Institute of
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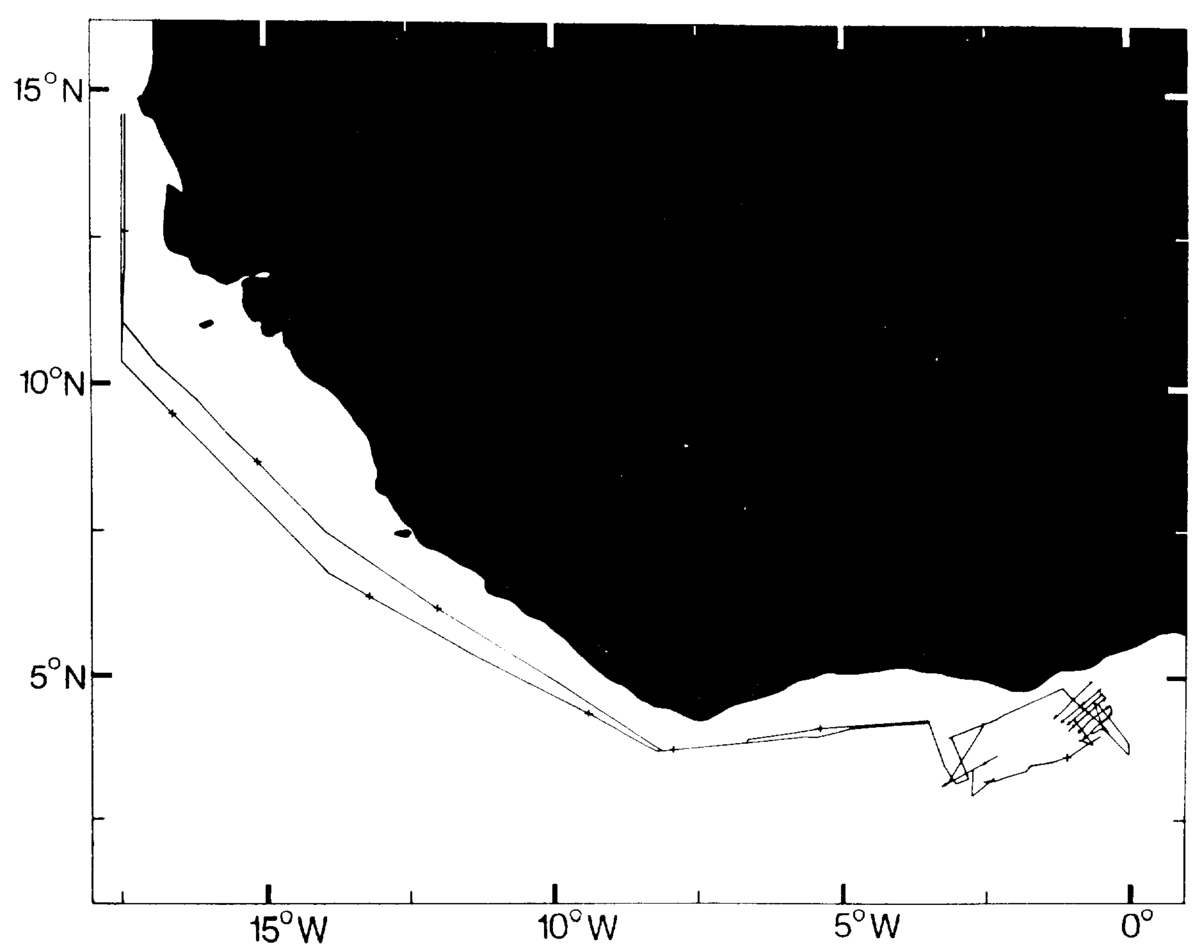
Deacon Laboratory

RRS Charles Darwin Cruise 55

06 Jan - 05 Feb 1991

Geophysical investigations of the Ghana transform continental margin, Gulf of Guinea

Cruise Report No 224 1991



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CRUISE REPORT NO. 224

RRS CHARLES DARWIN CRUISE 55
06 JAN - 05 FEB 1991

Geophysical investigations of the Ghana transform continental margin, Gulf of Guinea

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ABSTRACT

The principal objective of the cruise was the study of the deep crustal structure across the continent-ocean transition off Ghana where the major equatorial Romanche Fracture Zone shapes the continental slope. This margin was chosen for a number of scientific and logistical reasons not least of which was the fact that the shallow structure had already been extensively studied by Jean Mascle and colleagues from Université Pierre et Marie Curie/CNRS, Villefranche among others. We wished to discover the nature and width of the continent-ocean transition and to relate this to the structural and thermal history of the margin recorded in seismic reflection profiles and in other data. Although the execution of the original objective has been delayed for many years we still expect this margin to become one of only three well-explored transform margins in the world.

The objectives of the cruise were fully met. This was possible due to the excellent weather, the reliability of the equipment and hard work by all on board. Seven OBS seismic refraction lines were shot off Ghana using a 7000 in^3 airgun array or explosives. Some 1200 line kilometres of seismic reflection profiles, gravity and magnetics were also acquired. Two further refraction lines were shot adjacent to the Ivory Coast-Ghana ridge to supplement lines shot by N.O. Nadir in 1990. A new external sensor package was also successfully tested on one OBS.

In addition to the geophysical activities an ornithological survey was conducted throughout the cruise with the particular aim of establishing the migration route of the Roseate Tern.

KEYWORDS

BATHYMETRY
BIRDS
"CHARLES DARWIN"/RRS - cruise(1991)(55)
CONTINENTAL MARGIN
CRUSTAL STRUCTURE
GEOPHYSICS
GHANA
GRAVITY
IVORY COAST
MAGNETIC DATA
OBS
OCEAN-BOTTOM SEISMOGRAPH
OCEAN CONTINENT TRANSITION
SEISMIC REFLECTION
SEISMIC STRUCTURE
TRANSFORM MARGIN

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CONTENTS

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ANDERSON, D.E.	Second Engineer
ANDERSON, J.E.	Third Engineer
PARKER, P.G.	Electrical Engineer
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SWENSON, J.J.E.	Ship's Cook
ACTON, P.C.H.	Second Steward
JENKINS, D.E.	Steward
ELLIOTT, C.J.	Steward

CRUISE OBJECTIVES

This cruise had a long gestation. Its origins go back to a desire in 1986 to study the deep crustal structure of transform continental margins which are relatively poorly known when compared with the extensively studied rifted margins. A first proposal to study the Perth Escarpment off Western Australia, as part of the *RRS Charles Darwin* global circumnavigation in 1988, although successful in obtaining shiptime was cancelled by Director IOS due to a lack of funds for explosives. A revised proposal to study the Ghana transform margin was also successful but was delayed for logistical reasons until 1990/91 and even then was not programmed until January 1991.

