DEPARTMENT OF
MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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RECORD 1974/192

GEOPHYSICAL SURVEYS OVER THE CONTINENTAL MARGIN OF PARTS OF EAST AND WEST AFRICA

by

J. PINCHIN.

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SUMMARY

This report is written in response to an enquiry by the Offshore and International Division of the Department of Minerals and Energy, which in turn arose from a report by the Australian delegation to the U.N. Law of the Sea Conference.

All available published information concerning geophysical surveys of the continental margins of Ghana, Kenya, Liberia, Mauritius, Nigeria, and Tanzania has been studied, and that which is most pertinent is summarized herein. Further marine geophysical reconnaissance surveys are needed of the margins of these countries, either to delineate more precisely the extent of the continental margin or to assess its economic potential or both. For the six countries studied here these suggested surveys would total 25 000 nautical miles and cost about A$3 million.

An addendum extends the study to Sierra Leone.

1. INTRODUCTION

The confidential report of the Australian delegation to the Caracas Session of the United Nations Law of the Sea Conference led to a request from the Offshore and International Division of the Department of Minerals and Energy that BMR provide information on the continental margins of Ghana, Kenya, Liberia, Mauritius, Nigeria, and Tanzania.

This report provides the following information:

1. The extent and type of reconnaissance surveys that could be required to delineate the outer edge of the continental slope and the outer edge of the continental rise.

2. The surveys required to delineate the transition zone between oceanic and continental crust as determined from gravity measurements.

3. The surveys required to delineate and assess the general resources potential of the continental margins, both within the 200 nautical mile zone and between that zone and the outer edge of the continental rise.

4. A list of the principle contractors who could be interested in such work.

5. The cost of such surveys.

Those countries bordering the Indian Ocean (Plate 1), viz. Kenya, Tanzania, and Mauritius, are discussed first; and then Liberia, Ghana, and Nigeria, which border the Atlantic Ocean (Plate 3). The data presented here are merely from those reports and maps currently available within BMR library and as such are very incomplete. It should also be noted that the maps are sketches and should not be regarded as being completely accurate.

2. PRESENT INFORMATION - WESTERN INDIAN OCEAN (Plate 1)

Kenya

TOTAL Exploration has taken an offshore petroleum exploration lease which extends from near the shelf break out to about 3000 m of water. They planned a seismic survey there for 1973 (Cortesini & Minner, 1973).

The main sedimentary basin is the Lamu, which is a southerly extension of the Somali Basin. Carboniferous-Permian (Karroo) to Quaternary sediments are present.

The only marine survey that we know of consists of a series of refraction profiles shot by HMS Owen and RSS Discovery in 1963 as part of the British contribution to the International Indian Ocean Expedition. Francis, Davies & Hill (1966) used the results to draw a cross-section from Lamu in Kenya to the Seychelles (Fig. 1); the section shows that a thick sedimentary wedge underlies the continental slope and rise. At a point 200 n. miles offshore the Tertiary-Cretaceous sedimentary thickness is about 4 km.

The Glomar Challenger drilled 1174 m into the sediments of the East African continental rise at Site 241, about 170 n. miles off north Kenya (Simpson et al., 1972). The oldest rocks recovered were Middle Cretaceous mudstone, shale, and siltstone. These data are in agreement with the cross-section of Francis, Davies & Hill.

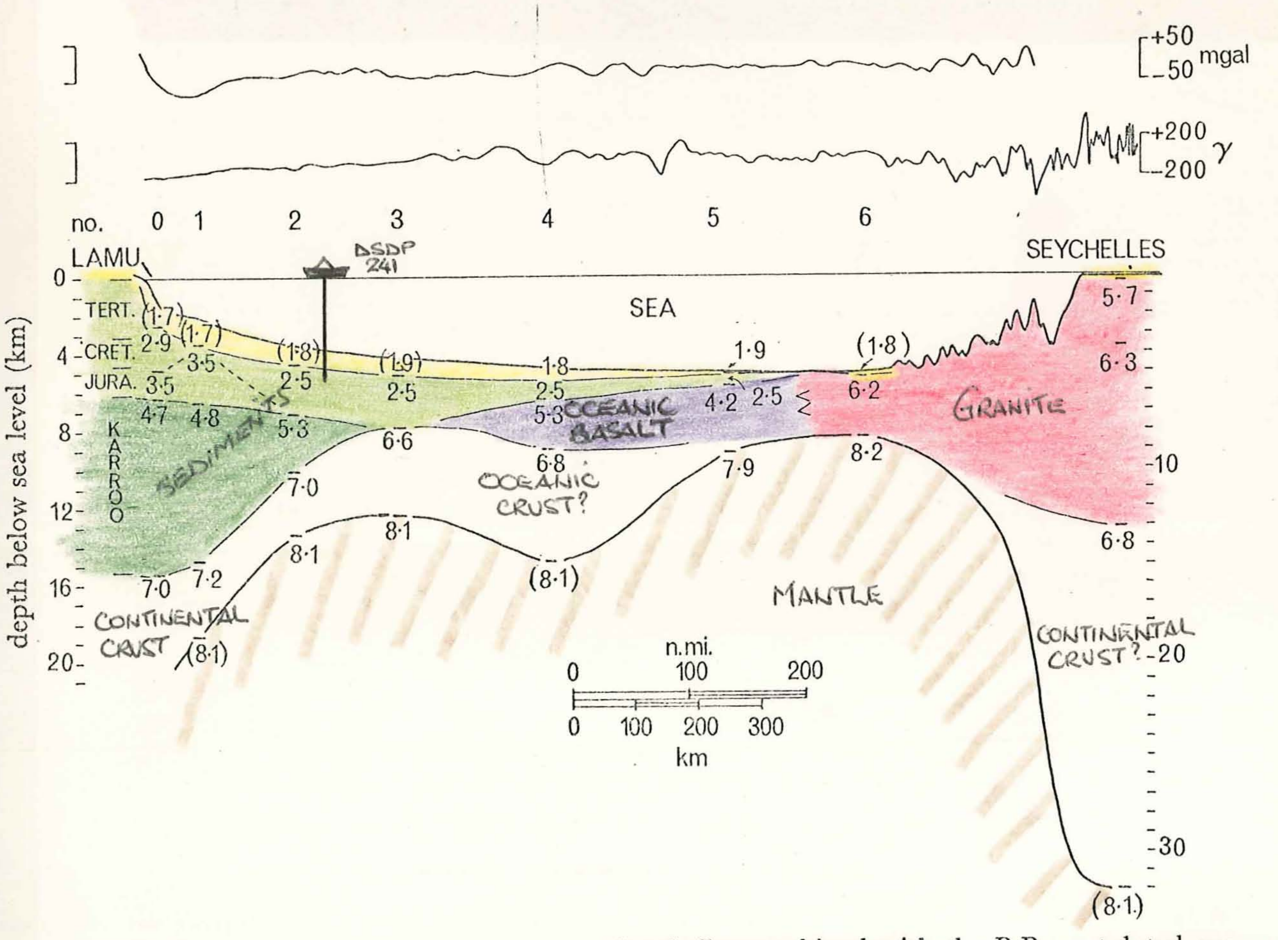


FIGURE 19. The seismic section from Lamu to Seychelles combined with the B.P. postulated geological column at Lamu. The seismic velocities are given in kilometres per second; the vertical exaggeration is 30:1. Gravity and magnetic profiles of H.M.S. *Owen* are included.

FIGURE 1 (FROM FRANCIS, DAVIES AND HILL, 1966)

32-2

Ewing et al. (1969) have drawn a generalized sediment thickness map of the Indian Ocean (Fig. 2) which shows that over 2 km of sediment lies below the continental slope and rise off Kenya and Somali.

Insofar as the morphology of the Kenyan continental margin is concerned, Heezen & Tharp (1965) show the continental rise to extend about 350 miles offshore where it adjoins the Somali Abyssal Plain at about 5000 m depth.

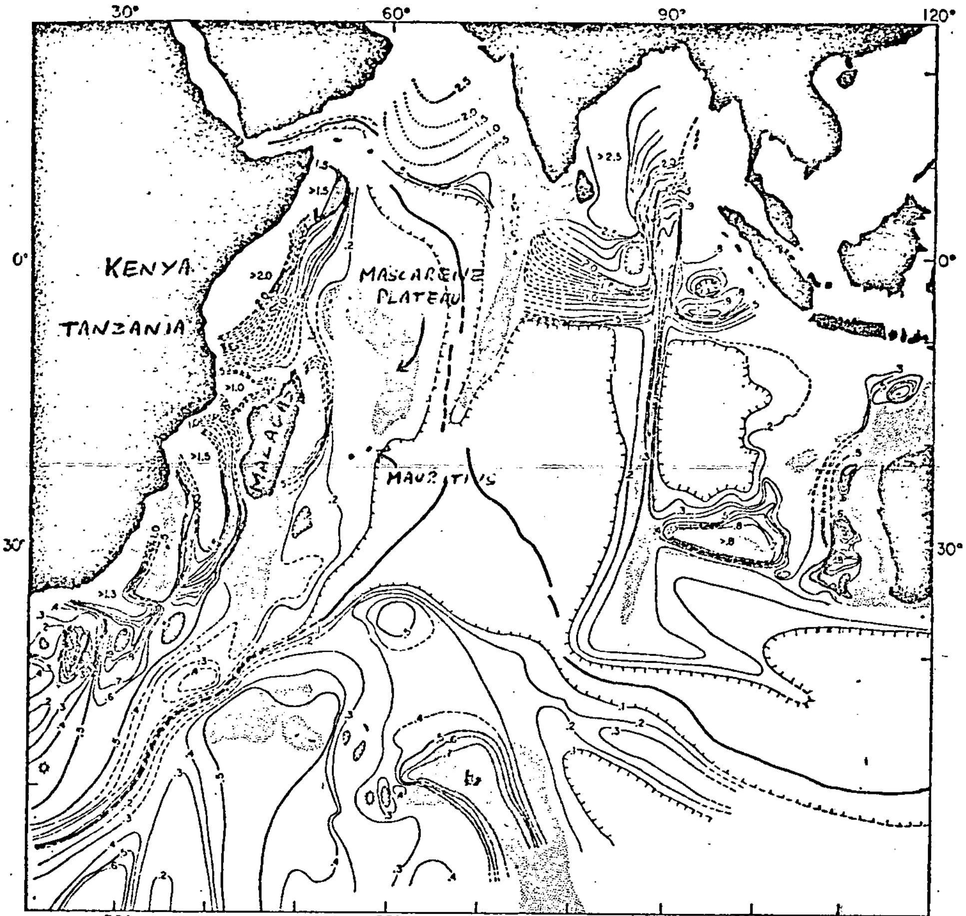


Fig. 3. Isopach map of unconsolidated sediments. Contours are in tenths of seconds of two-way reflection time (0·1 sec approximates 100 m). The axis of the mid-oceanic ridge is represented as a bold line, dashed where poorly known. Shaded areas represent aseismic ridges and plateaus, outlined by arbitrary isobaths defining best the extent and shape of each feature. Dotted isopachs on the Indus cone are after NEPROCHNOV (1961).

Figure 2. (From Ewing et al., 1969)

Tanzania

No offshore exploration licences are shown by Cortesini & Minner (op. cit.).

Ewing et al. (1969) show one survey track of either Vema or Conrad to lie offshore from Tanzania, but no specific results have come to light. Their sediment thickness map (Fig. 2) shows that the sediments thicken northwards below the continental shelf and slope from a possible basement ridge which runs from the southern border of Tanzania to the northern tip of Malagasy.

A sedimentary basin underlies the coastal strip of Tanzania (Kent et al., 1971). The general form of this basin is a wedge of sediments thickening towards the east. Regional subsidence of the continental margin accompanied by normal faulting down to the east has occurred since pre-Triassic times, and there is about 12 km of Jurassic to Miocene sediments at the coast. The same basin extends northwards to Malindi in Kenya.

Mauritius

Plate 2 gives an alternative version of the bathymetry of the Mascarene Plateau area compiled by Fisher, Johnson & Heezen (1967), which is probably more accurate than Plate 1. Fisher et al. give a comprehensive description of the known geology of the area together with several topographic profiles across the Plateau.

Texaco Mauritius Inc. is the sole holder of several large exploration leases in the shallower waters of the Mascarene Plateau. It conducted marine seismic and magnetometer surveys in the area during 1973 (World Oil, 1974).

Site 237 of the Deep Sea Drilling Project was drilled in 1630 m of water on a saddle between the Seychelles and the Saya de Malha Bank, both of which lie on the Mascarene Ridge. The hole penetrated 694 m of Recent to Paleocene materials chiefly nanno chalk and ooze, and did not reach acoustic basement. The results showed that the site has subsided from a shallow marine environment during the Paleocene to its present depth (Fisher et al., 1972).

In 1962 the research ships Argo and Horizon of Scripps Institution of Oceanography carried out seismic refraction work over the Mascarene Plateau. Shor & Pollard (1963) interpreted the results as showing that the Saya de Malha Bank is formed of volcanic rocks over which lie sediments up to 1 km thick in places. The Seychelles Bank on the other hand is composed of granite with about 2 km of sedimentary cover; it appears to be much older.

In 1964 the R.V. Chain of Woods Hole Oceanographic Institution carried out a gravity, magnetic, and seismic sparker survey of the northwest Indian Ocean. Bunce, Bowin & Chase (1966) interpreted the results as showing that the Mascarene Plateau or Seychelles-Mauritius Ridge comprises two sections. The southern section from Mauritius to the north of the Saya de Malha Bank is probably a volcanic ridge. The sparker results are poor but show little sedimentary cover over the ridge. The tops of the banks have been eroded flat. The northern section from just north of the Saya de Malha Bank to the Seychelles is probably a granitic plateau and shows horizontal sedimentary stratification.

It appears from the topographic profiles shown in Figures 3, 4, and 5 that there is no continental rise as such along the east and west sides of the Mascarene Plateau. A continental rise is formed by an apron of sediments derived from the continental slope, and since the volume of sediments over the Plateau is probably small, this hypothesis is reasonable. The sides of the Plateau in places are steep, linear, and possibly faulted. However, the profiles do not extend far off the Plateau and the sparker sections are not of good quality, so further work will be needed to confirm this interpretation.

