International Hydrographic Review, Monaco, LXI (2), July 1984

MORPHOMETRIC PROCESSING OF SOUNDING PROFILES AND COMPARISON WITH VISUAL ANALYSIS

by J.M. FROIDEFOND(*) and L. BERTHOIS(**)

ABSTRACT

Morphometric analysis based on data processing of sounding profiles is presented in this study. The process involves segmentation of profiles so that units of equal length are dealt with, and calculation of the following characteristic parameters : maximum amplitude — relief — ruggedness of bottom features. The programme developed is applied in the study of 21 sounding profiles recorded between the shore and an offshore depth of 25 m, south of the Gironde estuary (S.W. France). The quantitative results are compared with visual analysis of the echograms. Comparison of the various charts obtained (figs. 7, 9, 10 and 11) shows that the results are complementary. Visual analysis has a higher power of resolution and enables areas of strikingly contrasting morphology to be rapidly located. Quantitative analysis enables the undersea features to be strictly classified, even in complex areas where the eye cannot distinguish the many shades of difference. This process has been conceived to define the characteristics of the superficial physical structure of the sea floor, but use of a digital sounder seems necessary if the process is to be developed and its use to become accepted.

INTRODUCTION

The undersea relief is often an indication of the geological composition of the rocky underlayers or of the conditions in which the soft superficial sediments have accumulated. Therefore, basic research has been carried out in our Laboratory,

(*) Laboratoire associé au C.N.R.S., n° 197, Institut de Géologie du Bassin d'Aquitaine, 351, cours de la Libération, 33405 TALENCE CEDEX France.
(**) 6, rue de Viarmes, 35000 RENNES, France.

both on analysing bathymtric charts (NAUDIN, J.J., PRUD'HOMME, R., 1971) and on analysing echo-sounder traces (BERTHOIS, L., FROIDEFOND, J.M., 1981).

On such traces, the details of the undersea relief appear clearly by reason of the exaggeration of the scale of elevations. But on the other hand, the general shape of the features is not very apparent compared with what is revealed on bathymetric charts. Therefore, the analysis of sounding profiles would be preferred for use in geology for the detailed study of superficial sediments. So far, two methods of analysis have been proposed for the morphologic exploitation of sounding profiles :

1. Visual analysis, following selection of several morphologic features; this is the method advocated in 1957 by R.D. TERRY and R.E. STEVENSON and which was further developed by D. MONAHAN and R.F. MACNAB in 1974.
2. Morphometric analysis, following selection of several parameters, according to the procedures of L.K. LEPLEY (1966) and G.V. BOGOROV and A.V. LLIN (1971).

Very recently, as part of their work, the French "Service Hydrographique et Océanographique de la Marine" (SHOM Report, 1979) launched a research programme to determine characteristic parameters of the micro-relief.

The execution of this programme was entrusted to our Laboratory. The results of the study were described in a report submitted to SHOM in 1981 (FROIDEFOND, J.M., GRIBOULARD, R., PRUD'HOMME, R., 1981).

As a follow-up to that research, it appeared necessary to develop a comprehensive suite of software for processing sounding profiles and comparing the results obtained from morphometric analysis with those derived from visual observation of the sounding profiles.

I. ANALYSING TECHNIQUES

1. PROCESSING THE DATA AND THE PARAMETERS DEFINING THE CHARACTERISTICS OF THE MICRO-RELIEF

We used the computer facilities of the IGBA (Institut de Géologie du Bassin d'Aquitaine) Laboratory of Geomorphology to develop the data processing programme.

The data on the sounding profiles and those provided by the ship's position plotter are recorded on tape by means of a Haromat digitizing table.

They are then processed, using a Digital Equipment PDP 11/10 mini-computer (memory of 24 K words of 16 bits). The results are transcribed on a BENSON 132 plotter. The programme, written in BASIC, performs the following operations :

a) Schematic algorithm (DENSO-BAS programme)

Integration of sounding and positioning data (corrections for variations in ship's speed). (1)
Calculation of sounding points regularly spaced by linear interpolation. (2)
Division of the data into segments of equal length. (3)
Analysis of each segment using morphometric parameters. (4)
Cartographic plotting of results. (5)

We will not elaborate further on stages (1) and (5), concerning integration of the sounding and positioning data and the cartographic plotting of the results, since this type of processing is current practice in many Hydrographic Offices. Neither will we say more concerning measuring accuracy with respect to the angular aperture of the acoustic beam, pulse frequency, the effect of swell, and the influence of the tide.

A study of measuring accuracy was carried out and described in the I.G.B.A. Report to the Service Hydrographique et Océanographique de la Marine (S.H.O.M.). It forms the subject of a chapter in the work : "Traité de Bathymétrie" (L. BERTHOIS and J.M. FROIDEFOND, 1983).

But it is necessary to elaborate on the segmentation process and on the morphologic parameters we selected.

b) Segmentation of data

From the initial points chosen on the sounding profile and recorded on the digitizing table, secondary points, regularly arranged in very close formation are generated by linear interpolation. (Stage 2 of the algorithm).

When the distance "d" (fig. 1), processed in this way, attains a length equal to the length of segment chosen by the user (1,000 metres, in the present case) all the depths contained within this segment L_1 are transferred into the sub-programme for morphometric processing.

When this first part of the processing operation is complete, the programme retains in memory half of the data from segment L_1, i.e. that part included between

500 m and 1,000 m, and adds to these the data included between 1,000 m and 1,500 m (segment L_2), and so on.

In this way, the segments analysed half overlap one another (see fig. 2), which reduces the boundary effect.

