

MULTI-DISCIPLINARY SURVEY OF THE SÉNÉGAL/GAMBIA CONTINENTAL MARGIN

by A. RUFFMAN, L. MEAGHER, J. McG. STEWART

Geomarine Associates Ltd, Halifax

and D. MONAHAN

Canadian Hydrographic Service, Ottawa

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The paper, although more concerned with geophysical research than is normal for the I.H. Review, addresses the major contribution to bathymetry made by obtaining sounding data held by others, and thereby underscores the potential importance of the world bathymetric data service now being maintained by 18 IHO Member States' Hydrographic Offices. (*Editor's Note*).

ABSTRACT

The hydrographic results of a major Canadian Hydrographic Service and Atlantic Geoscience Centre multi-disciplinary survey using *CSS Baffin* off Sénégal and The Gambia are presented.

A compiled bathymetry map of the shelf and continental margin of Sénégal and The Gambia has been produced for the area from 11° N to 18° N and 15.5° W to 22.5° W. The continental shelf north of Dakar is relatively narrow and is highly incised by active canyons that pass across the continental slope and rise to feed two channel systems that drain south to the Gambia Abyssal Plain. Immediately south of the Cayar Canyon, which has incised the shelf almost to the shoreline, there appears to be a lack of active canyons, and there are only two canyons west and southwest of Dakar ; both are probably inactive features that ceased to operate when

the Cayar Canyon captured their sediment supply. The Cayar and Mauritania/Nouakchott Canyon systems flow into the Cayar and Mauritania deep-ocean channel systems respectively and both drain south onto the Gambia Abyssal Plain.

Various seamounts are mapped offshore. Slumping is mapped on the continental slope including the major Cayar Slide complex which has moved from north of Cayar Seamount and flowed west over 400 km to collide with the Bafoulabé Rise. The density and possibly the initiation of canyons along the shelf edge and slope is believed to be related to the amount of slumping.

Additional salt domes are mapped off the Casamance. Minor variations in depth on the shelf are caused by salt dome intrusion, exposed volcanic rocks, sediment piled into ridges by longshore drift or wave conditions and by relict beaches. Aeolian-laid sediment deposition may be responsible for flattening of the shelf and prograding of the shoreline just north of Sénégal off southern Mauritania.

INTRODUCTION

When the Canadian International Development Agency requested the Canadian Hydrographic Service (CHS) to carry out a multi-disciplinary offshore survey off Sénégal in 1976 the initial response of CHS was to suggest adequate pre-cruise planning time and a deferral of the actual survey till 1977. As it turned out, CHS in conjunction with the Atlantic Geoscience Centre (AGC) of Bedford Institute of Oceanography mobilized CSS *Baffin* on less than a year's notice and carried out a survey from January to April of 1976, beginning and ending in Halifax with 3 port calls in Dakar, Sénégal.

CHS ran the cruise and handled the onboard collection of bathymetric data using a Raytheon Deep Sea depth-digitizer with a hull-mounted 12 kHz transducer with a full beam width of 34 degrees ; positioning was provided by a satellite navigation system interfaced with a Loran-C Accufix receiver (MARSHALL, 1977). A chemical oceanographic sampling program (POCKLINGTON, 1977) and a continuous bird and sealife observation program (BROWN, 1977) along with oil and surface tows were integrated with the program. CHS also set up an offshore current and tidal station (MARSHALL, 1977).

The geophysical/geological program consisted of continuous measurements of the earth's total magnetic field and gravity field. Shallow seismic data were obtained in the second phase, using a 40 cu. in. airgun over the slope and a Huntec deep-towed boomer system on the shelf (MEAGHER *et al.*, 1977).

CHS was responsible for publication of the initial results of the cruise and undertook to have the bathymetry of the area compiled, while AGC undertook the responsibility of producing the gravity, magnetic and seismic report. From the beginning, CHS was concerned that the 30 km line spacing (14 km on slope and shelf edge) would not provide sufficient data on a slope that was in all probability dissected by a number of shelf-edge canyons ;



FIG. 1B. — Map of survey area showing all the additional lines of bathymetry which were compiled into map 839A. All these lines were either from scientific research vessels of various nations or were judged to have a high quality of positioning which would permit them to be integrated with the *Baffin* data. Sources are all detailed in the tables of RUFFMAN *et al.* (1977 a, 1977 b).

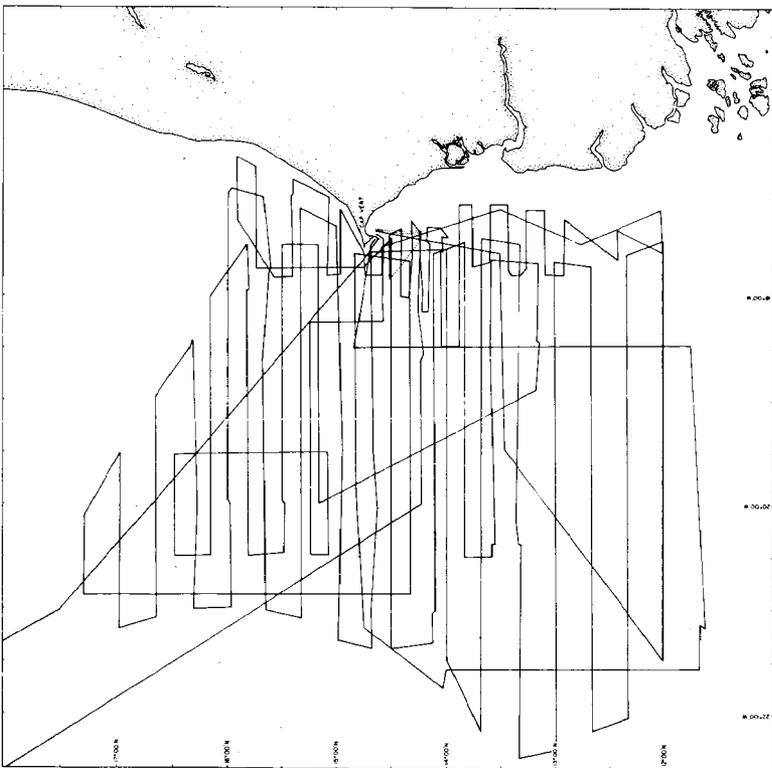


FIG. 1A. — Map of survey area from 11°N to 18°N and 15.5°W to 22.5°W showing tracks of *CSS Baffin* data. All tracks have bathymetry, most have gravity and magnetic data and a lesser number of tracks across the continental margin have seismic data.

Cayar Canyon was already known to traverse the whole shelf and slope north of Dakar (DIETZ *et al.*, 1968). Dakar is the major port between the Gulf of Guinea and Morocco and it was well-known within CHS that a number of American cruises such as the I.D.O.E. cruises of Woods Hole Oceanographic Institution, and those of Lamont-Doherty Geological Observatory as well as British and West German cruises had entered Dakar for port calls. It was therefore CHS's concern to amplify *Baffin's* grid of east-west lines with whatever other data could be gained from the oceanographic community. A contract was let to Geomarine Associates Ltd. of Halifax to compile the bathymetry and write an interpretative report (RUFFMAN *et al.*, 1977). The same firm had provided technical support for the cruise and a chief geoscientist for Phase I, and later Geomarine Associates was also to produce the geophysics/geology report (MEAGHER *et al.*, 1977).

No one realized how successful the process of assembling other data would be. This was only done for bathymetry; the gravity and magnetic maps were constructed almost entirely from *Baffin* data with only minor input from 2 other sources. *Baffin* collected about 16 000 km (8 600 n. mi.) of bathymetric data in the survey area on her regular and systematic pattern of lines. Geomarine Associates was able to assemble the digitized data of over 33 other vessels of at least 8 nations through the cooperation of at least 17 agencies. This process permitted approximately an additional 37 000 km (19 950 n. mi.) of raw deep-ocean data to be compiled and integrated with *Baffin's* data (Figs. 1 A and 1 B).

The assembly process is not straightforward. There was no index map and no data centre could provide such an index. Much of the process depended upon personal knowledge of cruises and a series of phone calls and letters to draw out the data. In most cases the data were released through a desire for interagency co-operation or through the fellowship that exists in the scientific community; CHS's obligation in return was to produce a final map and circulate it. Cost to the CHS was limited to the cost of computer printouts or in some cases duplication.