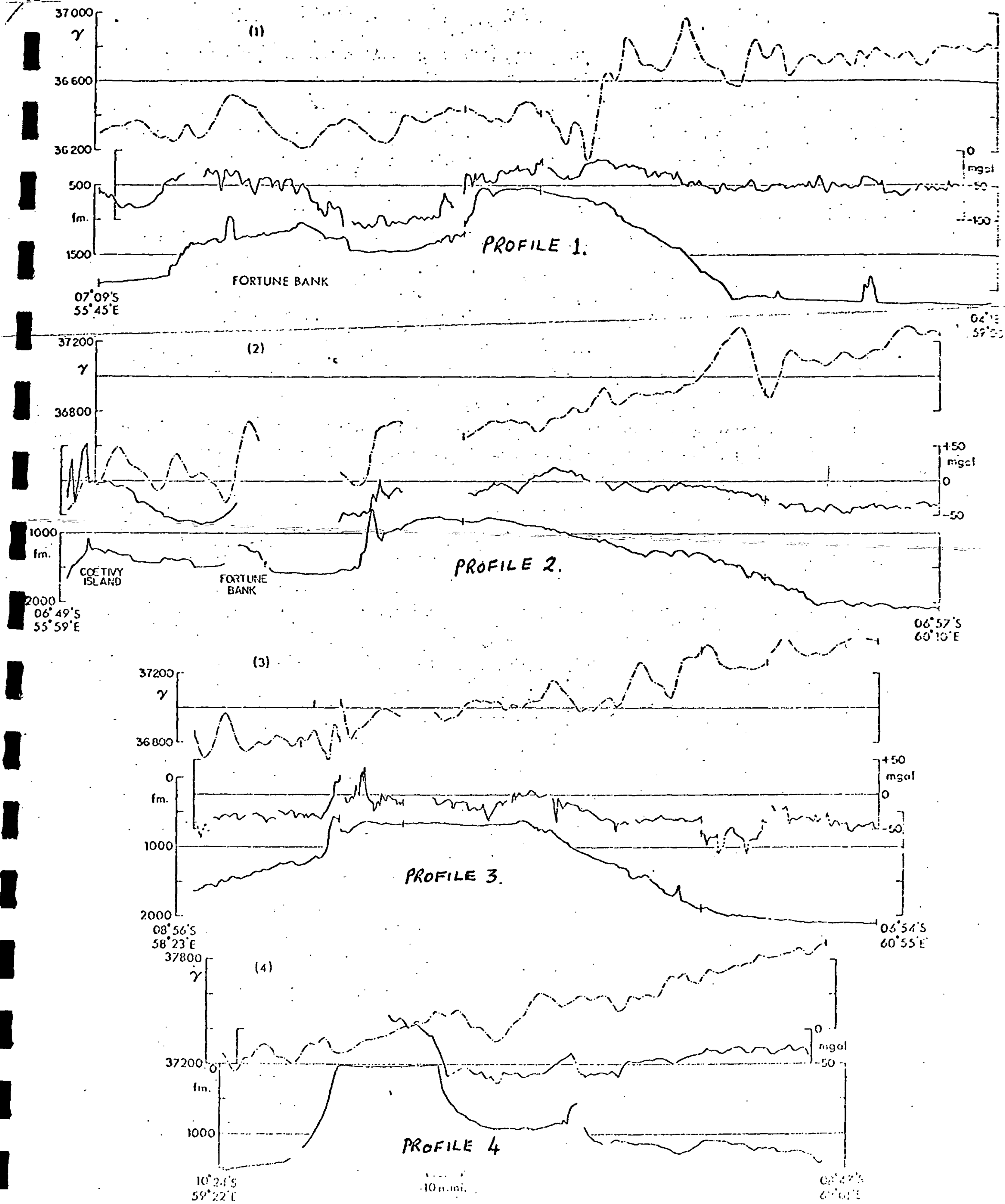
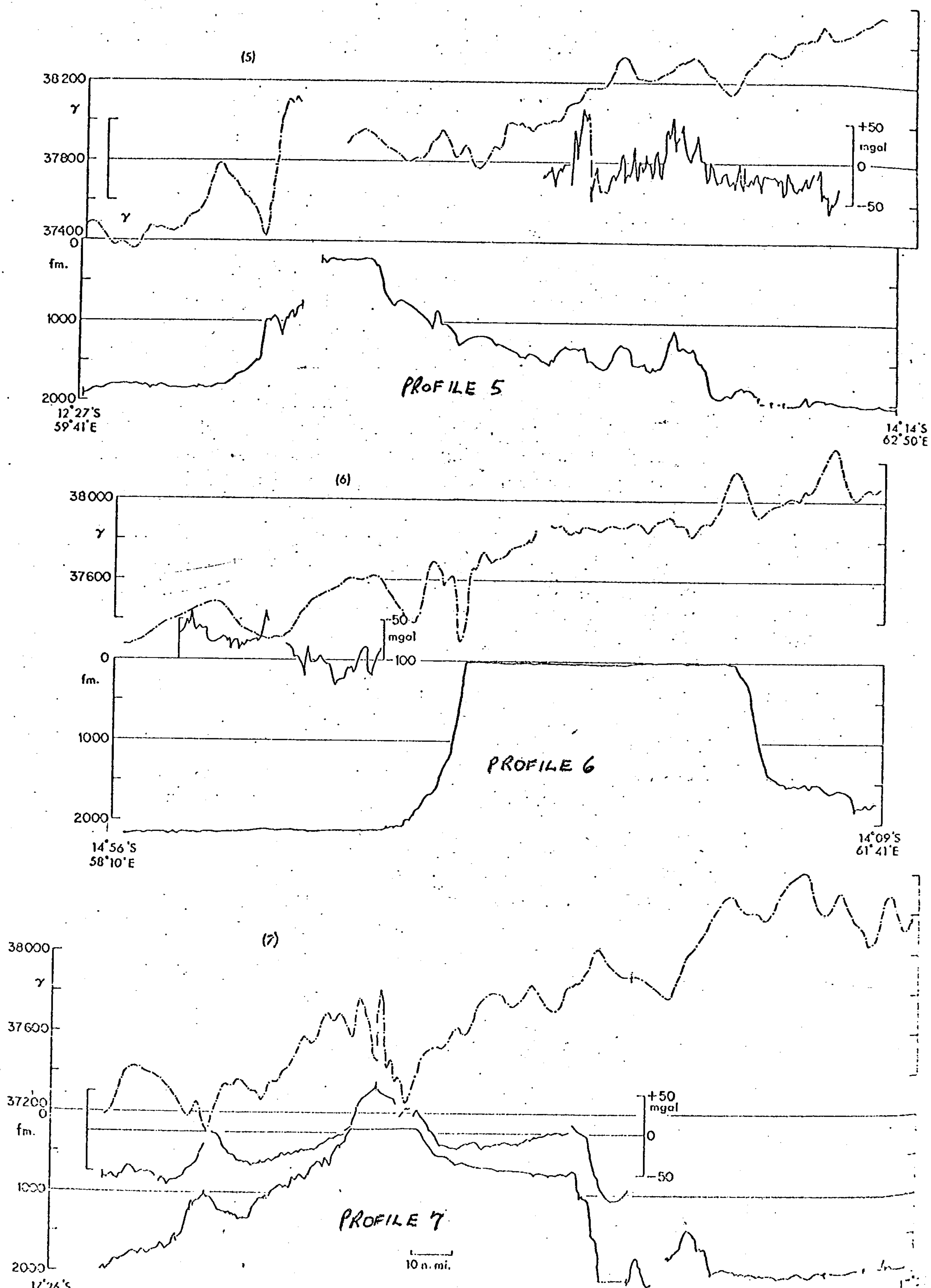


FIGURE 4. Seychelles–Mauritius Ridge: profiles immediately south of Seychelles Platform to north part of Saya de Malha Bank. Total intensity magnetic field, free air gravity anomaly, and bathymetry. (1) Immediately south of Seychelles Platform (bearing 045°); (2) midway between Saya de Malha Bank and Seychelles Platform (bearing 090°); (3) between Saya de Malha Bank and Seychelles Platform (bearing 050°); (4) north part of Saya de Malha Bank (bearing 050°). (From Bunce, Bowen and Chase, 1966)

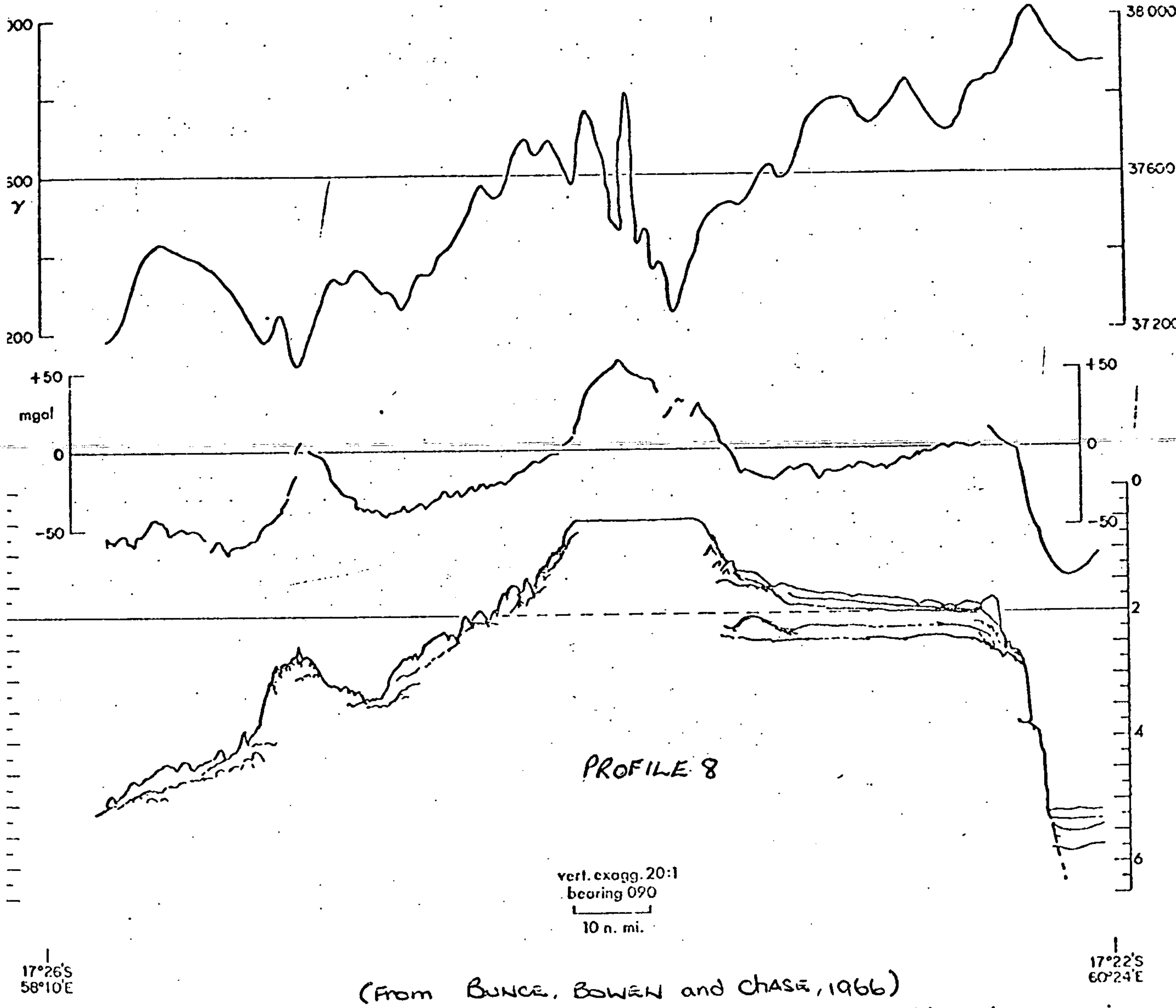
FIGURE 3



(from Bunce, Bowen and Chase)

FIGURE 4

FIGURE 5. Seychelles-Mauritius Ridge: Profiles south of Saya de Malha Bank to south of Cargados Shoals. Total intensity magnetic field, free air gravity anomaly, and bathymetry. (5) Between



(From Bunce, Bowen and Chase, 1966)

Figure 6. Seychelles–Mauritius Ridge: south of Cargados Carajos Shoals. Total intensity magnetic field, free air gravity anomaly, and seismic reflexion profiles.

Figure 5

3. PRESENT INFORMATION - EASTERN ATLANTIC OCEAN (Plate 3)

Liberia

In 1973 Aracca/Oxoco was awarded a two-year seismic option with subsequent acreage selection out to 3000 m of water, (Cortesini & Minner, 1973); it has presumably completed some seismic work by now. The continental shelf out to the 200 m isobath is divided into several petroleum exploration concessions. Four offshore wells have been drilled; the deepest, to 3000 m, encountered a thick section of Cretaceous sediments. The continental shelf is, however, thought to have limited prospects (Economic Commission for Africa, 1974).

The chief survey off Liberia was carried out during November 1971 by the US Geological Survey, the Liberian Geological Survey, and Instituto Geologico y Minero de Espana. A chartered ship, the Unitedgeo I ran 2900 n. miles of geophysical profiling at a spacing of 15 n. miles; the lines extended from the coast out to about 3000 m water depth (see also Fig. 6). A proton magnetometer, stable platform gravity meter, and a 140 kJ seismic sparker system were used. The seismic signals were recorded via a single-channel 100-element hydrophone cable. Satellite navigation supplemented by sonar Doppler was used, and a position accuracy of 1 km was achieved. The results are reported in two papers (Behrendt, Schlee & Robb, 1974; Schlee, Behrendt & Robb, 1974).