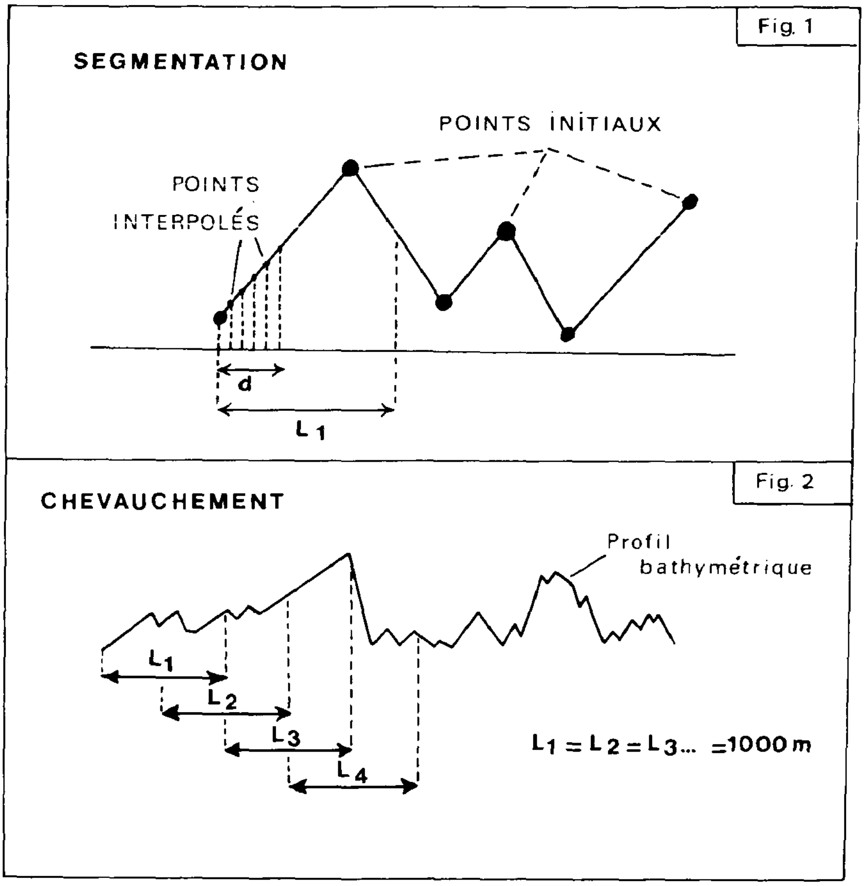


FIG. 1. — Segmentation of data. Interpolated points. Initial points.

FIG. 2. — Overlapping. Bottom profile.

c) Morphometric processing

This operation corresponds to stage 4 of the algorithm. The parameters used were developed during the study of the micro-relief undertaken on behalf of S.H.O.M.

These trials, carried out on very varying types of morphology — coral features, hydraulic dunes, tidal channels and outcrops — revealed that such parameters might apply to segments of different lengths as a function of the desired objective : study of the micro-, meso- or macro-relief.

The proposed parameters were selected with four criteria in mind :

- Checking of digital results must be rapid and simple.
- Classification of the segments according to morphometric values must not be in contradiction with what is observed visually.
- The morphometric classifications obtained must differ from one another.
- The digital results must not vary when an increase in the number of data used for the calculations produces no change in the shape of the profile.

After numerous tests on the plotter, three parameters emerged and were classed in order of importance.

1) Maximum amplitude (DEN) (see fig. 3).

This is the difference in depth between the lowest point (z min) and the highest point (z max) of the segment :

$$DEN = z\ min - z\ max.$$

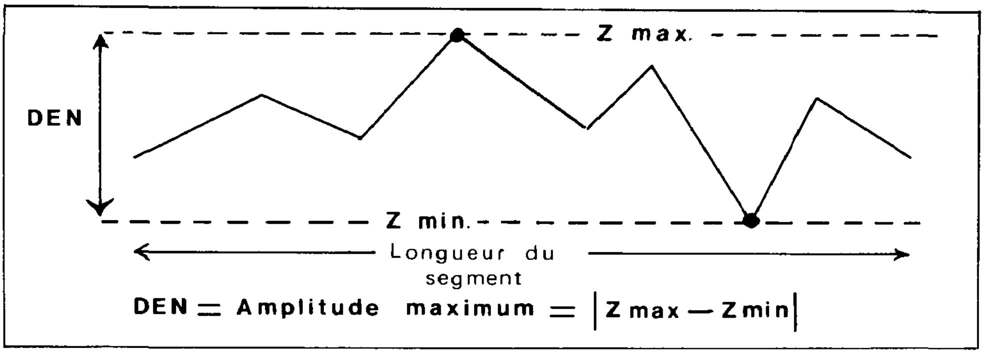


FIG. 3

2) Relief (REL) (see fig. 4).

This is the sum of all differences in elevation in the segment :

$$REL = r_1 + r_2 + r_3 + \dots r_8.$$

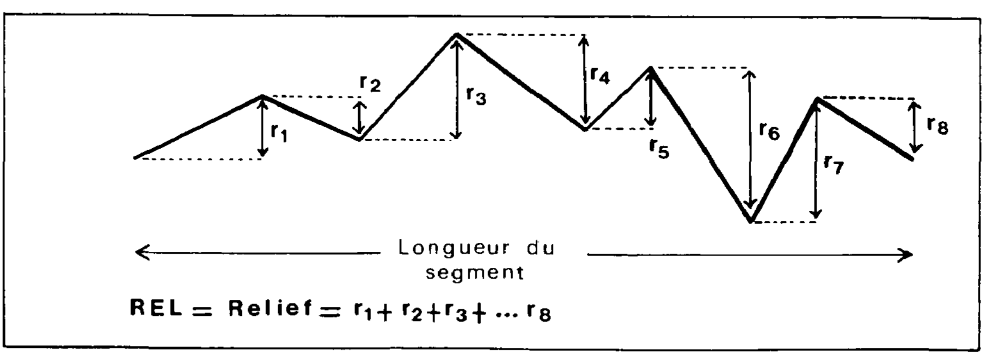


FIG. 4

3) Ruggedness (or irregularity) (RUG) (see fig. 5).

This is equivalent to the difference between the relief and the maximum amplitude of the segment :

$$RUG = REL - DEN.$$

The detailed algorithms of the calculation process and the definition of two other parameters for more specific application were described in an earlier article (FROIDEFOND, J.M. and BERTHOIS, L., 1983).

Before comparing the morphometric analysis with the visual analysis it is necessary briefly to call to mind the latter procedure.

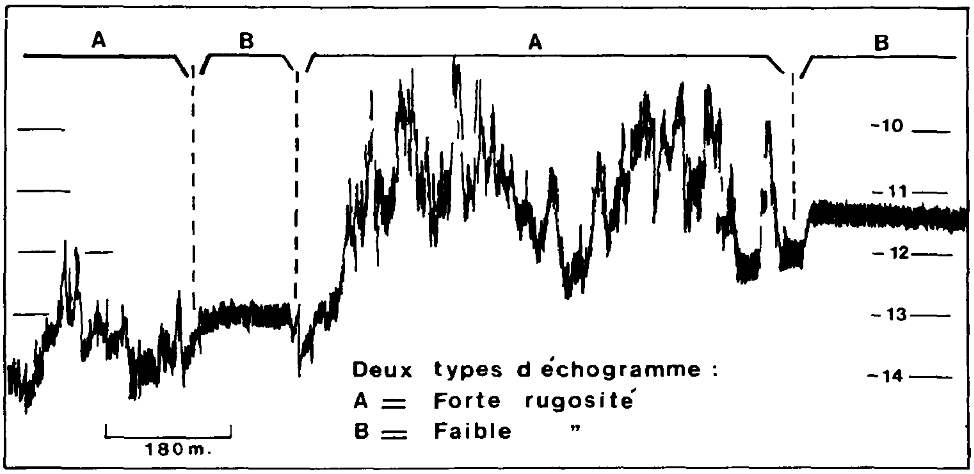


FIG. 5. — Two types of echogram showing — A : high degree of ruggedness; B : low degree of ruggedness.

