A STUDY OF SOME CARTOGRAPHIC TECHNIQUES USED BY BRITISH OCEANOGRAPHERS

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This study was carried out as part of an investigation of the cartographic techniques employed by oceanographers and was presented to the ICA Working Group on Oceanic Cartography at its meeting held in conjunction with the Seventh International Conference on Cartography, Madrid, April 1974. An examination was made of the oceanographic literature, especially *Deep Sea Research*, since 1970 and additional ideas and information were obtained by personal contact and from correspondence with British oceanographers.

Cartographic methods used by British oceanographers to illustrate their work appear to fall into two main categories. They either show relationships between (and spatial variations in) parameters and describe processes at any given point in time; or they indicate the variations of these parameters and processes over an interval of time, or the frequency of occurrence of particular phenomena.

Firstly, those maps or diagrams which aim to show the situation at a given time — although all the observations and acquisition of data illustrated would not necessarily have taken place simultaneously.

The simplest diagram in use is the graph, used to relate two dependent variables, and readily lending itself to automatic plotting. Since the well-known *line graph* is more usually employed with time as an independent variable, *scatter graphs* appear to be more appropriate for the instantaneous picture. PINGREE and PLEVIN (1971, figure 1) show the common salinity temperature diagram with scatter values distinguished by different forms of symbol to illustrate the depths at which observations were taken. Sigma-t lines have been superimposed. LINDEN (1973, figure 2) has used the scatter technique to determine the exact relationship between the width of salt fingers and temperature gradients within them. Logarithmic scales have been used, being particularly suitable for showing rates of increase rather than absolute changes in quantity.

Bar graphs, on the other hand, emphasise actual quantities in comparing separate elements, rather than variations or relationships. JONES (1971, figure 3) uses this technique to show the composition of core samples. The best-known medium for the illustration of processes and distributions

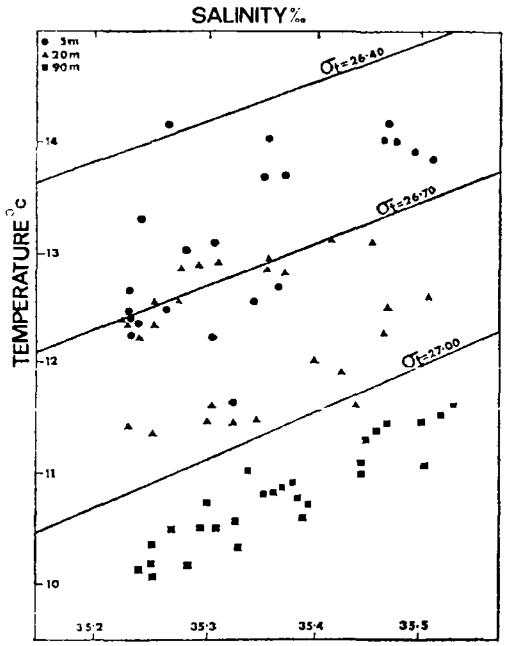

FIG. 1. — Temperature and salinity values for the upper 100 m between 10 June and 4 July 1970.

R.D. PINGREE and J. PLEVIN. A description of the upper 100 m at Ocean Weather Station "Juliett", *fig. 7(b)*. *Deep Sea Research*, January 1972, Pergamon Press Ltd.

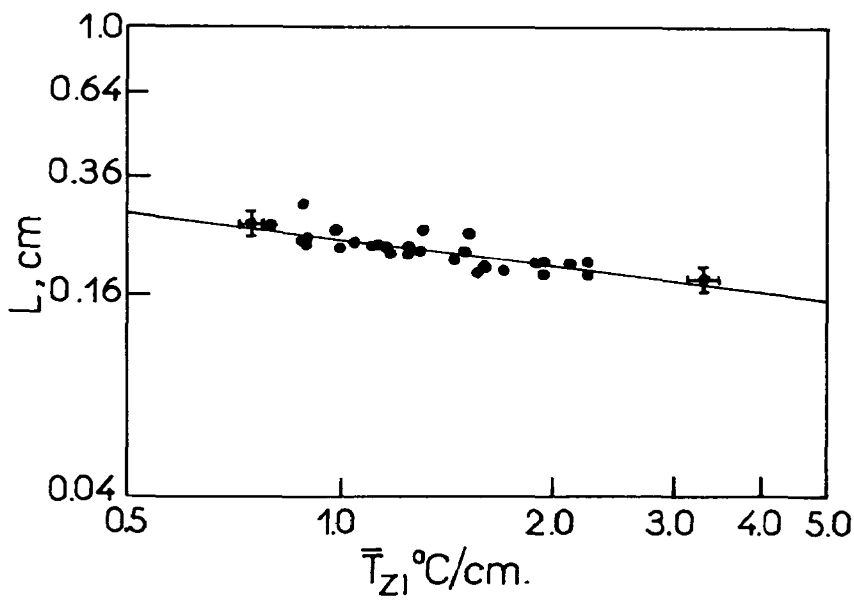

FIG. 2. — The width of the fingers L plotted against the temperature gradient $\bar{T}_z$ in the fingers. The line is a fit to the data with slope —1/4.

P.F. LINDEN. On the structure of salt fingers, fig. 5. *Deep Sea Research*, April 1973. Pergamon Press Ltd.

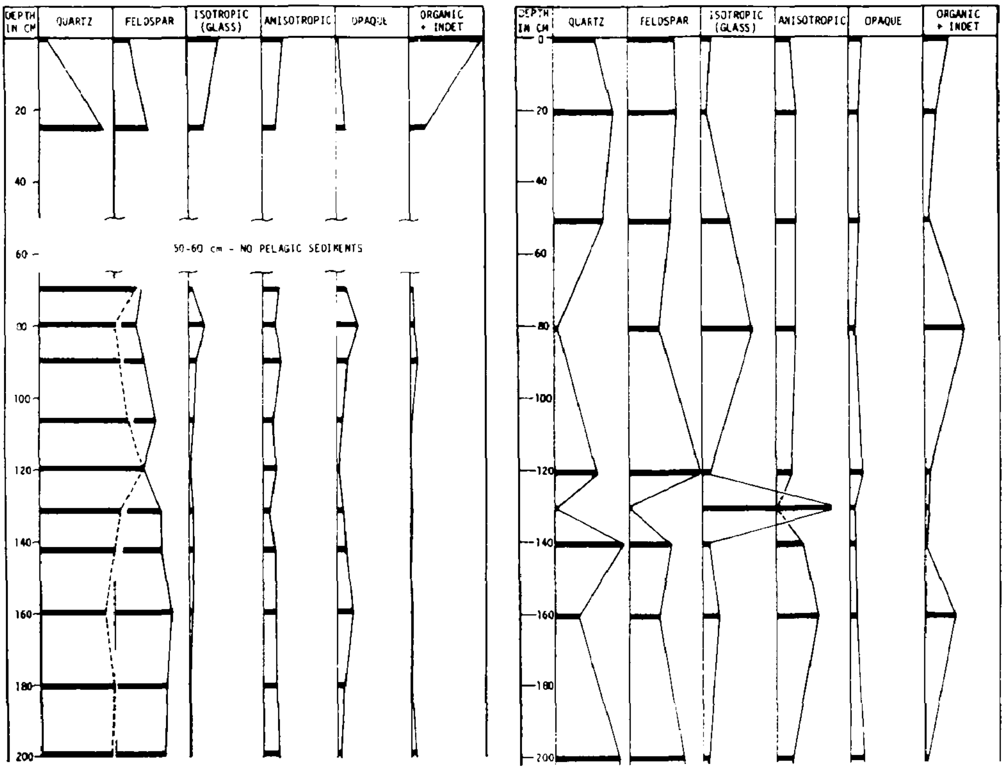

FIG. 3. — Composition of the sand-sized acid insoluble material in cores D5638 and D5620. The series of curves for D5638 are presented on the right half of the diagram with those for D5620 on the left. Several hundred grains were counted in each sample and the results are displayed in percentages. The full width of each column represents 50%.