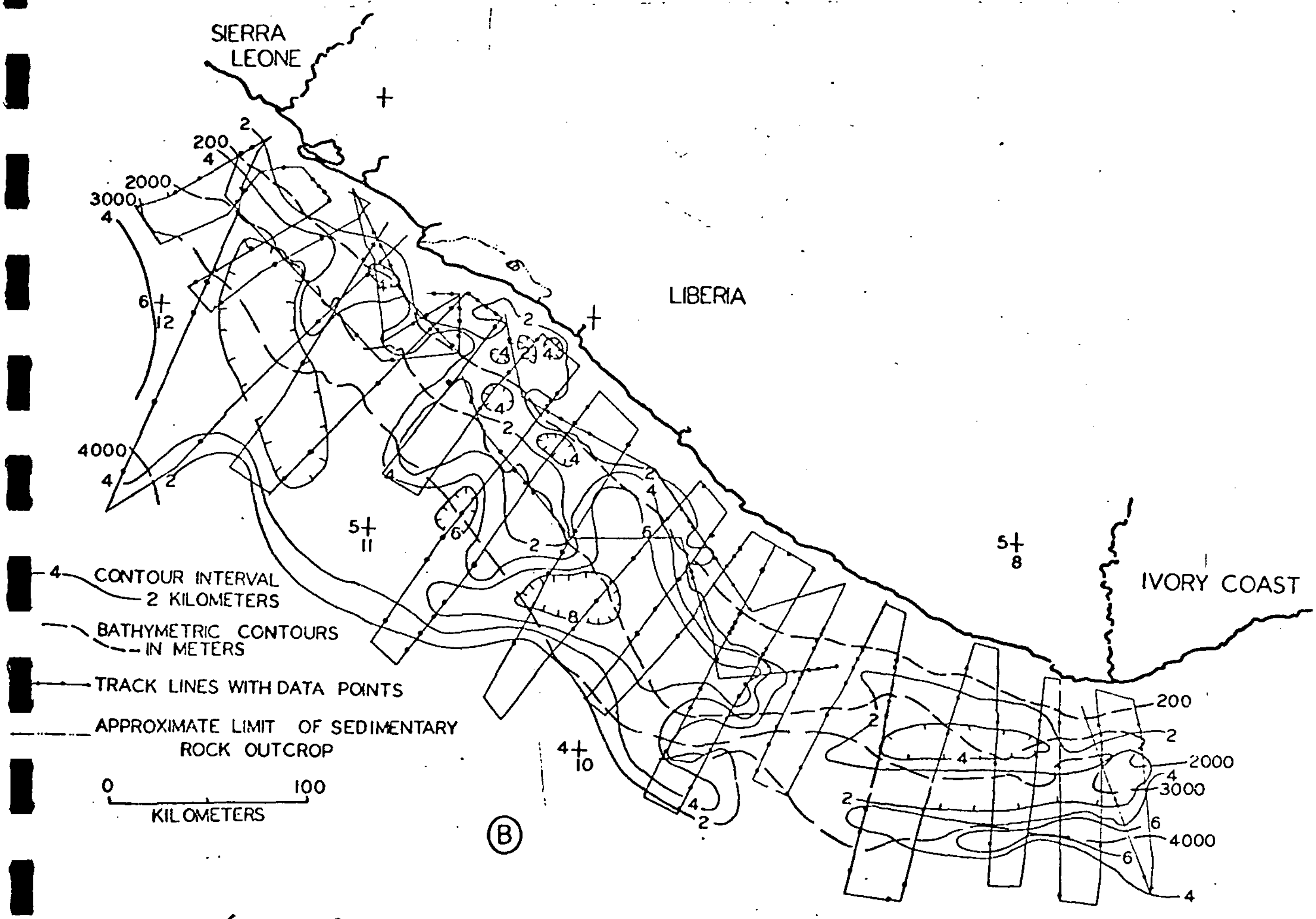


FIGURE 6 (FROM BEHRENDT, SCHLEE and ROBB, 1974)

Figure 12B. Map showing inferred thickness of sedimentary rocks above magnetic basement. Constructed by removing water depth from depth to magnetic basement.

A thickness of 4 to 5 km of Cretaceous to Tertiary sediments underlies the lower continental rise. This sequence thins gradually seaward, and thins abruptly below the continental slope. A deep-sea fracture zone intersects the continental margin in the southeast of Liberia. Large Precambrian and Palaeozoic fault blocks below the continental slope are covered with 1 km of Cretaceous to Tertiary sediments. Small sedimentary basins 3 km deep lie in between these blocks (Figs. 6 and 7).

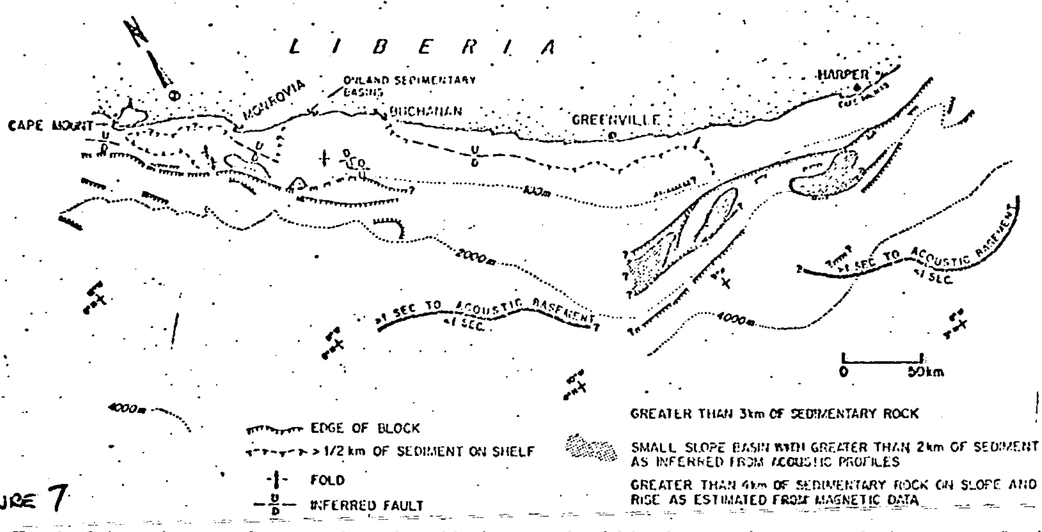


FIGURE 7

FIG. 7—Schematic map of structural-stratigraphic framework of Liberian margin based on bathymetry, reflection profiles, and magnetic surveys. General east-west alignment of elements off southeastern Liberia is probably result of intersection of St. Paul's fracture zone plus auxiliary zones with margin. Northwest alignment of structural elements off remainder of Liberia is parallel with Pan African trend and with diabase belts emplaced during rifting of North America and Africa. (FROM BEHRENDT, SCHLEE + ROBB, 1974)

Figures 8, 9, and 10 illustrate the seismic reflection profiles recorded by the Unitedgeo I off Liberia; the numbers on the profiles refer to the line numbers as shown in Plate 3. None of the profiles appear to reach the outer edge of the continental rise, although the small scale shows insufficient detail to be certain. All profiles show at least 0.5 km of sediments at their seaward ends.

Figure 11 shows a Bouguer anomaly map, and Figure 12 some computed gravity models over the continental margin. The models show that the transition zone between continental and oceanic crust lies about 40 n. miles (75 km) offshore in the region of Bouguer anomaly change from 150 to 200 mGal.

Ghana

Petroleum exploration leases over the continental shelf out to 200 m are divided between nine companies. The first offshore well drilled in 1970 discovered two oil-producing horizons, but since then success has been poor. Numerous fault blocks, unconformities, and lateral facies changes have created a complex geology, and detailed exploration will be needed (Economic Commission for Africa, 1974).

Atlantic Oil Co. carried out seismic exploration on their 'deep water acreage' during 1973 (Cortesini & Minner, 1973), but it is thought that this lies close to the 200 m isobath.

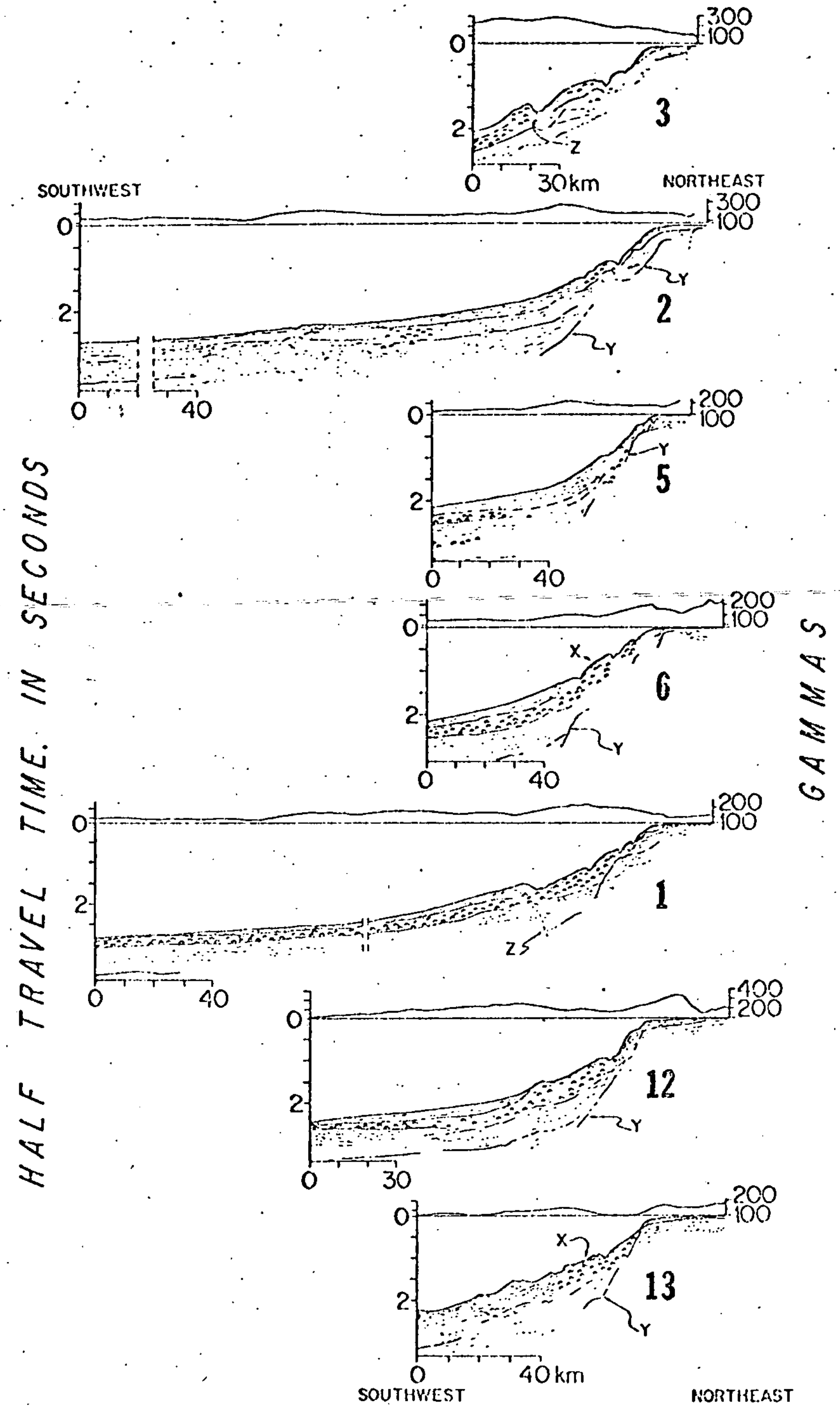


FIGURE 8

VERTICAL EXAGGERATION OF TOPOGRAPHY ABOUT ×9; SUB-SURFACE REFLECTORS ×5 OR LESS

FIG. 4—Interpreted seismic-reflection profiles for northwestern sector of Liberian continental margin. Notice buried discordant reflectors beneath slope (points Y), slump(?) scars (points X), antithetic faults (points Z), and gullying of slope. Above each profile is total magnetic intensity with International Geomagnetic Reference Field (IGRF) removed. Data used to plot magnetic profiles were sampled at 2.5-km intervals from original more closely spaced observations; hence, profile is overly smooth above shallower magnetic basement of continental shelf.

(FROM BEHRENDT, SCHLEE AND ROBB)

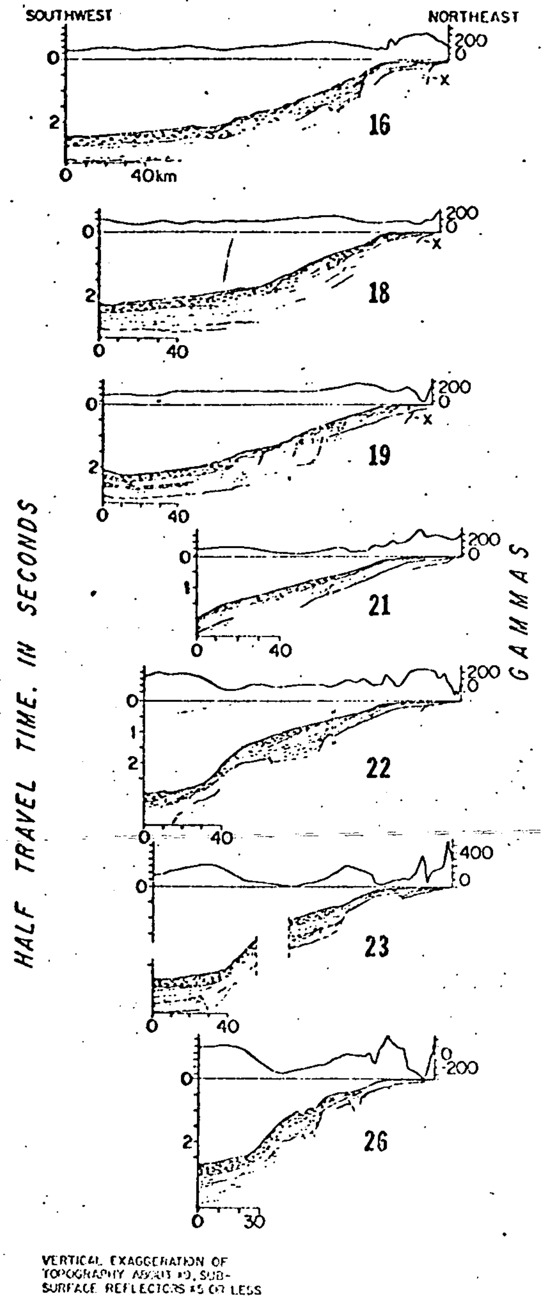


FIG. 3—Interpreted seismic-reflection profiles for central sector of Liberian continental margin. More prominent reflectors are shown in heavier lines. Notice steepened boundaries (points X) on profiles 16–19 and marked progradation of sediment over foundered blocks under slope, particularly for profiles 19–26. Above each profile is total magnetic intensity with International Geomagnetic Reference Field (IGRF) removed. Data used to plot magnetic profiles were sampled at 2.5-km intervals from original more closely spaced observations; hence, profile is overly smooth above shallower magnetic basement of continental shelf.

FIGURE 10
(From Behrendt, Schlee and Robb)

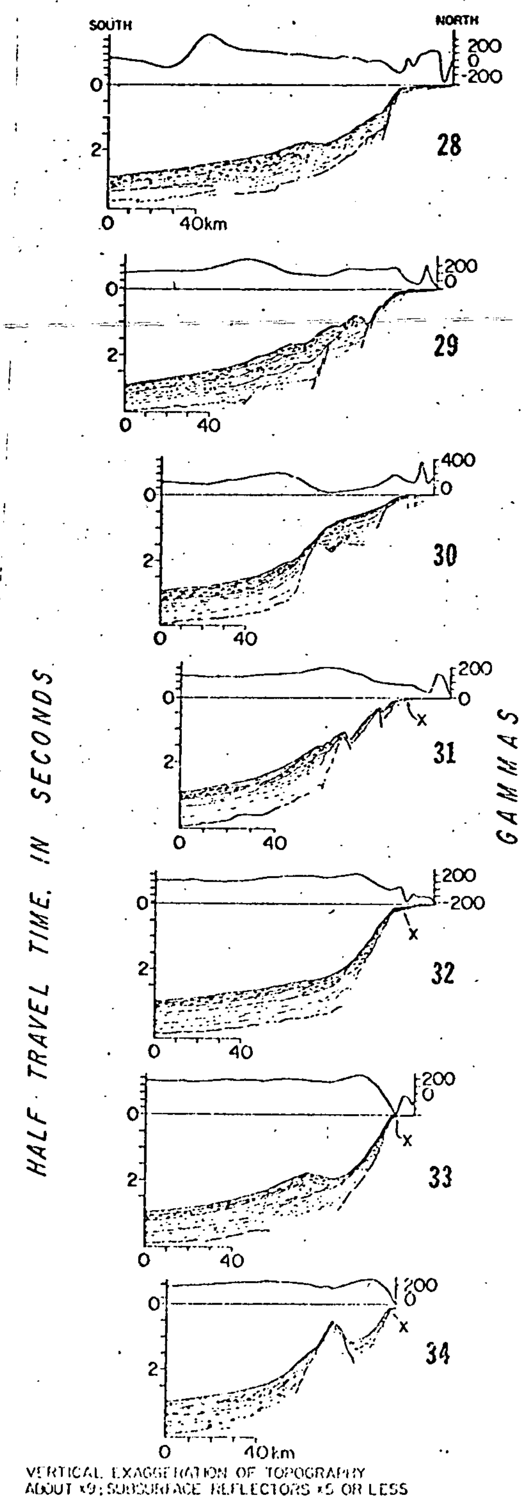


FIG. 2—Interpreted seismic-reflection profiles for southeastern sector of Liberian continental margin. Notice thin sediment cover on continental shelf (points X). More prominent reflectors are shown with heavy line. Discontinuous reflectors, probably slump deposits, are shown by small crescentic marks. We have included only part of each line normal to coast and have deleted "dog-leg" segment parallel with coast. Above each profile is total magnetic intensity with International Geomagnetic Reference Field (IGRF) removed. Data used to plot magnetic profiles were sampled at 2.5-km intervals from original more closely spaced observations; hence, profile is overly smooth above shallower magnetic basement of continental shelf.