2. VISUAL ANALYSIS : STUDY AND INTERPRETATION OF ECHOGRAMS

As regards visual analysis by the study and interpretation of echograms we referred to the research by MONAHAN and MACNAB (1974) who made a very sound presentation of the value of this method; DAMUTH (1975) used a similar procedure for the observation of traces recorded by a 3.5 kHz sounder. According to these authors, it is a matter of visually locating several categories of echogram, each corresponding to a "morphologic feature". For the area of Flemish Cape, for example, MONAHAN and MACNAB distinguish four categories of echogram : profiles of the angular, irregular, wavy or smooth type. They also take the ruggedness of the terrain into in their classification. With a shallow seismic profiler of 3.5 kHz, and for an area positioned in the equatorial East Atlantic, DAMUTH classifies echoes according to their thickness and structuring (for example, continuous echoes with sub-jacent parallel reflectors, echoes with overlapping hyperbola, ...). He then correlates them with the nature of the sediments sampled by coring.

II. EXAMPLE OF APPLICATION : COMPARISON BETWEEN VISUAL AND QUANTITATIVE MORPHOLOGIC ANALYSES CONCERNING SOUNDING PROFILES RUN ALONG THE COAST OF MEDOC (S.W. FRANCE)

For this study we used 21 sounding profiles, totalling about 250 nautical miles, run with the help of a Toran radio-positioning system and a Raytheon narrow-beam echo-sounder aboard the survey launch *Ebalia* of the I.G.B.A. (RESSEGUIER, A. DE and FROIDEFOND, J.M., 1978).

1. CHARTING THE AREAS OF GREATER OR LESSER RUGGEDNESS ACCORDING TO VISUAL ANALYSIS

Observation of the sounding profiles enabled distinction to be made between two types of echogram, illustrated in fig. 5 : type A, with very rugged bottom relief, and type B, with flat or regular features.

Several diving expeditions in various sectors in the area studied enabled us to interpret these two types of echogram : "A" echoes, with characteristic pronounced ruggedness corresponding to submerged outcrops, and "B" echoes from soft sediment deposits.

The distribution of these two types of echo was then referred to the length of the sounding profiles (see fig. 6).

By extrapolation, we linked the sectors which showed the same types of echo, which enabled fig. 7 to be drawn, showing the distribution of "rugged" echoes characteristic of outcrops broken in various places by natural indentations (channels) filled with soft sediments : the Amélie, Gurp, Espagnol, Montalivet, Frayres and Mourey channels. This document was drawn up by an experienced person in about 10 days.

2. QUANTITATIVE ANALYSIS

a) Considerations on data recording

We recorded the variations in the traces of the sounding profiles by using a digitizing table on which data is determined point by point, which means that many details must be disregarded.

The number of depth figures recorded in the cassette was in the region of 6,000, whereas the total number of variations recorded along the sounding profiles

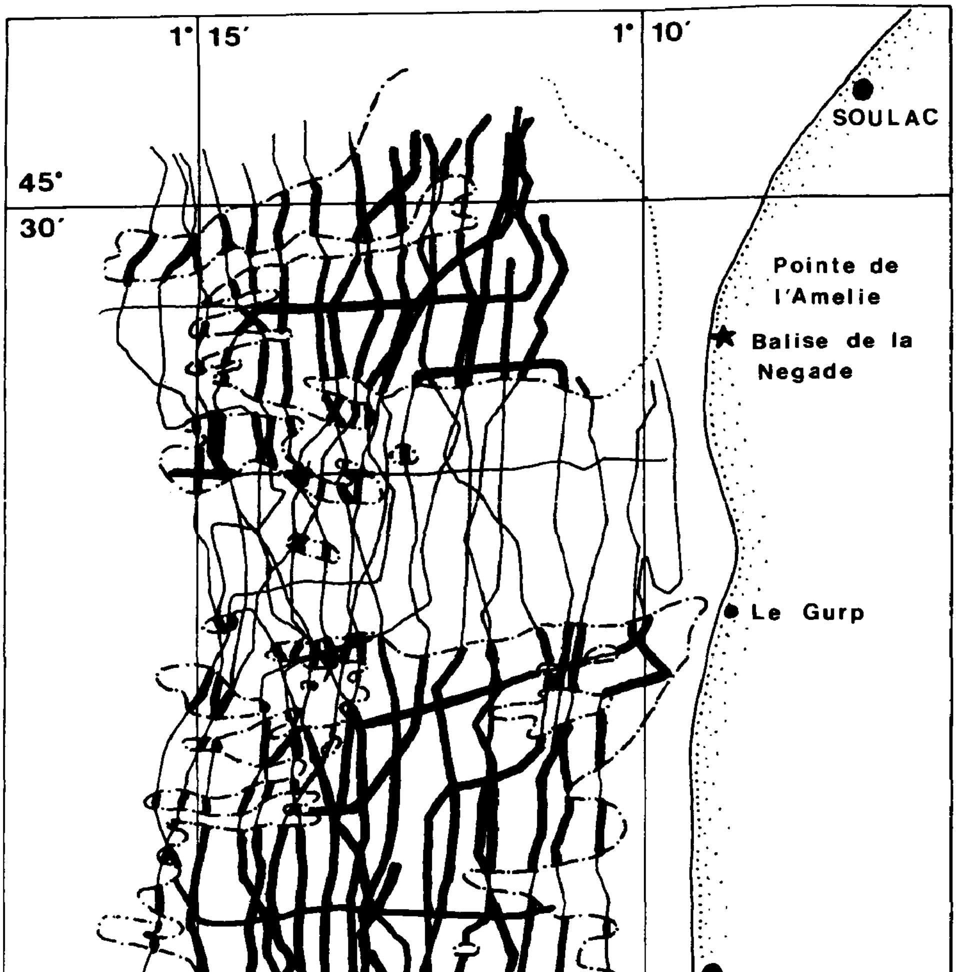

1° 15′
1° 10′
45° 30′
45° 20′
SOULAC
Pointe de l'Amelie
Balise de la Negade
Le Gurp
MONTALIVET
2 km.
Gironde
Cordouan
Monta-livet
FRANCE