T.A. DAVIES and E.J.W. JONES. Sedimentation in the area of Peake and Freen Deeps (mid-Atlantic Ridge), fig. 7. *Deep Sea Research*, June 1971, Pergamon Press Ltd.

spatially is, of course, the *map*. The simplest form restricts itself to two dimensions only, usually showing the locations of stations or ships' tracks or the quantitative distribution of parameters with the use of isopleths. Any attempt to introduce the third dimension of depth must involve a further technique. For instance, COOPER (1960, figure 4) in his description of streamline patterns uses the thickness of line to show whether the streams are sinking or rising. LANGHORNE (1973, figure 5) spaces his sounding lines sufficiently far apart to be able to have them plotted, automatically, as vertical sections *in situ*, facilitating the further stage of superimposing morphological zones. A method of obtaining a good three-dimensional effect, which has become feasible with the advent of automatic plotting, is the *anaglyph map*, e.g. the map of the bathymetry of the Gulf of Aden by LAUGHTON (1970) [1]. Each contour has been drawn twice, in red and green, the red contours being displaced to the right and the green contours to the left, or vice versa when depicting relief on land. The amount of displacement is proportional to the actual depth or height of the contour, and when viewed through red and green spectacles the

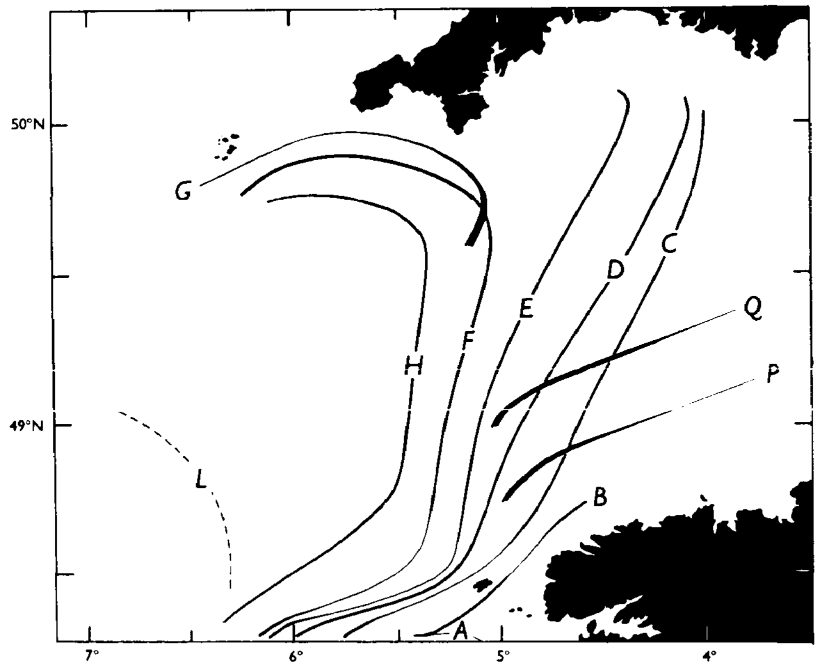

FIG. 4. — The pattern of streamlines of the deeper water in August 1950. The direction of movement is from the south-west towards the north. Attenuation of the line indicates sinking, strengthening of the line indicates rising of a water stratum.

L.H.N. COOPER. Water flow into the English Channel from the South-West, fig. 12. *J. Mar. Biol. Ass. U.K.* (1960), Vol. 39, pp. 173-208.

impression is one of a three-dimensional model. A successful three-dimensional effect is also given by CASTON (1969) by means of a series of salinity sections (figure 6) with a key map (figure 7) of the stations occupied along the ship's track in the Golfe du Lion.

Vertical sections themselves are an extremely common method of showing meridional or zonal circulation or distribution of parameters. GILL (1971, figure 8) uses them to show circulation in a model ocean as calculated from numerical experiments. He has used logarithmic scales to accommodate the relatively large vertical range in depth. COOPER (1960, figure 9) shows the zonal distribution of density west of Ushant and distinguishes the separate water masses by variations in intensity of stippling.

Another technique in the depiction of three dimensions is the *block diagram,* usually in simplified form illustrating the characteristics of water masses, as in COOPER's representation of the twisting of a streamline as it passes north-west of Ushant (1960, figure 10). Since few of the rather intangible oceanographic parameters lend themselves to this particular technique block diagrams are not commonly used.

The illustration of processes rather than quantifiable parameters can be achieved by *flow charts* — a simplified method of showing successive