FIGURE 9 (From Behrendt, Schlee and Robb)

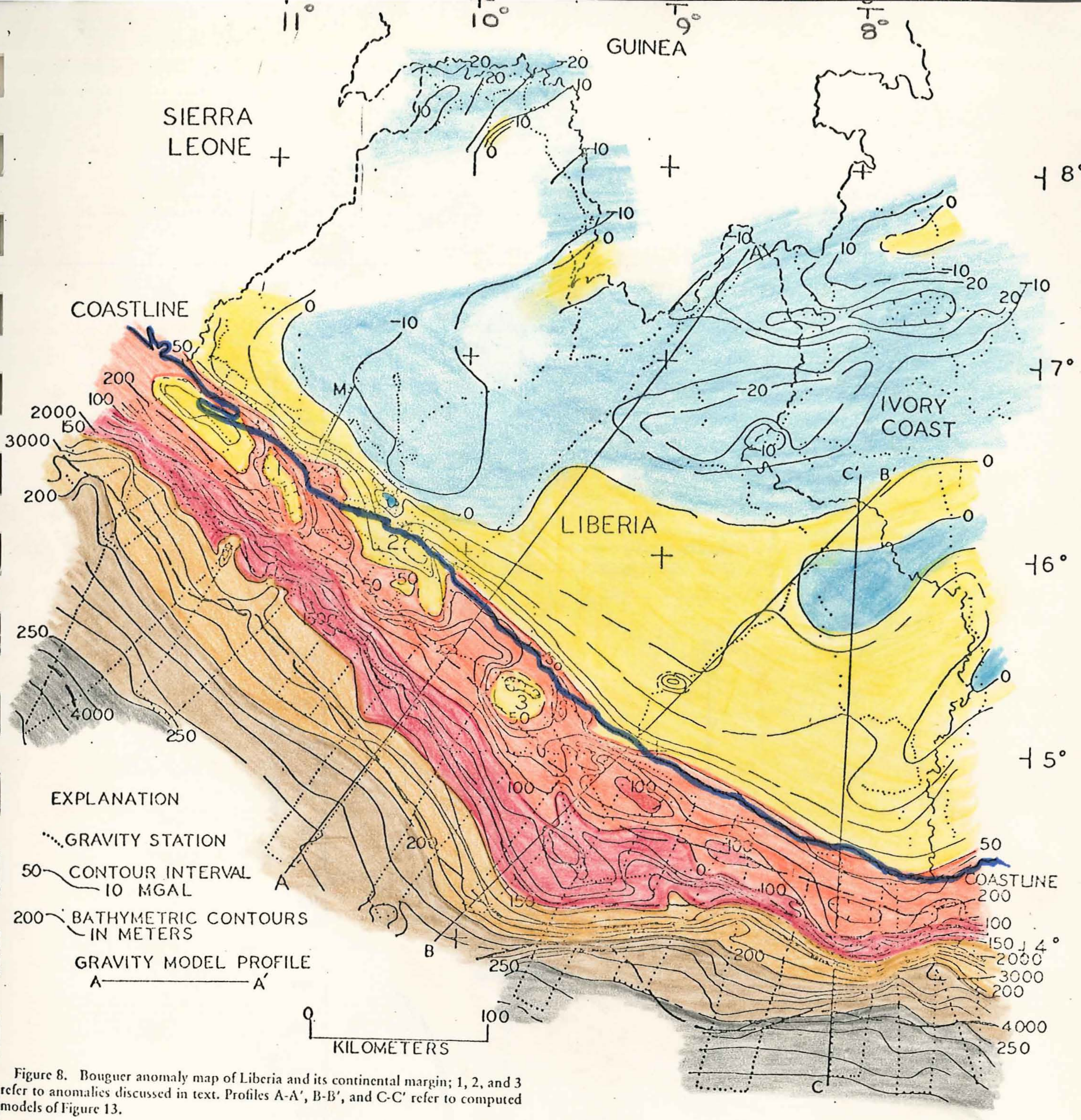


Figure 8. Bouguer anomaly map of Liberia and its continental margin; 1, 2, and 3 refer to anomalies discussed in text. Profiles A-A′, B-B′, and C-C′ refer to computed models of Figure 13.

FIGURE 11

(FROM Berendt, Schlee and Robb, 1974)

COLOUR KEY

- -50 → 0 mGal
- 0 → 50
- 50 → 100
- 100 → 150
- 150 → 200
- 200 → 250
- 250 → 300

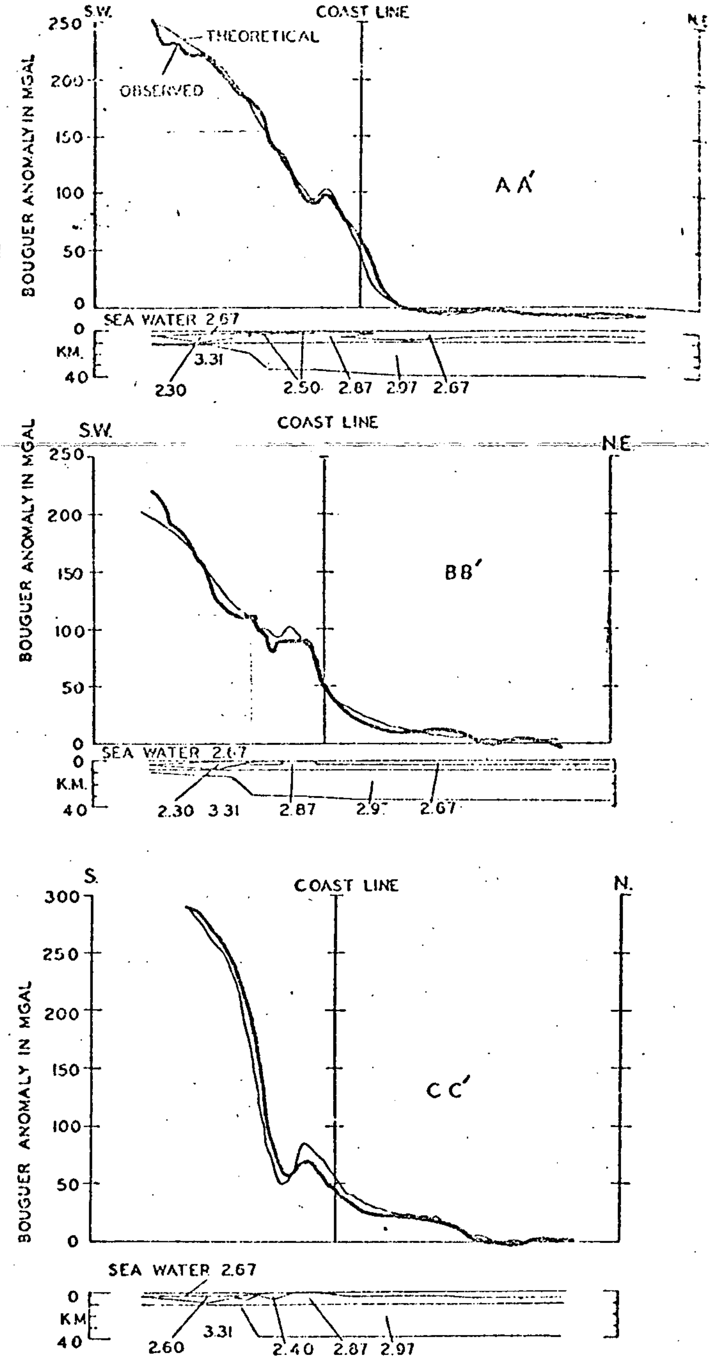
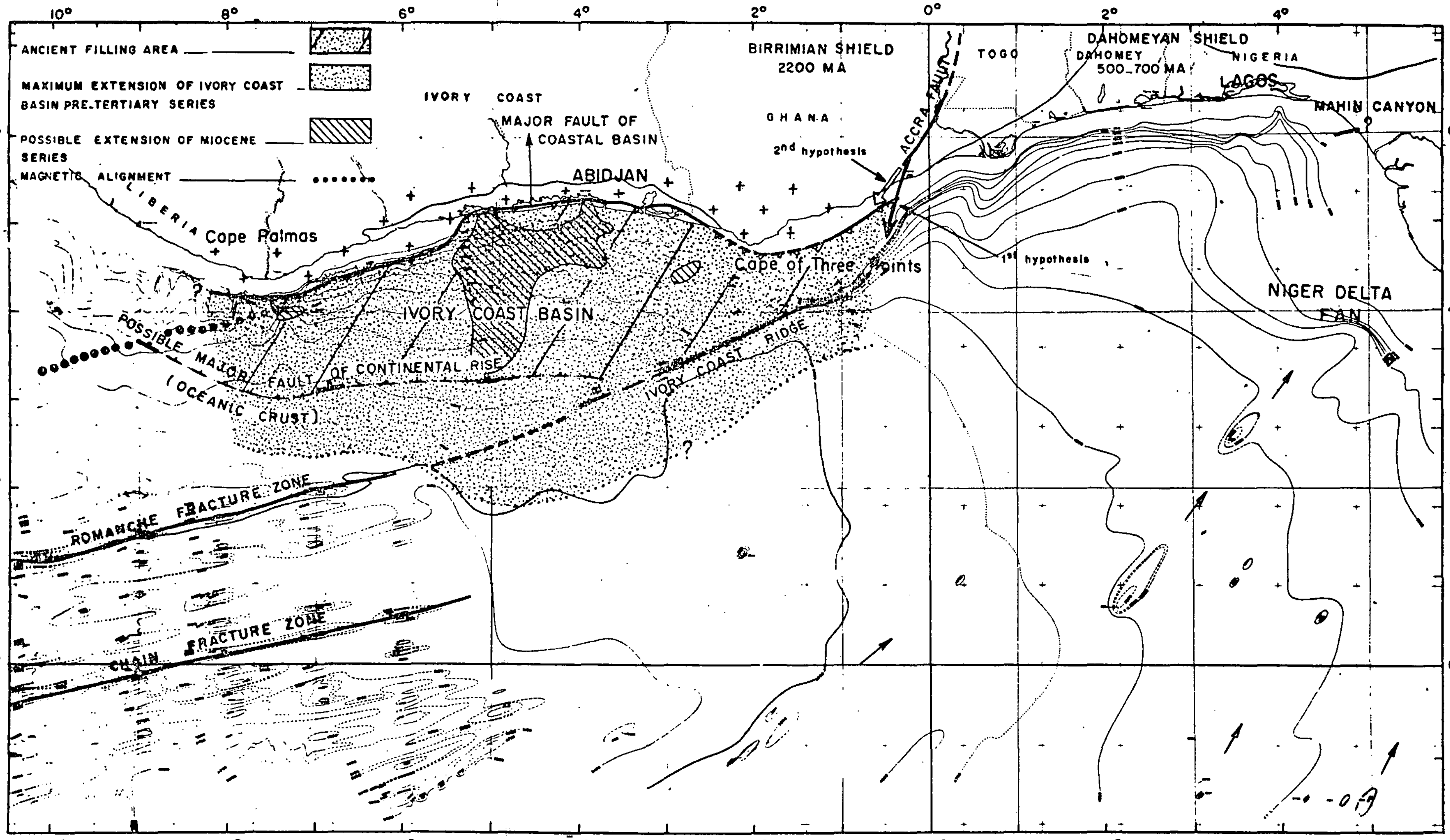


FIGURE 12

Figure 13. Theoretical two-dimensional gravity models fitted to observed data for profiles A-A' (line 17), B-B', and C-C' (line 30) in Figure 8. Densities are indicated in g/cm^3. A higher density was required beneath the slope on C-C' than beneath A-A' and B-B'. Depth to magnetic basement (Fig. 12A) was used in constructing the model. Mantle depth at oceanic end of profile was assumed, based on Sheridan and others (1969). The 2.67 density of the southwest end refers to the Bouguer correction for sea water. Model A-A' suggests a thrust fault at the coastline.

(From Behrendt, Schee and Robb, 1974)



Accra fault passing through continental shelf (1st hypothesis)

Correlation between Accra fault and major Ivory Coast fault (2nd hypothesis)

Fig. 8. Interpretative palaeogeographic sketch of the northern Gulf of Guinea. The Romanche and Chain fracture zones extend eastwards in the northern Gulf of Guinea. Further east, the Romanche crest continues as the Ivory Coast ridge. The possible major fault of the continental rise and the Ivory Coast-Ghana ridge would correspond to a limit between a northern area of cratonic crust and a southern one of oceanic crust. Upper Cretaceous and Tertiary (except Miocene) series seem to pass slightly southwards beyond to the topographic high of the Romanche and Ivory Coast-Ghana ridge.

