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INNOVATIONS IN MARINE CARTOGRAPHY AT SHOM

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1 - INTRODUCTION

Hydrography has benefitted, during the present century, from many technological revolutions. Modernisation of sounding techniques, introduction of radio position-fixing systems, and the possibility of collecting and managing the increasing flow of data, have transformed the work of the hydrographer, resulting not only in an increase in the quality and quantity of information acquired, but also enabling the diversification of such information through the development of new means of acquiring it. The contributions made by acoustic sounding, radio positioning and computer science applied to hydrography have been widely described in this Review (TRIPE, 1981, RITCHIE, 1982, MACDONALD, 1982, BOLTON, 1984). In the course of the last twenty years, the possibility of acquiring and processing ever greater quantities of data has made it possible to develop swath sounding, first of all with side-scan sonar (RUSBY, 1970, BRYANT, 1975), then with multi-beam bathymetric sounders for deep water (BURKE and ROBSON, 1975, RENARD and ALLENOU, 1979) and for shallow water (CHIMOT, 1990). Measurements at sea in coastal areas, have been simplified thanks to photogrammetry and airborne remote sensing using lasers (ENABNIT, 1980), satellite bathymetry (LYZENGA, 1978, LE GOUIC, 1987), and satellite altimetry (LE QUENTREC, 1990). These many new techniques raise hydrography to new heights. Even though they do not always offer the accuracy of conventional methods, these new methods of data acquisition make it possible to increase our knowledge of the marine environment.

However, all this progress is not really perceived by the mariner, as marine cartography consists in extracting the most important information and integrating it into standard graphic form. The improvement in the quality of charts is thus largely obscured; the greater accuracy of the topography or the bathymetric information or the surveying of all obstructions, thanks to swath sounding, are not directly apparent to the user.

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After the development of interactive workstations and cartography based on digital data, Hydrographic Offices are preparing for the advent of the electronic chart. However, several years will be necessary for the latter to become operational and several decades thereafter before it replaces paper documents, which for several centuries have carried the information required by the mariner to ensure his safety when navigating.

Divergences in purpose that are sometimes encountered between the information shown on nautical charts and that obtained using new technologies have led to the publication of various "new-generation" charts. Bathymetric charts developed from digital data or created from multi-beam sounding data allow the underwater relief to be visualised by means of varying blue tints and isobaths. Similarly, side-scan sonar mosaics have been published in the form of charts or atlases to characterise the large geomorphological structures. Such charts no longer have as their object the safety of navigation, but rather, the knowledge of the environment required for submarine navigation, oceanographic research or industrial applications, such as cable laying, seabed mining and oil exploitation.

Such charts, in the oceanic field, have been produced or are being developed at SHOM; however, the aim of this article has been deliberately restricted to innovations in the charting of coastal areas, since there have already been a great many of these. Indeed, to answer the needs of mariners in such areas, SHOM publishes three types of chart making use of modern techniques for acquisition and plotting of data, which are produced in a different way from that used for conventional nautical charts. These charts, when they appeared, were created to fill the needs of pleasure craft users (P charts), fishermen (G charts) or to bring up to date old charts of little-known areas (spatiocharts). They may be used for navigation purposes in the same way as conventional charts since they contain all the requisite information portrayed in accordance with current cartographic standards.

2 - P CHARTS

Providing charts adapted to the needs of users is one of the principal concerns of SHOM. Large-format paper charts are not always suitable for use on the chart tables of pleasure craft. Visualisation of the whole of these charts, their storage, and access to the relevant document cannot be carried out in optimum conditions when lack of space is the norm.

These considerations led SHOM to publish, as from 1983, folded, practical charts intended for pleasure craft users and referred to as P Charts. Trials had been attempted before that, in particular, by the Canadian Hydrographic Service, but had not met with the success expected of them (KERR, 1976).

This new (in 1983) product is based on technological developments in printing and support media. The basic originality of these charts is their presentation : the medium is in fact a water-resistant non-tearable "paper" which

can be folded without becoming warped or worn; all the information from the corresponding basic chart is preserved. Other particular features are the pouch in which each chart is carried, one of the three flaps of which, forms the cover, the addition of information on, or on the back of, certain charts, and, lastly, the way in which they are kept up to date.

The P Chart has assumed an important place among SHOM's publications. First of all limited to the Brittany coasts, those most frequented by pleasure yachtsmen in 1983, they now cover the whole of the French and Spanish coasts, the south coasts of England and Ireland, the west coast of Italy and the French West Indies. Included in the 205 charts published, about 10 are reproduced in facsimile; the distribution of these is limited to France.

2.1 - Keeping P Charts up to date

The status of a chart is characterised by its publication reference number and a reference to the latest correction included (Fig. 1). The conventional method of printing a limited number of the paper charts makes it possible to incorporate therein any modifications which have arisen since the last edition. Certain of these, particularly important for the safety of navigation, but limited in extent, may lead to hand-correction of stocks.

For P Charts, the system is quite different, as updating for the latest correction is carried out at regular intervals, between 1 and 2 years, as a function of the demand. Between times, the charts are sold as they are. This fundamental difference is fully described on the chart pouch so as to inform the yachtsman who is not always familiar with the correction technique (see Inset No. 1):

"P Charts are subject to updating reprinting at intervals of one or two years.