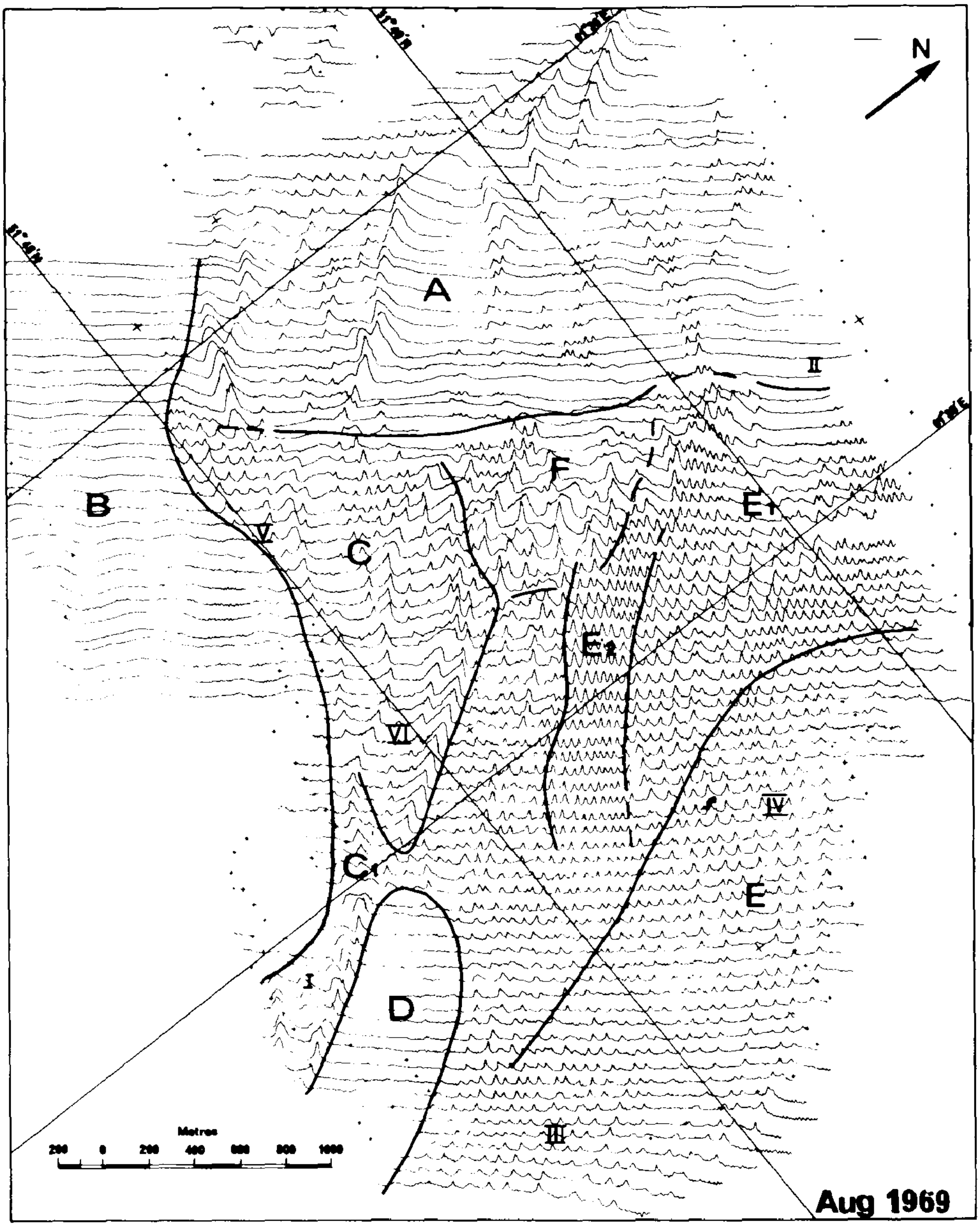

Fig. 5. — Spatial diagram of the sandwave field with superimposed morphological zones. Vertical to horizontal scale ratio 20/1. (Roman numerals I-VI locations of side-scan sonar records).

D.N. Langhorne. A sandwave field in the Outer Thames Estuary, fig. 3. *Marine Geology*, Feb. 1973.

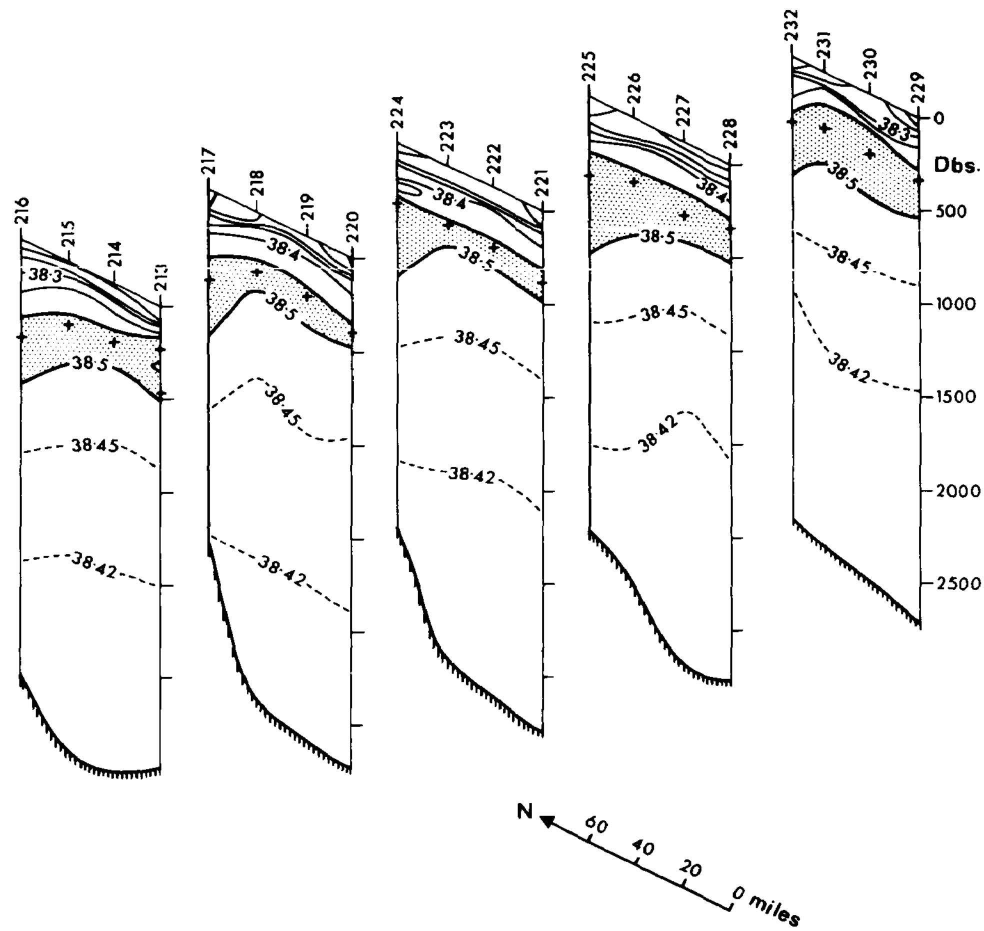

FIG. 6. — Salinity sections in the Golfe du Lion.
G. CASTON. Institute of Oceanographic Sciences, 1969.