FIGURE 13. (FROM ARENS et al, 1970)

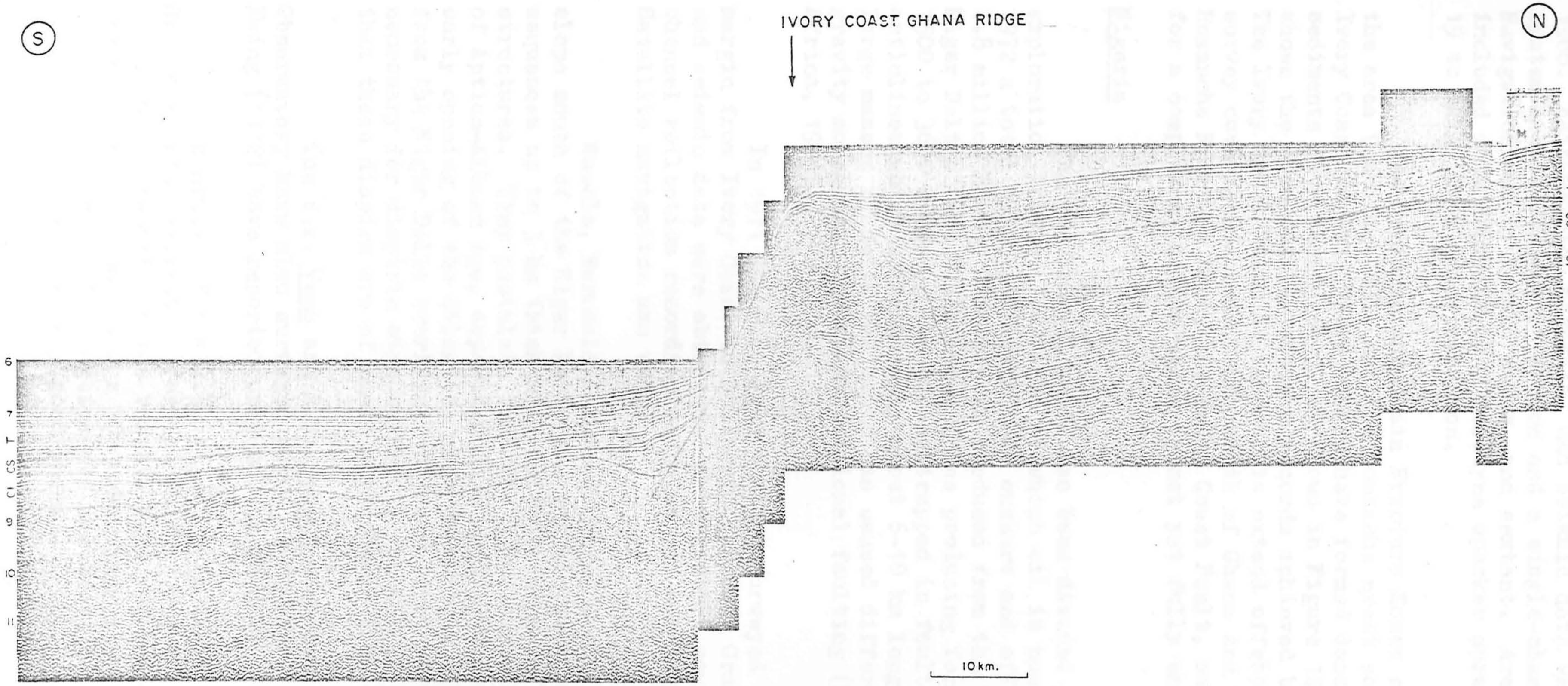


Fig. 6. Seismic profile No. 8. The Ride de Côte d'Ivoire-Ghana (Ivory Coast-Ghana Ridge) is well marked by a basement uplift, faulted to the south. This feature closes the marginal plateau of the Ivory Coast which extends northwards, filled with pre-Cretaceous or Cretaceous to Miocene (M) and Lower Tertiary (T) recent sediments. In this area, the basement position is undetermined. In the abyssal plain, Cretaceous sediments become thinner below turbidites of Tertiary to recent age and should disappear southwards. Upper Cretaceous, CS; pre-Upper Cretaceous, CI; Undifferentiated substratum, S.

FIGURE 14. (FROM ARENS et al. 1970)

The R.V. Jean Charcot surveyed the northern Gulf of Guinea in 1968. Bathymetric, magnetic, and seismic data were recorded. The seismic system used a 'flexotir' source and a single-channel recording system. Navigation was by Toran, radar, and sextant. Arens et al. (1970) have included data recorded by a Teledyne sparker survey and by Vema on cruise 19 to make their interpretation.

The Romanche and Chain Fracture Zones cut across the south of the area (see Fig. 13), and the Romanche crest continues eastwards as the Ivory Coast Ridge. These ridges have formed dams behind which terrigenous sediments have accumulated, as shown in Figure 14. This illustration also shows the good quality seismic records achieved by the 'flexotir' system. The Ivory Coast Basin is thought to extend offshore from Ghana, but the survey coverage is less dense south of Ghana and the convergence of the Romanche Fracture Zone, the Ivory Coast Fault, and the Accra Fault make for a complex situation which is not yet fully understood.

Nigeria

The continental shelf has been divided into many petroleum exploration leases, from some of which oil is now being produced. In 1972 a total of 75 oilfields both onshore and offshore were producing 1.8 million BOPD. Most oil is produced from the Tertiary basin of the Niger Delta. The Oligocene-Miocene producing formations are generally 1500 to 3600 m deep. The oil is trapped in fault-bounded roll-over anticlines which are generally about 6-10 km long and 3-5 km wide. The large masses of delta sediments has caused differential compaction, gravity movements, and syndepositional faulting (Economic Commission for Africa, 1974).

In 1971 the R.V. Jean Charcot surveyed the African continental margin from Ivory Coast to Southwest Africa. Gravity, magnetic, bathymetric, and seismic data were obtained. A 'flexotir' source was used for single-channel reflection recording and also for sonobuoy refraction profiles. Satellite navigation was used.

Mascle, Bornhold & Renard (1973) report that over the continental slope south of the Niger Delta the seismic sections show sedimentary sequences up to 3 km thick with definite signs of deep-seated diapiric structures. They postulate that the diapirs are composed of evaporites of Aptian-Albian age, deposited in a major evaporites basin during the early opening of the Atlantic. The tremendous volume of Tertiary sediment from the Niger Delta overlying the salt layer provided the pressures necessary for diapiric structures. Burke (1972) mentions the possibility that these diapirs are of shale composition (see Figs 15 and 16).

The R.V. Vema and R.V. Conrad of Lamont-Doherty Geological Observatory have also surveyed south of Nigeria, but Leyden, Bryan and Ewing (1972) have reported only on the results from the Angola Basin.

A cruise of the R.V. Atlantis II was planned by Woods Hole Oceanographic Institution for the Gulf of Guinea (Emery, 1972) during 1973, but no reports of the results have yet been received. If the seismic records from the 2 x 300 cubic inch air gun source are as good as they were on the 1972 cruise off southwest Africa, then the seismic penetration should be very good indeed.

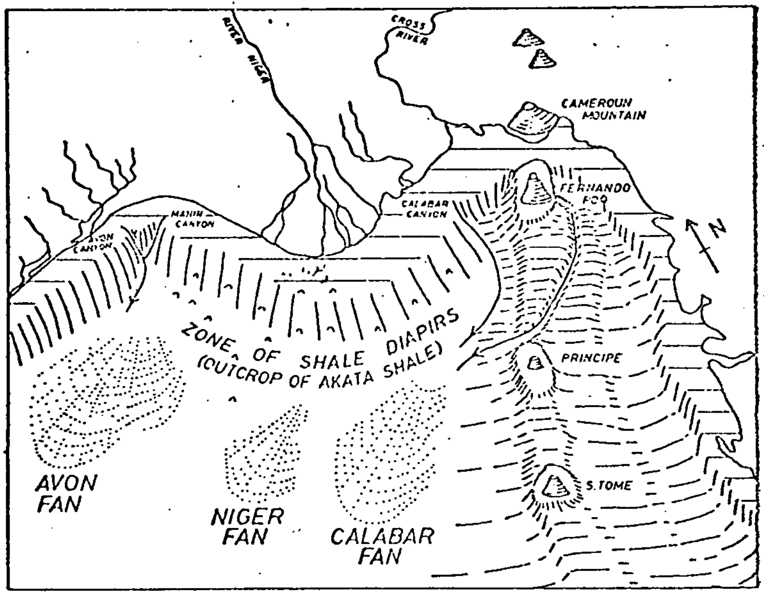


FIGURE 15

Fig. 3—Physiographic sketch of Niger delta looking northeast and showing Avon and Calabar fans fed by submarine canyons at corners of delta. Niger fan on delta axis is fed from Niger trench at times of low sea level but probably is inactive at present. Two shale diapirs that crop out on continental shelf are plotted from Allen (1964, Fig. 1c); others are represented schematically. Sketch is based on published bathymetric maps, especially Allen (1964, Fig. 2b for water less than 1,000 m deep); International Tectonic Map of Africa (Assoc. African Geol. Surveys, 1968), and Arens *et al.* (1971, Fig. 2).

(FROM Burke, 1972)

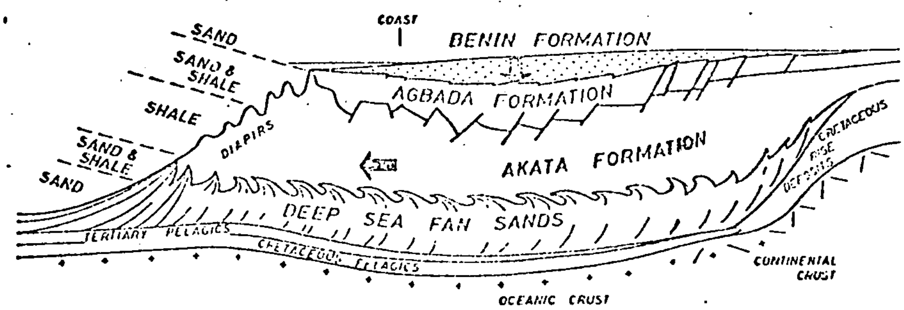


Fig. 10—Schematic structural cross section of Niger delta, modified from Merki (in press) and Weber (1971, Fig. 2) to include submarine fan element. Akata shale overlies submarine fan sand unit at bottom of delta which lies on pelagic sediments over oceanic crust. Transitional shale-sand unit between Akata shale and bottom sand is sketched as dragged forward by motion of Akata.

FIGURE 16 (FROM BURKE, 1972)

4. SURVEYS REQUIRED

Two different types of reconnaissance survey will be required over the continental margins of these six countries.

(a) The first type is needed to delineate and assess the general resources potential of the continental margins. The suggested traverses for these surveys are marked in Plates 1 and 3 with solid coloured lines.

The ship should be about 60 m long, and at least 1500 tonnes displacement. It should have a range of about 10 000 n. miles and a cruising speed of 15 knots. Satellite/sonar Doppler navigation will be required, together with other radar and radio positioning systems for work close to shore. Bathymetric, magnetic, gravity, and seismic data should be recorded. Since one of the aims of the survey is to look for thick sedimentary accumulations the reflection seismic system should be of good quality. A powerful seismic source and a multi-channel (up to 24) seismic streamer cable will be necessary. Subsequent digital seismic data processing of selected profiles will probably be required. A survey speed of 6 knots is probably the highest that is consistent with good recorded seismic data.

(b) The second type of reconnaissance survey is that required to roughly map the outer limits of the continental margin. The suggested traverses for these surveys are marked in Plates 1, 2, and 3 with broken coloured lines.

The ship and equipment will be as for the first survey type with the exception that a single-channel seismic system will be satisfactory and a survey speed of 10 knots may be used. The emphasis during these surveys will not be on seismic data but more equally spread between seismic, bathymetric, and gravity data.

Kenya

Requirements for a marine geophysical survey of type (a) here depend entirely on the results of existing surveys within and possibly outside of the TOTAL offshore acreage. A survey was carried out there in 1973 and possibly one in 1974 but we have no further information. The one refraction traverse offshore shows thick sediments, so petroleum prospects are good. It now remains to determine the structural style, and to pin-point areas for a more detailed petroleum search. A line spacing of 20 nautical miles (37 km) is therefore recommended since the onshore geology shows a fair amount of faulting and structural complication. About 4000 nautical line miles would need to be surveyed, and at 6 knots this would take 28 days.

There is a probability that the thick sedimentary wedge extends past the 200 mile zone to the limit of the continental rise. Six reconnaissance traverses of type (b) would give sufficient information to delineate the extent of the continental rise and the outer limits of the crustal transition zone. The traverses should extend well over the Somali Abyssal Plain to ensure that the edge of the continental margin has been reached. These traverses total about 2200 n. miles; at 10 knots this would take 9 days.

It would be useful to record several seismic refraction profiles using sonobuoys at selected sites across the entire width of the continental margin during both surveys (a) and (b).

Tanzania

A survey similar to that suggested for Kenya would be required offshore from Tanzania. However, since the lower parts of the continental rise lie closer to the Cosmoledo Group of islands than to Tanzania, only one regional excursion of survey type (b) is proposed.

A total of 4200 n. miles of survey type (a) at a 20-mile line spacing would take 29 days, and the 600 miles over the outer continental slope would take 2½ days.

Mauritius

Any survey proposed for Mauritius and its dependancies should be based on the results of Texaco's work of the last two years. Since the southern part of the Mascarene Plateau is of volcanic origin, probably composed mainly of oceanic basalts, it is not expected to have a 'continental margin' as such. However, a survey of the margins and an investigation of the economic potential of the area could be combined into a single round-trip reconnaissance survey of type (b). The total mileage proposed is 4200 n. miles, taking 18 survey days.

Liberia

The Unitedgeo I survey has provided sufficient data for a regional interpretation. The data appear to be very good, and could be improved on only by using a more powerful seismic source coupled with a multi-channel recording system. The crustal transition zone has been well defined by the gravity results, but it appears that the outer edge of the continental rise was not delineated.

Several lines spaced about 70 miles apart extending from the shelf out to the Sierra Leone and Guinea Abyssal Plains could be run in between existing survey tracks. This survey, of type (b), would delineate the outer limits of the continental rise; the 2600 n. miles would take 11 days to complete at a survey speed of 10 knots.

Ghana

A survey is definitely needed over the eastern part of Ghana's continental margin to provide further information on the complex tectonic pattern and to extend the existing coverage. The data from the 1973 cruise of Atlantis II and from the cruises of Vema and Conrad are needed before the survey could be planned. In view of the complex geology, a type (a) survey of the continental shelf and slope at a line spacing of 10 n. miles is suggested. The 2600 n. miles would take 18 days at 6 knots.

A few additional reconnaissance lines of survey type (b) could supplement the information from the many existing regional traverses over the outer continental rise. These add up to 1000 n. miles and would take 4 survey days at 10 knots.

Nigeria

The petroleum potential of the continental margin south of Nigeria appears very favourable. There is the possibility of further oilfields within the Tertiary deltaic sediments and also within the underlying Cretaceous section. It is suggested that the margin be surveyed in two or more stages. Firstly a regional reconnaissance of survey type (a) at a 20 n. mile line spacing is required, then detailed surveys should be made over areas of interest using a 5 or 2 n. mile spacing in order to delineate more clearly any anticlines or diapiric structures. The survey need not extend over the continental shelf as this has been adequately surveyed. The results of the 1973 cruise of *Atlantis II* will have to be studied before further planning of this survey. The total mileage is about 3200 n. miles, which would take 22 days at 6 knots.

Two regional excursions of survey type (b) are suggested. One would extend over part of the outer edge of the continental rise and the other over the Calabar Fan (see Figs 15, 16). About 600 n. miles would be required, which would take $2\frac{1}{2}$ days at 10 knots.