By "updated reprinting" is meant a reprint which takes into account all information affecting safety of navigation which has given rise to a notice of correction through weekly groups of Notices to Mariners.

A publication entitled "Series of chart corrections", published yearly, at the beginning of April, includes all the notices of correction to P Charts from 1 February of the previous year to 31 January of the current year. This publication can be purchased, or merely consulted, at your local chart agent.

This chart is printed on water-resistent paper.

Use:

- *a soft-lead pencil to mark on it your positions, routes or bearings;*
- *a white corrector fluid to mask printed information;*
- *a fine ball-point pen to insert new information;*
- *all-purpose glue if you wish to fix on a graphic annex.*

Each notice of correction is identified by a number formed of three 2-figure groups identifying, in this order, the year of promulgation (last two digits),

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DE LA POINTE DE SAIRE A PORT-EN-BESSIN

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Documents à utiliser sur les côtes Nord de France

— Instructions Nautiques
C 2.1 de la frontière belge aux Casquets
C 2.2 des Casquets à Belle-Ile
— Livre des Feux CA
— Annuaire des marées, ports de France
ou Tables des hauteurs d'eau
— Courants de marée
— Répertoire des radiosignaux

CARTE SPÉCIALE 'P'

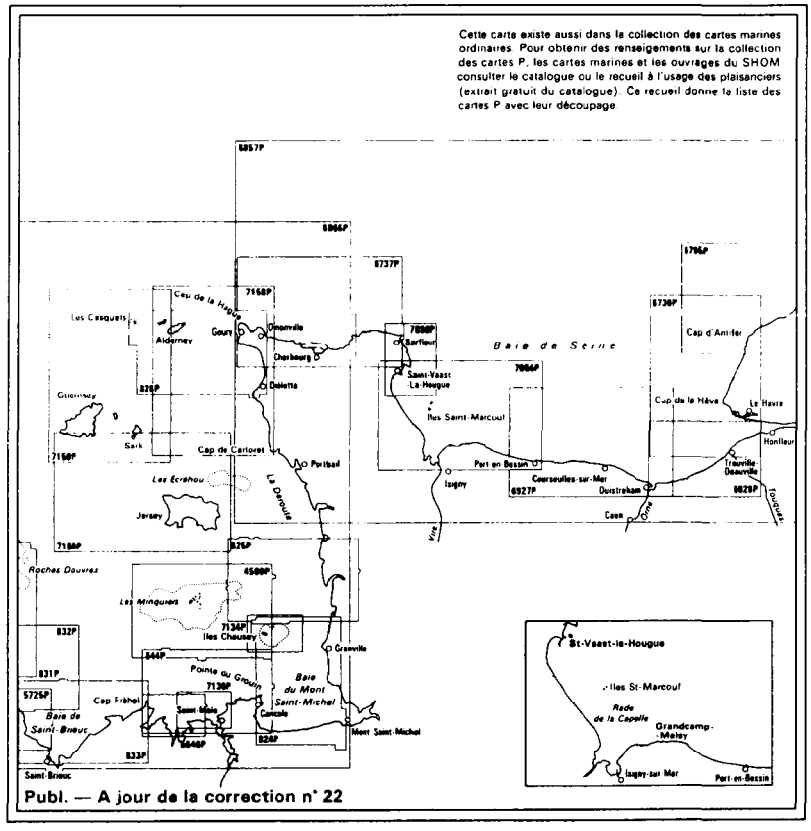

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FIG. 1.- Cover of a P chart.

number of the group within the year (from 01 to 52) and the number of the Notice within the group (exceptionally, this number may be over 99); each Notice also indicates the order number of the correction which affects the chart.

Thus the correction counter shown in the south-west corner of the chart makes it possible to determine the order of the latest correction taken into account and the number of the corresponding notice of correction:

1983-0443 means that correction No. 12, promulgated by Notice 83 04 43 12, has been inserted."

End of Inset No. 1

2.2 - Titles and legends specific to P Charts

The principal advantage of a P Chart is its minimum stowing size; whatever the format of the chart, its dimension when folded is 21x29.7 cm and its thickness is about 4 mm. The pouch is an extension of the same width as the chart folded into three flaps. One of these carries the note described in the previous paragraph. The jacket, or cover, of the chart (Fig. 1) and the third flap give supplementary information such as:

- the format of the chart;
- the nautical documents to be used in the region concerned;
- the geographical situation of the chart and the limits of adjacent P Charts;
- the principal symbols and abbreviations (extract from the "Navigator's Guide") representing, as appropriate, old or modern French cartographic standards, international standards, and the type of buoyage: European (A) or American (B).

2.3 - Addition of data on or behind P Charts

A study group from the German Hydrographic Office (SCHMIDT, 1979) considered that the back of a chart was not an appropriate place to print information. Such charts, printed on both sides, have nevertheless been published by various Hydrographic Offices, including SHOM, which has, for example, printed the evolution of mean tidal currents in the course of a cycle. Few such charts have been published but the requirements expressed by fishermen should lead to a renewal of this technique when G Charts are published (Section 3).

