BATHYMETRIC SURVEYING ON THE CONTINENTAL SHELF

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I.1. With oceanographers there is no need to plead the cause of bathymetric surveys. Every one of us is aware of the need for a good knowledge of bottom topography and the detailed structure of its features, as well as for a good determination of the geometry of the water mass. However, it will certainly be useful to stress the special requirements of bathymetric surveys, for these are often considerably more stringent than is the case where other oceanographic or geophysical data are concerned, and are sometimes poorly understood.

I.2. Not so very long ago, so soon as the depth was more than several tens of metres the depth data became both difficult and tricky to obtain, and moreover the position of the sounding vessel could not be accurately determined out of sight of land. Furthermore, the very slow pace of bathymetric surveys in oceanic depths necessarily made these long term projects. Until quite recently only a very few and somewhat inaccurate reconnaissance surveys existed beyond the coastal zone, and this even where the continental shelf is wide and where the area has great economic importance, particularly for fishing.

I.3. The traditional techniques of bathymetric surveys were disrupted first by the appearance of the echo sounder, and then after the second World War by the development of methods of accurate radio positioning at increasingly greater ranges. Without going into the history of these techniques I may remark that in their present state of development echo-sounders are now almost the simplest of an oceanographer's instruments, as well as being the most reliable and the easiest to handle.

This being so, soundings risk being considered a by-product of oceanographic activity outside the zones where knowledge of them is of direct interest to navigation, and not to merit the efforts that Hydrographic Offices put into this work. Obviously, in view of the cost of keeping a ship at sea it would be senseless not to use the occasion to acquire the largest possible amount of geophysical data at the same time as depth data. Nevertheless it is the specific requirements of a bathymetric survey that govern the survey's detailed programme. To take the case of continental shelf surveys only, these requirements essentially relate to :

a) Density of soundings.
b) Accuracy of positioning.

II.1. Traditionally, soundings are obtained by continuous analogue recordings with an ultrasonic hull-mounted sounder. For the range of depths encountered on the continental shelf the performance of these instruments need not be exceptional, and so the standard sounders employed during the last 15 years will normally suffice. Let us review briefly the factors governing the accuracy.

II.1.1. *Beam Width.*

An ultrasonic beam of small width is not essential on the continental shelf, as is the case for areas where the slope and depths are more pronounced. The leading edge of the return signal gives the bottom depth directly below the sounder with negligible error. Only a small and isolated obstruction (e.g. a wreck) is likely to be plotted with a positional error of the order of 100 m and a height error of the order of a few metres. These are small errors, and with suitable work procedures they can be reduced to negligible proportions. Briefly, sounders of standard beam width are entirely satisfactory for precise surveys of the continental shelf.

II.1.2. *Sounding Accuracy.*

This depends both on the sounder's operational qualities and on the quality of the corrections. As regards the first point, it is to be regretted that manufacturers of the classical instruments have not always given enough thought to regulating the speed of the style-drive, as this is what conditions the accuracy of the measurement. Certain manufacturers supply equipment in which this essential element is not always as accurate as the rest of the instrument. There do, however, exist today sounders that are entirely satisfactory from this point of view. Furthermore the availability of digital recording (in addition to the classic analogue recording), a procedure that is already used and one that is rapidly becoming generalized, will provide a very definite improvement since an entirely electronic time-basis can be used. Another improvement might also result from the necessarily more sophisticated electronic processing of the return signal.

As regard the corrections, these concern both tides and velocity of sound. The mean velocity of sound can be obtained with entirely satisfactory accuracy by means of direct hydrologic observations at the time of the survey. However, to obtain a tidal correction that is truly reliable poses a difficult problem. In areas where the tidal amplitude is fairly large — as for instance along the European coasts of the Atlantic continental shelf — it is certain that this is the major source of inaccuracy at present. Today, the determination of tides depends on coastal observations and a knowledge, necessarily imperfect, of the network of cotidal lines and lines of equal tidal amplitude. In the very near future, the use of deepwater tide gauges, capable of recording the tide in very deep waters, will enable this problem to be resolved. To my knowledge no instrument of this type for use in depths of several hundred metres, as required in a continental shelf survey, is yet actually in operational use.

II.1.3. *Performances.*

There is another important cause that limits the accuracy of soundings. In order to make the best use of the ship's time, sounding work cannot be restricted to periods of fine weather only. It is therefore essential that the performance of a sounder should deteriorate as little as possible in relation to the state of the sea. Experience has shown that on adequately large vessels not only can hull-mounted sounders, when competently fitted (i.e. with their bases standing well away from the hull) give satisfactory reception (signal/noise ratio, absence of blanks, etc.) even in sea states of 4 or 5, but also that for continental shelf surveys it is not necessary to resort to stabilized narrow-beam sounders. These are much more costly and should be reserved for the continental slope and for oceanic depths.