The data assembly was not limited to gathering deep-ocean data. The French Hydrographic Service, the British Admiralty and two oil companies had done a large number of surveys on the Sénégal shelf itself and 65 nearshore field sheets were assembled (fig. 1 C). The final coloured map is CHS map 839 A enclosed in a pocket of RUFFMAN *et al.* (1977 a, 1977 b). No estimate has been made of the number of kilometres of data in the nearshore sheets but we suspect that it represents a further 25-35 000 km. In total it is estimated that over 125 documents beyond the basic seven field sheets of CHS were used in the compilation of the final map. In addition the data or interpretation of 18 authors were incorporated from the open literature or from preprints of unpublished manuscripts. The CHS report contains a full listing of all the data sources, field sheets, authors and vessels (RUFFMAN *et al.*, 1977). Suffice to say here that we recognize and welcome the tremendous contribution of other hydrographers and researchers to our final map produced in the CHS report.

In the case of the Sénégal survey a glance at figs 1 A, 1 B and 1 C along with the final map will indicate where *Baffin's* track might have been altered. The shelf edge is dissected by a tremendous number of canyons and few of the accurately fixed data run north-south along the shelf edge to permit recovery of a lot of this detail. The confluence of the Mauritania, Nouakchott and Cayar Canyon systems is a very complicated area with subtle changes in depth that requires more detail. The possible reefal structures west of Cap Vert at 500 m still remain a puzzle as does the lower end of the Dakar Canyon and the exact density of seamounts along the 13° N fracture zone.

One must hasten to add that in a multi-disciplinary survey such as this other features must be added such as density of previous gravity, magnetic and seismic data. There are significant other geophysical data but by no means the same amount as seen in the bathymetry. However in the case of potential field measurements often one does not need the same density especially in the deep ocean in the magnetic quiet zone. The need for overall synoptic measurements of temperature, oil tows or bird observations might again alter the pattern of a cruise ; the point is that it is extremely valuable to know the existing data base before a multi-disciplinary cruise is planned.

RELATIONSHIP OF BATHYMETRY TO GEOLOGY

Seamounts

As in all parts of the ocean, off Sénégal and The Gambia there is an intimate relationship between the shape of the bottom and the underlying

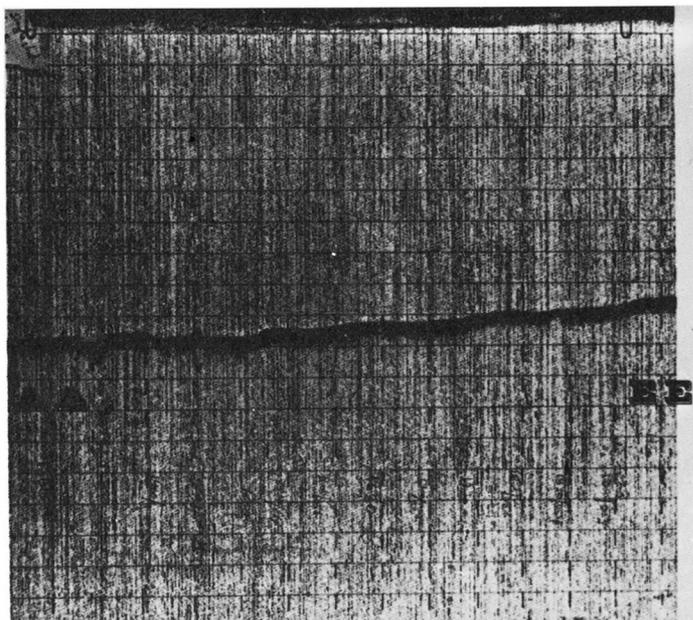


FIG. 2. — Bathymetry profile from 12°29.8'N, 18°30.0'W to 13°34.8'N, 18°30.1'W across a small high (v) that may represent the top of a buried seamount protruding through the sediment. (Full scale 10 sec, 375 m/division).

geology. The bathymetry profile AA-EE shown in figure 2 illustrates this problem. The small high on the bottom could be contoured as simply a small circular "bump" on the bottom or might be a linear feature with a number of orientations. The interpreter often will not have adjacent lines of data sufficiently close to resolve the question, nor will the hydrographer who is planning subsequent cruises to fill in areas or to delineate bottom features. Thus an understanding of the underlying geology is of paramount importance in both cases, and indeed it could be argued that in both cases the interpreter and hydrographer cannot really do their jobs properly unless they understand the geology.

In the example of figure 2 the high may result from a number of sources ranging from an outcrop of a resistant bed, an outcrop of the top of a seamount, topography related to slumping, drowned beaches, glacial moraines or reefs. Obviously the depth of water eliminates certain possibilities as does the feature's location. In the absence of other information the above example is judged to be a small volcanic outcrop of a solitary buried seamount. Figure 3, a profile across Bissau Seamount and figure 4,

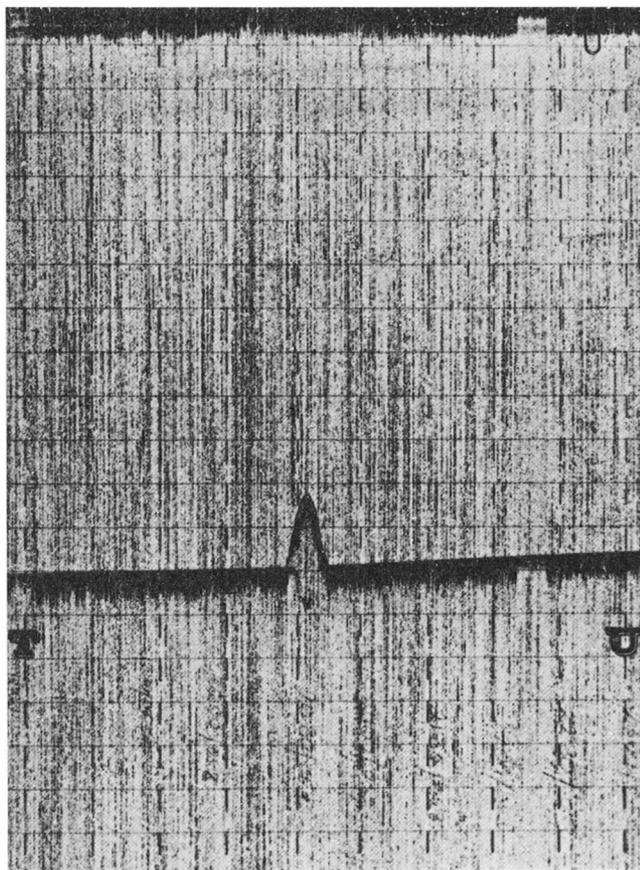


FIG. 3. — Bathymetry profile from $11^{\circ}39.5'N$, $20^{\circ}25.3'W$ to $11^{\circ}41.5'N$, $19^{\circ}40.5'W$ across buried Bissau Seamount that stands about 600 m above the surrounding area. (Full scale 10 sec, 375 m/division).