In order to facilitate navigation by pleasure sailors, who do not always carry the necessary nautical documents when far from their home port, some P Charts of the Mediterranean coasts were printed in 1991 with, on their reverse side, photographs of the coast or of noticeable landmarks and plans of the ports. These plans and photographs being carried on the back of the chart, with the coastline also figured, should facilitate navigation for pleasure sailors. However, these publications are still too recent to enable an analysis of their impact on this category of mariners to be made.

On very large-scale P Charts relating to specific ports, symbols and information have been printed in magenta. These concern the position of fishing ports and yachting harbours, docks for small craft, fuel pumps, the position of the tourist office, marina equipment, etc.

2.4 - 10 years of P Charts

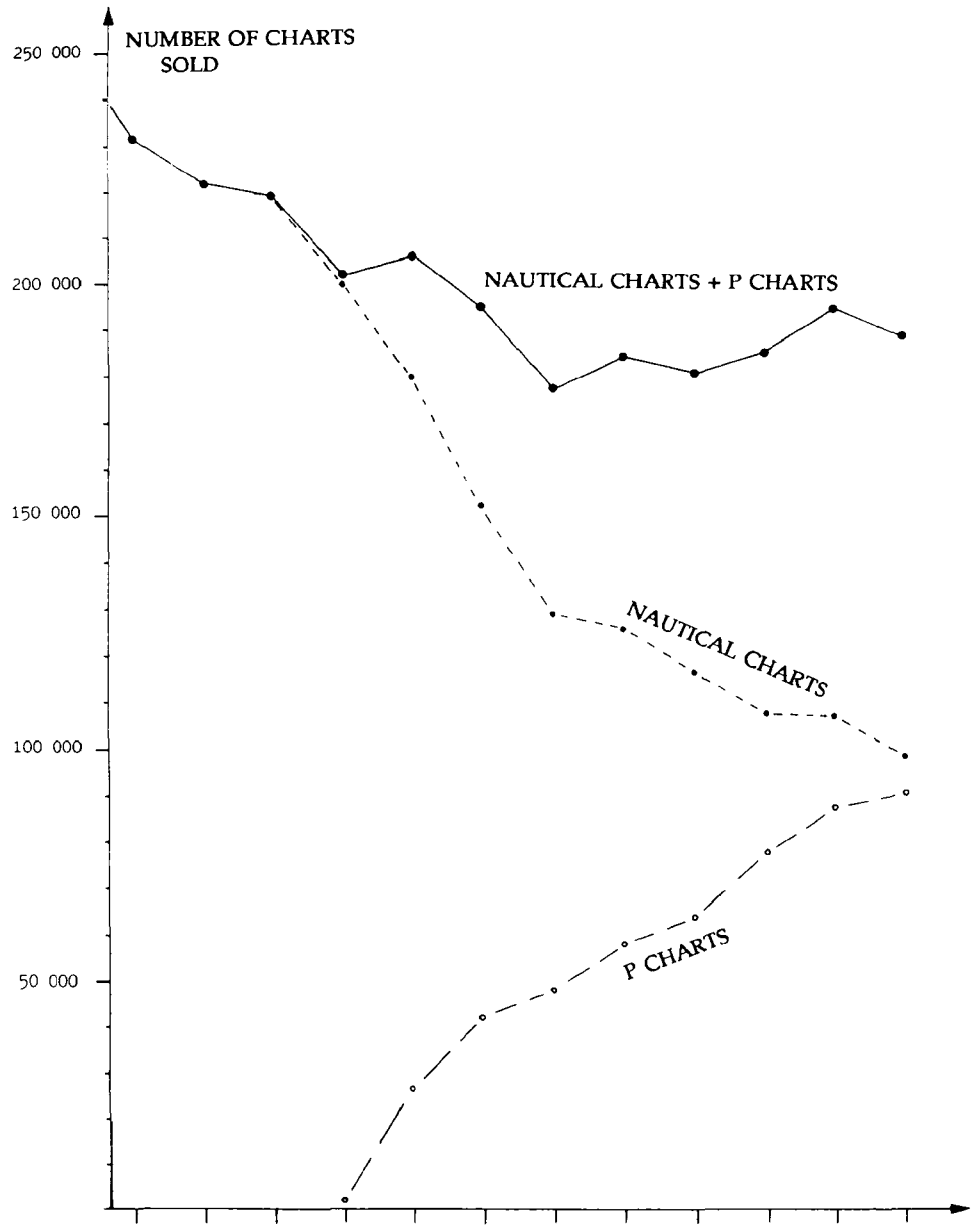
In ten years, the P Chart has assumed an important place among SHOM's productions. The increase in sales of these charts has, however, not compensated for the decrease in sales of traditional charts caused by the reduction in the number of charts in the national series from 2 000 to 1 300 and by the reduction in size of the merchant and fishing fleets. In 1990, 45% of charts sold were P Charts, yet they represent only 178 variations of the 1 300 charts in the national series (Fig. 2). It is now accepted that the P Chart has lived up to expectations, since, by 1989 already, the set of "P" variations were more widely distributed than the corresponding basic charts. For coastal navigation charts at 1:50 000, the correlation between the product and users' needs is even more pronounced.

The P Chart is, however, not really a new type of chart; it is, rather, a new presentation, well adapted to one category of mariner. Intended from its conception for the pleasure yachtsman, the P Chart is now accepted by many professional seafarers who are also concerned by problems of lack of space arising from the increase in electronic and computer systems installed at the expense of the chart table.