5. POSSIBLE CONTRACTORS

The following is a provisional list of geophysical contracting companies that may be interested in these marine surveys.

1. Compagnie Generale de Geophysique, France
2. Digicon, USA
3. Geophysical Services International, USA (office in Sydney)
4. Petty-Ray Geophysical, USA
5. Seismograph Service Corporation, USA
6. Seismograph Service Ltd, England
7. Teledyne, USA
8. United Geophysical, USA
9. Western Geophysical, USA
10. Seiscom-Delta, USA
11. Eastern Marine Associates, USA
12. Prakla, Germany

6. COSTS

Statistics collected by the Subsidy Section of the Petroleum Exploration Branch of BMR indicate that during 1972 a large marine seismic survey off Australia cost about $120 per mile. Inflation has probably now increased this figure, but on the other hand it can be reduced by paying for the contract on a time basis instead of mileage and accepting risks of non-productive time. I have therefore assumed a figure of $120 per mile for a survey at 6 knots, and reduced the figure in proportion for a survey speed of 10 knots to $72 per mile.

The latest fees quoted by Geophysical Services International of Sydney for digital processing and stacking of 24-fold CDP marine seismic data are about $80 per mile.

These costs have been incorporated into Table 1 to produce an estimate of the total costs for each survey. They would apply to a survey which started during the first half of 1975; thereafter they should be increased at the general rate of inflation.

The mobilization and positioning costs could range from $100 000 to $500 000 depending on how far a ship has to travel to start the survey and how much equipment modification is necessary. The cost of this per survey would be significantly reduced if the surveys were consecutive. The daily running costs could also be reduced for a long-term operation.

Table 2 gives the costs for alternative surveys which would provide bathymetric, gravity, magnetic, and single-channel seismic data for a brief reconnaissance of the entire margin.

TABLE 1. SURVEY MILEAGES AND COSTS

(Costs are in thousands of A$)

Country	Survey mileage: (a) Multi-channel seismic at 6 knots	Survey mileage: (b) Single-channel seismic at 10 knots	Operating Costs: (a) at $120/ mile	Operating Costs: (b) at $72/ mile	Operating Costs: Total (a) + (b)	Seismic processing costs, assuming 20% of data from (a) is processed at $80 per mile	Total survey costs excluding mobilization and positioning fee
Ghana	2600	1000	312	72	384	41.6	425.6
Kenya	4000	2200	480	158.4	638.4	64	702.4
Liberia	0	2600	0	187.2	187.2	0	187.2
Mauritius	0	4200	0	302.4	302.4	0	302.4
Nigeria	3200	600	384	43.2	427.2	51.2	478.4
Tanzania	4200	600	504	43.2	547.2	67.2	614.4
Grand Totals	14,000	11,200	1680	806.4	2486.4	224	2710.4

TABLE 2. ALTERNATIVE MILEAGES AND COSTS

(Reconnaissance survey from coastline to abyssal plain at 10 knots. Costs are in thousands of A$. No seismic processing. The traverses are not marked on the maps but would be similar to the broken lines).

Country	Line spacing (n. miles)	Mileage (n. miles)	Cost at $72/mile
Ghana	40	2000	144
Kenya	60	3400	244.8
Liberia	90	2600	187.2
Mauritius	Zig-Zag	4200	302.4
Nigeria	40	2000	144
Tanzania	60	2200	158.4
TOTAL		16400	1180.4

7. REFERENCES

ARENS, G., et al., 1970 - The continental margin off the Ivory Coast and Ghana. In: The Geology of the East Atlantic continental margin, Vol. 4, Afrioa. Great Britain Inst. Geol. Sci. Report 70/16 pp. 61-78.

A.S.G.A./UNESCO, 1968 - International Tectonic map of Africa 1:5 000 000. Association of African Geological Services/United Nations Educational Scientific and Cultural Organisation.

BEHRENDT, J.C., SCHLEE, J., & ROBB, J.M., 1974 - Structure of the continental margin of Liberia, west Africa. Bull. Geol. Soc. Am., Vol. 85, pp. 1143-1158 (July 1974).

BUNCE, E.T., BOWIN, C.O., & CHASE, R.L., 1966 - Preliminary results of the 1964 cruise of R.V. Chain to the Indian Ocean. Phil. Trans. Roy. Soc. London, Series A., Vol. 259. No. 1099, pp. 133-298.

BURKE, K., 1972 - Longshore drift, submarine canyons and submarine fans in development of Niger Delta. Bull. Am. Assoc. Pet. Geol., Vol. 56. No. 10, pp. 1975-1983.

CORTESINI, A., & MINNER, J.R., 1973 - Petroleum developments in central and southern Africa in 1972. Bull. Am. Assoc. Pet. Geol., Vol. 57. No. 10. (Oct 73) pp. 2008-2056.

ECONOMIC COMMISSION FOR AFRICA, 1974 - The sedimentary basins in Africa and their hydrocarbon resources. UN Economic and Social Council, ECA Secretariat - Regional conference on petroleum industry and manpower requirements in the field of hydrocarbons. Tripoli, Feb 1974.

EMERY, K.O., 1972 - Eastern Atlantic continental margin, some results of the 1972 cruise of the R.V. Atlantic II. Science (AAAS), Vol. 178. No. 4058, pp. 298-301.

EWING, M., EITTREIM, S., TRUCHAM, M., & EWING, J.I., 1969 - Sediment distribution in the Indian Ocean. Deep Sea Res., Vol. 16, pp. 231-248.

FISHER, R.L., et al., 1972 - Deep Sea Drilling Project in Dodo land. Leg 24. Geotimes, Vol. 17. No. 19, pp. 17-21.

FISHER, R.L., JOHNSON, G.L., & HEEZEN, B.C., 1967 - Mascarene Plateau, western Indian Ocean. Bull. Geol. Soc. Am., Vol. 78, pp. 1247-1266.

FRANCIS, T.J.G., DAVIES, D., & HILL, M.M., 1966 - Crustal structure between Kenya and the Seychelles. Phil. Trans. R. Soc., Series A, Vol. 259, pp. 240-261.

FRANCIS, T.J.G., & SHOR, G.G., 1966 - Seismic refraction measurements in the northwest Indian Ocean. J. Geophys. Res., Vol. 71, No. 2, pp. 427-449.

HEEZEN, B.C., & THARP, M., 1965 - Physiographic diagram of the Indian Ocean. Lamont Doherty Geological Observatory, Contribution No. 778.

HEIRTZLER, J.R., & BURROUGHS, R.H., 1971 - Madagascar's paleoposition, new data from the Mozambique Channel. Science, Vol. 174, No. 4008, pp. 488.

KENT, P.E., et al., 1971 - The geology and geophysics of coastal Tanzania. Inst. Geol. Sci., Geophys. Paper No. 6.

LEYDEN, R., BRYAN, G., & EWING, M., 1972 - Geophysical reconnaissance on the African shelf; Pt. 2 Margin sediments from Gulf of Guinea to Walvis Ridge. Bull. Am. Assoc. Petrol. Geol., Vol. 56, No. 4, pp. 682-693.

MASCLE, J.R., BORNHOLD, B.D., & RENARD, V., 1973 - Diapiric structures off Niger Delta. Bull. Am. Assoc. Petrol. Geol., Vol. 57, No. 9, pp. 1672-1678.

PAUTOT, G., et al., 1973 - Salt layer along south Atlantic African margin. Bull. Am. Assoc. Pet. Geol., Vol. 57, No. 9, pp. 1658-1671.

ROBB, J.M., SCHLEE, J., & BEHRENDT,J.C., 1973 - Bathymetry of the continental margin off Liberia, W.A. J. Res. U.S. Geol. Surv., Vol. 1, No. 5, pp. 563.

SCHLEE, J., BEHRENDT, J.C., & ROBB, J.M., 1974 - Shallow structure and stratigraphy of Liberian continental margin. Bull. Am. Assoc. Petrol. Geol., Vol. 58, No. 4, pp. 708-728.

SHOR, G.G., & POLLARD, D.D., 1963 - Seismic investigations of Seychelles and Saya de Malha banks, northwest Indian Ocean. Science, Vol. 142, pp. 48-49.

SIMPSON, Eric, et al., 1972 - Leg 25 DSDP; Western Indian Ocean. Geotimes, Vol. 17, No. 11.

TIMES CONCISE ATLAS, 1972 -

WORLD OIL, 1974 - International Outlook, Africa. International Edition.

ADDENDUM 1 - SIERRA LEONE

Present information

Crystalline basement rocks crop out along almost the whole coastline of Sierra Leone. There is a small belt, 400 m thick, of sedimentary rocks at the northwest end of the coast. Offshore, sedimentary rocks underlying the continental shelf and slope attain a thickness of 1200 m at 300 m water depth, and thicken to the southwest. There has been little petroleum exploration during the past decade and no drilling to date (Economic Commission for Africa, 1974).

Offshore petroleum licences over the continental shelf and upper slope are held by Clinton International and Occidental Petroleum, but a large proportion was considered unprospective and relinquished in 1972 (Cortesini & Minner, 1973).

The most accurate bathymetric survey of the margin to date was that by the USNS Kane in 1968 for the US Naval Oceanographic Office. Satellite navigation was used together with a 3.5 kHz echo-sounder which gave high resolution of the upper sub-bottom strata. Egloff (1972) combined these results with soundings from many other ships to produce the bathymetric contour map (Fig. 1A) and the accompanying physiographic diagram (Fig. 2A).

Sierra Leone appears from these results to have a fairly narrow continental margin; the shelf is 12 to 70 miles wide, the slope about 35 miles wide, and the rise 80 to 130 miles wide. The adjacent Sierra Leone Abyssal Plain is considered to be bounded by the 5050 m isobath and is generally over 5200 m deep. The Sierra Leone Rise is an area of minor plateaus and seamounts dissected by fracture zones, and is separated from the mainland by a channel 5000 m deep.

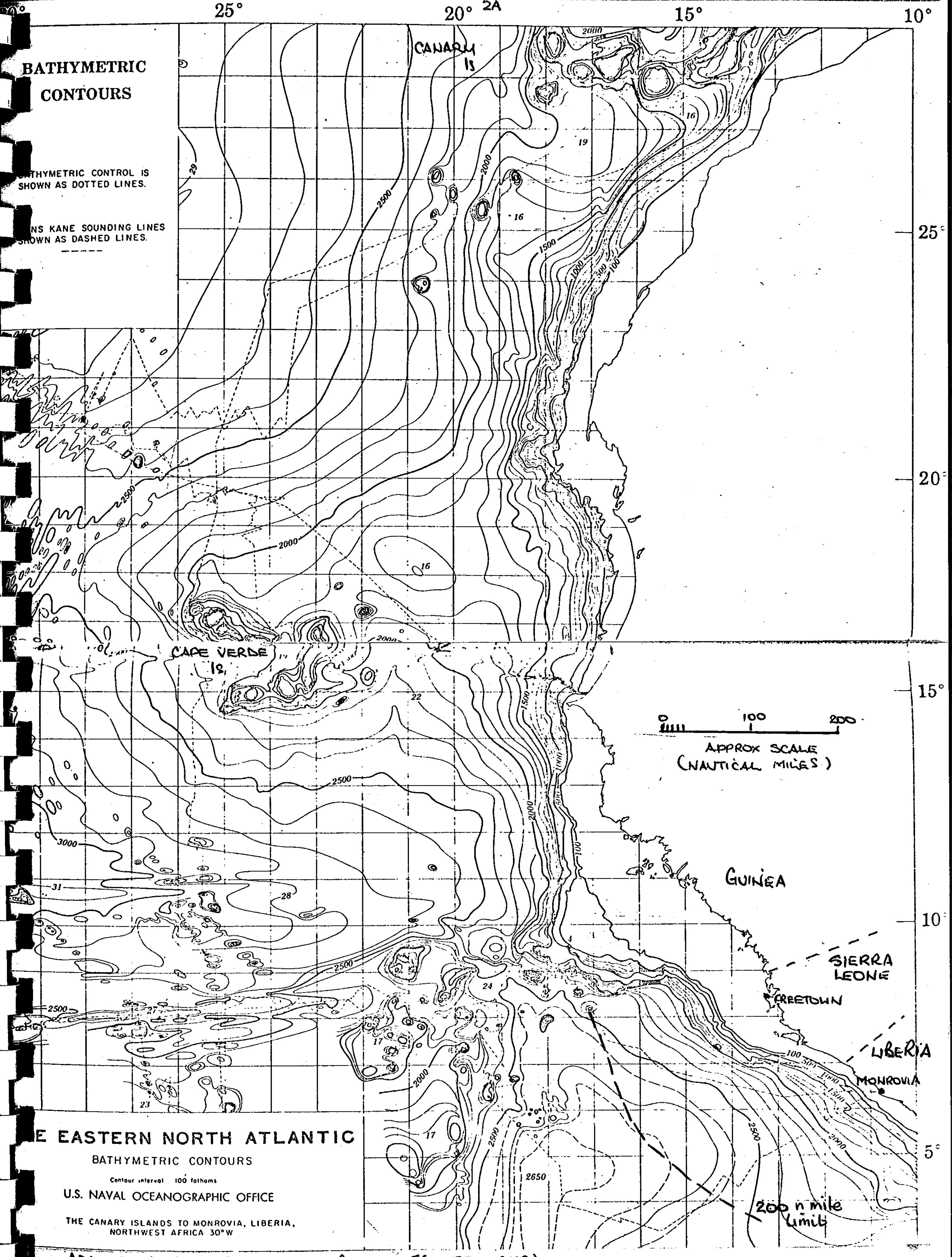
Templeton (1970) reviewed the known geology and structural framework of this part of West Africa. Two of his maps are shown here in Figures 3A and 4A. Figure 3A shows undifferentiated Precambrian rocks in the area of the Rokel River Syncline (Fig. 4A); however, Precambrian to Cambrian sediments were deposited here (Allen, 1968). Templeton's general conclusion was that much more needs to be known about the onshore geology of West Africa.

In 1952 Lamont Doherty Geological Observatory used the ships Atlantis and Kevin Moran to record a series of seismic refraction profiles across the Atlantic Ocean. The eastern end of the traverse crossed the Sierra Leone continental margin (Fig. 5A). The results were re-examined and presented in the light of more recent knowledge by Sheridan et al. (1969). Their interpreted cross-section (Fig. 6A) shows that over 2½ km of Cretaceous to Quaternary sediments underlie the continental slope and rise. These sediments thin gradually seawards below the Sierra Leone Abyssal Plain. If it is assumed that these post-Palaeozoic sediments formed the continental rise then, according to Figure 6A, the rise may extend as far as 300 to 400 n. miles from the coast.

Underlying the Cretaceous sediments in the area of the continental shelf and upper slope they postulated a sequence of Cambrian-Devonian sediments 2½ km thick which may be equivalent to those in the Rokel River Syncline (Allen, op. cit.).