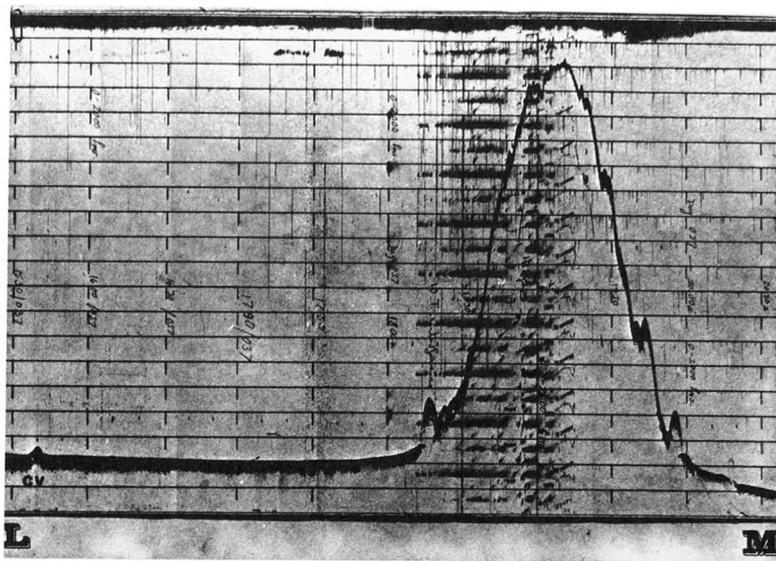


FIG. 4. — Bathymetry profile from $17^{\circ}49.7'N$, $22^{\circ}24.5'W$ to $16^{\circ}55.6'N$, $21^{\circ}48.0'W$ across a minor ridge of basaltic outcrop on the Cape Verde Rise (cv) and across Senghor Seamount that rises to 302 m. (Full scale 5 sec, 187.5 m/division).

a profile over Senghor Seamount illustrate two other seamounts in various stages of burial. Bissau Seamount is almost buried and is in the very south of the survey area near The Gambia Abyssal Plain. It may be related to east-west fracture zones detected by the magnetic surveys. Senghor Seamount, on the other hand, is only partially buried and rises close enough to the ocean surface to serve as an anchoring area for fishing buoys ; it clearly is related to the same volcanism that created the Cape Verde Islands and is simply an island that did not break surface. The tiny high to the northwest of Senghor Seamount may also be a buried volcanic peak but because of adjacent data is believed to be a low ridge probably related to the same volcanism.

Clearly one would like to be able to see into the masking sediments to discover the relationship of bathymetry to geology. This can be done with the seismic method using airguns or sparkers or, to a lesser degree, a low frequency echo sounder or profiler such as a hull-mounted 3.5 kHz system. Figure 5 shows a 40 cu. in. airgun profile over a section of the Labrador Sea of similar depth. The vessel was moving at regular survey speeds of 10-12 kt and in addition to the regular high frequency echo sounding data a whole wealth of sub-bottom geological data has been gathered that allows less ambiguous interpretation of various highs. *Baffin* carried an airgun system but its use was restricted in general to the shelf edge and continental slope ; only 5 lines ran into the deep ocean and none crossed the volcanic occurrences of figures 2, 3 and 4.

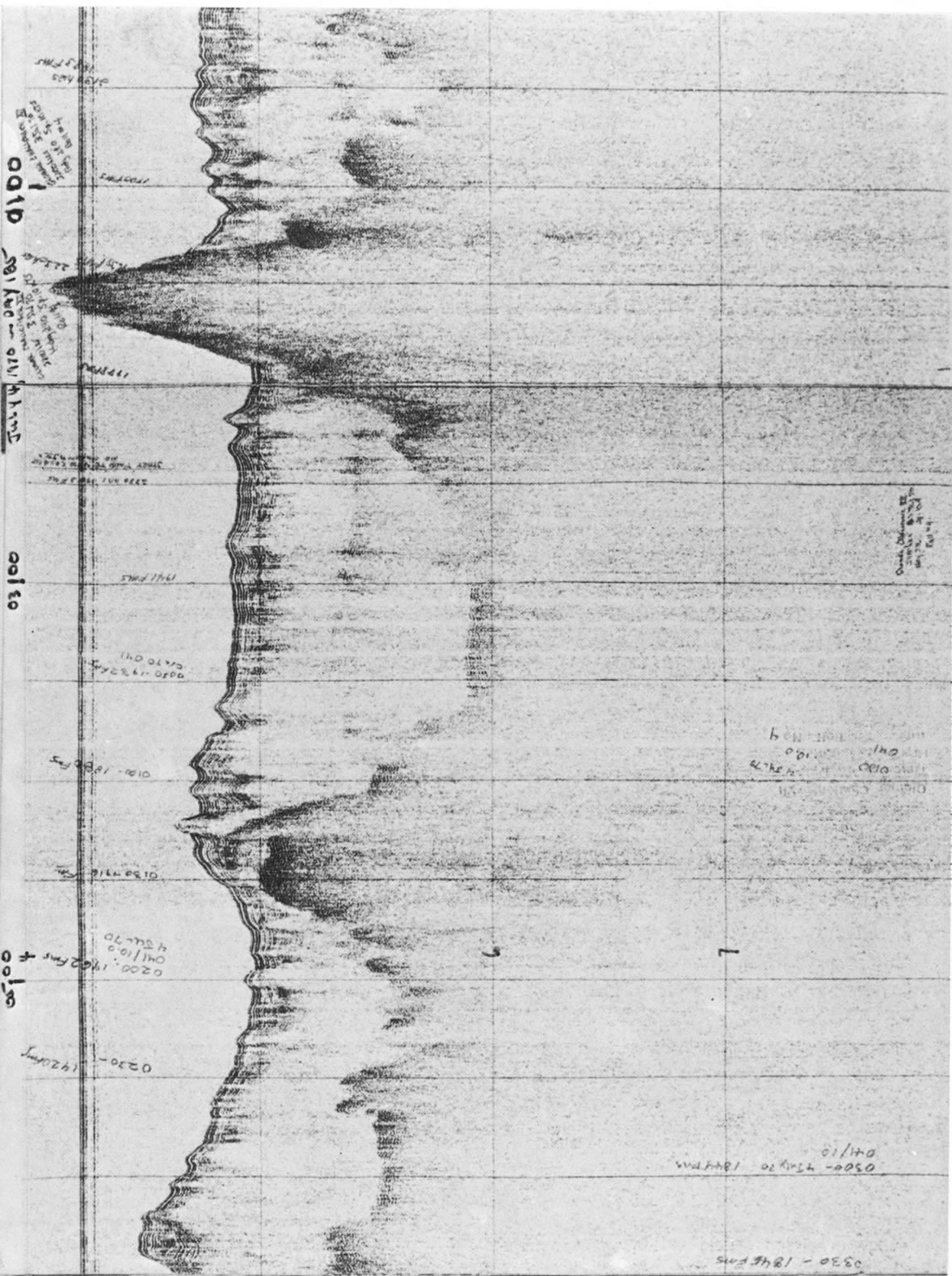


FIG. 5. — Portion of 40 cu.in. airgun record of *Gfomar Challenger* obtained at 10-12 kts in the Southern Labrador Sea. Various seamounts protrude through the sediments and the buried basement joining their bases can be seen.

Drowned beaches

Profile P-Q west from Cap Vert crosses a probable drowned beach (br on fig. 6) in about 70 m of water. MASSE (1968) interpreted this rise to be a linear relict beach and CROT (Centre de Recherches Océanographiques de Dakar-Thiaroye) (1975) and DOMAIN (1977) interpreted the rises to be a series of "bancs rocheux" lying along the 50 m and 70 m contour south of Dakar (fig. 7). These features are too small to be recorded on the bathymetry map of MASSE or of CROT and indeed are too small to appear on our 1 : 1 000 000 map. In certain instances the highs may represent outcrops of the Cap Vert volcanics (e.g. Banc du Séminole), but these areas are clearly indicated by very high frequency, high amplitude anomalies in the magnetic field.

These breaks or ridges on the shelf at 50 m and at 70 m are almost certainly the record of stillstands of sea level and related relict beaches. McMASTER *et al.* (1970) found that a number of submerged lithified beaches off the Bijagos Delta were lithified at their crests. We suggest that the "bancs rocheux" are very similar especially since they are parallel to the regional slope of the shelf (fig. 7). The beaches were probably lithified prior to their submergence and there may have been selective algal growth or breaching in certain locations along their lengths since submergence.