The principal objective of the cruise was the study of the deep crustal structure across the continent-ocean transition off Ghana where the major equatorial Romanche Fracture Zone shapes the continental slope. This margin was chosen for a number of scientific and logistical reasons not least of which was the fact that the shallow structure had already been extensively studied by Jean Mascle and colleagues from Université Pierre et Marie Curie/CNRS, Villefranche among others. We wished to discover the nature and width of the continent-ocean transition and to relate this to the structural and thermal history of the margin recorded in seismic reflection profiles and in other data. Although the execution of the original objective has been delayed for many years we still expect this margin to become one of only three well-explored transform margins in the world.

To optimise the acquisition of seismic refraction data we needed more than just the four IOSDL ocean-bottom seismographs (OBS). We were fortunate in being able to obtain, at short notice, the use of two further OBS which were operated by Durham University.

RBW,RAS

INTERNATIONAL COLLABORATION

The cruise was planned and executed in full collaboration with the group of Dr. Jean Mascle in Villefranche, France. His group had previously carried out a number of cruises to the Ivory Coast-Ghana transform margin with the objective of studying the shallow structure and sea bed. By chance they also had reached the phase in their research of wishing to look at the deep structure at about the same time as our proposal was being written. The result was that in early 1990 both a multichannel seismic reflection cruise (Equasis) and a seismic refraction cruise (Equaref) took place on board the French ship *N.O. Nadir* over the transform margin adjacent to the Ivory Coast-Ghana Ridge. U.K. scientists participated in both cruises; in the second case a significant contribution was made by the presence on board of two IOSDL staff who operated two digital ocean-bottom seismographs (DOBS). These cruises worked in an area to the west of the Ghana margin where the transition is from thinned continental crust to oceanic crust. This work complemented our own studies of an unstretched continent-ocean transition off Ghana. In the same spirit of collaboration we were pleased to welcome on board our cruise Jean-Yves Royer from Villefranche; the planned participation by the Villefranche OBS group was unfortunately prevented by a conflict of cruises. It is expected that our collaboration will continue during the subsequent analysis of the data from all three recent cruises to the area.

RBW,RAS,JYR

NARRATIVE (Figures 1 - 3)

The majority of the scientific party arrived by air in Dakar, Senegal late in the evening of 5th January 1991 (day 005). Although it had been planned for the ship to sail almost immediately a problem with the main engines necessitated an overnight delay. The ship moved to a bunkering berth at 0920 next morning and refuelling was completed by 1312/006 when we departed Dakar. Since there was a five-day passage ahead of us there was plenty of time to unpack, set up and test the various systems and equipment to be used later during the cruise as well as to plan the scientific programme in detail. On day 007 the GPS system stopped giving fixes and the fault appeared to be land-based. A scientific meeting was held in the evening to outline the objectives of the cruise to key ship's personnel. At 1315/008 we slowed to 2.5 knots to conduct depth calibration tests of the various airgun tow arrangements to be used on the cruise. A single beam with a 766 and a 1000 ins^3 gun as well as a single 1000 ins^3 gun were towed at a variety of speeds and their depths measured. After a number of problems the tests finally began at 1530 and were completed by 1810. One result was the discovery that the beams were rigged with only a 10-metre line to their surface floats; this was increased to 12 metres to achieve the required gun depth of about 15 metres. Since GPS was still inoperative RVS were consulted. It appeared that there was no problem with the RRS Challenger receiver and therefore that the problem was shipboard. After reinitialisation the GPS receiver began to work normally. Day 009 was spent in further preparation of the airgun beams, maintenance of the PES fish and in detailed planning of the first two seismic refraction lines. The new Marinet link with RVS was tested for the first time and apparently worked. At 1400/010 the PES fish was streamed to test it and it worked satisfactorily. During the day we also began to come under the influence of the Guinea current the strength of which was to become an important factor later in the conduct of the cruise. For example it became apparent that to reduce strain on the airgun beam system, yet achieve a reasonable speed over the ground, we would have to tow with the current rather than against it wherever possible. For this reason we altered course to head for the east end of the first refraction line at the edge of the Ghanaian shelf. By the evening of day 010 all systems were ready for the activity of the following weeks. The only problem at this stage was overheating of the Computer Room; its air-conditioning is not fully adequate for equatorial regions.

On day 011 we arrived at the east end of the first refraction line (Line 1). The area was frequented by small canoe-like fishing boats which caused some navigational difficulties at times. An important computer file needed to calculate airgun waveforms was successfully transmitted from IOSDL via RVS by the Marinet system. The first of three DOBS was deployed at 1342. The deployment of the first airgun beam began at 2125. There was a delay when the outboard starboard umbilical winch began to creep; a serious hydraulic leak was discovered. The winch was temporarily stopped off pending repairs. The last beam was finally deployed by 0022/012 and the remaining two 1000 ins^3 guns by 0250/012 when we came up to speed and began firing. The line was completed by 1440. Beam recovery was prolonged by the snagging of the two starboard beams. All three DOBS were recovered without problems by 0124/013. One DOBS was released acoustically even though the water depth was only 80 metres. Generally the data were very good although somewhat noisy due to the very shallow depth in which the DOBS had been deployed. Two 300 ins^3 airguns, the streamer and magnetometer were then deployed in order to acquire a reflection profile along the next refraction line (Line 2). During the morning the gravimeter developed problems with cycling of the gyro heater and unfortunately had to be switched off thereby denying us the opportunity to unambiguously measure the drift of the meter between ports. A disposable sonobuoy was deployed at 1221 as was an XBT later in the afternoon.

The first of three DOBS deployments began at 1515/013 for Line 2. The deployment of the airgun array went very smoothly and we were in position to fire the first shot at 0158/014. Later in the morning one of the 1000 ins^3 guns failed (an O-ring had broken and jammed the shuttle) and was switched off. The gravimeter gave further problems this time attributed to over-cooling by the lab air-conditioning; the problem was easily rectified by wrapping the meter in cling film to exclude draughts! The last shot was fired at 1740 and then a test was done to check the feasibility of altering course while towing the array, a feature we planned to incorporate in future lines. A rate of 3° per minute proved suitable. On recovery one gun was found to be hanging from its hose; the weld on a chain link had failed and the link had sprung open. DOBS recoveries proceeded in the early hours of day 015. One of the Durham DOBS had leaked slightly but fortunately no significant damage was sustained. The day was also remarkable for the first rain of the cruise. So far we had enjoyed calm and mainly sunny weather.