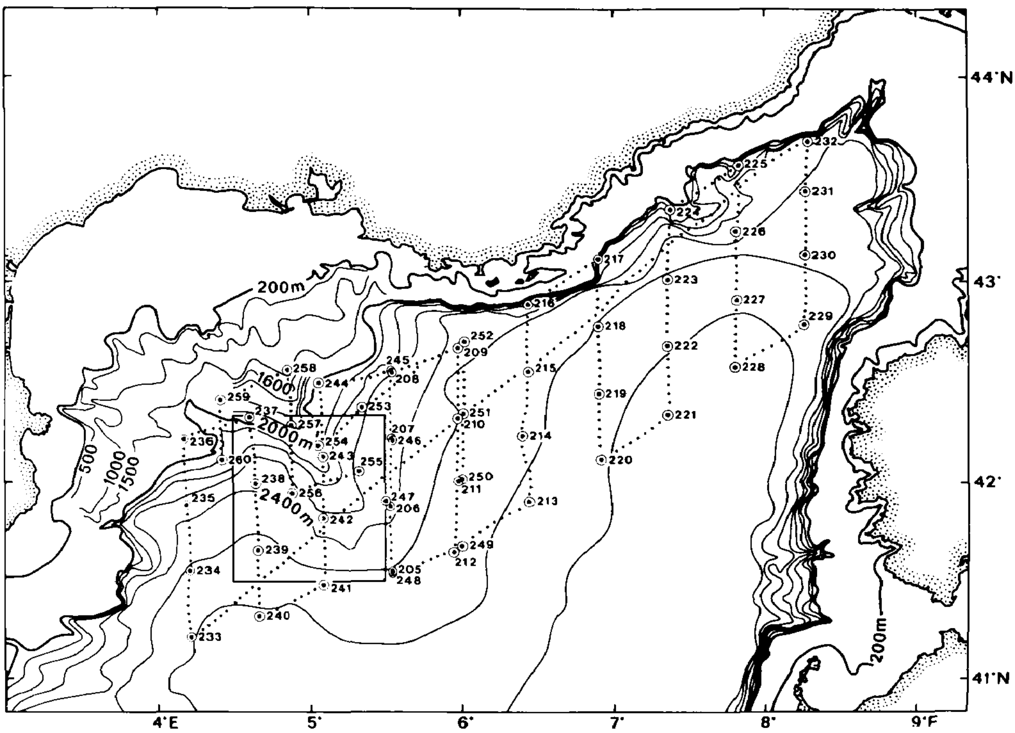

Fig. 7. - Ship's track and oceanographic stations, Golfe du Lion. G. Caston. Institute of Oceanographic Sciences, 1969.

movements through a process, e.g. Mauchline (1972, figure 11) demonstrating the transfer of nutrients. Another interesting method is the succession of profiles and pictorial diagrams indicating the stages of a process used by Woods and Wiley (1972, figure 12) to illustrate billow mixing.

This idea of a series of diagrams or maps depicting the situation at different stages or times is the simplest form used in the *second* category of cartographic methods, which is concerned with showing how parameters vary with time.

Steele, Baird, and Johnston (1971, figures 13A and 13B) use two successive series of maps of the same area to show observations of four parameters taken on two separate occasions, twelve days apart. Although a graded series of shading has been used to enhance the visual effect, the technique is not completely successful since the sequence and values of shading vary from parameter to parameter and between successive observations of the same parameter. However, the choice of black to represent the maximum values of salinity and nitrate and the minimum values of temperature and chlorophyll effectively shows the correlation between them.

Another way of solving the temporal problem is by the use of a *progressive vector diagram*. Here, vectors at one point, for example where

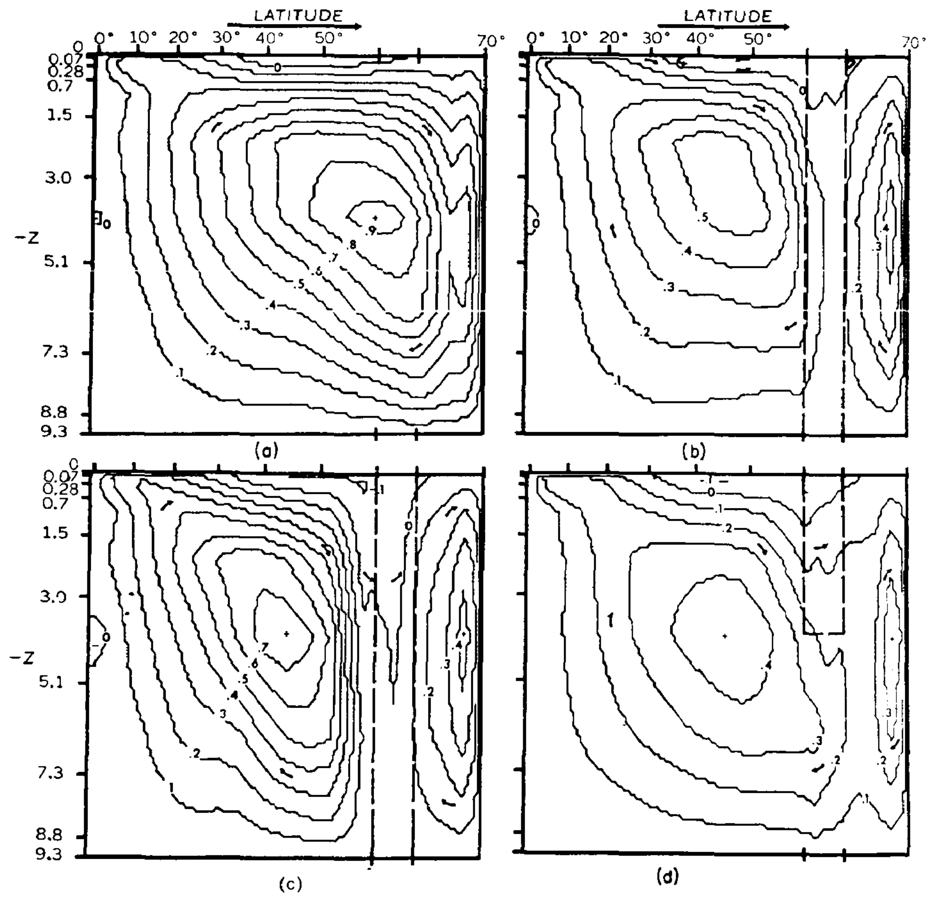

FIG. 8. — Meridional circulation in the model ocean for cases (a) 14-1 (closed basin), (b) 15-1 (deep gap, linear surface-temperature distribution), (c) 16-1 (deep gap, curved surface-temperature distribution), and (d) 18-1 (shallow gap, linear surface-temperature distribution).

A.E. GILL and K. BRYAN. Effects of geometry on the circulation of a three-dimensional southern-hemisphere ocean model, fig. 6. *Deep Sea Research*, July 1971. Pergamon Press Ltd.

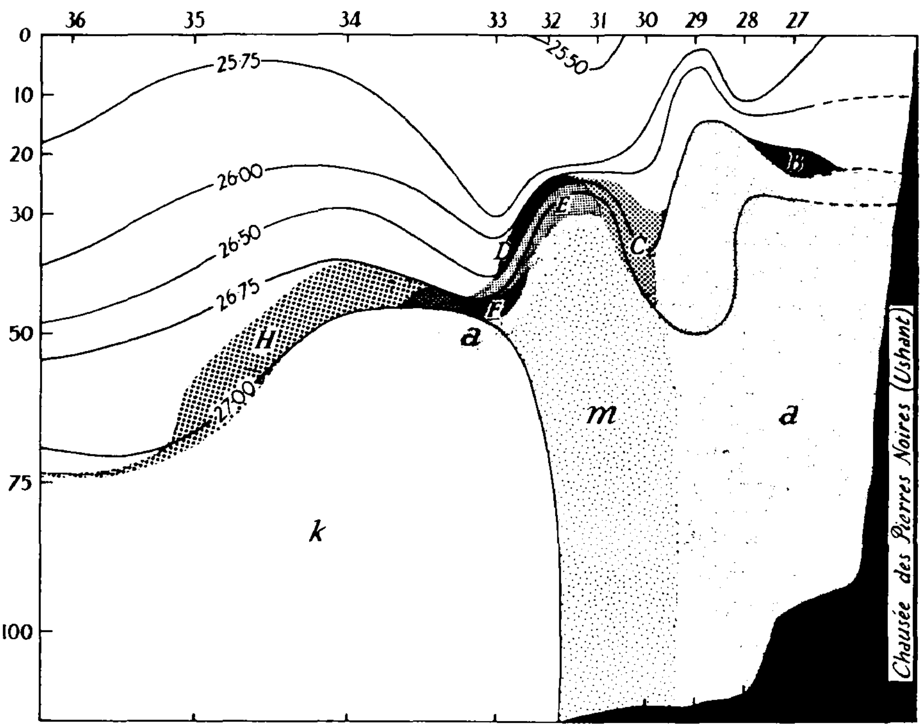

Fig. 9. — Density (σ_t) section west of Ushant along latitude 48° 20′ N on 7 August 1950 with destinations of the water in and below the thermocline. Waters which were to enter the English Channel east of a line drawn from Ushant to Scilly are denoted by capital letters, whereas lower case letters indicate waters which were not to enter the Channel.