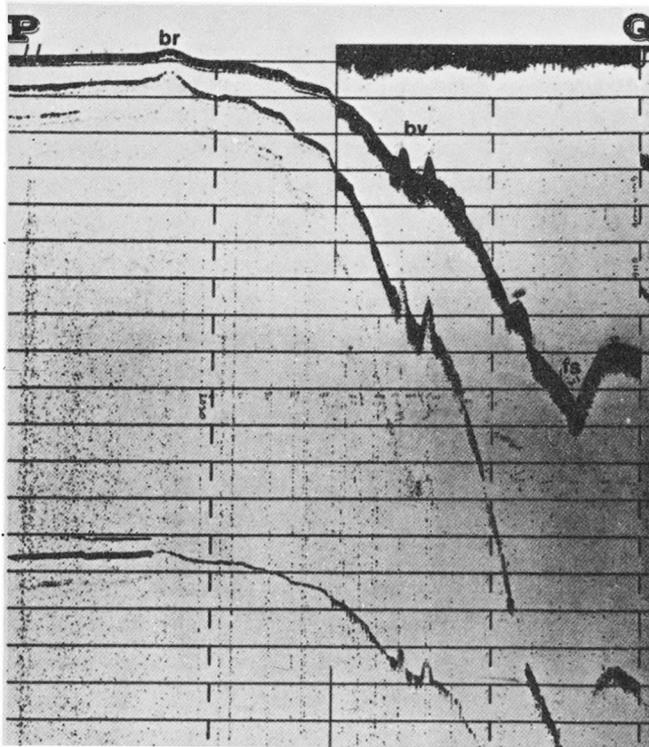


FIG. 6. — Bathymetry profile $14^{\circ}40.0'N$, $17^{\circ}33.1'W$ to $14^{\circ}47.2'N$, $17^{\circ}41.4'W$ across a slight rise near the shelf edge (br) and two sharp peaks (bv). (Full scale 2 sec, 75 m/division).

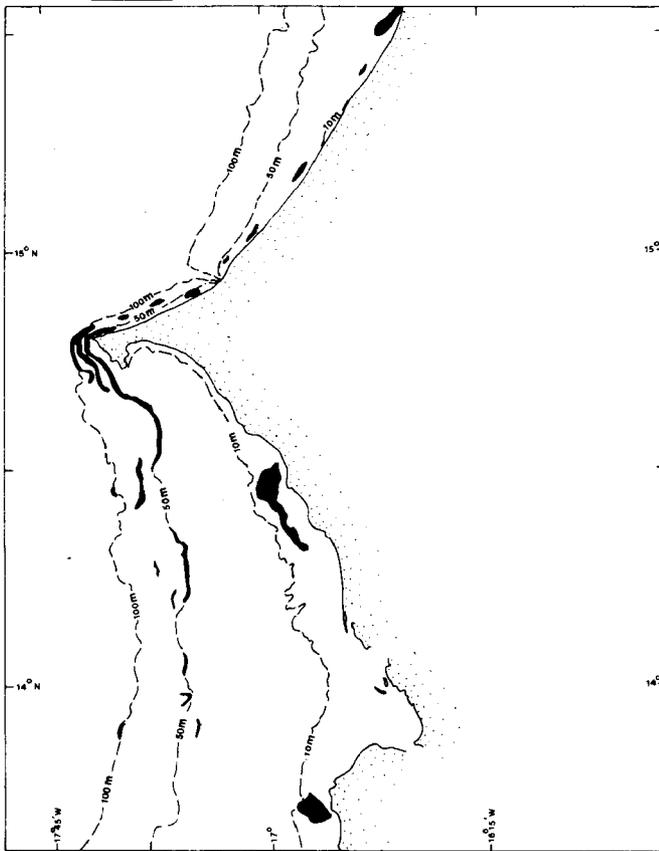


FIG. 7. --- Map of " les banes rocheux " discussed in text.

Reefal structures

On figure 6, at a depth of 400 m there are two peaks standing 20-30 m high and marked "bv". These peaks and their origins are subject to considerable speculation. Initially the authors assumed that they were simply more outcrops of Cap Vert volcanics because of their proximity to the Cap. However G. WISSMANN of the German Federal Institute for Geoscience and Natural Resources who was working on the *Meteor* data brought these features to our attention. (Personal communication, 1976). We re-examined our data in this area and recontoured the data between 300 and 700 m at the head of Sarakolle Canyon to show a series of north-south ridges outcropping on the continental slope (fig. 8).

When we wrote the bathymetry report we tended to dismiss WISSMANN's suggestion that these ridges may have been reefal in nature. However the zone of high intensity magnetics mapped by MEAGHER *et al.* (1977) does not extend as far west as these features and they show no anomalous magnetic signature. We now believe these ridges may represent old reefs that grew near the shelf edge at one time and have been further submerged through a combination of post-Pleistocene rising sea levels and subsidence of ocean

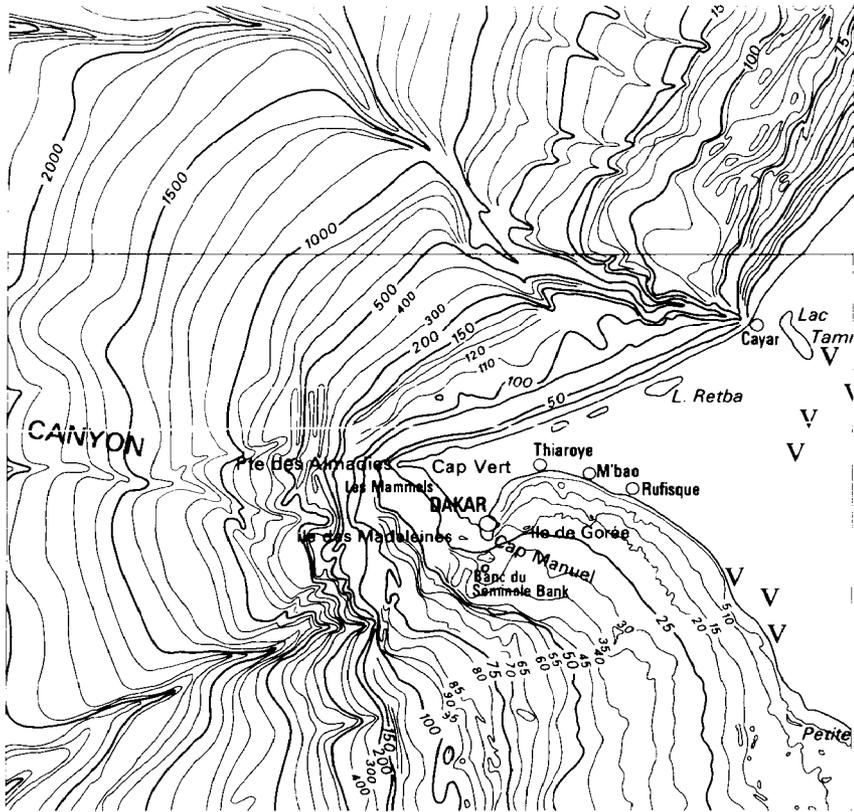


Fig. 8. Portion of bathymetry map 839 A showing area west of Cap Vert.

floor. They do remain as one of the "bumps" on the bottom that are still a puzzle.

Canyons, channels and channel systems

Cayar Canyon (fig. 9) was reported in the literature as early as 1968 (DIETZ *et al.*) and was documented by P. BONNIN in 1934 on his field sheets entitled *Région de Cayar* (1934). Almost certainly the fishermen of Cayar knew of the canyon for many years previously and indeed one may hypothesize that Cayar, a famous Sénégalaise fishing village, was not located by accident in the coastal reentrant at the head of the canyon. There are almost certainly associated physical oceanographic effects of deep water approaching almost to the shoreline and these effects would have been observed by early fishermen.

Cayar Canyon is as striking as Scripps Canyon in California and is lacking only the onshore gulch to be totally comparable. The canyon dissects the shelf to within a few hundred metres of the beach and is responsible for the marked inflection of the shoreline; there may even be a relict onshore portion indicated by the low of Lac Tamna.