Two 300 ins^3 guns, the streamer and magnetometer were deployed by 0900/015 to begin a second seismic reflection profile along refraction Lines 3 and 4. In the afternoon this profile was quite spectacular with sill-like features within the sediment column. The reflection profile was finished at 0530/016. DOBS deployments for the next two lines (Lines 3 and 4), which were to be shot in a single operation, began shortly afterwards. We had decided to shoot two lines at a time with the guns since there were enough DOBS to do this and it reduced the wear and tear of deployments on both the gun array and the RVS staff. The only complicating factor was the strength of the Guinea current which had reached 2 knots at times. Five DOBS had been deployed by 1629/016. After a short delay the guns were then put out. The guns fired all night and by the morning of day 017 the current, which had been against us, had slackened off thereby allowing a slight reduction in ship's speed. In the late morning it became apparent that two guns on the starboard beams were leaking. At 1330 we finished Line 3 and there was time during the turn onto Line 4 to bring in and repair one of the guns on the outboard starboard beam. Other minor problems were also encountered before the beam could be swung out again. During the day news of the beginning of hostilities in the Gulf reached the ship and our thoughts were often elsewhere. Firing of the airguns was renewed at 1634 and continued during the night. Speed was reduced to 3.5 knots because of the strength of the following current. Line 4 was completed by 0500 and the airgun recovery process was finished by 0715/018. DOBS recoveries proceeded during the day with some annoying failures of the acoustic transmitter boxes when loaded by a single element on the hull transducer. WDOBS2 also failed to respond acoustically but eventually released itself on its back-up clock on schedule. Because of this difficulty there was time to acoustically release the neighbouring WDOBS1, which also proved difficult, and return just in time to recover WDOBS2. We began to suspect that there was a problem with using the hull transducer to communicate with the IOSDL acoustic releases and on subsequent occasions we relied on a single element in the PES fish instead. This suspicion was reinforced by the fact that it eventually proved possible to switch on the transponder of WDOBS2 in mid-water during its recovery. Lines 3 and 4 ended with the recovery of the last DOBS at 0037/019.

Next a pressure test of the leaky Durham DOBS was carried out on the midships winch. After the sphere had been 'soaked' at 500 metres for half an hour a small quantity of water was found in it. A cracked connector was suspected. This test was followed by a reflection profile along Lines 5 and 6 which started at 0419/019. A planning meeting was held to discuss the explosives shot firing on Line 7 across the Ghanaian margin. There was some concern about the adequacy of the slow-burning underwater fuses (an unfamiliar type had been supplied) and two test shots were planned. A disposable sonobuoy was dropped over the southwestern half of Line 6. The reflection profiling ended at 0700/020. This was followed by the test firing of two 25 kg shots which was entirely and gratifyingly successful.

Four DOBS were next deployed between 0930 and 1625/020 in preparation for shooting Lines 5 and 6. This was enlivened by a squall with thunder, lightning and rain. Deployment of the gun array began at 1727 but after the first beam was out GPS stopped working. In the forlorn hope that it would soon restart we began to steam in a full circle but in fact had to continue with Transit satellite fixes. Gun firing began at 2006/020 in the teeth of a stiff 1.3 knot current. Nevertheless good progress was made during the night and GPS returned at 0430/021. Line 5 was finished at 0944. During the time required to make the slow turn onto Line 6 some urgent maintenance was carried out on the compressors. The guns were firing again at 1254 to begin Line 6 with one knot of current behind the ship. At 1626 a fractured high pressure pipe was discovered in a compressor which was immediately shut down. Ten minutes later the two guns were set to fire on a 4-minute cycle which could be maintained at the required pressure with the remaining compressor. After consultation with RVS by phone it was decided to attempt to weld the fractured pipe and at the second attempt this was successful. Shooting at a 2-minute interval was resumed from 2104 until 2310 and the gun array was recovered at 0035/022. The Line 5/6 DOBSs were recovered during the early hours of day 022; the last was inboard by 1430.

A second pressure test of the leaky DOBS sphere followed and this was successful. At the same time the PES fish was brought inboard for a short while for maintenance. Two 300 ins^3 guns, the streamer and magnetometer were then put out and we began reflection profiling at about 1700 along a number of tracks mainly to the east of the main transect to provide tie lines for our own and other profiles. Progress was not as fast as expected and the survey was foreshortened to return to the beginning of Line 7 which was to be shot across the transform margin itself.

DOBS deployments for Line 7 began at 2208/023. Further deployments of the remaining five DOBS proceeded through the night and ended at 0852/024 next day. In preparation for the explosives run 2.25 tonnes were shifted to the afterdeck from the magazine. Shot firing began at 0930 and continued until 1230. After a rest period shot firing was resumed at 1430 and continued until 1736. 45 shots of 125 or 50 kg were fired without a misfire. The airgun array was then deployed to re-shoot Line 7 with closely spaced shots. Gun shots began at 2200/024. By early next morning problems had developed again with the GPS system. It was giving positions with random jumps of at least 0.5 miles when compared with Transit satellite positions. A further problem was that one of the guns was not sealing after every shot so that air was lost. Gun firing stopped when the water depth reached 31 metres at 1730. Some difficulty was expected in finding the DOBS because of the navigational problems and the shallow water. Surprisingly however acoustic contact was made at a range of 800 metres and the ship arrived alongside the DOBS just as it surfaced after being released by its back-up clock. Time was also short when we arrived at the second DOBS which surfaced at least half a mile from the ship. This only helped to reinforce our conviction that GPS was faulty. The last DOBS was recovered at the south end of Line 7 at 1104/026. A magnetometer heading correction experiment was then carried out because steps in the total magnetic field, which was generally very smooth anyway, had been noticed which were associated with major course alterations.