Fig. 6

was ten times greater. The result was that the profiles recorded were smoothed in comparison with the actual echogram trace (fig. 8). This smoothing effect plays a minor part in calculation of maximum amplitude since that parameter uses only the extreme points from a portion of 1,000 m in length. Conversely, the elevation of protrusions and the ruggedness of the bottom are greatly attenuated, but we shall see from figures 10 & 11 that the relative variations are maintained. The geographic co-ordinates of the ship's tracks were recorded on a different cassette so as to reduce the effect on the profiles of variations in ship's speed. As regards timing, the recording work necessitated the employing of two persons for about fifteen days. The recorded cassettes were used to draw up plotting sheets at a scale of 1/12 500 and to plot morphometric maps at a scale of 1/25 000. It is obvious that use of a digital sounder and — even more so — of a multi-beam sounder, would be much better adapted to this type of work and would have enabled us to save time and gain very appreciably in accuracy.

b) Maximum amplitude (see fig. 9)

The digital values for maximum amplitude were plotted automatically, using a digitizing table at a scale of 1/25 000 — one figure every 500 metres, though expressing the morphological character for a length of 1,000 metres, since the segments overlap by half.

In order to fulfil the conditions of the experiment, the isometric contours were drawn without taking into account the bathymetry and the arrangement of the outcrops.

Comparison between fig. 7, representing the arrangement of outcrops, and fig. 9, where maximum amplitudes are shown, gives rise to the following remarks :

- The Amélie channel is insufficiently well portrayed; its shape is not apparent; this is replaced by a rather high amplitude at its eastern extremity, by values from 3 to 5 at 45°29′ and 1°13′; in addition, seawards at 45°28.7′ and 10°15′, there exists a peak with an amplitude of 5.
- The Gurp channel is more characteristically portrayed with amplitudes of less than 1 or between 1 and 2; there is a limited area where this rises to œ 3. However, peaks between 45°26′ and 45°27′ and 1°15′ are not apparent in the amplitudes.
- The Espagnol channel is marked by low amplitudes between 1 and 2; the same is true of the Frayres channel.
- The Mourey channel is marked by amplitudes of less than 1.

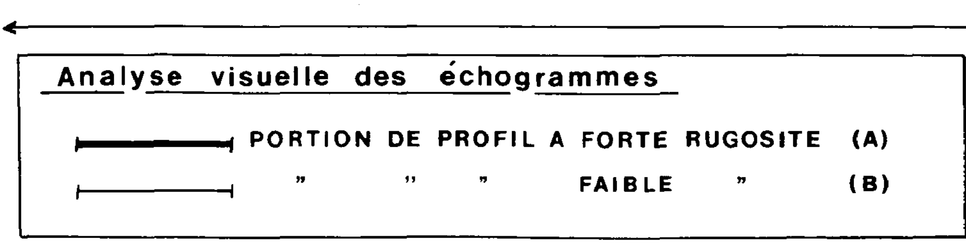
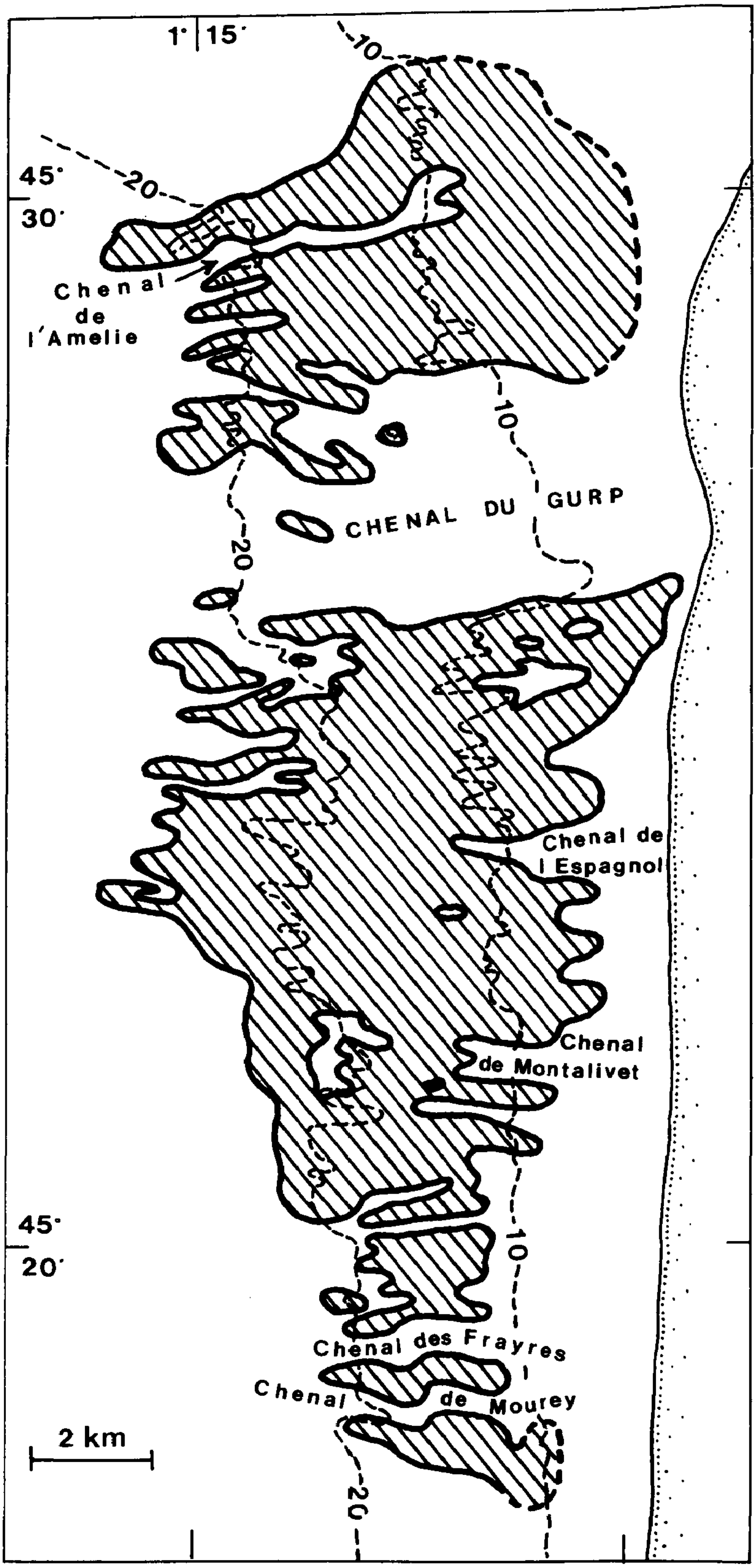


FIG. 6. — Read at bottom of figure : Visual analysis of echograms. Length of profile showing high ruggedness (A) or low ruggedness (B).