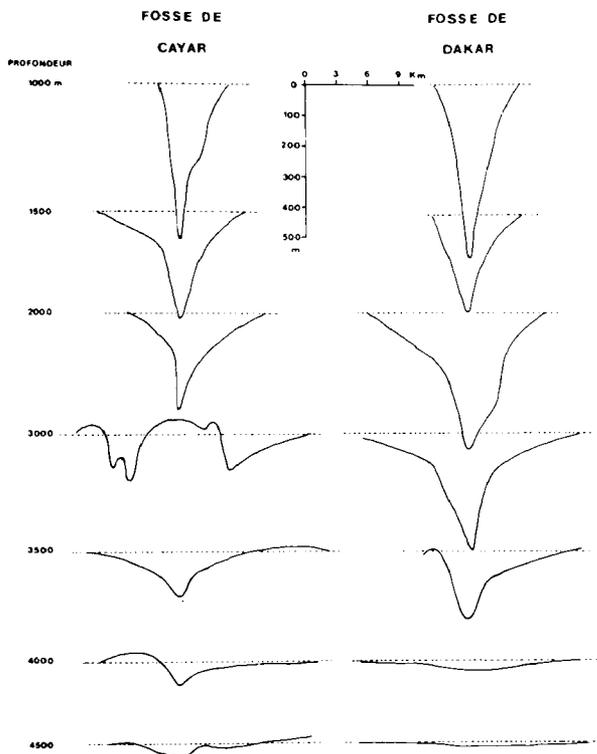


Fig. 9. — Bathymetric cross-sections of the Cayar and Dakar Canyons at 500 m depth intervals.

Most of the Sénégal/The Gambia shelf edge and slope is cut by a series of canyons that generally originate at the shelf edge, although north of Dakar several incise the shelf, Cayar and Mauritania Canyons being the most prominent. The canyons are highly dendritic and we found even at our 1 : 300 000 working scale we could not document all the detail. In contouring the shelf edge and the heads of the canyons the slightest positioning errors became critical and when combining the data of several sources extreme care had to be taken. Constant reference back to the raw analogue data was absolutely necessary rather than merely using the digitized values.

The concentration of canyons along the continental margin seems about constant. There are two exceptions ; one is real and one simply fortuitous. There appears to be few canyons in the north between the Mauritania and Nouakchott Canyons ; this is not real and reflects only the absence of recent data with good positioning which is contained in two French Field Sheets which were not available to the project (*). However the

(*) These two sheets have since been obtained and contoured. It is our intention to publish a revision to Map 839A in its very northeast corner in the Bulletin de Liaison, Association Sénégalaise pour l'Etude du Quaternaire Africain (RUFFMAN, in preparation). It will be at 1 : 1 000 000 so it may be pasted directly onto Map 839A. Canyon density is now known to be constant in the area and the same as further south toward Dakar.

short stretch of shelf edge without canyons southwest of Cayar Canyon and again south of Dakar Canyon appears to be real. The reason for the paucity of canyons may reflect particular (and unknown) bedrock conditions possibly related to the presence of the Cap Vert volcanics. A more likely reason, that will be detailed in the next section on geologic processes, is that the major canyons draw off so much of the sediment that is normally moving along the shelf from north to south that there is no erosive material immediately available to cut new canyons.

The major canyons pass across the slope and, with the exception of the Dakar Canyon, finger into two major deep-sea channel systems. We use the term channel system introduced by LAUGHTON (1960) to recognize the fact that the channel systems have a somewhat dendritic nature. Thus the Cayar Channel System is linked to Cayar Canyon and the Mauritania Channel System to the Mauritania and Nouakchott Canyons. The two channel systems appear quite distinct throughout the area and are found in the deepest part of the basin. They may join at about 11° N; we do not have sufficient data in these areas to do any more than speculate.

Deep sea channels are missed by hydrographers who depend upon only digitized data. Their signature on an echo sounder is subtle, especially if one operates an echo sounder at full scale and slow paper speeds, and if one does not have a programmable sounder following the bottom on an expanded scale. We show a traditional channel in our area on figure 10 and another crossing on figure 11. Levees were not common in the map area.

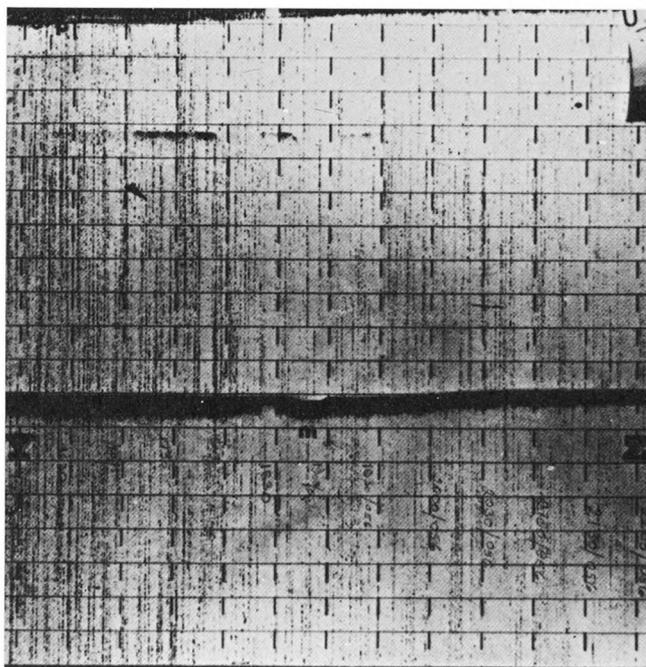


FIG. 10. — Bathymetry profile from $13^{\circ}41.0'N$, $21^{\circ}57.9'W$ to $13^{\circ}41.0'N$, $20^{\circ}51.7'W$ across the Mauritania Channel System (m). This crossing of the 60 m deep channel shows the typical shape of a deep-ocean channel. There is no indication of levees. (Full scale 10 sec, 375 m/division).

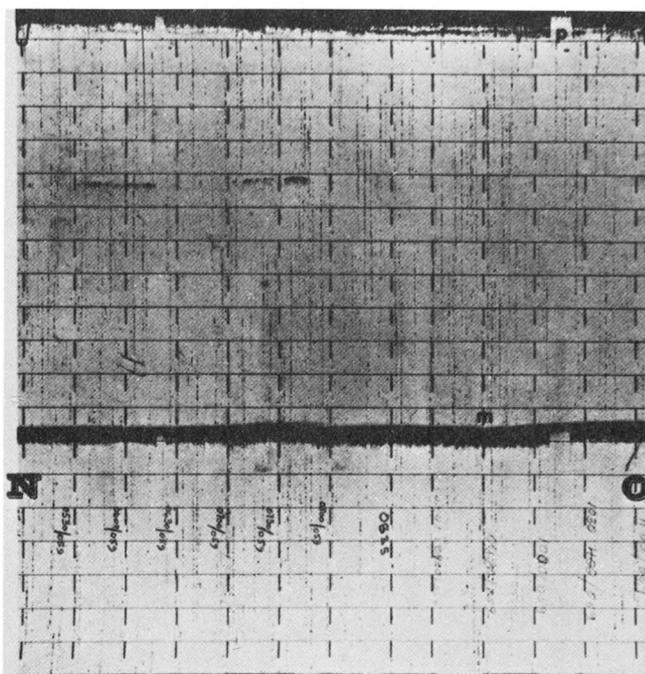


FIG. 11. — Bathymetry profile from $12^{\circ}59.3'N$, $22^{\circ}13.6'W$ to $12^{\circ}59.9'N$, $21^{\circ}07.4'W$ across a poorly defined portion of the Mauritania Channel System. The small shoulder at 0747/059 marks the western margin of one arm of the channel, and the very slight low (m) marks the axis of the main channel. (Full scale 10 sec, 375 m/division).

The small shoulder between 0730 and 0800 is significant and one must make constant reference to the raw sounding rolls to delineate and follow these features when compiling deep-sea data.

The study of the channels and feeder canyons leads us from the inter-relationship of bathymetry and geology to the relationship of bathymetry to geologic processes in the next section.

RELATIONSHIP OF BATHYMETRY TO GEOLOGIC PROCESSES

It is important to realize that the shape of the ocean floor is not only a response to the underlying geology but also to the processes that are actively affecting the bottom. Nature is constantly transferring material from the continent to the shelf and via the canyons and other processes moving it on down onto the abyssal plains. Erosion and deposition are relentless processes which may not make their presence felt during any one hydrographer's lifetime, but the bathymetry measured during any survey and that published after a compilation such as ours is the result of a long dynamic process that we freeze but for an instant on our maps. Indeed our map is an average instant because we have used data from 1934 to 1976.