On the other hand, even if it is assumed that deck movement does not decrease the accuracy of the measured depth, correction for the vertical movements of the transducers with respect to the mean water level is essential. To the best of my knowledge there is as yet no equipment in existence which can make this correction. In actual practice when the bottom is regular the manual smoothing of the analogue record makes it possible to obtain bottom topography with acceptable accuracy. But when the bottom has local irregularities (rocky outcrops) or when its features are microtopographic (ripples) whose apparent wavelength would be very nearly identical to that of the vessel's vertical movement, then all the details on the record will be masked by smoothing. A truly efficient sounder should be equipped with a device for cutting out swell, thus correcting the measurement for the effect of vertical movements in relation to the mean water level (and perhaps at the same time for the variation in draught of the sounder's bases) by means of pressure and acceleration sensors and electronic integrators. I believe that one manufacturer is at present studying such equipment, and I consider that this would be significant progress.

II.2. I have already mentioned digital recording of soundings. Today this progress is an accomplished fact — and equally significant. Its use is certain to become rapidly more widespread even though the equipment is considerably more costly. In the first place its interest obviously lies in the fact that it simplifies the work of data processing, since as a rule it cuts out all manual work in the first phase of the automated processing of data (the digitizing of data). Digital recording also presents the already noted advantage of increasing the quality of the measurement (the time base quality, the cutting out of range-change errors, etc.), provided that it is carefully compared with the analogue record. The latter method should, however, be retained since it provides fuller information than digital sounding, and there are cases when it is important that this information should not be lost.

II.3. Thus, with classical sounding methods all we obtain is a series of discrete profiles of the bottom. Although this was an improvement on the former lead line soundings, which only supplied scattered soundings, we are still a long way from the ideal method which would be to have a complete picture of the surface of the bottom — much in the same way as that provided by aerial photography in land surveying. The very recent appearance of horizontal beam echo sounding equipment gives us a pointer to a possible solution to this problem. However, these instruments — the SONAL developed by the "Institut Français du Pétrole", for example — supply results which are still mainly qualitative, and which must be interpreted with great care. Apart from possible future improvements, it is certain that already such instruments :

(a) Are invaluable for complementing the study of areas of moderate or uniform topography because they enable both localized topographic features and isolated obstructions on an otherwise uniform bottom to be positioned and evaluated with very good accuracy. It also means that the choice of profile interval and interpolation procedures can be based on reliable information.

(b) Supply pictures which in zones of complex topography or micro-topography are extremely difficult to interpret. Principally, they permit accurate delimitation of such zones, and this is of the greatest interest when planning the execution of soundings.

There is, however, room for further improvement.

II.4. The question that arises both before and during a bathymetric survey is the choice of a suitable density for the sounding profiles. We are guided in this by considerations that are essentially heuristic — and also by others which are not always entirely hydrographic in nature. We have to compromise between the object of the survey and the time and means that can be assigned to it. No general rules can be given.

For example, we can be guided by the scale of the desired product. The profile interval must accordingly be chosen so that the plotting of contour lines gives rise to the least possible amount of interpretation, account being taken of all that is known about the general character of the topography in the survey area. (This may be defined by a careful study of certain well chosen sectors).

By combining the use of a sounder and a SONAL we may also attempt complete cover of the whole survey zone. In this case the profile interval's upper limit will be conditioned by the SONAL's horizontal range, by the width of the masked strip beneath the ship, and by the need to cover the distance twice if possible, with the SONAL beam pointing in opposite directions.

In any case — unless it is merely a question of a simple reconnaissance survey — the profile density will always need to be *considerably higher* than for any oceanographic, geologic or geophysical study of the same region. Thus it is simply the study of the geometry of the bottom which finally conditions the distance to be run and the time to be spent at sea.

III.1. The problem of accurate positioning of a ship out of sight of land is today practically resolved. So far as continental shelf surveys are concerned, short and medium range radiolocation systems, appropriately used, continuously supply a fix satisfying all the requirements of accuracy and repeatability.

III.2. For many years the French Hydrographic Office has been using two phase measurement radiopositioning systems — RANA and TORAN — which both use frequencies between 1.5 and 2 megacycles, and hence have suitable hyperbolic lanewidths. These systems permit work under excellent conditions up to a distance of the order of 200 km from the coast, both by night and day. And this without too much inconvenience, apart from a limiting of the range by ionospheric propagation. For greater distances the French Hydrographic Office today uses a more powerful version of TORAN, making it possible, as experience has proved, to operate up to considerably more than 500 km from the transmitters. This enables us to solve nearly all the problems of a continental shelf survey. At such distances, since the equipment does not include a special device for correcting for ionospheric propagation, we are obliged to restrict operations to daylight hours when the skywave merely gives rise to tolerable fluctuations of the measured phase. More precisely, we have to confine ourselves to the "radioelectric" day. In summer this very nearly coincides with the solar day, but in European latitudes is a good deal shorter in winter. With this reservation the mean square error in positioning with TORAN appears to remain about 10 m over long distances.