Sheridan et al. also suggested that the anomalously high crustal velocities in the vicinity of the Sierra Leone Rise were caused by regional metamorphism which accompanied the intense igneous activity of the area.

2A



ADDENDUM 1. FIGURE 1A (FROM EGLOFF, 1972)

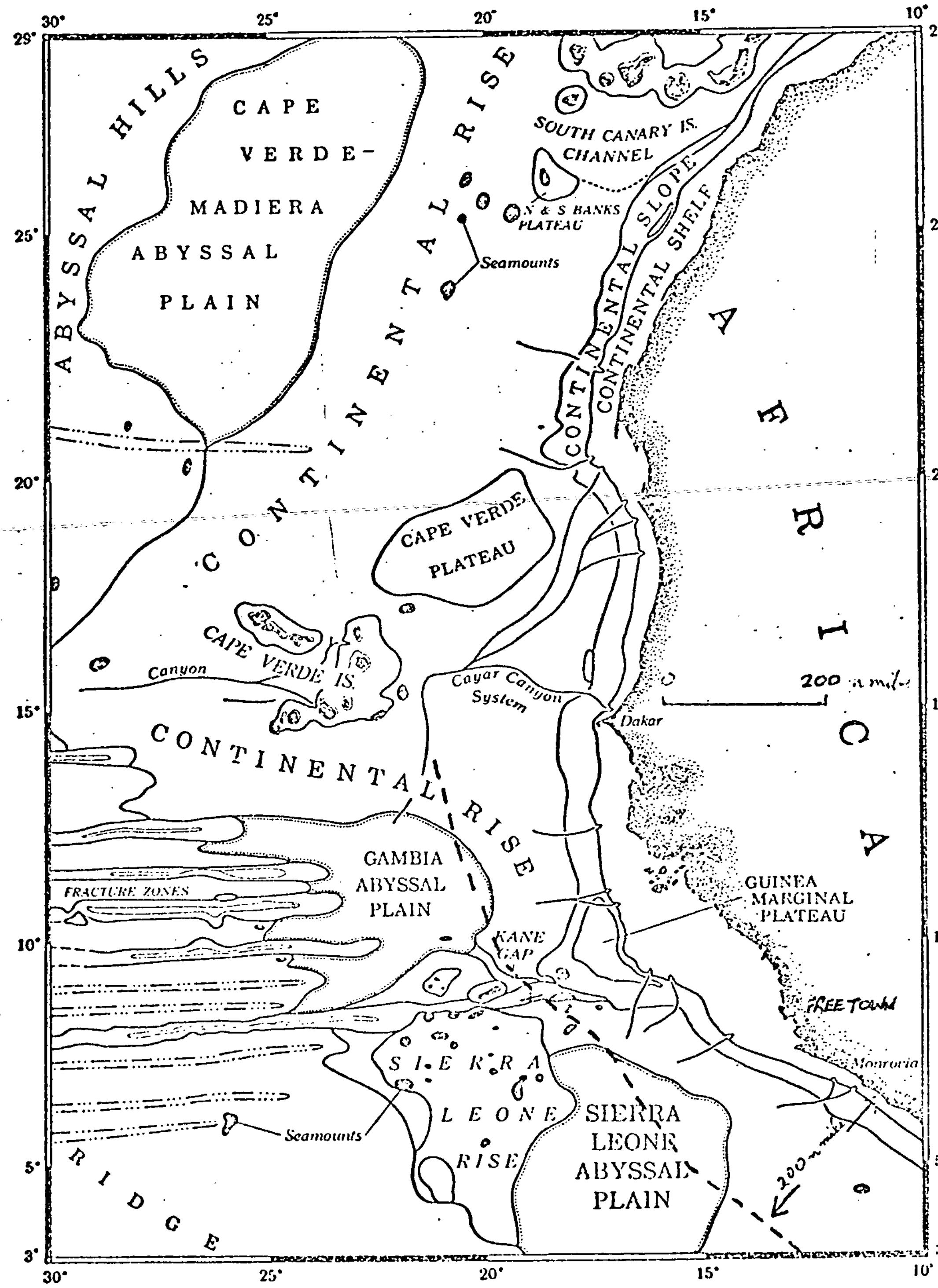


FIG. 2—Physiographic provinces (areas of similar slope gradients, derived from bathymetric contour map, Fig. 3).

ADDENDUM 1 FIGURE 2A (FROM EGLOFF, 1972)

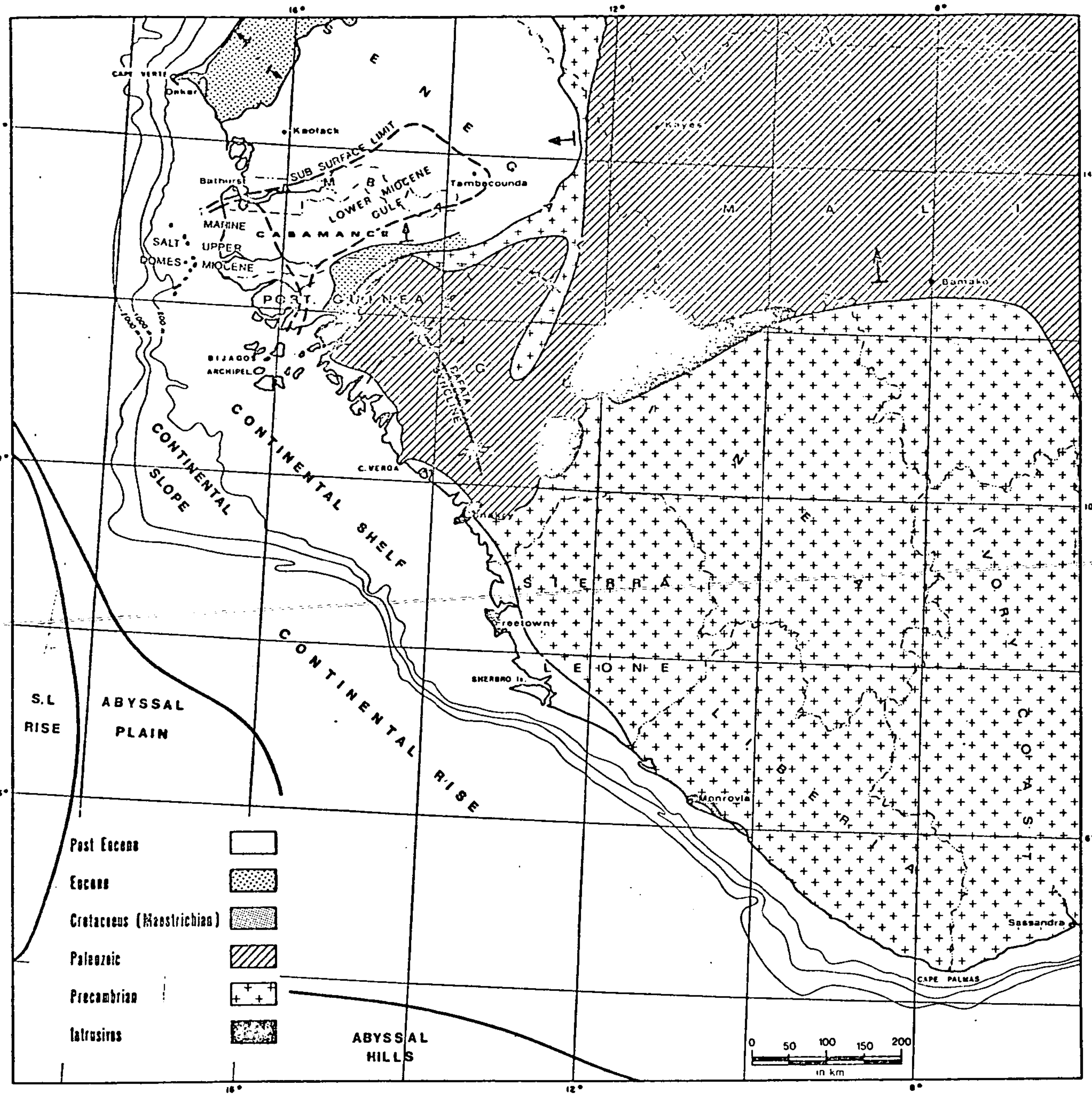


Fig. 1. Geological sketch map of part of West Africa

ADDENDUM 1, FIGURE 3A (FROM TEMPLETON, 1970)

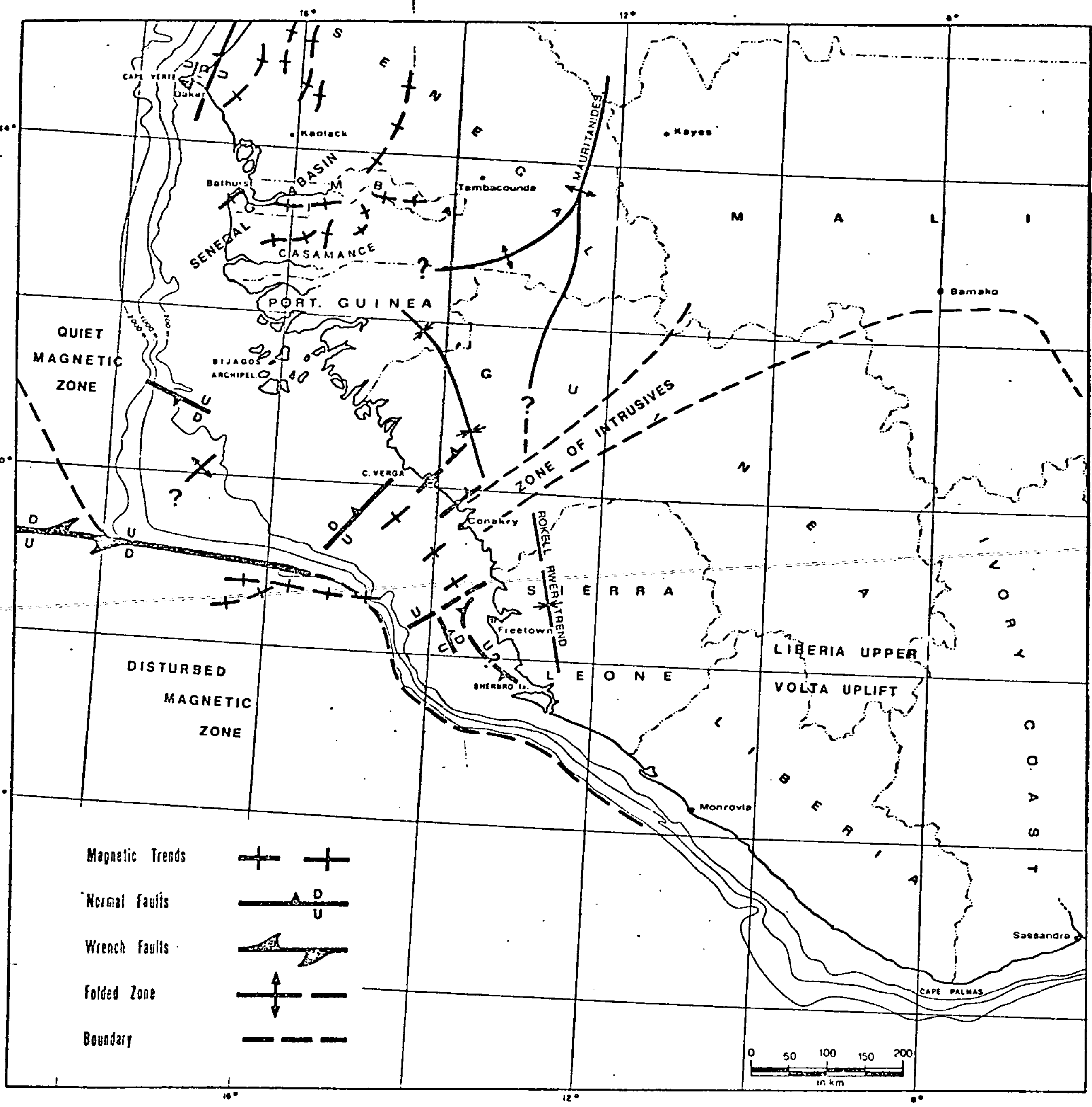


Fig. 9. Generalised tectonic map of part of West Africa

ADDENDUM 1, FIGURE 4A (FROM TEMPLETON, 1970)

In 1971(?) the R.V. Trident measured the magnetic field off Sierra Leone. The Guinea and the Sierra Leone Fracture Zones were delineated (see Fig. 7A). The magnetic rocks of the Fracture Zones appear to be covered with thick sediments although the exact thickness was not calculated. (McMaster, Ashraf and de-Boer, 1973).

The US Coast and Geodetic Survey used the OSS Discovery to record bathymetric, gravity and magnetic data in 1968 off the West African coast, including Sierra Leone (National Geophysical and Solar-Terrestrial Data Center, 1972). No reports of the survey results have been obtained.

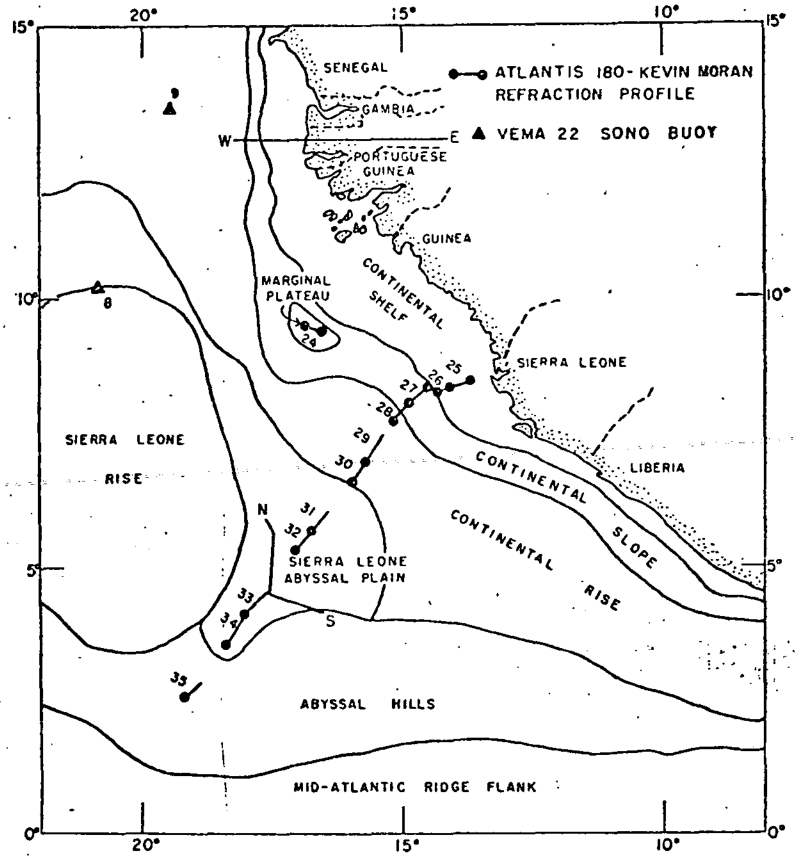


Fig. 1. Location of seismic-refraction profiles and major physiographic provinces. The location of structure section W-E through Senegal [after *Aymé*, 1965] is also shown.