Longshore drift and canyon capture

The coastline north of Cayar through to Mauritania is one long continuous smooth beach with dunes developed in a number of areas. There is virtually no opening save for the mouth of the Sénégal River near St. Louis. All of this coastline is subject to wave-induced longshore drift of sediment from north to south.

Considerable work has been done on the area just north (or upstream in the longshore current) from Cayar Canyon in looking for offshore placer deposits (Bureau de Recherches Géologiques et Minières, 1974 ; HORN *et al.*, 1975 ; circa 1975). An ocean swell is documented of wavelength 300 m, period 14 s and a velocity of 21 m/s. This suggests that during storm surges sand at depths to at least 30 m is reworked. DEMOULIN (1967), MASSE (1968) and DIETZ *et al.* (1968) have documented a swell from the northwest that impinges on the Cayar Coast and on Cap Vert and a swell from the southwest that strikes the coastline immediately south of Dakar in Baie de Gorée. The resultant longshore movement of sediment is from north to south along almost all of Sénégal's coastline, with some reversal south of Thiaroye and M'bao just east of Dakar. The predominant north to south movement of sediment is reflected in the southward extensions of river mouth bars at the mouth of the Sénégal, Saloum and parts of the Casamance Rivers. The longshore drift and wave action also affects the offshore bathymetry.

This influence is probably seen in the wavelike form of the 10 m contour at 12°05' N (fig. 12). It may show up again in microtopography, off M'bour (14°20' N, 17°07' W) and possibly offshore in the same area (13°45' N, 17°13' W) although it is difficult to differentiate between bathymetry affected by earlier stillstands and relict beaches without more geological data.

The contouring of the very detailed data on the shelf from the French field sheets revealed considerable detail, despite some problems with the positioning of the earlier surveys. In the north from 16°45' N to 17° N on the continental shelf a series of north-south ridges less than five metres high are interpreted nearshore (fig. 13). These appear to be grouped up-current from the head of a major canyon system — the Mauritania Canyon. An even more pronounced series of ridges are observed up-stream of the head of Cayar Canyon (fig. 8). Both series of low ridges are sub-parallel to the shoreline and to the regional slope of the shelf. We suspect that this apparent relationship between the ridges and the head of a major canyon is not fortuitous but rather reflects a more intimate relationship.

One might continue DIETZ *et al.*'s (1968) arguments with respect to the Cayar Canyon and suggest that not only is there a marked north to south movement of sediment under the influence of the steady northwest swell but also that there is an "overloading" of the "longshore current". Thus in an analogy with river currents when the longshore "current" overloads there is deposition. The overloading and deposition of the ridges seen on the bathymetry map then may be hypothesized to be a seasonally related phenomenon, or more likely related to the particular geometry (and depth)

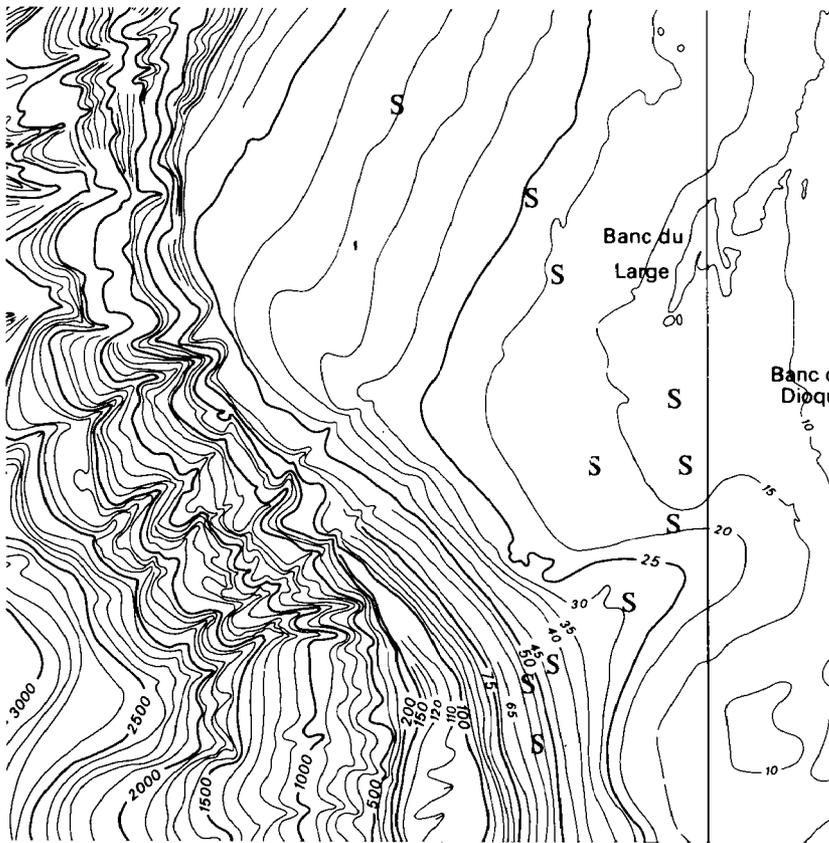


FIG. 12. — Portion of bathymetry map 839 A off the Casamance River. S marks the location of known salt domes. Latitude $12^{\circ}05'N$ is approximately across the bottom of the figure.

of the shelf and coastline. Thus in the areas of overloading the observed ridge system develops, and it may even be that the overloading and build up of sediment in certain shelf areas can be responsible for the initiation of the formation of certain canyons.

There is a considerable difference between Dakar Canyon and Cayar Canyon when considered in profile at their distal or downstream ends (fig. 9). Cayar Canyon cuts across the shelf and starts at the coastline; it continues as a well developed channel system into the abyssal depths. On the other hand, Dakar Canyon starts at the shelf edge and terminates at 4100 m and does not continue as a channel system. This suggests that Dakar Canyon is inactive and represents a relict feature. However, both Dakar and Cayar Canyons are erosional features and both show truncated beds in section. The lower end of the Dakar Canyon appears to be marked by turbidity flow material from slide-generated turbidity flow deposits; there is however no cone of sediment forming at its lower end. The head of the Dakar Canyon is presently in 100 m of water and the canyon cannot tap the active paralic zone of sand transported by longshore drift as mentioned by DIETZ in his study of Cayar Canyon.

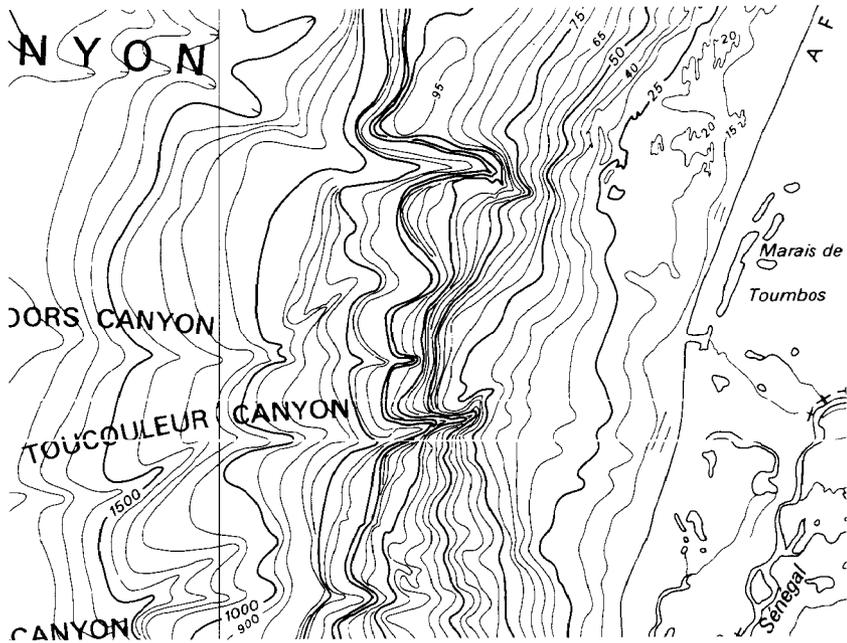


FIG. 13. — Portion of bathymetry map 839 A off the Senegal River and Marais de Toumbos.