These systems pose the problem of lane identification or "resolving the ambiguity". I do not want to enter into the technical complexities of TORAN, but I must mention that this problem has not yet been satisfactorily solved, and this makes exploitation difficult. It also renders the equipment (in its classical form, as used by the French Hydrographic Office) unsuitable for use in ordinary navigation by ships lacking suitably trained personnel. It is to be hoped that suggested future versions will eliminate this drawback.

III.2.1. At distances of over 500 km, a relatively accurate positioning remains possible with such long-range systems as LORAN and OMEGA. On account of propagation fluctuations at great distances, these systems normally provide an absolute position with much less good accuracy than TORAN, for example. However, we may consider such fluctuations as remaining fairly insignificant over a period of several hours, and so the accuracy can be considerably improved if we can check the position frequently and then reset the readings. The TRANSIT satellite navigation system permits such a re-setting at suitable intervals (of the order of 2 to 4 hours). Thus, the combined use of TRANSIT and OMEGA, for example, should be able to provide a permanent positioning anywhere at sea with the accuracy of a TRANSIT position. It is difficult to evaluate this accuracy as this depends chiefly on the characteristics of the vessel used and the way it is navigated. It is probable that this accuracy can be improved. To give an order of magnitude, let us fix it at about 100 m.

III.2.2. I should mention in passing that when a relatively better accuracy than that provided by radio-positioning is required, it remains possible, for a fairly small area, to set up a local positioning system by laying a network of acoustic beacons.

III.3. Manufacturers of radionavigation material are now supplying receivers able to sample positional data in digital form. In the case of systems such as TORAN, this advance follows the same general tendency towards automation in hydrographic surveying as the digitizing of soundings. When TRANSIT and OMEGA are used in combination it will be difficult to see how they can be operated without an onboard computer capable of working out a fix in real time, or at least with a short enough delay to allow continuity of survey work.

IV.1. The processing of survey data is traditionally done by hand. Soundings are read from the analogue recorder, then corrected, reduced, and entered on plotting sheets. These plotting sheets are the cartographer's basic tool, the documents sold to the public being the nautical charts themselves. These are generally at a much smaller scale than the plotting sheets, and do not contain all the information gathered on the spot. Specialist users (scientists, prospectors, etc.) naturally have the possibility of obtaining copies of original plotting sheets — unless of course there are good military reasons against this, and in certain circumstances this may be the case.

IV.2.1. The plotting sheets themselves show only selected soundings taken from the continuous record. The choice has here to be guided by the need to reduce the number of soundings to be shown — but taking care to lose the minimum of pertinent information. This operation is for the most part still done manually, but it would certainly be fairly easy to automate it by using sounding and tidal data manually processed on digital instruments such as automatic pencil followers, or else digital records obtained directly from the measuring instrument. Nor does the plotting of selected soundings on the sheet by means of an automatic plotter present any particular difficulty.

IV.2.2. However, this is not the case when we come to finalizing the sheets by plotting the contour lines, although there are, of course, already many programmed algorithms for enabling us to solve both this problem and many others. One such algorithm consists of drawing up a digital model of the bottom topography by inserting any additional sounding interpolated for any given point from among the scattered soundings shown on the plotting sheets. Once this model is established it can be used not only for calculating the contour lines point by point but also — in theory at least — for obtaining bottom profiles, for plotting slopes, ridges and thalwegs, and for recognizing given patterns, etc. To write such an algorithm we have to seek an "estimator" enabling us to choose the most likely depth value at any one position from the information resulting from the selection of soundings. As far as I know, present day procedures treat the selected soundings as a discrete scattering of completely independent values. However, this does not correspond to the actual way in which plotting