Once the 300 ins^3 airguns, streamer and magnetometer had been deployed we headed west at 7.5 knots to follow a seafloor-spreading flowline as far west as the area south of the Ivory Coast-Ghana Ridge in which earlier French cruises had operated. As we passed westwards the sediment layer thinned and reflectors were seen onlapping onto younger and younger ocean crust. An airgun had to be brought in for repair at one stage. On passage bottom charges were prepared for use the following day. At 1255/027 the gear was recovered and a DOBS deployed. This DOBS was a specially adapted version with an external sensor package. It was its first use with the IOSDL DOBS and for comparison both internal and external geophones were included. As soon as the DOBS had been laid preparations were made to deploy the bottom shots. These shots were a test to see whether they would detonate in depths approaching 5500 metres as required in a proposal submitted to NERC for work off the Lesser Antilles. Once the shot timers were available this proceeded smoothly and fairly rapidly. The last charge was dropped at 1644. GPS was still performing unsatisfactorily and the distances from the DOBS were monitored using slant ranges from the DOBS acoustic transponder. Two of the three shots detonated at the expected time. Next two 1000 ins^3 guns were deployed and fired out to a range of 20 km from the DOBS to provide data for a comparison between the responses of the internal and external sensors. The guns were also fired on return to test an event triggering algorithm in the DOBS. The guns were recovered at 2300 and the experimental DOBS was recovered safely at 0142/028.

After a short magnetometer survey during the night the first of two DOBS was deployed next morning at 0925/028 for a refraction line (Line 8) designed to fill in a gap left in the earlier French Equaref refraction lines across the transform margin off the Ivory Coast-Ghana Ridge. While steaming to deploy the second DOBS however a potentially serious breakdown in insulation was discovered in the ship's main bus-bars. This needed almost immediate repair. To facilitate this, and in view of uncertainties about the length of time required for repairs plus the fact that the DOBS was already programmed to record in a window which could not now be used, it was decided to recall the DOBS. This was done just after it arrived at the sea bed and it was back on board by 1250. The repairs started at about 1300 with the complete shutdown of all ship's power supplies and services. Power was restored around 1540 and after about one hour the humidity and condensation in the lab areas had decreased sufficiently that equipment could be safely switched on again. While the repairs were going on it was realised that the aborted Line 8 could be shot without collecting a seismic reflection profile along it because in effect such a profile could be reconstructed from existing French data. The time saved equalled the time lost by the insulation repairs. The first DOBS of the re-started Line 8 was deployed at 1858 and the second at 2258. The gun array was then put out in a violent squall with pouring rain and 30 knot winds and, after a navigational problem necessitating a 360° turn, shooting began at 0306/029. It was at this stage in the cruise that we began to suspect that the quality of GPS fixes had been seriously degraded, probably as a result of the Gulf war, and it became necessary to ignore GPS and to revert to the infrequent Transit satellite fixes. We were not helped in this regard by the difficulty of obtaining any information about GPS from RVS at a time when it was sorely needed. Shooting finished about 5 km short of the end of the line when recording time ran out. The first DOBS was released with difficulty compounded by navigational uncertainties (for example the DR recovery position was 4 miles away from the DR lay position!) which also severely hampered the recovery of the second DOBS. After a 6-hour steam during the night we arrived at 0440/030 at the beginning of the last seismic refraction profile of the cruise. Line 9 was intended to reoccupy a line initially shot during the French Equaref cruise in 1990 but which encountered technical problems leading to the loss of most of the OBS data. It was important to complete this work across the Ivory Coast-Ghana Ridge which represented a complementary transect to our own. We planned to shoot the line quickly with the remaining explosives since there was not time to do so with the slower airguns. Two DOBS were laid at 0441 and 0721 both as close as possible to satellite fixes. Shifting of 58 cases of explosive from the main magazine was delayed for half an hour by an electrical fault on the ship's crane. Nevertheless shot firing began on time at 1000/030 and continued, after a meal and rest break, until 1736. 38 shots of 25, 50 and 125 kg were fired without a misfire following which a small quantity of surplus explosive and detonators was detonated. DOBS 1 was inboard by 2001 and DOBS 2 by 2355. A magnetometer survey was then begun which filled in gaps in data over the Ivory Coast-Ghana Ridge. This was completed at 1300/031. The magnetometer and PES fish were recovered and the ship set course for Dakar. En route the gravimeter was left running and a scientific watch was kept on it. The ship arrived off Dakar, Senegal and disembarked scientific personnel by boat at 0910/036.

RBW

SEISMIC REFRACTION PROFILES

The collected data

Nine seismic refraction profiles were shot during the cruise (Table 1). The primary set was shot across the transform margin off Ghana and consisted of six lines parallel to the margin and a seventh 140 km-long line across the margin from the Ghanaian 12 mile limit to the deep ocean (Figure 2). The latter line had already been covered by a multichannel reflection profile during the Equasis cruise. The parallel lines varied in length from 80 km in deep water to 120 km at the edge of the shelf. All seven lines were shot with the large airgun array firing every 2 minutes at about 4 knots over the ground (see Large Airgun Array section of this report) but in addition the seventh line was shot with explosives because of the expected poor transmission across the transform fault zone and because of the greater range needed to penetrate the thick continental crust. The seventh line was also recorded by a number of stations set up in Ghana. Although it is too early yet to assess the data quality fully first results played out at sea are very encouraging and suggest that the airgun array was an adequate source. The sole significant problem is likely to be the rather noisy conditions, and therefore poor signal:noise, encountered on the shallow continental shelf.

The other two refraction lines were shot near the Ivory Coast-Ghana Ridge and were designed to complement lines already shot during the Equaref cruise in 1990. The 80 km-long

Line 8 was shot using the airgun array and filled a gap over the approximate position of the transform fault zone (Figure 3). The 104 km-long Line 9 reoccupied a line which had experienced severe technical problems during Equaref and needed to be re-shot. This was done using our remaining explosive because time did not allow us to use the airguns.

A third activity was the use of a DOBS with an external sensor package. This was deployed to assess its effectiveness by comparing the signals, recorded concurrently by internal and external sensors, from a 2 x 1000 ins^3 airgun source . First results suggest that the smaller external package is not only quieter but also surprisingly picks up some signals which are completely absent on the internal sensor recordings.

RBW

Onboard display of DOBS data

To facilitate the rapid checking of the PDAS seismic traces at sea, and to provide a quick look display, a program was needed to plot several traces simultaneously. Data is downloaded from the PDAS onto an IBM PS/2 and then archived to data cartridge on an Everex tape streamer. The program TRACES was written using PC Professional Fortran, together with a separate IBM PC plotting system, and run on an IBM PC AT. The data was uploaded onto this machine using a similar tape streamer.