1° 15'
45° 30'
45° 20'
10
20
Chenal de l'Amelie
CHENAL DU GURP
Chenal de l Espagnol
Chenal de Montalivet
Chenal des Frayres
Chenal de Mourey
2 km

FIG. 7

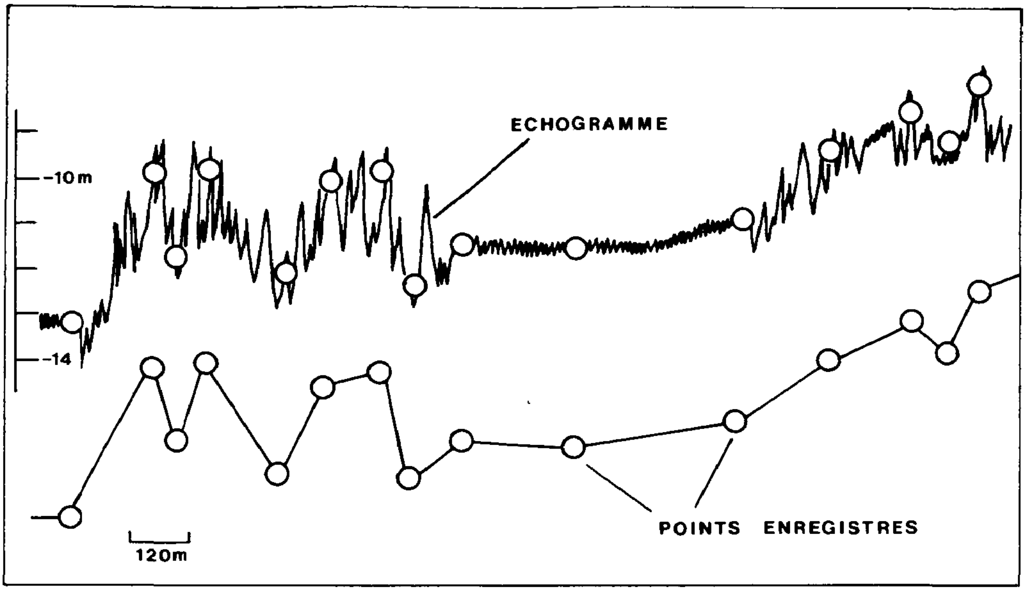


FIG. 8

On the whole, the amplitude variations clearly distinguish the rocky areas but do not portray limits of these with as much accuracy as visual analysis.

c) **Ruggedness** (see fig. 10)

Ruggedness values may reach more than 20 at certain points. In order to simplify and shorten the work, therefore, one may draw isometric contours at intervals of 5, which will provide the 5 values in fig. 10.

Comparison between figures 7 and 10 shows fairly good correlation of limits of rocky areas and areas of pronounced ruggedness.

The Amélie channel is marked by only one indentation to the west.

The Gurp channel is very well identified by very little ruggedness. The small rock outcrops situated towards the western exit appear in some values of 5 which are not always at the exact latitude.

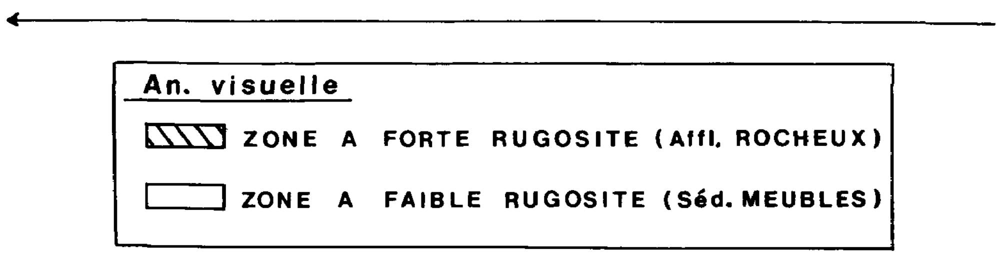


FIG. 7. — Read at bottom of figure : Visual analysis. High ruggedness area (rock outcrops). Low ruggedness area (soft sediments).