L.H.N. Cooper. Water flow into the English Channel, fig. 9. *J. Mar. Biol. Ass. U.K.* (1960), Vol. 39, pp. 173-208.

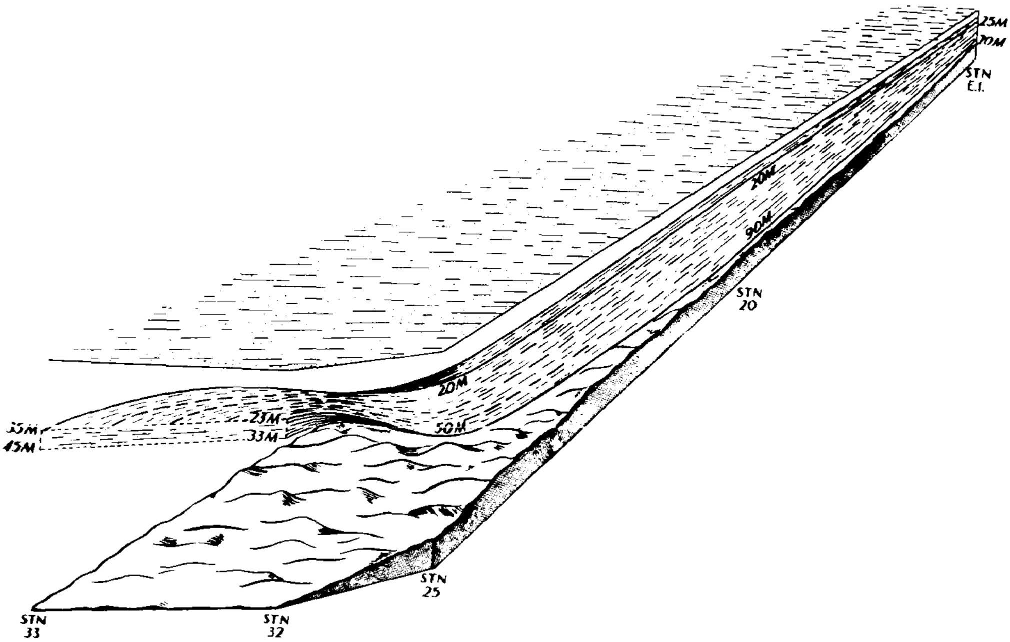

FIG. 10. — A block diagram to show how water lying horizontally in the thermocline west of Ushant twists in a vertical plane through a right angle as it passes north-west of Ushant to occupy the subthermocline vertical column in mid-Channel (station 20) and at E.I. The lower contour passes through the position of station 25 at 50 m depth. The upper contour, however, passes not through station 25 but through a position some miles to the north-west.

L.H.N. COOPER. Water flow into the English Channel, fig. 8. *J. Mar. Biol. Ass. U.K.* (1960), Vol. 39, pp. 173-208.

a current meter is situated, are joined in succession. SWALLOW (1971, figure 14) has used a computer-generated vector diagram for readings from current meters on the Biscay Slope — changes in rate and direction may be determined, but there is a false impression of spatial movement. He has also illustrated water movement in the Golfe du Lion by means of a film technique, the frames consisting of successive diagrams of data from current meters and floats. One set of diagrams represents readings at 12-hourly intervals, broken lines showing vectors at each current meter and solid lines the movement of each float. The second set of diagrams shows the same situation at 2-hourly intervals by the use of coloured dots which appear to move outwards from each meter station. Fig. 15 is a composite of the first set of diagrams.

The most usual way of showing variations of characteristics with time is by the use of *line graphs*. PITT, CARSON and TUCKER (1973, figure 16) have shown how wind and current speeds altered over ten days and the relationship between them, by superimposing the graphs of the two parameters, which are distinguished by different line symbols; the velocities are also correlated with changes in their directions, which are indicated by arrows above. The different velocity units can conveniently be applied to a single set of sub-divisions on the vertical axis. Multiple line graphs

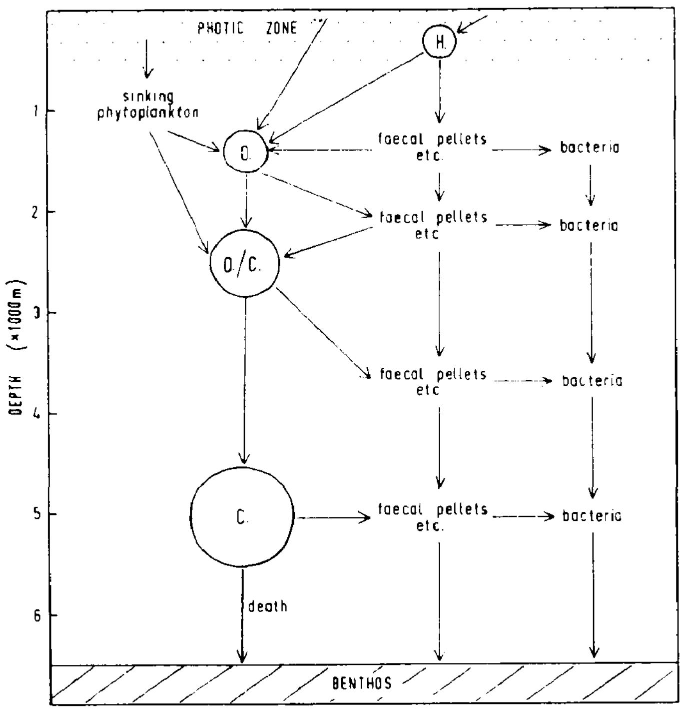

FIG. 11. — Mechanism for the transfer of nutrients produced by phytoplankton to the benthic hadal environment. H, very small herbivores; O, small omnivores; O/C, larger omnivores, probably biased towards a carnivorous diet; C, large carnivores. All these animals can migrate vertically and horizontally to meet the ones above and below them.

J. MAUCHLINE. The biology of bathypelagic organisms, especially Crustacea, fig. 11. *Deep Sea Research,* Nov. 1972. Pergamon Press Ltd.