3 - SEDIMENT CHARTS: G CHARTS

The fishing industry makes use of more and more sophisticated systems, such as specialized sounders and radars, so as to obtain maximum benefit from days at sea. Fishermen also need a good knowledge of the environment and therefore of the morphology and the nature of the sea bed. Requests made to hydrographic offices have not always been fulfilled in the past, since these necessary data were incomplete or insufficient, or because the creating of sediment charts, not usable for navigation was the responsibility of another authority.

In the last few years, the development of side-scan sonar imaging, which offers quality data, making it possible to differentiate between various qualities of the bottom, has been accompanied at SHOM by an increase in activity in the field of sedimentology. The increase in the number of acquisition systems aboard survey vessels (3.5 Khz sediment sounder, EGG260 side-scan sonars, Shipeck scoops, Küllenberg corer, RoxAnn system, etc...) is for the purpose of increasing knowledge of the sea bed and thus enabling the development of SHOM's Sedimentology Data Base (in French: Base de Données Sédimentologiques -BDSS) created for the needs of the Defence Ministry. The publication of sediment charts of the French continental shelf (G Charts) represents an example of putting to valuable use the efforts spent in this field.



	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
No of nautical charts	1927	1932	1939	1939	1861	1447	1359	1347	1342	1341	1345	
No. of P Charts	0	0	8	27	49	82	109	144	151	168	196	

FIG. 2.- Evolution of the yearly number of charts sold by SHOM from 1980 to 1991 compared with that of the total series.

3.1 - History of French sediment charts

France's first sediment chart was published by the Hydrographic Service in 1897. It concerned the approaches to Brest and came from the compilation of thousands of data obtained by lead line. Such data were analysed in 1912 by M. THOULET, lecturer at the University of Nancy, in order to chart the whole of the French continental shelf. New charts were then published by various authorities, and at various scales, in the 1960s. Dredging and scoop sampling used to produce these charts made it possible to improve the description of the sediments and to increase the number of symbols and diagrammatic portrayals on the charts. The density of information available was, however, often sparse and the limits of the various features remained imprecise.

With side-scan sonar imaging, the sedimentologist has finally obtained a visual display of the sea bed which allows him to know the limits of the sediment features, characterized by laboratory analysis of samples. A precise charting of sediments has thus been possible at large scales (1:5 000 - 1:15 000) in the context of specific studies (AUGRIS et coll., 1988) or following hydrographic surveys. Such charts are still rare and it will obviously take several decades before the whole 160 000 km² of the French continental shelf have been fully covered by side-scan sonar data.

At the same time, some sediment charts of coastal regions at small scales have been issued by the BRGM (Bureau de recherches géologiques et minières) and IFREMER (Institut français de recherche pour l'exploitation de la mer) and charts at 1:500 000 of the Channel (LARSONNEUR et coll., 1979) and of the north of the Bay of Biscay (KLINGEBIEL and LESIEUR, 1985) have been published during the last twenty years. The systems of projection, the support, the scales and the presentation of information are, however, not adapted to the needs of the fishing industry and often these charts are too complex for users who are not sedimentology specialists. No French organization having taken upon itself to chart the surficial nature of the sea bed on the French continental shelf, and the demand for this being great, SHOM, which in any case had at its disposal large quantities of sediment data acquired, in particular, by hydrographic vessels, launched, in 1989, studies to define the sediment chart. With the publication in 1992 of the first G Chart, SHOM has as its objective the fulfilment of the needs of the fishing industry and already a cartographic plan, inventories of existing data and cooperation with universities and other organizations of the State has begun.

3.2 - Systems for acquisition of sediment data aboard SHOM's survey vessels and data processing

With the acquisition of several EGG260 digital side-scan sonars, SHOM is equipped with instruments carried aboard enabling it to acquire high-quality sea bed images. These "sonograms", conventionally used in hydrography for seeking wrecks and dangerous obstructions, also serve to chart the areas covered by sediments. Analysis of the data for purposes of sedimentology enables differentiation to be made on morpho-sediment charts at 1:10 000 between rocky areas, limits between coarse and fine sediments and sediment features such as

mega-ridges, sandy ribbons and sand waves (Fig. 3). This digital interpretation is used to produce chart at the desired scale to:

- respond to a particular need,
- specify the mobile areas and serve as a basic document for future surveys,
- draw up sediment charts.

The university laboratories remain the principal possessors of granulometric data resulting from the analysis of the sediment samples. Cooperation with them has therefore been resumed, in order to be in a position to integrate all existing data into the G Charts. Furthermore, the 200 samples taken each year by the missions and analysed in SHOM's laboratory are constantly enriching the knowledge of the sea bed and make it possible to render such knowledge consistent.

The granulometric data integrated in the BDSS are then subject to computer processing, at the outcome of which the greater part of the sedimentology parameters are obtained, such as:

- the name of the sediment,
- the proportion of different classes (pebbly gravel, fine gravel, large-, medium- and fine-grained sand, muds),
- the median, the average grain, asymmetry, classification.
- the physical properties : density, porosity, ...