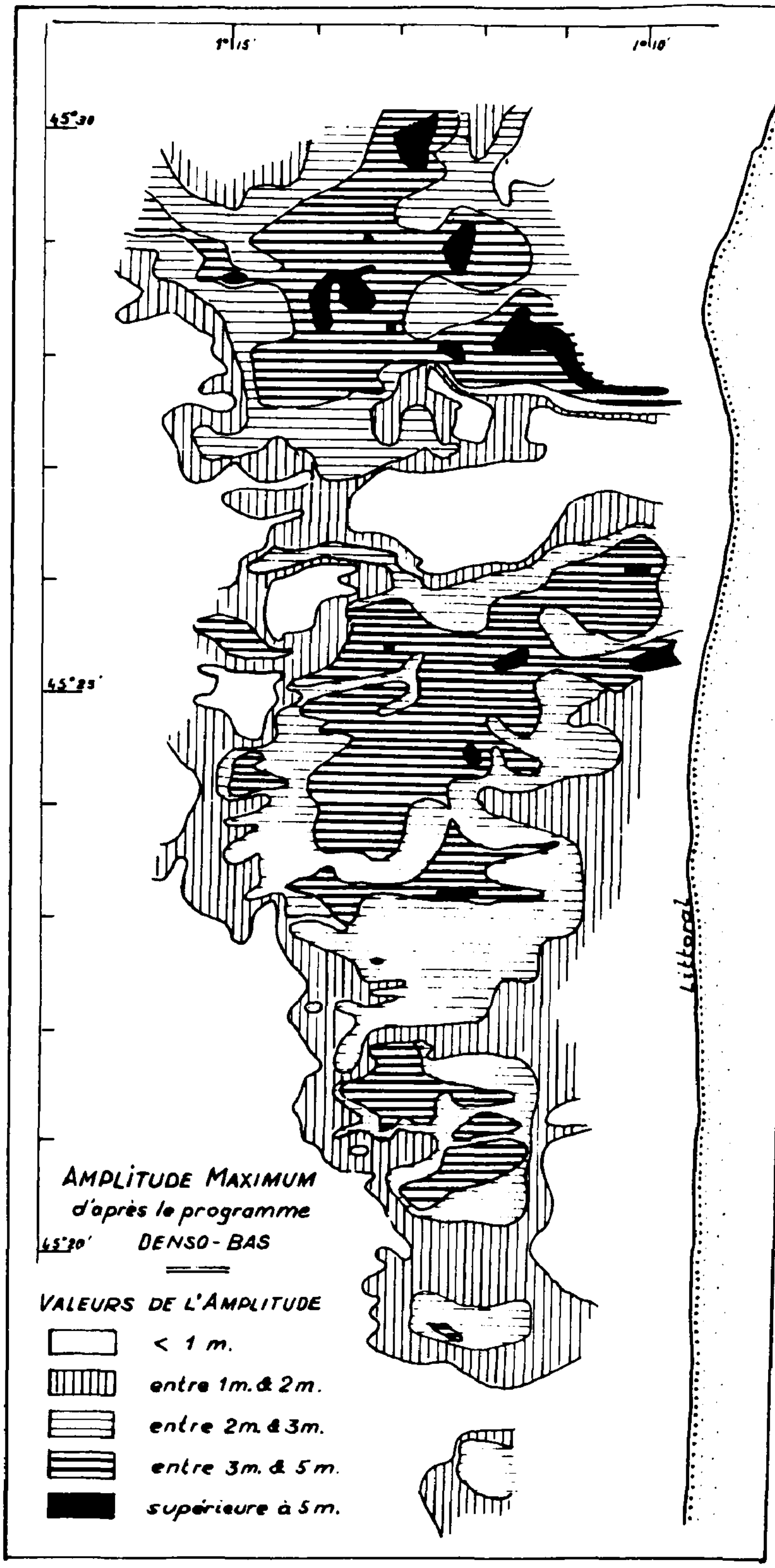


FIG. 9. — Read at bottom of figure : Maximum amplitude according to DENSO-BAS programme. Amplitude values : < 1 m; between 1 and 2 m; between 2 and 3 m; between 3 and 5 m; over 5 m.

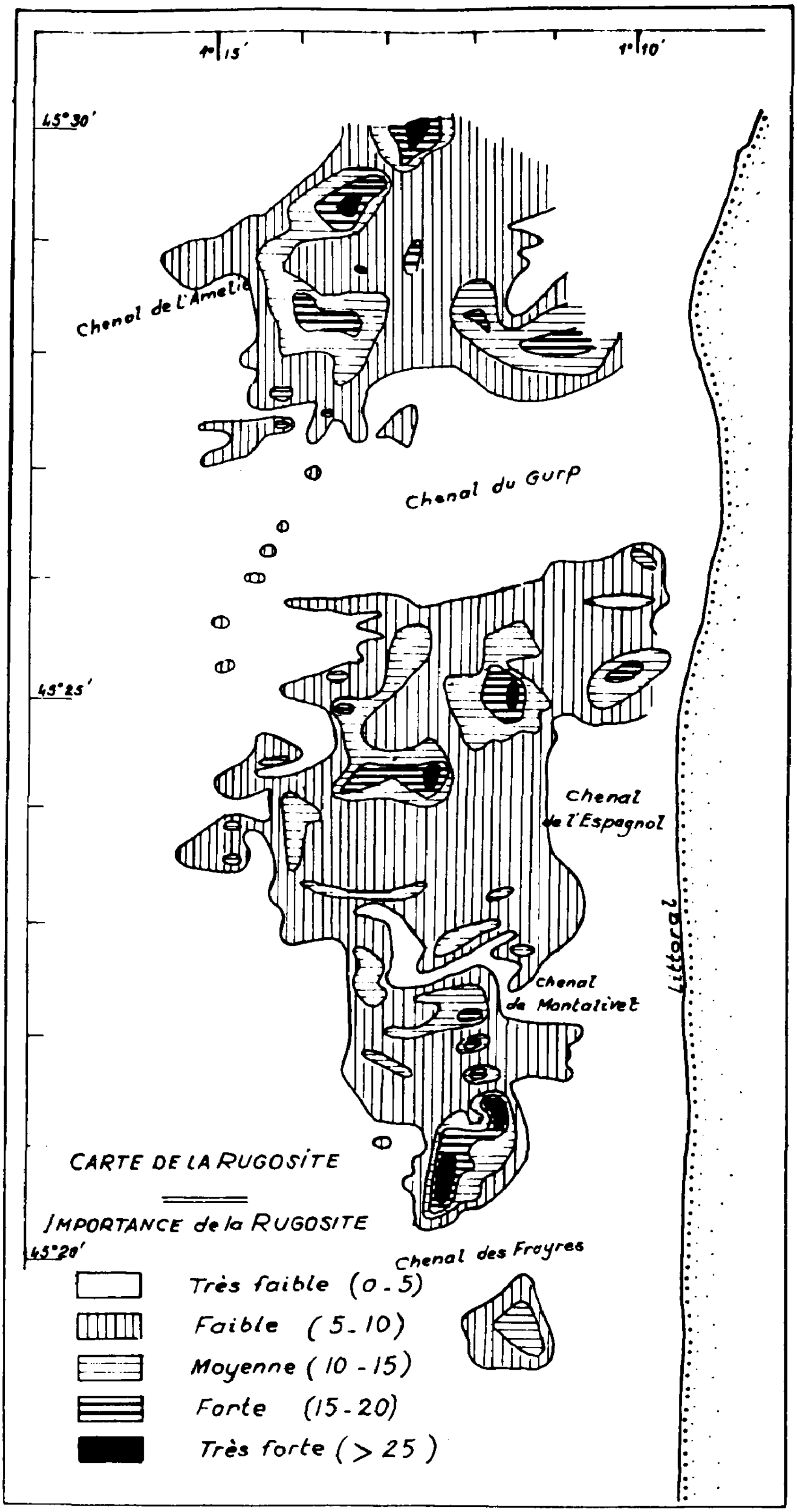


FIG. 10. — Read at bottom of figure : Ruggedness map. Significance of ruggedness values : very low (0-5); low (5-10); mean (10-15); high (15-20); very high (> 25).

The Espagnol and Montalivet channels are situated in areas whose ruggedness is less than 5; the sandy area to the west of the Montalivet channel is marked by a falling of the ruggedness value to 5.

The sandy spit to the south of Montalivet at 45°21.5′ ends in the west in a rocky peak marked 10-15 (i.e. average ruggedness).