The question then arises as to the relative ages of Dakar and Cayar Canyons. The Dakar Canyon cuts a seismic discontinuity D_2 that has been mapped as Oligo-Miocene in age by UCHUPI and EMERY (1974) and hence is younger than about 25 million years. RUFFMAN *et al* (1977) and MEAGHER *et al* (1977) suggest a two-step process for the formation and stagnation of Dakar Canyon related to the two ages of volcanism seen on Cap Vert. The intrusive events on Cap Vert are mapped as Oligo-Miocene and Plio-Pleistocene. Possibly prior to these intrusions there was no major westward protrusion of the shoreline at Cap Vert. Initially the intrusion of the volcanics at Cap Manuel, due east of the head of Dakar Canyon in the Oligo-Miocene may have formed islands off the coast and caused the initial interruption of longshore drift and the formation of a large tombolo. Baie de Gorée was then south-east of the new tombolo and a long continuous beach stretched north from Cap Manuel through the Lac Tamna area near the town of Cayar and on north towards St. Louis. The formation of the Dakar Canyon begun sometime after the Oligo-Miocene volcanic activity. Thus, the sediment moving south along the coastline via longshore drift would have accumulated and periodically passed down the Dakar Canyon (assuming that the Cayar Canyon did not exist at this time).

When the younger Plio-Pleistocene volcanics that form Pointe des Almadies and Les Mamelles erupted 0.9 to 1.2 million years ago, north of Cap Manuel the curvature of the beach would have been again interrupted and a new beach developed between the Lac Tamna area and Cap Vert with an inflection point developed at about the town of Cayar. It appears that the sediment load feeding the Dakar Canyon was cut off for a period

of time while the new coastline developed and during this time an "overloading" occurred in the shelf west of the town of Cayar with the subsequent initiation of Cayar Canyon (RUFFMAN *et al*, 1977). Cayar Canyon then would have pirated the sediments feeding Dakar Canyon. If the above sequence is correct then Dakar Canyon has been relatively inactive since the initiation of Cayar Canyon 0.8 to 1.2 million years ago. The Sarakolle Canyon directly west of Cap Vert also dies out at 3 200 m and may too have been relatively inactive for the same period of time.

As sea levels rose after the Pleistocene, Cayar Canyon erosion has kept pace with the transgressing sea and the head of the canyon still lies very close to the shoreline and still captures most of the longshore drift. The stagnation of Dakar Canyon is analogous to stream capture on shore and could be dubbed "canyon capture". The near complete draining off of longshore drift sediment can be seen in a number of ways. DIETZ *et al* (1968) recorded that the beach for one kilometre south of the head of Cayar Canyon was almost devoid of sand and very narrow and irregular beyond that for a significant distance. HORN *et al* (1974, 1975 a, b) noted that characteristic heavy minerals present in sediment samples north of Cayar Canyon did not occur in samples south of the Canyon. The shelf also noticeably narrows and steepens south of Cayar Canyon (fig. 8). The lack of sediment south of Cayar is also reflected in the inactivity of Dakar and Sarakolle Canyons and in the reduced number of shelf-edge canyons immediately south of Dakar Canyon.

Slumping on the continental slope

To this point in the paper we have been talking about features that are related to either highs or lows on the ocean floor as seen on the echogram. Figure 14 shows a profile G-H running east-west north of Cayar Seamount down the continental slope across the Cayar Slide Complex (JACOBI, 1976). The record shows a textural variation which would have been seen much more clearly had the recorder been operated with a one-second sweep and faster paper speed to avoid the severe compression of data seen on records recorded at a 10-second sweep. JACOBI has correlated the textural variation seen on G-H with evidence of a massive slump complex that has moved downslope leaving a pronounced "slide scarp" (ss on fig. 14) that can be traced over almost 200 km in an elongate horseshoe-shaped pattern north of Cayar and Little Cayar Seamounts (JACOBI, 1976 ; MEAGHER *et al*, 1977). JACOBI had an added interpretative tool in that the Lamont-Doherty Geological Observatory survey vessel had a low frequency (3.5 kHz) echo sounder that gave a certain amount of penetration into the upper sedimentary layers and allowed one to see the contorted and disturbed bedding in the lower parts of the slide complex. In addition *Vema's* lower frequency continuous seismic profiles gave even more definition of deeper internal structure. *Baffin's* program generally restricted the use of the airgun to the shelf and shelf edge areas and few lines ran down the slope into the deep ocean. However two of *Baffin's* deep water airgun lines did cross the Cayar Slide Complex and this data in combination with JACOBI's (1976) low frequency 3.5 kHz profiler and our compressed bathy-

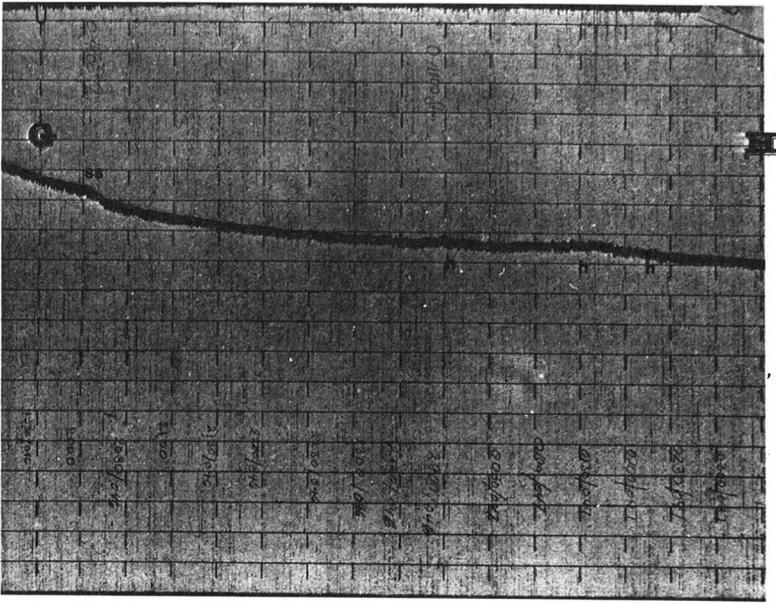


FIG. 14. — Bathymetry profile G-H from $16^{\circ}00.3'N$, $17^{\circ}23.5'W$ to $16^{\circ}00.5'N$, $18^{\circ}55.7'W$ across the continental slope and rise north and northwest of Cayar Seamount. This is one of the few records of *Baffin* on which deductions as to the nature of the seafloor can be made despite the compressed nature of the record resulting from a very slow paper speed. The change in slope at (ss) marks a slump scar, and downslope a series of hyperbola or small bumps on the record (h) give visual evidence of the rough surface of a massive slump. (Full scale 10 sec, 375 m/division). JACOBI (1976) has named this feature the Cayar Slide Complex.

metry records did allow us to define the extent of this massive downslope movement of material. The Cayar Slide Complex stretches as a tongue from its cusped slide scar on the slope between about 100 m and 200 m westward over 400 km into depths of 4 000 m.

Figure 15 shows a portion of a similar but much smaller complex in the marine clay deposits of the Champlain Sea. The only difference is that the Champlain Sea was a Pleistocene sea in the Ottawa region and now stands well above sea level. The slope of the original field seen along the top of the photo is similar to the true slope of the ocean floor along profile G-H (fig. 14) and the downslope sliding of the marine clays at South Nation is similar in nature to its modern analogue with a major upslope slide scarp and a series of subsidiary arcuate shallow slide scarps downslope. Figure 16 shows a line drawing of an airgun profile D'-D across the southern slope off Casamance. This section displays only 3 seconds vertically and has much more vertical exaggeration than the bathymetry profile G-H. Here a series of small slump scars are in evidence, along with associated faults and contortion of bedding. The analogy should be drawn to the South Nation photo of figure 15; profile D'-D consists of a number of slumps each of which is of a similar size to that shown at South Nation.

There may well be a relationship between continental slope slumping and the initiation of canyons. Off Sénégal and The Gambia, especially in



FIG. 15. — View of slump in Pleistocene age marine sediments now exposed on the South Nation River near Ottawa. The main slump seen appears from the right middle ground to the background. Subsidiary fault planes which have given the slump its rough upper surface are visible in centre of photograph. Compare with figures 14 and 16.

