sea is dependent on a number of factors, not the least of which is the accuracy of the course and speed used in the computation. A one knot error in speed can produce an error in position of as much as 500 metres while a one degree error in heading will account for 50 metres.

The average accuracy of an acceptable satellite fix at sea, using course and speed data derived from gyrocompass and sonar doppler, is in the order of 75 metres which provides adequate absolute accuracy for bathymetric mapping at 1:250,000 scale, although insufficient for detailed hydrographic survey.

The interval between which fixes can be obtained varies with latitude and also is affected by the satellite orbits not being evenly spaced around the world. The maximum time between useable passes in mid-latitudes is about three hours while on other occasions two satellites may rise at approximately the same time and cause cross interference of transmission, preventing a satisfactory pass being obtained.

It is therefore necessary to provide additional means to determine position continuously between satellite fixes. This can be achieved by dead reckoning at the lower end of the accuracy scale or by sophisticated inertial navigation at the other. In practice, and in keeping with the accuracies required, sonar doppler and precise gyrocompass are being used extensively as they are compatible with the satellite positioning equipment and operate independently of any shore installations.

The sonar doppler system consists basically of an electronics console with display panel and a hull mounted transducer array. A signal is transmitted through the water in a 3^o beam from each of four transducers set at 30^o to the vertical towards the fore, aft, port and starboard of the vessel respectively. A portion of the signal is returned from the seabed and the effect of pitch and roll is cancelled by comparing the fore received signal with the aft and the port received signal with the starboard.

The system electronics then computes the velocity in each component and displays the velocity and cumulative distance travelled along and across the longitudinal axis of the vessel. The addition of a synchro-output from the gyrocompass enables the display to be related to a desired heading or, in an alternative mode, in respect of true north.

The equipment will operate on signals received from the bottom to a depth of 2-300 metres. At depths greater than this the signal is reflected off a sub-surface water layer which decreases the accuracy due to unknown current movements of the water layers. Normally the sonar doppler will provide results accurate to $\pm$ 1% while the gyrocompass error is of the order of $\pm$ 0.5^o. With adequate calibration and adjustment of observed position against satellite fixes as necessary, the total system can produce positioning data with an average error of less than 150 metres. Photographs of typical satellite and sonar doppler equipment are at Annex C.

THE BATHYMETRIC MAPPING TASK

The Australian Continental Shelf to a depth of 200 metres comprises approximately 2.1 million square kilometres. Of this, some 20% has already been surveyed by the RAN Hydrographic Service, in dispersed blocks of varying size, to acceptable modern standards.

In order to depict the shelf in sufficient detail for 1:250,000 scale bathymetric mapping, lines of soundings are usually surveyed at a basic 1500 metre spacing, generally between the 20 metre contour at the inshore boundary and the 300 metre contour at the outer edge of the shelf. This spacing of sounding lines can be varied depending on the relief of the seabed and it is expected that two thirds of the continental shelf area can be adequately portrayed by sounding lines spaced at 3000 metres. On the other hand, areas of complex seabed topography will require special sounding patterns.

The Bathymetric Mapping Branch of the Division of National Mapping commenced the programme in 1971 with a small staff and contract assistance. Staff and equipment are currently being augmented with the object of making the Branch more self-sufficient and increasing the rate of production.

Three contracts have been completed covering the area of the shelf between Sandy Cape on Fraser Island, Queensland and the N.S.W./Victorian border, and an area off Port Hedland W.A. It was a requirement of the first contract that dual positioning systems, one of which must be satellite/sonar doppler, be used to provide an assessment of the accuracy of the latter for bathymetric survey. This proved that the system was suitable and the Division subsequently acquired such a system for its own use.

Divisional operations were commenced in May 1973 using the Department of Transport Navaids vessel M.V. "Cape Pillar" on charter to carry out a survey in the Timor Sea area. The impetus on acquisition of data will be speeded up during 1974 and the whole programme is currently planned for completion in 1980.

During the survey, the positioning and uncorrected depth data are plotted continuously as well as being recorded in a sounding log book. In this way predetermined lines of sounding can be maintained, positioning data is checked and areas of seabed relief requiring further sounding are brought to notice whilst in the area. The plot sheet is then used to provide a base from which the manuscript map is drawn at a scale of 1:150,000. This shows each fixed position, usually at approximately 1000 metre spacings along the sounding lines, and the depth data corrected to mean sea level from which contours are interpolated.

The bathymetric maps derived from the manuscripts are produced in two colours and follow basically the same sheet lines and format as the 1:250,000 topographic map series of Australia. An index to the bathymetric map series showing also the appropriate 200 metre isobath around Australia is at Annex D.

Some planimetric detail is shown on land areas while isobaths from mean sea level at 20 metre intervals to the 300 metre isobath form the major information contained on the map. Spot depths are shown to indicate significant changes from an even gradient between contours. No information is shown at depths greater than 300 metres due to the generally less accurate and often sparse information available. A cut from the Wide Bay bathymetric map is attached at Annex E.

The map carries a caution note to the effect that it is not produced for navigation purposes as, unlike hydrographic charting, no effort is made to indicate possible hazards to shipping or depict navigational information, nor are the depths related to the type of datum used for charts.