To the south, between 45°21.5′ and 45°20′, the rocky area is identified by ruggedness rising to 25.

The Frayres and Mourey channels have ruggedness values of 1 to 5, but the rocky area to the south east of Mourey, at 45°19′, is identified by a ruggedness value of 10.

To sum up, despite the simplification adopted in drawing the isocontours of degrees of ruggedness, one obtains a more satisfactory portrayal than from the contours of maximum amplitude.

d) Superimposing the contours of outcrops and the iso-values of degrees of roughness (see fig. 11)

This is a portrayal by iso-contours drawn every 2 m. This contouring, less schematic than the previous example, is carried out with the same calculated results :

NORTHERN AREA from 45°30′ to 45°28′

To the north of the Amélie channel. There are two points marked by ruggedness greater than 20 which clearly identify the area of pronounced relief.

Between the Amélie and Gurp channels. One encounters high ruggedness values here, though these are less than 20. They are numerous south and south west of the rocky area but gradually disappear towards the east and especially to the north east.

To the north west of the Gurp channel, between 45°27.5′ and 45°27′. A rocky patch with a very complex outline and with degrees of ruggedness between 4 and 10.5. There exists, in addition, a small rocky patch situated to the east of the former; it lies in an east-west direction and is rather modestly represented by an area lying in a north-west direction with a maximum degree of ruggedness of 6.6.

It must finally be noted that in the part considered to be sandy there is one ruggedness value of 12.6 and another of 10.

The Gurp channel is a sandy area lying right across the bathymetric survey area in an east-west direction. The degree of ruggedness is for the most part less than 2, which is very satisfatory. However, we note :

- a ruggedness of 12.4 near the south-east limit of this area;
- ruggedness of 5.1 and 5.4 near the western limit of the sandy area; the second of these values is adjacent to a columnar peak;
- the very small peaks are not identified by any noticeable increase in ruggedness.

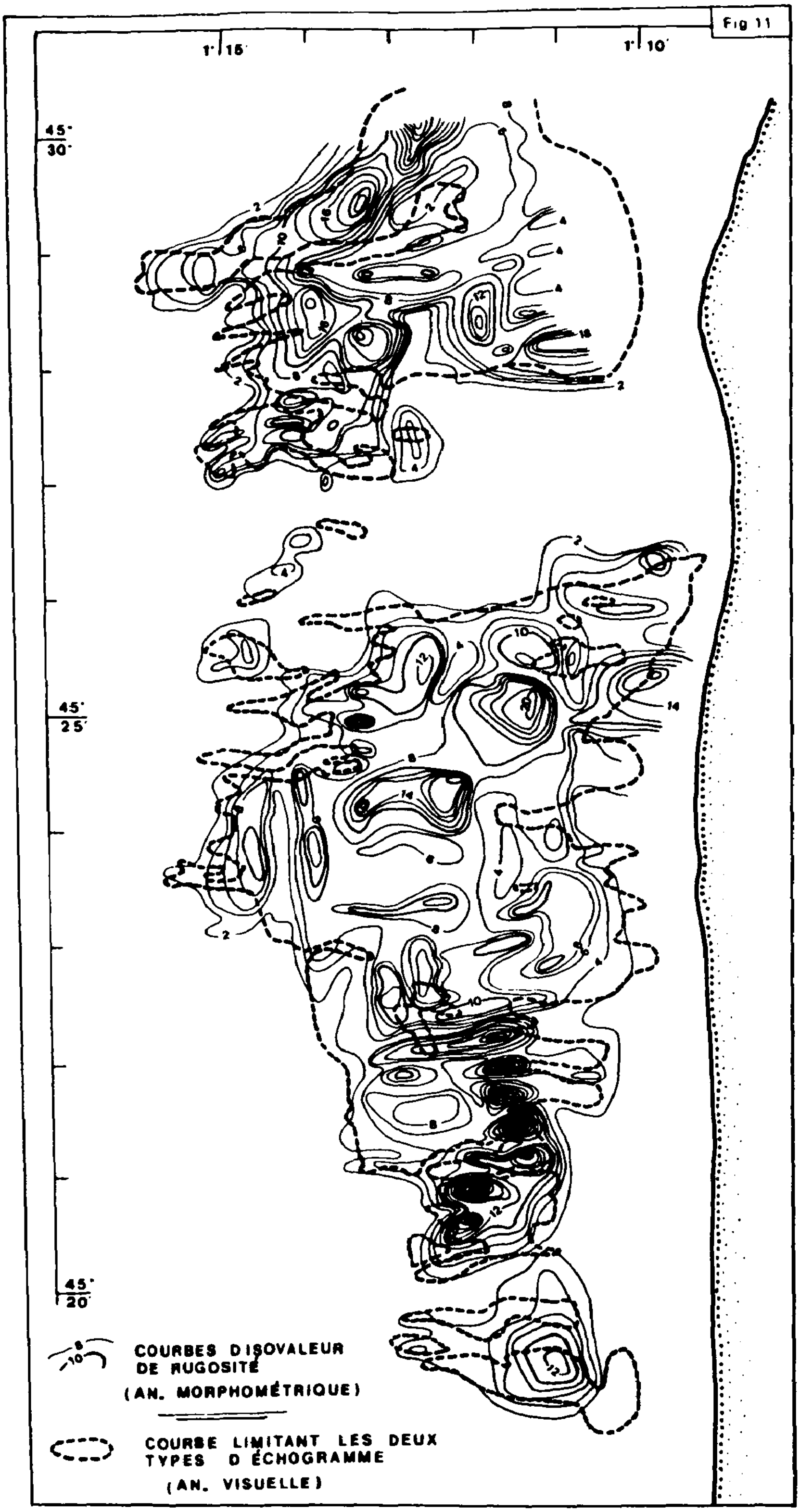


FIG. 11. — Read at bottom of figure : Iso-contours of ruggedness (morphometric analysis). Curve delineating the two types of echogram (visual analysis).

SOUTHERN AREA

— *Rocky area* extending from the Gurp channel, i.e. between 44°26′ and 45°24′, the latitude of the Espagnol channel.

The distribution of the ruggedness values is satisfactory on the whole, the values for this parameter being between 22.5 and 11.5. Some anomalies are noted, however :

1) Near the eastern limit, at 45°25′, there is a ruggedness value of 19.8 lying just at the edge of the rocky area.
2) At 45°24.5′ a sandy spit which cuts into the western limit intersects a ruggedness value of 11.9.

— *Rocky area* extending from the Espagnol channel to the Montalivet channel.