The program allows up to 15 traces to be displayed on the screen simultaneously and these can then be printed on an IBM Compact Printer using a screen dump facility provided within the program. The first 4000 samples (typically 40 seconds) are read from each PDAS data file and displayed on the screen in a series of equally-spaced horizontal traces together with a scaled time-axis. Due to the number of events recorded by each DOBS, commonly over 400, only every tenth trace is displayed. The time window can then be reduced by the user to suit requirements, thus expanding any particular feature that may be of interest. The vertical scaling of each trace is calculated automatically ('normalised') to make a standard deflection regardless of any bias or the amplification in the original signal. This generally works well when large returns are present, such as a water wave arrival. However if no large signals are present the noise is amplified significantly.

Two options are present to increase the seismic signal:noise ratio and to assist trace-to-trace correlation of arrivals. A bandpass filter of 4 to 20 Hz reduces the noise considerably. However due to the size of the data being handled only the first 2000 samples can be filtered, the remaining 2000 samples are left unchanged. The second option is to display reduced travel times. For this the distance from DOBS-to-shot is required and can be obtained simply from the onboard navigation. A data file can be transferred from the ship's computer system to the IBM PC via a networked IBM PS/2. A reduction velocity of 6km/sec was used as standard.

Two examples are shown (Figure 4); one is an ordinary 15-trace plot with no filtering or reduced travel times, and the second is of exactly the same data but with filtering and reduced travel times. Processing time for reading 15 traces and plotting the first display is commonly 5 minutes. However if filtering is also required the processing time is significantly increased to about 15 minutes (per 15 traces) and this severely detracts from the ease of use. Using a faster IBM PC, such as a PS/2 Model 55sx (386) or an even newer 486 machine, would speed up operations considerably, with little or no program update required. However a workstation, such as a SparcStation I, would be even better as it would have better graphics, more memory and faster processing, as well as being able to cope with other programs such as Maslov ray-tracing. Connection to the IBM PC environment could be by Ethernet or LAN.

TPL

SEISMIC REFLECTION PROFILES

Data acquisition

Approximately 1200 km of seismic reflection profiles (Lines 2-6, 20-27; Table 2) were collected in the work area, giving a transect across the Ghanaian transform margin, Figure 2. Profiles were obtained along those lines studied in the seismic refraction experiment to provide additional control on the OBS data processing and interpretation. No seismic reflection data was collected on the continental shelf due to the good coverage already available in this area from the Halliburton survey of 1983. Profiles were also shot normal to the transform margin in positions chosen to complement French data already acquired and to complete a grid over the area. Line 27 provided a profile of the oceanic crust along a flowline to the south of the margin.

The data were collected using a simple system designed to show sediment thickness and basement character. The source was two 300 ins^3 airguns towed at a depth of approximately 16 m. The shot interval was 12 s. The streamer had two active sections which gave signals on separate channels. Three paper record sections were played out with the following parameters;

Interval	Bandwidth
4 - 12 s	10 - 50 Hz
4 s sweep	1 - 100 Hz
4 s sweep	20 - 120 Hz

The data were also recorded on digital tape to enable processing and redisplay at a later date. The tapes recorded two channels with 6 s records and sampling at 500 samples/second. The data quality was overall of a very high standard except for line 2, shot along the top of the continental slope, where modifications were still being made to the system.

Preliminary interpretation

A preliminary interpretation of the profiles was carried out on board from the paper records. This showed a basic stratigraphy similar to that seen on previously recorded data in the lower slope and Guinea Basin area, where a highly diffractive basement is overlain by a succession of thick layers of sediment of up to 3.0 s TWT total thickness, (Figure 5). The deepest sediment package shows a series of well-layered reflectors which onlap onto the basement below. This is overlain by a unit which has a diffractive top, possibly representing sediment slides. The remaining sequences are more transparent. An interesting feature, not previously seen in this area, is the presence of localised highly reflective events at 0.5 s TWT below the sea bed, (Figure 6). These are thought to correspond to sills which have been intruded into the sediments. Mapping these features shows them to be most abundant close to the bottom of the continental slope. It is not possible at this stage to establish any continuity of individual sills between profiles.

Line 27 is positioned to the south of the transform margin and therefore over oceanic crust. The sediments on this line can be seen to onlap onto the younger oceanic crust to the south-west. This line also shows some localised sediment packages with diffractive upper surfaces which appear to correspond to sediment slides.

Future work on this data will include tying in the profiles to those previously collected in the area to enable more accurate contouring of the basement and sediment packages seen. Using the French data it should be possible to define a more detailed stratigraphy and provide a better understanding of the more localised features such as sills and slides.

RAE,RAS

NAVIGATIONAL SYSTEMS

A file of 30-second navigational information was generated by the Level C computer system from raw data collected by the navigational Level A's, (GPS, Transit Satellite, Ship's Log and Gyro Compass). The calculated variables included latitude, longitude, ship speed, heading and drift.

Navigation was calculated primarily from GPS satellite fixes, generally available every 4-6 seconds. During periods when GPS fixes were unavailable Transit Satellite data was used in conjunction with Ship's Log and Gyro Compass data.

The Transit Satellite Navigator received a satellite fix on average every 100 minutes whilst in the survey area. The satellite fixes were accepted or rejected according to their associated elevation angles and iteration counts. Navigational data for the periods between 'good' Transit Satellite fixes was 'dead-reckoned' using the relative motion data from the Ship's Log and Gyro Compass.

In theory there should have been complete 24-hour GPS coverage for the entire survey period, however on two occasions during the cruise there were problems with the GPS receiver that caused the Transit Satellite Navigator to be used as the primary navigation source. In the first instance, days 006-007, there was a period of approximately 24 hours during which time the GPS receiver was unable to receive satellite fixes. Later in the cruise (day 020) a similar 'black-out' occurred lasting about 12 hours. When the GPS receiver resumed normal operation the fix information over the subsequent days became increasingly erratic causing instantaneous 'jumps', in both latitude and longitude, of over a mile. As a result of the apparent unreliability of the GPS data the processed navigation from pm/024 to pm/030 was calculated from Transit Satellite data. The GPS receiver was completely re-initialised, on advice from RVS Barry, and the resulting satellite fixes, from pm/030, showed none of the erratic behaviour previously described.