COOPERATIVE ACTIVITIES

Apart from the close liaison maintained with the Hydrographer, RAN, to avoid duplication of effort and ensure that bathymetric surveys assist the hydrographic charting programme, other requirements have emerged for which data can be usefully collected during the course of bathymetric survey operations.

Inclusion of other scientific data collection activities in conjunction with survey operations is restricted to those which do not interfere with the basic purpose of providing bathymetric information at the required production rate. Thus, seismic, gravity and bottom sampling work is not undertaken as these would slow down the progress of the survey by at least 50%. However, the operations already include the following secondary observations for other agencies.

Sea surface temperature is continuously recorded at the request of CSIRO Division of Fisheries.

Bureau of Meteorology equipment is carried, from which six hourly weather reports are telegraphed to the Bureau whilst the vessel is at sea.

Magnetometer observations are recorded using equipment provided by the Bureau of Mineral Resources in order to provide detailed magnetic anomaly data.

The Bureau of Mineral Resources has also requested that sub-bottom profile data be acquired and this is currently being investigated with a view to providing suitable data for their purposes. The Bureau has already made use of the bottom profiles, from which the bathymetric data is extracted, to study the micro geomorphology of the seabed.

Recently the Division of Fisheries of the Department of Primary Industry has studied the echosounder charts obtained in previous surveys and has found that a great deal of information can be extracted on the nature of the seabed and fish distribution to assist in trawling operations. Further cooperation is currently underway to provide more adequate information in this regard.

There seems little doubt that further cooperation will develop during the course of the programme and that, even though the surveys remain basically bathymetric, much additional scientific data of value to various disciplines can be collected without detriment to the programme.

THE FUTURE

It is, of course, quite impossible to foresee what bathymetric mapping will be like in a hundred years time. Undoubtedly the oceans will be thoroughly mapped and activities we now consider the epitome of advanced technology will be commonplace.

Deep sea drilling, manned seabed stations, accurate position determination on a world-wide datum anywhere at any time come to mind as a few of the possibilities.

In the more immediate future, however, a number of aspects are reasonably certain and can be described to give some impression of what will probably eventuate. As mentioned earlier, the present definition of the continental shelf allows for its extension beyond the 200 metre limit where exploitation permits. A more definitive limit is currently being discussed at the U.N. Seabed Committee meetings preparatory to the Law of the Sea Conference in 1974. Whatever the outcome it appears certain that the limit of national jurisdiction in the resources zone of each country will extend generally beyond the continental shelf. This will give rise to the need for an extension of the mapping programme to regions beyond 200 metres in depth. The Bureau of Mineral Resources has already completed a regional geophysical survey of the continental margin as a result of the same Cabinet Decision which initiated the bathymetric mapping programme.

As far as the current programme is concerned, the amount of work involved will necessitate an expansion of activity to the extent that at least four ships will be required for survey operations. In appropriate areas use will be made of what is known. as consort sounding where the primary vessel is positioned by normal methods while a second, and usually smaller vessel, is kept on station from the primary vessel to sound the adjoining line. In this way production can be virtually doubled without duplication of the more expensive positioning systems and it is even possible to use two or more consort vessels at a time under favourable conditions.

These consort vessels, being smaller and thus of shallower draught, will also be used in an independent role to sound the inshore and shallow areas, probably utilizing conventional shore based positioning systems.

With the successful introduction of the satellite/sonar doppler system for primary positioning, advantage will be taken of its potential for integration whereby data from each component of the system is fed into a central computer and integrated by it to provide "on demand" output of adjusted positions. The next step is of course to feed depth and other data into the computer as well, to provide a fully automated data acquisition system.

Bathymetric mapping operations lend themselves ideally to the application of such automated methods. Data is collected electronically, is basically repetitive in nature, and can be processed through to virtually a final product without manual intervention. Experience overseas shows the advantages accruing from automation in this area, but also provides a warning that it should be progressively and very cautiously introduced before total reliance on automated methods can be expected.

It is intended that automation be progressively introduced into the bathymetric mapping programme but only after comprehensive study of overseas experience and detailed investigation of the problems involved, and procedures and equipment best suited to the programme.

Obviously, the most difficult area to be surveyed and yet one of the most important is the Great Barrier Reef. Here it is hoped to acquire reef detail by photogrammetric procedures using position controlled aerial photography. The potential ability of the Laser Terrain Profiler, suitably modified to penetrate to depths of about 20 metres, may also provide a means of surveying shoal areas so that vessels can proceed to sound areas of deeper water without the precautions and slower progress associated with sounding in shallow water.

CONCLUSION

The increasing demand for natural resources and the new technologies which permit the extraction of these resources from previously inaccessible areas of the sea, have created the need for increased knowledge of the sea and what lies below it. At the same time efficient management of these resources, the control of exploitation and the prevention of pollution require adequate planning and an appreciation of the limitations which must be placed on these activities to prevent wastage and despoilation of our environment.

The current programme of bathymetric mapping being undertaken by the Division of National Mapping will play an important part in this future development by providing a basis on which further studies can be undertaken and it is hoped that this paper has given some understanding of the mapping task.