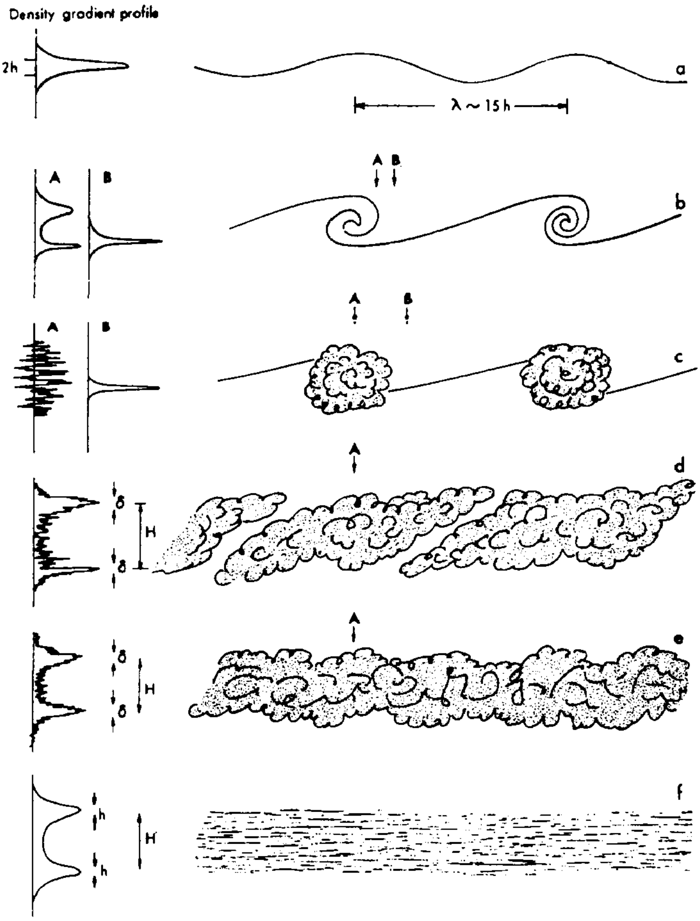

FIG. 12. — Stages in the evolution of a billow mixing event.
J.D. WOODS and R.L. WILEY. Billow turbulence and ocean microstructure, fig. 1. *Deep Sea Research*, Feb. 1972. Pergamon Press Ltd.

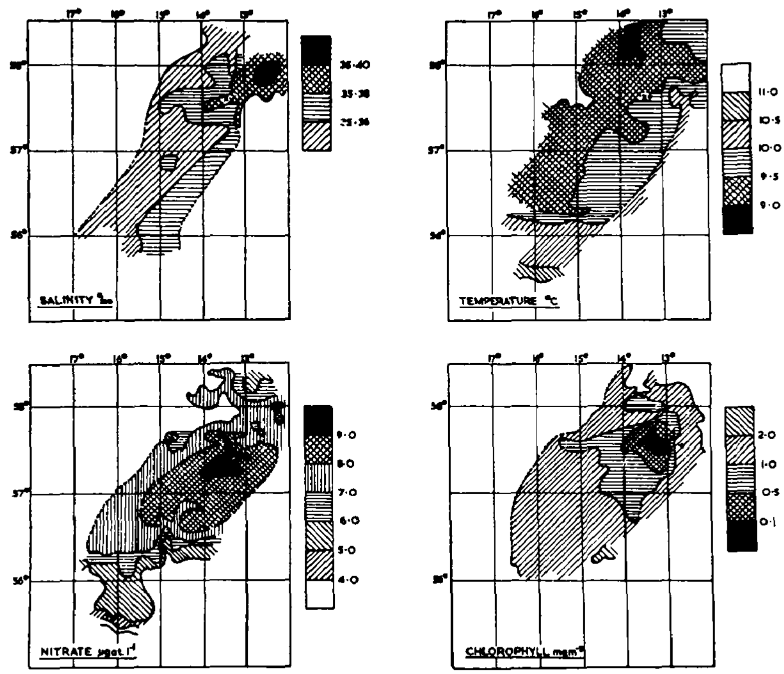

FIG. 13A. — Observations at 3 m on first survey (note: the solid black areas for temperature and chlorophyll indicate minimum values).

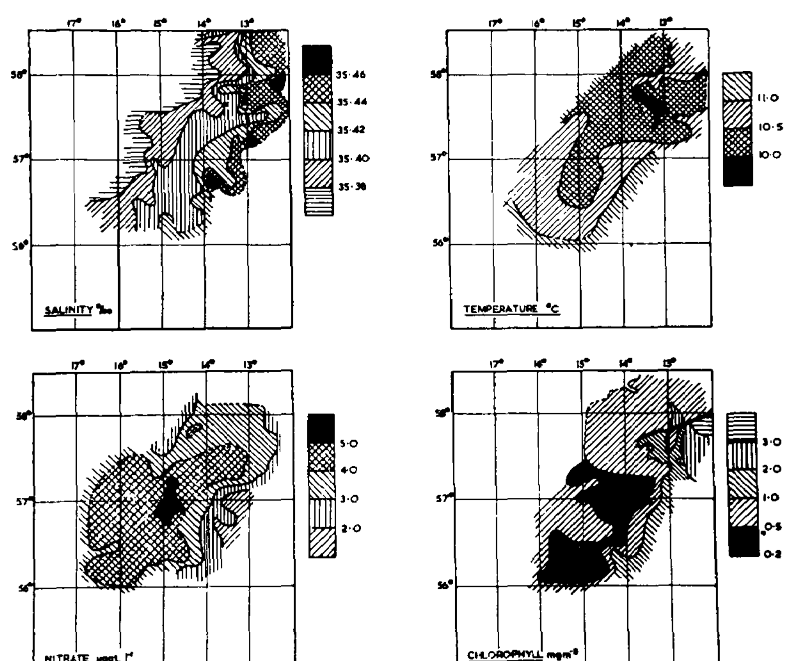

FIG. 13B. — Observations at 3 m on second survey (note: the thick line to the northeast separates the differing chlorophyll values at the start and end of the survey).

J.H. STEELE, I.E. BAIRD and R. JOHNSTON. Evidence of upwelling on Rockall Bank, figs 2 and 3. *Deep Sea Research*, Feb. 1971. Pergamon Press Ltd.