Among these parameters, only the proportions of the various classes and the degree of limestone in the sediments are used to make the G Charts. The other data are archived in order to look again, in the light of this new information, at the nature of the seabed shown on nautical charts, which is often very old, or to answer future needs not yet expressed.

3.3 - The G Chart - A sediment chart intended for fishermen

Like the P Chart, the sediment chart is a variation of the basic nautical chart. The films for printing in black and white, in "bistre", and in magenta, are thus fully used. The blue film is replaced by a film for printing in green and showing the limits of the sediment features (facies) differentiated by eight diagrammatic forms (shading). The film is made according to the standards established by SHOM in contact with fishermen. From all the data assembled on the chart, a compilation is carried out by the scientists at SHOM and at the university laboratory responsible for studies in the region concerned. The limits of rocky areas, pebbly gravel, fine gravel, sands, fine sands, muddy sands, fine muddy sands, and muds are portrayed on a transparent support then digitized by means of a scanner. Shading of the areas with the diagrammatic symbols is then generated automatically; the film with the nature of the sea bed at the scale of the nautical chart is thus made, limiting the hand operations to the work of compilation and interpretation only. G Charts have the following characteristics:

FIG. 3. - Exploitation for purposes of sedimentology of side-scan sonar imaging (A: Pebbly gravel and gravel; B: Sands; C: Sandy ribbon; D: Mega-ridges; E: Sandwave crest and amplitude, wreck with sandy ribbons).

- folded charts on waterproof paper,
- accessory information such as the amount of calcium carbonate, the limits of areas where silting is temporary, ... etc., is shown in diagrammatic form on the cover of the pouch,
- charts of mean currents during a tidal cycle may be printed on the back,
- the cover is made in the same way as that of P Charts,
- updating will be made in the same way as that of P Charts
- updating will be carried out at the same time as the updating of the corresponding P Charts, with, in addition, correction of the sedimentology film if new data has been received to improve knowledge of the seabed,
- G Charts carry on the pouch and on each chart the logo(s) of the organization(s) which has/have participated alongside SHOM in the creation of the chart.

The first charts of the Bay of Seine were created by several scientists of the University of Caen (under the guidance of J.P. AUFFRET). In 1992 the chart of the Abords du Havre (Approaches to Le Havre) (67736 G), an extract from which is given in Figure 4, will be published; in the six years to come, eight coastal charts at 1:50 000 and two charts at 1:150 000 of the Bay of Seine and the Sud de la Bretagne (South Brittany) will be published in this way. In as far as users show an interest in these new charts, the whole of the coast of mainland France may subsequently be covered.

4 - NAUTICAL SPATIOCHARTS

The French EEZ in the South Pacific extends over 7,675,000 km². The present state of hydrography therein is limited to reconnaissance surveys, surveys of the principal well-known fairways and approaches and a survey of the lagoon of New Caledonia. With current methods, more than a century would be necessary to carry out to acceptable standards the surveys required in the hundred or so French islands and reefs in the Indian Ocean and the Pacific. One understands, therefore, why SHOM has taken an interest in all techniques able to facilitate and supplement hydrographic work. Analysis of satellite images, as well as satellite altimetry and photogrammetric plotting using an analytic stereoplotter are among such techniques.

4.1 - System for processing satellite images

The process leading to the creation of a nautical spatiochart consists of synthesising the field data resulting from hydrographic surveys and those extracted from satellite images (Fig. 5). In the course of the last twelve years, moving from Landsat images to SPOT images, the methods of calculating models and the setting up of the procedure of spatio preparation have made it possible to move on from studies to the integration of satellite information into nautical charts, then to the publication in 1990 of the first nautical spatiochart. As this