The cause of the GPS problems has yet to be identified though it is suspected that military activity in the Middle East caused a number of the GPS satellite vehicles to be switched off and moved. This in itself could have caused some corruption of the parameters held in the GPS receiver RAM and thus resulted in a period of erratic position fixing, lasting until the receiver RAM was cleared.

RP

ECHO-SOUNDING AND ACOUSTIC TELEMETRY

The ship was equipped with a Simrad EA500 echo-sounder and a Mk.III PES. The Simrad worked admirably as an echo-sounder once we became familiar with the extensive menus of control parameters. The flexible waterfall screen display gave just over an hour's data and the printer provided a permanent record with automatic annotation of depth and time. The scales of these displays could be set separately. Perhaps the most annoying feature is the assumption of a non-standard soundspeed of 1470 m/sec on the graphical and paper displays even though the digital display gives a different but conventionally 'correct' depth assuming 1500 m/sec. The paper record, produced on a rather 'tinny' Hewlett-Packard Paintjet printer, is quite unsuitable for real-time analysis and inspection.

The Mk.III PES was extensively used with the IOSDL acoustic release system incorporated within the DOBS. The incompatibility between the Simrad and Mk.III PES systems has already been documented elsewhere. Here it is only necessary to say that we hope that the problem can be resolved speedily. The Mk. III equipment is old and subject to breakdown. There also seemed to be a loss of acoustic output to the seafloor when a single element on the hull transducer was used. This may be caused by the physical shadowing effect of the ship's hull or else it indicates a real electrical mismatch between the hull element and the Mk.III PES. This was suspected to be the case at one point because of the frequency with which power transistors in the acoustic transmitter boxes were blowing up. Both problems were resolved by using a single element in the PES fish after which no more transistors failed. It also seemed that there was room for improvement in the way different combinations of echo-sounder and hull and fish transducers were chosen. At present this depends on changing connectors; a switched arrangement would be much easier to use and less prone to accidents.

RBW

MAGNETIC MEASUREMENTS

Total field magnetic anomaly data were already available on a widely-spaced network of randomly oriented tracks and from two detailed surveys, one in the Ivory Coast Basin by the Laboratoire Géodynamique Sous Marine, Villefranche and the other over the Ghanaian shelf and slope by Halliburton Geophysical Services. Although the detailed surveys were not inspected before the cruise, the other tracks indicated that there are anomalies over the Ghanaian slope. The Ivory Coast Basin, the Ivory Coast-Ghana Ridge and the Guinea Basin are all magnetically quiet, the last of these being on oceanic crust of the Cretaceous magnetic quiet zone.

It was intended to collect magnetic data along all seismic reflection profiles and transit tracks in the work area wherever possible. Three specific objectives were:

i) to supplement existing data in and around the area of the Ghana margin seismic refraction profiles (lines 0, 2-7, 20-26; Figure 2);

ii) to obtain an ENE-WSW oriented oceanic flow-line profile (lines 27, 28; Figures 2 & 3) in an area where no such profiles exist; and

iii) to collect some profiles over the Ivory Coast-Ghana Ridge as requested by our French collaborators (lines 28, 29, 31-33; Figure 3).

Total field magnetic anomaly values were calculated relative to IGRF85. Apart from some high values over the Ghanaian shelf, only weak anomalies of no more than 100nT peak-to-peak occur throughout the survey area. A preliminary contour map of our data across the Ghana margin (Figure 7) suggests the presence of several interesting anomalies. However, the irregularity of the contours around 4°30'N, 0°12'W also suggests serious misties at track cross-overs. Misties of up to 100nT are in fact present and assume enormous importance in this area of quiet magnetic field. An experiment (at 4°10'N, 0°7'W) to determine the effect of the magnetic field of the ship on the observations showed that heading corrections are only of magnitude +/-15nT. Diurnal variations of the earth's magnetic field are therefore the principal cause of the crossover errors. The magnitude of the errors and the amplitude of the anomalies themselves as a function of time of day both clearly show that a diurnal variation of over 50nT is present. In seeking to interpret significant anomalies of only a few tens of nT peak-to-peak it will be essential to make careful diurnal and heading corrections to the data. A plot of magnetic anomalies along tracks (Figure 8) shows that there are correlatable anomalies to be studied.

The oceanic flow-line profile revealed weak anomalies of no more than 100nT, as might be expected in a magnetic quiet zone in the vicinity of the magnetic equator where any sea-floor spreading anomalies would be oriented roughly north-south. Profiles 29 and 32 crossed magnetic lows at the foot of the Ivory Coast-Ghana Ridge where the transition from continental to oceanic crust would be expected to occur.

RAS,JYR

GRAVITY MEASUREMENTS

LaCoste-Romberg gravity meter no. S84 was operated throughout the cruise. The meter tie at Dakar was made during bunkering on day 006 at mole 8 berth 82 where the base value is 978467.09 mgal. A free-air correction of -0.57 mgal was applied to give a corrected ship base value of 978466.52 mgal with the meter reading 9701.7 units. The meter calibration factor was 0.9967.

The meter was located in the Controlled Temperature Laboratory which was also used as a PC workroom. It was felt that this area was overcrowded and inevitably staff used the space between the gravimeter and the Compaq cabinet for access. If this room is to house the meter in future then it MUST be relocated to make more ergonomic use of the space and to protect the meter frame. Even better, a more satisfactory, but not too distant, space should be found for the meter elsewhere in the ship.

Two problems occurred which may adversely affect the acquired gravity data. First, on days 013 and 014 the efficiency of the air-conditioning twice caused the heaters to stop cycling and the meter was shut down by the system. On restart some adjustment to the temperature level in the room and the exclusion of draughts by shrouding the meter in cling film solved the problem. Second, on day 028 the ship suffered a total electrical shutdown for repairs which lasted between 1250 and 1600 hrs. The actual effect of these interruptions to the meter supply will not be clear until the meter can be tied at Tenerife but at present it appears that any data 'tear' is minimal and, if present, can be estimated and corrected for through cross-over analysis.

More important was the loss of confidence in the GPS navigation which introduced some noise in the processed gravity. This was improved by reverting to Transit satellite navigation between 1815/024 and 1900/030 when GPS appeared to be functioning correctly again.