The ruggedness values are a little lower than the previous ones; the maximum attained is only 13.9. There is no significant anomaly to point out.

— *Rocky area* extending from the Montalivet to the Frayres channel.

The ruggedness values are notably higher than in the previous area : they are over 25 in four cases and over 15 in four. It is in the north eastern zone that they are the lowest.

It is interesting to note that in a sandy spit situated to the south of the Montalivet channel a peak is observed at the eastern end of this deposit, marked by a high ruggedness value of 16.2.

— *Rocky area* to the south of the Frayres channel and the Mourey channel.

1) The rocky area between the Frayres and Mourey channels is not identified by any notable variations in ruggedness.
2) Near the western entrance of the Mourey channel there is a rocky area of limited extent which is identified by a slight increase in ruggedness, i.e. from 2 to 4.
3) In the most extensive rocky area which lies to the south east, there is a marked increase in ruggedness, rising to a maximum of 13.3. It is relevant to note that this increase in the ruggedness parameter partially extends into the eastern part of the Mourey channel.

Thus the new interpretation of the ruggedness of bottom features with contours drawn every 2 metres is better than the previous drawing where they were spaced at 5-metre intervals.

CONCLUSION

The visual analysis of sounding profiles is certainly more thorough and provides information that no calculation of parameters or any planimetric portrayal of the morphology could obtain with the same accuracy. An experienced person can recognize at first glance the presence of rock outcrops, or of undersea dunes and ripples, for example, and if the sounder is a low frequency type (30 kHz) one can also distinguish the structure of the superficial sediments (hardened or soft rocks). The study of figures 7, 9, 10 and 11 showed that morphometric analysis by segmentation was less accurate in delimiting rocky areas in the case considered. In fact, the processing attributes to each bracket a value representing 1,000 m, i.e. the morphologic features existing in that portion of the sounding profile. The result is that the limit between a rocky area and a sandy area will not be marked by a line but by a less pronounced fall in the relief parameters. That is why, when a very narrow channel is encountered, it rarely appears as an area totally without relief, but rather as an area with less pronounced relief. It is possible, of course, to reduce the length of the segment to increase the power of resolution. But in shortening the segment we reduce the data sample, which is prejudicial for cartography. As regards zones of pronounced ruggedness (outcrops of rock), visual analysis could not be used because the variations in the relief were too diverse and too numerous to be memorized by the observer. For these regions, morphometric analysis provides an appreciable amount of information. Variations in amplitude and in ruggedness show that outcrops are of different types. For example, to the north of the Gurp channel the amplitude is very high, whereas it is distinctly less so to the south of the Montalivet channel where, on the other hand, the degree of ruggedness is very high. Thus the morphometric analysis completes the visual analysis in areas where the latter is not effective. The digital values of the data sample also lend themselves better to comparative evaluations whether for studying acoustic backscatter from the bottom or geologic reconnaissance of superficial sediments.

REFERENCES

BERTHOIS, L. (1977-1978) : Pratique de la bathymétrie. *Bull. Inst. Géol. Bassin d'Aquitaine*, Bordeaux, No. 21, 224 p., 106 fig. & No. 23, pp. 225-296, 47 fig.

BERTHOIS, L. & FROIDEFOND, J.M. (1981) : Contribution à l'étude des vallées sous-marines de la côte Est-Africaine. Essai d'un traitement informatique des profils de sondage. *Bull. Inst. Géol. Bassin d'Aquitaine*, Bordeaux, No. 30, pp. 97-124, 39 fig.

BERTHOIS, L. & FROIDEFOND, J.M. (1983) : Traité de bathymétrie. *Mém. Bull. Inst. Géol. Bassin d'Aquitaine*, Bordeaux, No. 15, 159 p., 160 fig.

BOGOROV, G.V. & LLIN, A.V. (1971) : Toward a method of quantitative evaluation of bottom relief irregularity. *Oceanology*, Moscow, Vol. II, No. 2, pp. 270-276, 4 fig.

CHARLOT (1979) : *Rapport d'avancement sur « Etude de la condensation de la sonde aux différents niveaux, y compris la recherche des paramètres caractéristiques du microrelief complétant le choix de sonde archivé »*. Rapport No. 462, EPSHOM E.G.G., Brest, 112 p., 91 fig.

DAMUTH, J.E. (1975) : Echo character of the Western Equatorial Atlantic floor and relationship to the dispersal and distribution of terrigenous sediments. *Marine Geology*, Amsterdam, vol. 18, pp. 17-45, 12 fig.

FROIDEFOND, J.M., GRIBOULARD, R. & PRUD'HOMME, R. (1981) : *Etude des paramètres caractéristiques du microrelief sur les profils de sonde*. Rapport SHOM, Brest, Convention 7/79, 171 p., 85 fig.

FROIDEFOND, J.M. & BERTHOIS, L. (1983) : Essai de représentation planimétrique des paramètres de morphologie sous-marine. *Bull. Inst. Géol. Bassin d'Aquitaine*, Bordeaux, No. 33, pp. 39-60, 19 fig.

LEPLEY, L.K. (1966) : Ocean terrain analysis. *Intern. Hydrogr. Review*, Monaco, vol. XLIII (1), pp. 97-113, 11 fig.

MONAHAN, D. & MACNAB, R.F. (1974) : *Meso morph map. The mapping of medium-scale morphology from echograms.* 13th Annual Canadian Hydrographic Conference, Burlington, Ont., pp. 111-126, 9 fig.

NAUDIN, J.J. & PRUD'HOMME, R. (1971) : Méthode d'analyses morphologiques et morphostructurales d'interprétation des topographies et des bathymétries dans les domaines continentaux et marins. *Bull. Inst. Géol. Bassin d'Aquitaine*, Bordeaux, No. 10, pp. 111-144, 54 fig.

PRUD'HOMME, R. (1972) : *Analyse morphostructurale appliquée à l'Aquitaine occidentale et au golfe de Gascogne. Définition d'une méthodologie cartographie interprétative.* Nat. Sc. Thesis, Bordeaux I Univ., No. 353, 365 p., 222 fig.

RESSEGUIER A. DE & FROIDEFOND, J.M. (1978) : Présentation d'une carte des affleurements rocheux sous-marins au sud de l'embouchure de la Gironde. *Bull. Inst. Géol. Bassin d'Aquitaine*, Bordeaux, N° 24, pp. 119-124, 3 fig.

TERRY R.D. & STEVENSON, R.E. (1957) : Microrelief of the Santa Monica Shelf, California. *Bull. Geol. Soc. Am.*, New York, vol. 68, pp. 125-128, 4 fig.