ADDENDUM I, FIGURE 5A (FROM SHERIDAN et al., 1969)

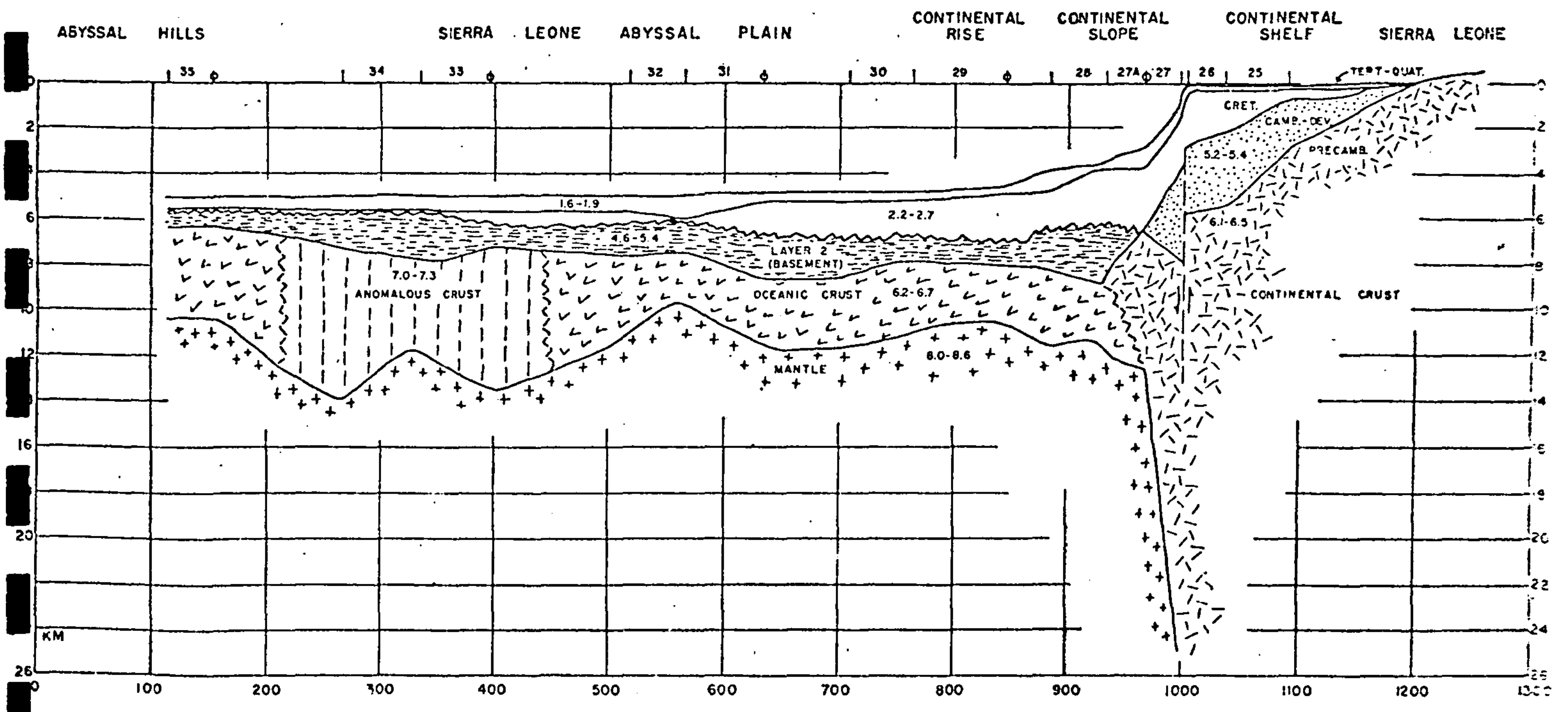


Fig. 3. Interpreted structure section based on seismic refraction data off Sierra Leone. Vertical exaggeration, 20:1.

ADDENDUM I, FIGURE 6A (FROM SHERIDAN, et al., 1969)

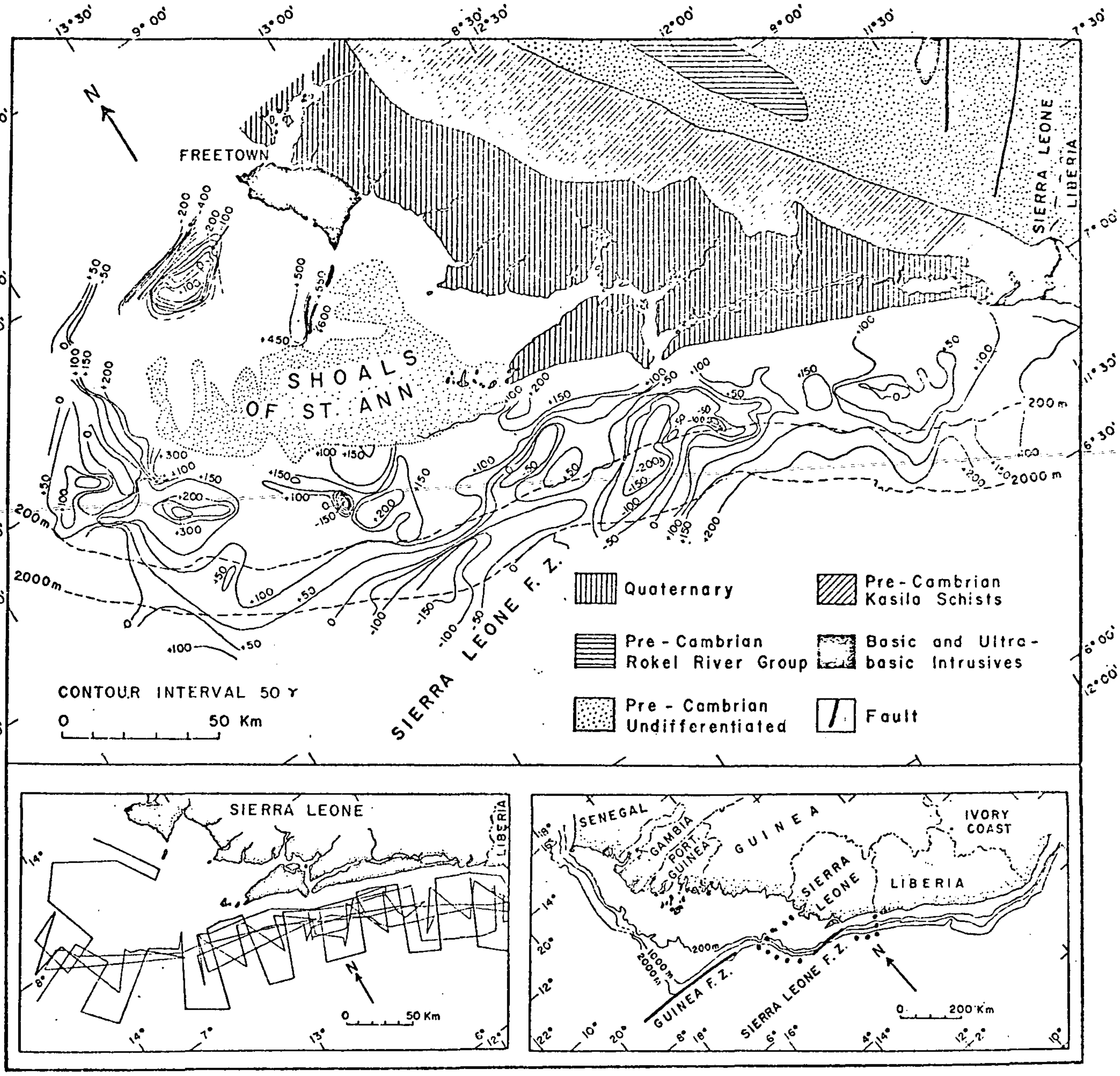


Fig. 1 Magnetic anomaly map of region off Sierra Leone with coastal land geology[4,5]. Inserts show location of study area and position of RV Trident's track lines. F.Z., Fracture zone.

ADDENDUM I. FIGURE 7A (FROM McMASTER, ASHRAF, AND BOER, 1973)

Surveys required

Relatively little systematic survey work has been done off Sierra Leone, so a survey of the shelf, slope, and rise at a line spacing of 20 n. miles is needed to delineate the extent of the margin and to estimate its economic potential. In addition one or two excursions across the abyssal plain would ensure that the outer limits of the continental rise were surveyed - this is alternative I. Alternative II is for a brief regional reconnaissance from the coast to the abyssal plain. The mileages and costs are listed in Table 1A.

TABLE 1A (details as for Tables 1 and 2)

Alternative	Survey mileage		Operating costs			Seismic processing costs	Total costs
	(a) 6 knots	(b) 10 knots	(a) $120 /mile	(b) $72 /mile	Total (a) + (b)		
I	2600	1200	312	86.4	398.4	41.6	440
II	-	2000	-	144	144	-	144

Further References

ALLEN, P.M., 1968 - The stratigraphy of a geosynclinal succession in western Sierra Leone, West Africa. Geol. Mag., Vol. 105, No. 1, pp. 62-73.

EGLOFF, J., 1972 - Morphology of ocean basin seaward of northwest Africa; Canary Islands to Monrovia, Liberia. Bull. Am. Assoc. Petrol. Geol., Vol. 56, No. 4, pp. 694-706.

McMASTER, R.L., ASHRAF, A., & de-BOER, J., 1973 - Transverse continental margin fracture zone off Sierra Leone. Nature, Phys. Sci., Vol. 244, No. 136, pp. 93-94.

NATIONAL GEOPHYSICAL AND SOLAR-TERRESTRIAL DATA CENTER, 1972 - Marine geophysical data catalog. National Oceanic and Atmospheric Administration, Boulder, Colorado.

SHERIDAN, R.E., HOUTZ, R.E., DRAKE, C.L., & EWING, M., 1969 - Structure of the continental margin off Sierra Leone, West Africa. J. Geophys. Res., Vol. 74, pp. 2512-2430.

TEMPLETON, R.S.M., 1970 - The geology of the east continental margin between Dakar and Cape Palmas. In: The geology of the east Atlantic continental margin, Vol. 4, Africa. Great Britain Inst. Geol. Sci. Report 70/16, pp. 43-59.

WESTERN INDIAN OCEAN
1 : 5 000 000
MARINE GEOPHYSICAL SURVEYS
PROPOSED SURVEY LINES SHOWN IN COLOUR
LEGEND
LIMIT OF 200 N. MILE ZONE
TERRITORIAL MEDIAN LINE
Bathymetry contours in metres
Track of 'VEMA' (Cr. 18, 19, 20, 22, 24) and 'CONRAD' (Cr 8, 9, 11) [EWING et al., 1969]
Track of R.V. "CHAIN", Nov - Dec 1970, [Heirtzler, 1972]
" " " ", April 1964,
" " " ", May 1964,
Cruise 43 [Bunce et. al., 1966]
Deep Sea Drilling Site, "Glomar Challenger", 1972
Refraction Profiles, "OWEN" and "DISCOVERY" [FRANCIS et al 1966]
Refraction Profiles, R.S. "ARGO" and R.S. "HORIZON", 1962 [Francis & Shor, 1966 ; Shor & Pollard, 1963]
Oil exploration lease
Oil exploration well (dry)
Bathymetry compiled from: ① International Tectonic Map of Africa, ASGA/Unesco, 1968. ② Heezen & Tharp, 1965
Kilometres (Approx)
Nautical Miles
UGANDA
KENYA
NAIROBI
SOMALI
RWANDA
BURUNDI
ZAIRE
TANZANIA
Zanzibar Island
DAR-ES-SALAAM
ZAMBIA
MALAWI
RHODESIA
MOZAMBIQUE
SOMALI BASIN
SOMALI ABYSSAL PLAIN
SEYCHELLES BANK
AMIRANTE TRENCH
Amirantes Islands
MASCARENE
SAYA DE MALHA BANK
NAZARETH BANK
Archipel des Comores
Aldabra
MALAGASY ABYSSAL PLAIN
MALAGASY
MADAGASCAR
MADAGASCAR RIDGE
MAURITIUS
PORT-LOUIS
RODRIGUEZ FRACTURE ZONE
FOR DETAIL IN THIS AREA SEE PLATE 3
PLATE 1

SUBMARINE TOPOGRAPHY OF THE MASCARENE PLATEAU, THE MASCARENE BASIN, AND PART OF THE MID-INDIAN OCEAN RIDGE

Note: From the Equator to 20°S, the crest of the mid Indian Ocean Ridge lies between 66° and 68+°E., just inside the eastern border of this chart. Note also that in areas of greater than 4000 m depth a 200-m contour interval was employed.

SENEGAL
GAMBIA
PORTUGUESE GUINEA
MALI
NIGER
UPPER VOLTA
CHAD
GUINEA
SIERRA LEONE
IVORY COAST
LIBERIA
GHANA
TOGO
DAHOMEY
NIGERIA
CAMEROUN
Fernando Poo (Sp)
Principe (Port)
RIO MUNI
Sao Tome
GABON
CONGO
ZAIRE
ANGOLA
Annobón (Sp)
SIERRA LEONE BASIN
GUINEA BASIN
MID - ATLANTIC RIDGE
Ascension (68)
EASTERN ATLANTIC OCEAN
1 : 5 000 000
MARINE GEOPHYSICAL SURVEYS
LEGEND
Traverses of R.V. "Atlantis II" planned for 1973 (Emery, 1972)
Traverses of R.V. "ATLANTIS II" 1972 (Emery, 1972)
Track of R.V. "JEAN CHARCOT" 1971 Cruise Walda (Pautot et al., 1973)
" " R.V. 'UNITEDGEO' 1971 (Robb et al., 1973)
" " USNS 'KANE' 1969 (- ditto -)
" " R.V. 'JEAN CHACOT' 1968
" " R.V. 'VEMA' Cr.19 1968
(Arens et al., 1970)
TELEDYNE SPARKER
Track of 'VEMA' (Cruise 27) and 'CONRAD' (Cruise 13) 1970 (Leyden et al., 1972)
DEEP SEA DRILLING PROJECT, LEG III Site 13.
PETROLEUM EXPLORATION LEASE
OIL WELL (DRY)
PRODUCING WELL
Bathymetric contours in metres
Approx scales
0 100 200 300 400 Km
0 100 200 n miles
EASTERN ATLANTIC OCEAN
1 : 5 000 000
MARINE GEOPHYSICAL SURVEYS
PROPOSED SURVEY LINES SHOWN IN COLOUR
Bathymetry compiled from:
1. International Tectonic Map of Africa, ASGA/Unesco 1968
2. Pautot, G. et. al., 1973
3. Arens, G. et. al., 1970
4. Times Concise Atlas, 1972.
LIMIT OF 200 N. MILE ZONE
TERRITORIAL MEDIAN LINE
PLATE 3