PRM

DATA LOGGING

The RVS 'ABC' computer system was used to record and process data from seven geophysical and navigational instruments. The specific instrument details, along with sampling rates and logging totals are given below:-

Instrument	Sampling Interval	Data Logged
GPS Receiver	4 seconds	30 Mbytes
Transit Sat Navigator	variable	70 Kbytes
EM Log	1 second	40 Mbytes
Gyro-compass	1 second	25 Mbytes
Echo-Sounder	30 seconds	22 Mbytes
Gravimeter	10 seconds	20 Mbytes
Magnetometer	6 seconds	12 Mbytes

Each instrument has an associated data logging unit, known as a 'Level-A', which collects data from the instrument. The Level A formats the data into standard SMP (Ship Message Protocol) messages which are then sent, via a serial RS232 interface, to a central data concentrator, known as the 'Level B'. The Level B receives SMP messages from all active Level A units and stores them on both 1/2" magnetic tape and winchester hard disk. The Level B also passes the collected data, via a secure 'V24' serial link, to the data processing computer system, known as the 'Level C'.

A network of three SUN workstations running UNIX provided the Level C system for cruise 55. One workstation was used to receive raw data from the Level B and store it on disk. A second workstation was used to generate a processed navigation file. The processed navigation file was used in conjunction with raw geophysical data to produce files of corrected depth, free-air gravity anomaly and magnetic anomaly relative to IGRF85. The third workstation was available as a back-up and to provide additional processing facilities when required.

RP

COMPRESSORS

The two Hamworthy 4TH190 compressors ran for a combined total of 553 hours. During this period they functioned very well. They provided either 3532 ins^3 of air at 2000 psi per minute to the gun array or 3000 ins^3 per minute for reflection profiling. There were two problems which caused one of the machines to be out of service for a short period. The first was an electrical fault on the solenoid dump valve and the other a fractured pipe in the third stage cooler. Both faults were rectified, the latter one by on board welding, and the machine put back into service.

WKS

LARGE AIRGUN ARRAY

A large volume airgun array was required as an alternative seismic source to explosive charges for the seismic refraction lines. Such an array has the advantage of relatively low running costs, a high firing-rate, precise electronically controlled timing, greater safety and, once deployed, runs with no more than one or two watch-keepers. The array had to be designed around equipment already available from RVS. Even so provision had to be made by the cruise Principal Investigators for the acquisition of two extra 1000 ins^3 chambers and for the construction of a third beam and umbilical winch by RVS. The P.I.'s are greatly indebted to NERC's Director of Higher Education Affairs for funding and to the Atlantic Geoscience Centre, Nova Scotia for the free loan of a 1000 ins^3 chamber.

The array consisted of two single 1000 ins^3 guns and three 6 metre-long beams, from each of which were suspended two 1000 and/or 766 ins^3 airguns. Two beams were towed on the starboard quarter and the third from the port quarter. The single 1000 ins^3 guns were towed from separate points under the stern A-frame. Each beam was suspended from a pair of large Hippo floats at a depth of about 15 metres. The 1000 ins^3 guns were towed at a similar depth. Although the beams were towed at least 55 metres astern it was not possible with the hoses provided to get the single guns further away than about 20 metres from the stern. Although the required separation could be arranged in the fore-and-aft direction the athwartships separation of the tow points could not be maintained because of the turbulence of the ship's wake. This tended to draw the beams and their floats together but not enough to cause the bubbles of their guns to merge. On the other hand the bubbles of the guns on any one beam, and of the two single guns, did appear to merge as only four distinct bubbles could be discerned when they broke surface. Consequently the array was probably not working at its optimum but nevertheless first results at sea were very encouraging. The beams were deployed by an ingeniously modified crane of RVS design and towed from special umbilical winches.

Very little time was lost due to failures of the airguns or of the beams or towing equipment in a total of 110 hours of towing (Table 3). One gun failed due to a cracked solenoid and two trigger leads also failed in one umbilical. A gun suspension chain also broke and the gun was recovered hanging from its hose and cable. With practise the whole system could be deployed or recovered in the space of 90 minutes or less. Operations were greatly helped by the excellent weather conditions. There were no significant waves and the swell was always less than about 2 metres. It is not clear however whether the same system would be as reliable under rougher weather conditions.

WKS,RBW

SHOT FIRING

A total of 83 ICI Opencast Gelignite Bulkpack charges initiated by oceanographic capped fuses with No. 6 detonators and ranging in size from 25 to 125 kg were fired. 45 charges were deployed along Line 7 and 38 charges along Line 9. No misfires occurred and all charges seemed to detonate fully. Three 10 kg bottom shots were also laid in a depth of 5050 metres. These consisted of 25 sticks of Powerprime 400 initiated by Primacord and a high-pressure electrical detonator. One of the three bottom charges failed to detonate for an unknown reason. The other two detonated on time. Besides the one misfire no other problems were encountered.

WKS

DIGITAL OCEAN-BOTTOM SEISMOGRAPHS

Six DOBS were used during the cruise, four from IOSDL and two from Durham University. The two Durham DOBS were being used at sea for the first time and were part of a batch of six instruments recently purchased from IOSDL. All six DOBS were of similar design mechanically and electronically and used Teledyne PDAS100 data loggers. These loggers were fitted with recently purchased 40 Mb hard disc drives. This gave a fourfold increase in data recording capacity over the standard solid state memory used in the loggers on our previous cruises. Due to low seabed temperatures (ca. 2°C) the disc drives were required to operate below their low temperature specification. Therefore the temperature sensing circuits were modified on all units, to prevent the data loggers from shutting down under marginally out-of-specification temperatures whilst on the seabed. Throughout the cruise these ruggedised units performed faultlessly however they were handled carefully under good conditions.

A total of 27 instrument deployments and recoveries was made without loss, with depths of deployment varying between 30 and 5074 m. Generally the acoustic releases performed well when the navigation, which was poor at times, enabled us to get within acoustic range of the instruments. One flashing light beacon failed on an IOSDL instrument but fortunately this was recovered in daylight. The permanently fitted steerable Yagi array was used for radio beacon location. This system worked adequately when used, however it is a slow system and requires a trained eye to get accurate fixes. A better option to have fitted aboard ship would be an electronically switched four-dipole array giving instantaneous bearing on the beacons. These systems are available commercially and have the advantage of using no moving antennas thus increasing mechanical reliability.

Data was recorded along nine refraction lines, together with one test deployment of a deployed geophone package. One deployment on line 8 had to be cut short due to engineering problems aboard ship.

Airgun and explosive sources used throughout the cruise were very reliable, due to the great efforts of the teams involved, and appeared to be very effective in generating seismic energy which was recorded at large ranges from the instruments.