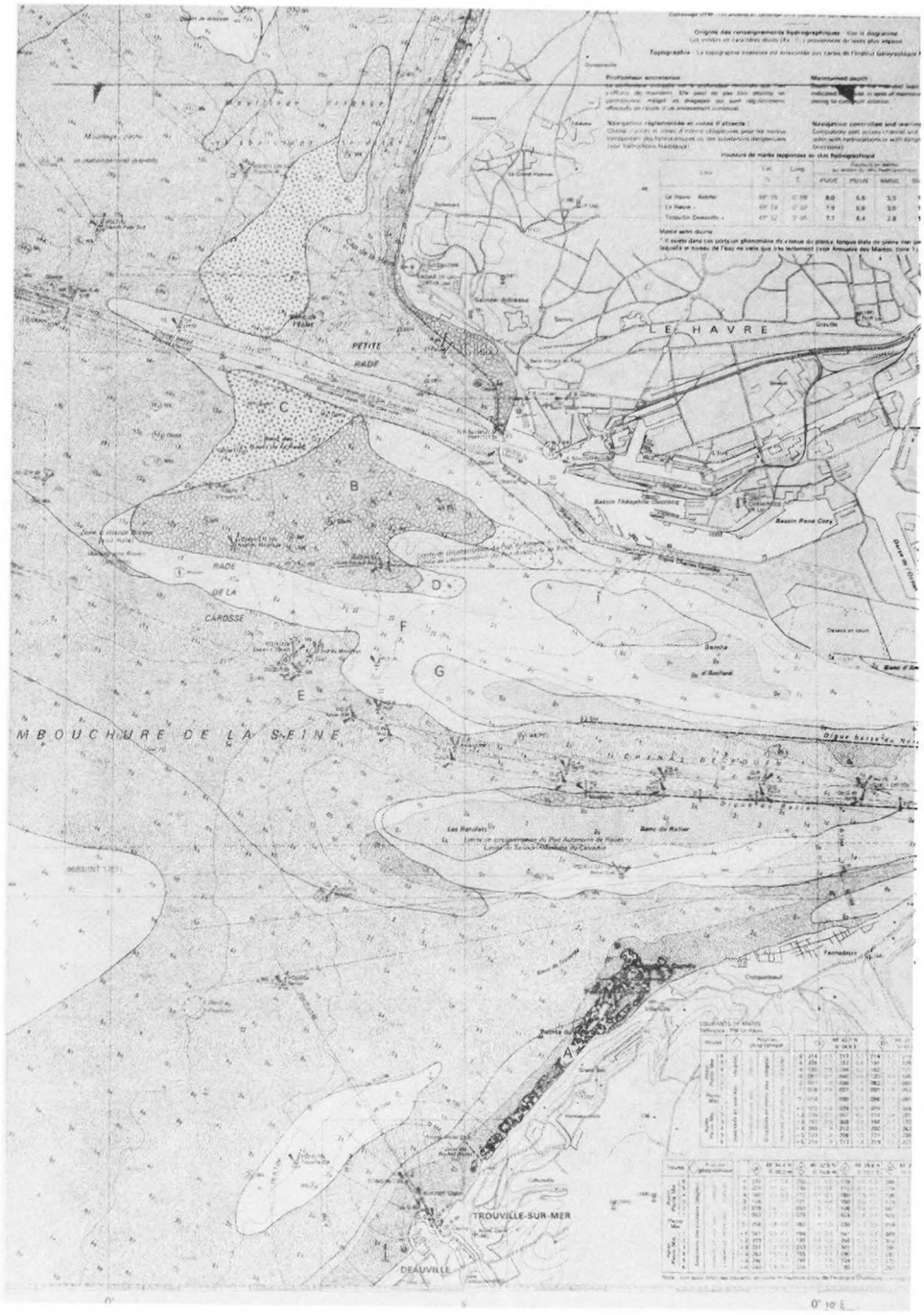


FIG. 4.- Extract from the sediment chart of Le Havre (6736 G) (A: Rock; B: Pebbly gravel; C: Fine gravel; D: Sands; E: Fine sands; F: Clay sands; G: Muds).