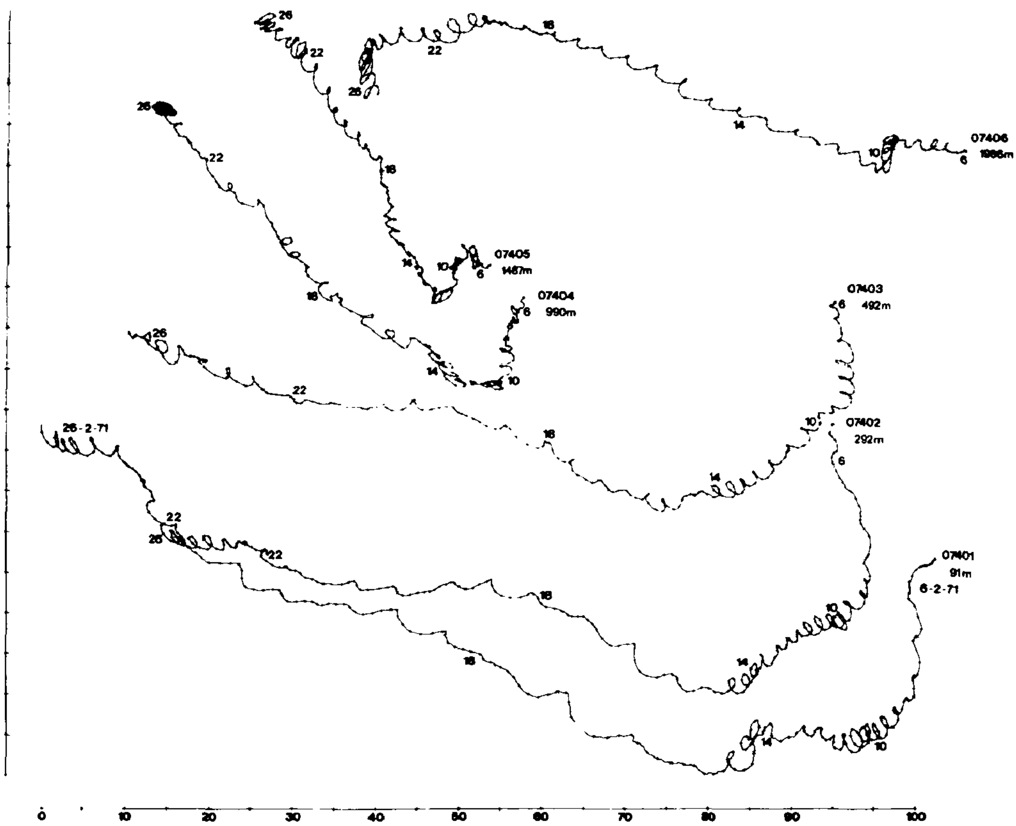

FIG. 14. — Readings from current meters on Biscay Slope.
J.C. SWALLOW. Institute of Oceanographic Sciences, 1971.

are commonly used for comparison between separate sets of values, although different vertical ranges may necessitate multiple sub-division of the vertical axis. RAYMONT (1971, figure 17) has used this to illustrate variations in composition of zooplankton over 11 months, although the topmost graph is far removed from the time scale and the month limits have been produced onto each line. To represent variations in relative proportions of three major constituents over the same period he has used a series of *divided rectangles* (figure 18). Since absolute values are not involved, the columns representing 100 per cent are of standard size and are divided on a percentage basis, carbohydrate, lipid and protein being distinguished by shading. The example has no intervening spaces between successive months and it therefore shows a "battleship" profile.

A further common requirement is to show frequency of occurrence, and divided diagrams, in this case *divided circles* or *pie diagrams*, can be used most effectively. ARMSTRONG [2] uses this technique : the pie diagrams are based on observations of sea ice of the U.S.S.R. since 1850 and are related to the station positions on a map of the area. A colour code

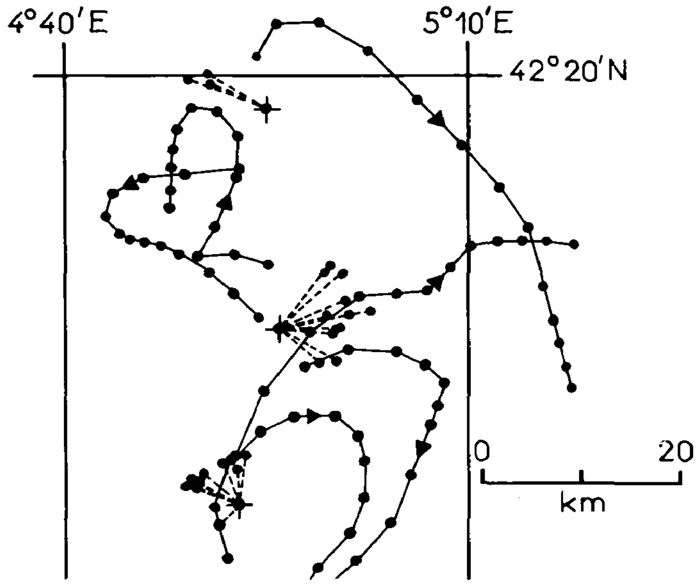

FIG. 15. — Composite of successive film frames showing data from current meters and floats, Golfe du Lion.

J.C. SWALLOW. Institute of Oceanographic Sciences, 1970.

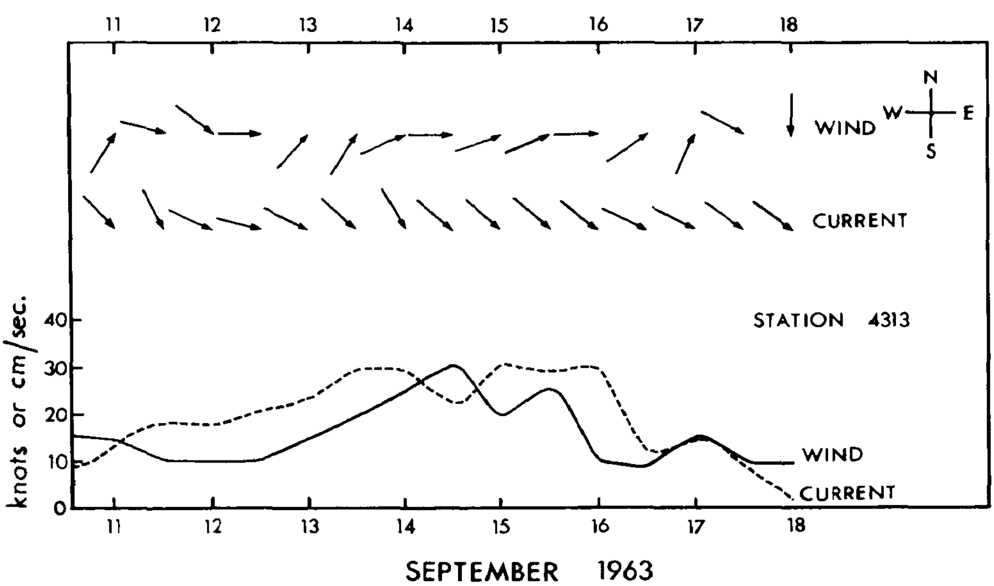

FIG. 16. — Changes in wind and current speed and direction.
E.G. PITT, R.M. CARSON and M.J. TUCKER. N.I.O. Internal Report A62, fig. 1. 1973.