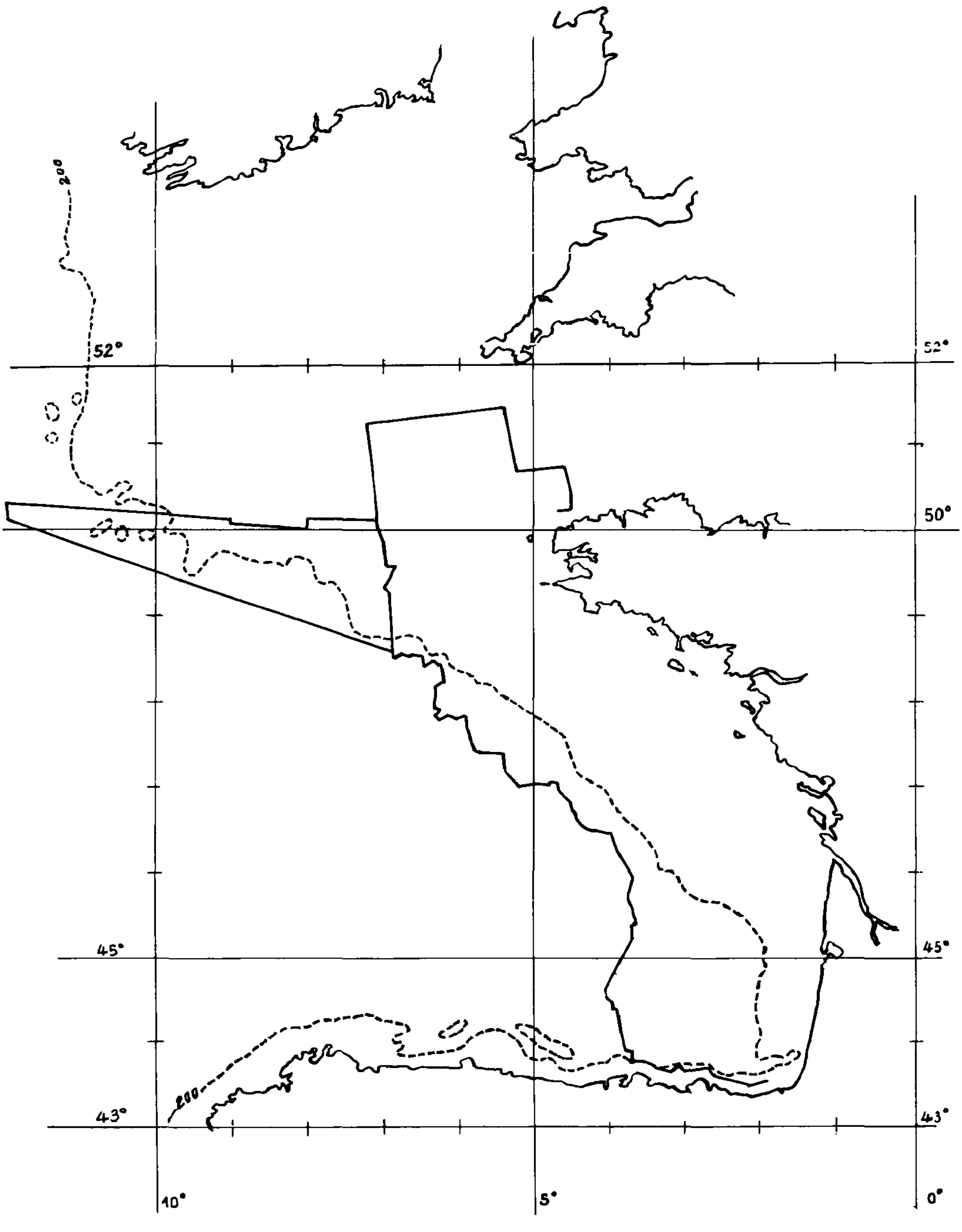

FIG. 1. — Survey of the Atlantic Continental Shelf carried out by the French Hydrographic Service.

sheets are drawn up, since soundings are not plotted at random but are aligned along profiles on which the depths to be interpolated are not presumptively indeterminate. If the recorded soundings have been carefully chosen, using accepted criteria, the intermediate depths can be supplied by linear interpolation between two adjacent soundings on the same profile, although there is no such relationship between two adjacent soundings taken from different profiles. It seems to me that an algorithm that ignores this fact cannot be considered satisfactory.

At the French Hydrographic Office an attempt has been made to apply the geostatistic methods used in the current processing of certain geologic and geophysical data to the depth variable. Results are not very conclusive in view of the practical difficulties of programming the computer. The work still remains at the theoretical stage, but deserves to be followed up. When an operational result is available, the complete automation of the chain of operations, from the gathering of data up to the drawing up of the results, will have been realised, and thus another decisive phase in the progress of this work will be complete.

V. In 1960 the French Hydrographic Office started a systematic survey of the Atlantic continental shelf along the coasts of France employing the methods I have just described.

The state of advancement of this survey is shown on the sketch reproduced here. Up to about Latitude 47°30′ the shelf is narrow enough to allow complete coverage with a medium range RANA radiopositioning system. North of this latitude the coastward part of the shelf (out to about 170 km) was surveyed first with RANA and then with the standard form of TORAN. The part further out to sea is at present being surveyed with a long-range TORAN. For this last phase of the work it was no longer possible to use French-based transmitters, and we had to ask if we might install our stations ashore in the United Kingdom and Eire. This permission was granted, and we would like to acknowledge the help afforded us by these two countries.