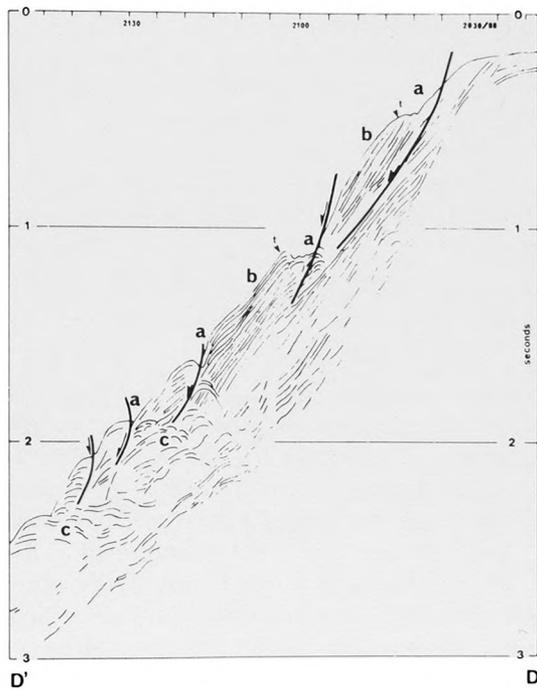


FIG. 16. — Line diagram of slumps on continental slope of profile D'-D across slope at $12^{\circ}54'N$. A series of upslope vertical or inclined fault planes become asymptotic to the bedding planes downslope. The slump mass probably slid downslope on a bedding plane fault, and there may be compression of beds in the foot of the slump (c). Truncated beds (t) can be seen at the upslope end of the undeformed slump strata (b), with the respective slump scars and related scarps (a) forming depressions that may later develop into part of a canyon system. There may also be underthrusting of slump slabs in this area as well. Drawing is from a 40 cubic inch airgun record which gave considerable penetration and delineation of subbottom structure.

the south of our map area, there appears to be a direct relationship between the density of canyons and even their existence and the amount of slumping seen. On figure 13 a number of the notches which mark slide scarps and slide scars have been interpreted to be minor arms of the dendritic canyon system found on the continental slope. The suggestion may be made that the topographic lows developed at slide scars and the associated faults serve as erosional foci for downslope movement of turbidity currents and evolve into eroded canyons. Immediately south of Dakar Canyon we earlier noted a near absence of canyons; this area also shows an absence of slumping. Work done by Geomarine Associates on the continental slope of Nova Scotia for a commercial customer shows 3 slump blocks separated by two minor canyons and lends strength to our interpretation off Sénégal and The Gambia.

Certainly one puzzle remains when one examines the bathymetry map of Sénégal-Gambia — “what is the source of all the sediment that makes the shelf south of Cap Vert so much wider than that north of Cap Vert and which gives rise to the larger amount of slumping in the south?”. In addition the continental slope south of Cap Vert is steeper than that north of the Cap which is another indication of outbuilding through sedimentation. Most of the sediment moved south by longshore drift is captured by Cayar Canyon and the shelf to the south, including Dakar Canyon, is starved of sediment at least from longshore drift. The slow moving rivers such as the Saloum, Gambia, Casamance and Geba do not appear to have any great erosive power and the sediment source is uncertain. While the southern rivers do not appear to be great sediment sources we know of no actual measurements of their sediment load or of the seasonal variation. The Archipel dos Bijagos represents a classic example of a drowned delta and implies that the Geba River at least in the recent past was a major source of sediment.

Aeolian influence

On a number of occasions during the *Baffin's* cruise the ship was coated with a layer of fine sand carried seaward by the steady northeast Harmattan that blows off the Sahara. RONA (1971) has suggested that aeolian transport of such fine desert material may have operated over a long enough time to shape the Cape Verde Rise and generally prograde the continental rise. We may see one local example of this north of St. Louis where there is a slight westward bulge in the shoreline, and offshore there is a seaward migration of the contours to delineate a broad flat area of the shelf off Marais de Toumbos (fig. 13). In this same area onshore in the south of Mauritania and extending right into the outskirts of St. Louis there are extensive longitudinal sand dunes oriented northeast-southwest to reflect the persistent Harmattan. The shoreline bulge and flattened area offshore may represent an area of increased aeolian sedimentation. The area on figure 13 could also represent a recent delta of the Sénégal River with Marais de Toumbos as part of an old channel which existed prior to the exit being cut off by longshore drift, and flow being directed southwards in a nearly 90° turn to the present exit near Gandiole.

Salt tectonism

Another geologic process that may be influencing the shape of the bathymetry is that of active salt intrusion. AYMÉ (1965) reported on the salt domes off the Casamance and our bathymetry map records 11 such features though AYMÉ's somewhat ambiguous paper can be interpreted to show up to 14. AYMÉ's contoured bathymetry map (AYMÉ, fig. 4) showed the 30 m contour wrapping around a dome ; our data show a similar disruption of the 30 m contour around a dome's rim syncline in what may be the old Casamance River embayment ($12^{\circ}17.5'N$, $17^{\circ}06'W$; fig. 12). The COPETAO and French field sheet data can be interpreted to give rise to another circular bathymetric feature at $12^{\circ}21'N$, $17^{\circ}13'W$ (fig. 12). There is no seismic data available over this feature and we can only assume that it too has resulted from salt diapirism.

We suspect that active salt tectonics may have had some influence on maintaining the shallowness of the area north of the major embayment including Banc du Large. This area of the continental shelf has the same dimensions as Sable Island Bank on the Scotian Shelf or as the Magdalen Islands high in the Gulf of St. Lawrence. All three areas are the focus of near-surface salt tectonics and all three have been drowned subsequently. All three areas may owe their relatively high relief to the influence of salt.

At $12^{\circ}35'N$ the shelf is marked by a broad ridge seen in the 25 to 40 m contours ; this ridge is probably not related to salt tectonics but rather may reflect the outbuilding process of the "Casamance Delta" in this area. Similarly the broad sinusoidal waves seen in the 100 m contour at $12^{\circ}05'N$, $17^{\circ}20'W$ are probably not related to salt tectonics but rather depict broad low ridges (sand waves) on the sea floor. These broad ridges do not represent poor positioning during the original survey since they are crossed by a number of tracks of data and only the one contour is affected.

CONCLUSIONS

As we move more and more into multidisciplinary surveys, it is important for hydrographers to realize that underneath all their bathymetry there is a fascinating geological story reflecting either rock and sediment type or a geological process that has shaped the bottom. The hydrographer who understands this intimate relationship will plan and execute a much better survey. So too will the hydrographer enjoy and understand the results more. As the CHS moves into multiparameter surveys, the mandate of the Service is changing from one of making charts for navigation to one of mapping the ocean floor for a whole host of uses including that of making charts. In this light we would advocate running recorders specific to the geological user with an expanded scale and faster paper speed. In addition when low frequency echo sounders are operated the total value of the survey will be greatly enhanced.

It is very important that before embarking on a foreign survey such as that off Sénégal and The Gambia, one does a complete assembly of

existing data and if possible a preliminary compilation. With this basic framework complete the hydrographer can plan a survey to highlight geological questions on areas with uncertain or thin coverage. With the preliminary compilations, decisions as to priority areas can be made with more certainty and the hydrographer in charge can better balance the demands of the various parallel surveys (bathymetry, gravity, magnetics, geology, biology, etc). We were surprised how much data was available off Sénégal and The Gambia and the same sort of density may well exist off the coasts of many developing countries if the time is taken to assemble it. The data will be made available, in our experience, if the time is taken to establish personal contact and if the agency approached can be assured that the completed map or report will be returned in exchange.

Finally, all cruises whether domestic or foreign will be much more rewarding in a scientific sense if the full range of users are kept in mind. This will require hydrographers with an interest in these other uses of their data and with a willingness to add certain equipment to increase the line-kilometer cost effectiveness of their vessels.

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- plus Granulométrie de la Fraction $< 63 \mu$ (north of Dakar) ; 1 sheet entitled Teneur en carbonates (south of Dakar) ; and 1 sheet entitled Granulométrie de la Fraction $< 63 \mu$ (9 sheets total). (See F. DOMAIN, 1977).
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