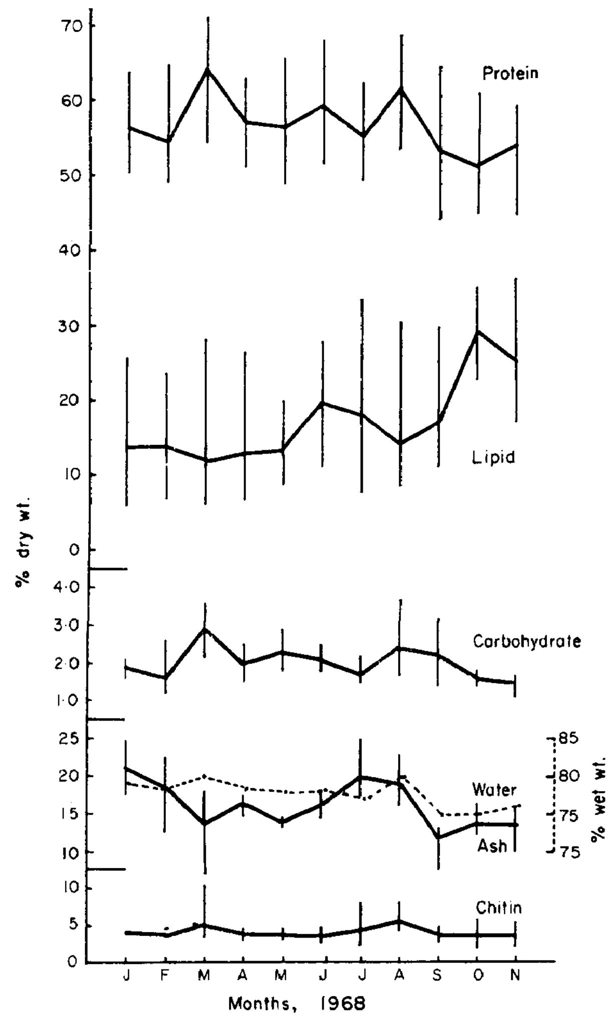

FIG. 17. — *Meganyctiphanes norvegica.* Variations in protein, lipid, carbohydrate, ash and chitin, expressed as percentage dry weight, and water content expressed as percentage wet weight. Means are given for each month together with limits of variation.

J.E.G. RAYMONT, R.T. SRINIVASAGAM and J.K.B. RAYMONT. Biochemical studies on marine zooplankton VIII, fig. 2. *Deep Sea Research*, December 1971, Pergamon Press Ltd.

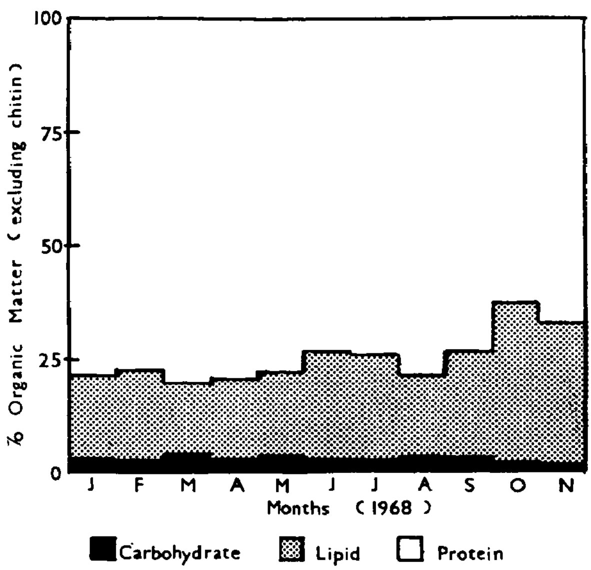

Fig. 18. — *Meganyctiphanes norvegica.* The proportions of the three major biochemical constituents, protein, lipid and carbohydrate, as percentages of total organic matter throughout eleven months.

J.E.G. Raymont, R.T. Srinivasagam and J.K.B. Raymont. Biochemical studies on marine zooplankton VIII, fig. 5. *Deep Sea Research,* December 1971, Pergamon Press Ltd.

represents four levels of severity of ice cover, and for each fortnightly period between May and December the relative sizes of the differently coloured segments show the proportion of observations of each type of ice to the total number of observations available. Refinements by Heap [3] include the addition of the number of the station and the total number of observations taken, in the centre of each circle.

A popular method for showing frequency is the *histogram,* e.g. Draper's histograms (1968) for percentage occurrence of crossing periods of waves (figure 19). An extension of this is Gould's diagram (1971, figure 20) which compares three histograms of temperature gradients over vertical distances of 10 m, 30 m, and 40 m at a given station.

The overall cartographic problem of oceanographers is one of representing four dimensions on two, in black and white. The film technique, however, if developed, will readily extend the dimensions of presentation to three to include, above all, time. Colours can also be used, expense apart, to enhance the appearance and clarity of maps and diagrams. The increasing use of computer output devices, such as automatic plotters, may be expected to have a profound effect on both the content and style of graphics produced by, or for, oceanographers.

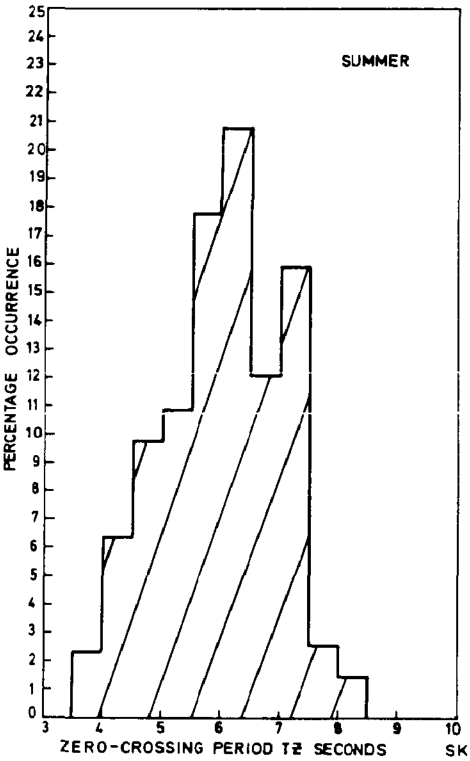

FIG. 19. — Percentage occurrence of crossing periods of waves.

L. DRAPER. N.I.O. Internal Report A33, fig. 7. 1968.

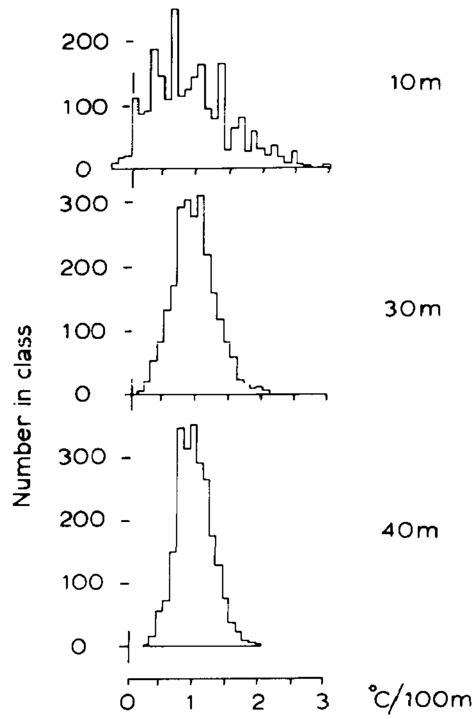

FIG. 20. — Temperature gradients over vertical distances of 10 m, 30 m, and 40 m at a station.

W.J. GOULD. Institute of Oceanographic Sciences, 1971.

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