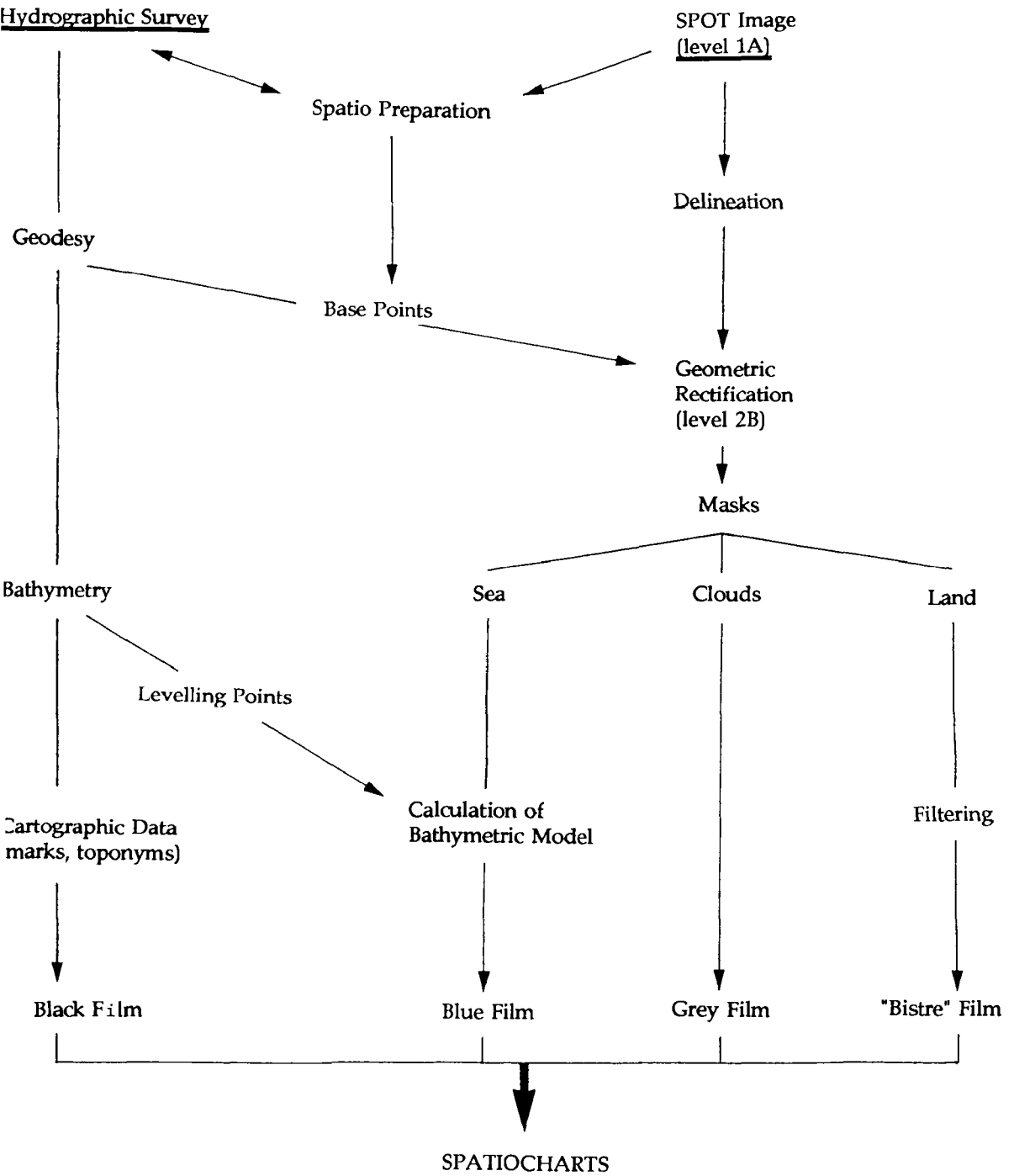


FIG. 5.- From the SPOT image to the nautical spatiochart.

processing having already been described elsewhere (GARLAN, 1989, JAMES et al, 1990, GARLAN, 1991), only a few salient points are mentioned here below:

- The geometric rectification, carried out by software developed by SHOM, makes it possible to generate, with a single base point, a corrected image with an error on the position of each "point" less than the size of the pixels of the multispectral images (quadratic mean of the disparity less than 10 metres). It is thus possible to define precisely the topography of an island, but also in continuing over several images to position an atoll whose location had remained imprecise.

- For the calculation of the bathymetry, multispectral SPOT images are used. The area of 400 m^2 represented by one pixel may seem too great for the recognition of shoals of small size, but studies have shown that all the coral pinnacles whose summits were less than 25 metres in depth were systematically detected, thanks to SPOT and that their presence was characteristically indicated (presence of a shadow).

The scale of the spatiocharts being somewhere between 1:50 000 and 180 000, one cm^2 of the chart corresponds to a number of pixels between 625 and 1089; the principal problem, therefore, is to highlight on the spatiochart the existence of a shoal when it is defined by only a small number of pixels. Application of the method of the bathymetric model supported by a few depth figures actually measured during a reconnaissance survey has made it possible to obtain less than 10% RMS error down to 22 metres' depth in inter-tropical areas of clear water. The results are provided in the form of an image where each pixel in the maritime area is portrayed not by radiometry measure by the satellite but by an estimate of the average depth. Depths are portrayed by different shades of blue (0-5 m, 5-10 m, 10-15 m and 15-20 m) on the spatiocharts and correspond therefore to an average depth over an area of 400 m^2 rather than to the discrete data represented by a single sounding on a nautical chart.

Once this processing has been carried out, the digital data are re-transcribed onto film by a laser plot. Each of the films corresponds to a colour in the final document. The land in "bistre", the clouds in grey, and the maritime area in blue are thus represented on superposable films made to the scale and on the geodetic datum desired. In the same way, the black and white and magenta films carrying the border, the toponyms, the marks, etc. are made by a cartographer. The four films will serve to print the spatiochart (Fig. 6). Three spatiocharts have been issued in this way (Ouvéa, Apataki, Manihi), two are in preparation (Ahé, Hao) and two spatiocharts have been produced by the firm Total.

The information arising from SPOT or Landsat images has also served in the production of nautical charts over the last ten years; for example, for the coral reef of New Caledonia, the topography of the Chesterfield Islands, the coastline of the Red Sea, the position of various tiny islets, atolls and reefs, and the charting of Tuamotu at 1:175 000.

SHOM has thus developed a system for the processing of satellite images so as to improve the charting of the archipelagic areas of the Overseas Territories. This system has some limitations:

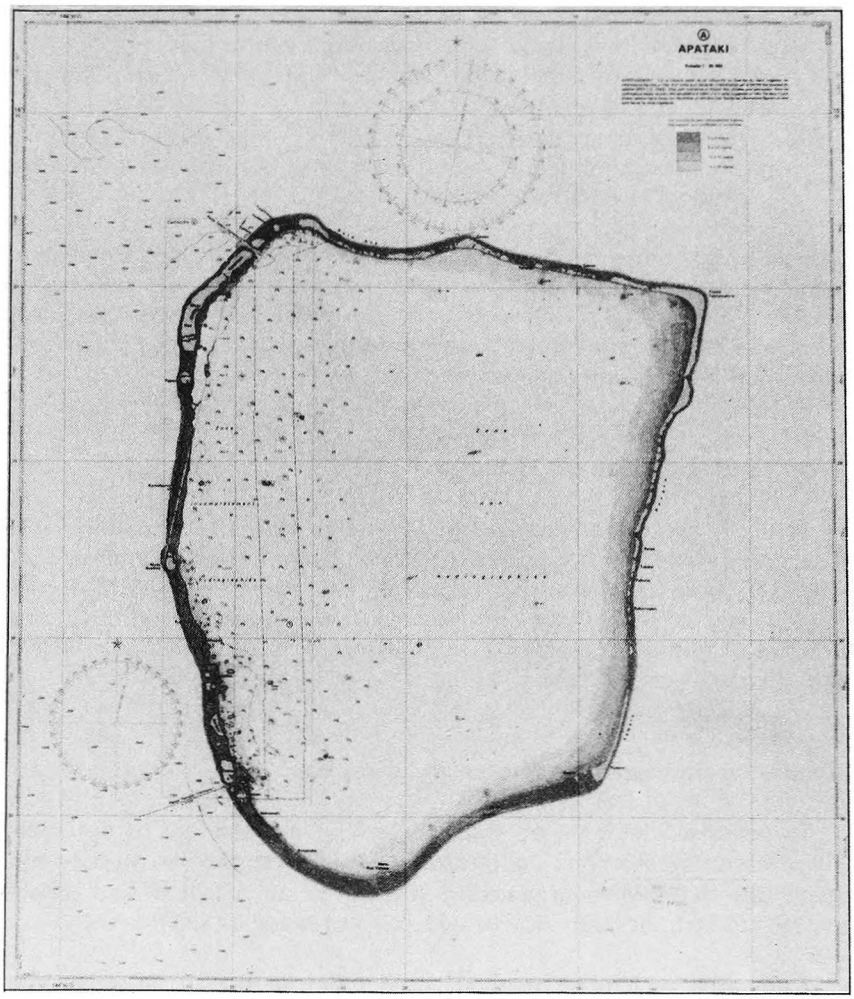


FIG. 6.- Spatiochart of Apataki, French Polynesia, 1/50 000. Extract from Chart 7248.

- the bathymetric calculation applies in regions of clear water;
- shallow water areas must be sufficiently well-developed for the isobaths to be discernible at 1:50 000;
- taking into account the variations in the nature of the sea bed is still imperfectly mastered;
- the bathymetric results do not offer all the guarantees of a sea survey and do not allow for charting at 1:10 000 or 1:20 000 of the straits or approaches to ports.

But, on the other hand, the system has many advantages. It makes possible:

- considerable gains in money and in time,
- relatively simple updating of the nautical charts of the regions where surveys are limited and sometimes over a century old,
- rapidity of execution: about 2 months to carry out the bathymetric analysis and to provide the colour films,
- location of reefs, discovery of shallow water areas dangerous for navigation, definition of the topography of islands, and atolls, and the promulgation of such information.

The programmes for processing satellite images developed over the last ten years are now being restructured and industrialized under a cooperation contract (SHOM-CELI-NAVFCO) so as to be in a position to offer professionals in the charting of the maritime domain an interactive product, that is standardized and portable: the "Spatiocarte" software.

4.2 - Other charts based on SPOT imaging

With the knowledge acquired by SHOM in the field of charting based on SPOT images, new charts not intended for navigation are now published in the South Pacific. These "iconocharts" produced in cooperation by IFREMER, SHOM and the Territory of French Polynesia, have economic objectives (portrayal of road infrastructures, airports, pearl-cultivation areas ...) and touristic objectives (location of hotels, beaches, ...).

4.3 - Nautical spatiocharts: advantages and prospects

In order to check on an isolated item of information, to optimize the work of the survey missions, to complete a partial survey, to update an old document, the processing of satellite images is an efficient and relatively inexpensive method, the utilisation of which is increasing at SHOM.

Compared with other methods used today in the coastal environment, remote sensing by satellite offers several advantages: that of rapid processing of vast areas, of independence as regards terrestrial infrastructures and the availability of representing a single reference system for all cartographers; but it has the disadvantage of furnishing only preparatory or supplementary data which must be validated by observations carried out using a tested method. An understandable counterbalance to the gains in time and money, the product obtained at the outcome of the work will not have the same value - according to whether the area has been completely or partially covered by a hydrographic survey. However, the joint utilisation of remote sensing methods and hydrographic methods at sea makes it possible to cater for an urgent need more rapidly.

Thanks to SPOT, the hydrographic and scientific community has at its disposal an efficient management and decision tool whose regular use will make it possible to improve considerably the general charting of extensive shoreline areas still imperfectly known today.

5 - CONCLUSION

The technological progress made by hydrography during the present century gives rise to a great increase in the flow of data from hydrographic vessels towards the bodies responsible for their management, their archiving and their use on nautical charts. Airborne and satellite remote sensing also provides increased knowledge of the coastal field and lightens the workload at sea. The navigator does not perceive the extent of these technical developments because all the information is, after interpretation, reproduced in the conventional graphic charting style.

With the three types of charts presented in this article, SHOM has sought to answer the needs of users. They are in fact variations of basic charts (P or G Charts) or documents specifically designed to replace very old nautical charts of islands and atolls (spatiocharts). After 10 years' existence, the P Chart has largely proved its adequacy for users' needs and should, in 1992, represent half the sales of nautical charts by the French Hydrographic Office. The G Chart published in 1992 is the first of a series of sediment charts intended to answer the needs of fishermen. The objective here is thus not to satisfy the needs of a large public but really to provide what is required for a community for whom knowledge of the environment is vital.

Other types of chart should be developed in the coming decade, to cater for the needs of navigators and those exploiting the environment (bathymetric charts, geomorphological charts, side-scan sonar mosaics ... etc.) before perhaps combining these in a more global system built around an ECDIS.

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