A test deployment was carried out using an external three component geophone set in addition to an internally mounted non-gimballed set. The external set in a gimbal-mounted pressure case was housed in an oil-filled pressure-balanced housing designed at IOSDL. Extensive trials had been carried out at Wormley and HMS Vernon (Portsmouth) during 1990 to test the impulse response and hydrodynamic stability of the external package and the DOBS respectively. The external package is designed to be released from a supporting arm and allowed to fall alongside the DOBS onto the seabed once it has reached the sea floor. It is hoped that this small package will more accurately record the signals we are trying to acquire. An initial look at this data is very encouraging and it is unfortunate that there was only time for one of these deployments to be carried out.

Throughout the cruise the six DOBS were operated by two specialists and two helpers. Deployment of the instruments and recoveries became fairly routine. The extra data capacity of the loggers (disc drives) meant that down-loading of data to computer and subsequent copying to cartridge tape was very time consuming, sometimes in excess of three hours per DOBS. This often meant the simultaneous use of two or even three computers. A quick-look program written during the cruise enabled us to monitor the data once it was copied to tape and proved tremendously useful. It would have been impossible to complete all of this work on anything other than a team effort basis.

Only one channel of data was lost on one logger, due to an internal fault, during the first recorded refraction line. Thereafter the data loggers performed as programmed. In excess of 676 Mb of data were recorded comprising 46,000 event windows with a data loss of only 1 per cent. A "first look" at the recorded data at sea suggests that the quality and coverage of arrivals are extremely good.

REK,CP

DISPOSABLE SONOBUOYS

Six sonobuoys were deployed during seismic profiling of the DOBS refraction lines. Details are shown in Table 4. These wide-angle seismic profiles will enable the interval velocities within the sedimentary units above acoustic basement to be calculated. This in combination with seismic reflection profiles will provide sediment thickness data to constrain velocity models. Best results are obtained when sonobuoys are deployed over a planar seabed and acoustic basement. Additionally it is useful to choose a location where boundaries between seismic sequences are clearly defined.

Two models of sonobuoy were used - SB6E4's from IOSDL, now superseded, and SSQ904A's which were kindly provided by RVS. The source was two 300 ins^3 airguns. All stations were successful. The data were received by a ICOM communications receiver ICR 7000, monitored in real time on an EPC recorder and recorded on a Store-4 tape-recorder for subsequent digitising ashore.

One new feature was the real-time digitizing of data from sonobuoy 5 using a DOBS PDAS unit. This provided a standard PDAS data set which will be processed and displayed in the normal way. The advantage of this method is the improvement of signal:noise by avoiding the use of analogue tape and the immediate access to the data post-cruise without secondary digitization.

PRM

TABLE 4

SONOBUOY DEPLOYMENTS

Day	Time	Lat. °N	Long. °W	Brg. (degr)	Range (km)	Depth (corr.m)	Sonobuoy Type
013	1221	4 °52.4'	0 °17.4'	041	15.0	2917	SB6E4
015	1340	4 °36.2'	0 °27.7'	043	12.3	3749	SSQ904A
015	2337	4 °29.5'	0° 26.6'	232	12.0	4024	SSQ904A
019	1354	4 °02.1'	0° 32.4'	049	15.5	4598	SSQ904A
019	1810	4 °19.5'	0° 11.2'	048	13.9	4308	SB6E4
020	0215	4 °27.1'	0° 16.4'	036	17.4	4174	SSQ904A

EXPENDABLE BATHYTHERMOGRAPHS (XBT's)

Five XBT drops were made using the Hydrographic Office controller and PC-based logger (Table 5). T7 and T5 units were kindly donated by RVS and the Marine Physics Group at IOSDL. A representative soundspeed profile is given in Figure 9. Temperatures were between 29.7 and 31.6°C at the surface but dropped steeply below 30m depth. The profiles showed no variation across the survey area and with historical deep water data will provide an accurate soundspeed profile.

PRM

TABLE 5

XBT MEASUREMENTS

Latitude °N	Longitude °W	Max. depth (m)	Probe type	Refraction Line No.
6°48.9'	12°55.7'	763	T7	
4°50.1'	0°20.3'	763	T7	2
4°42.4'	0°20.2'	763	T7	3
4°13.4'	0°18.7'	763	T7	6
4°04.5'	0°29.3'	1900	T5	6
4°13.0'	2°30.2'	763	T7	9

MARINET COMMUNICATIONS

During the cruise the newly installed Marinet system was tried out for the first time. This provides a form of electronic mail link by satellite to RVS and then to stations beyond by Janet. The convenience of the system was soon apparent to the scientific party when an important and relatively large data file required on board was transmitted from IOSDL via RVS to the ship. Other messages, some originating within the Janet system itself, were also received during the cruise. The main problems seemed to be in RVS when the absence of a key member of staff at sea and the relative unfamiliarity with the system caused several annoying delays and breakdowns in communication. Once the learning curve improves however this promises to be an invaluable means of official communication with the shore.

RBW

ORNITHOLOGY

Observations were made during the whole cruise to study the status and distribution of the Roseate Tern Sterna dougallii and other pelagic seabirds. The Roseate Tern Sterna dougallii is Europe's rarest and most threatened breeding seabird and both the NE and NW Atlantic populations have declined in recent years. Consequently a longterm ecological research programme in both the breeding and wintering quarters of the NE Atlantic population has been initiated by the Royal Society for the Protection of Birds (RSPB). Existing evidence indicates a large proportion of this population spends the early winter (October-late December) in Ghanaian waters. Data collected after this period are few.

The present survey was aimed principally at establishing the distribution and abundance of Roseate Terns at sea between Senegal and Ghana during the period 5th January and 5th February, 1991. Censusing of all other species of pelagic seabird was also undertaken during the cruise.

Methods

Estimates of seabird density were obtained using methods recommended by Tasker et al.(1984) involving concurrent observations of a 300 m band transect and complete 180° forward scan. Regular 360° point counts were also made. Watches generally ran for periods of 100 minutes each divided into 10 minute units. Approximately 800 10 minute units were completed.

Summary of results

Roseate Terns were not recorded south of latitude 6°57'N and were not located in the waters of the western Gulf of Guinea. This second point supports existing indications that dispersal from the initial core wintering area off Ghana occurs by the new year. Small numbers of Roseate Terns were observed between latitudes 7°21'N and 6°57'N in association with larger feeding parties of Black Terns Chlidonias niger and Common Terns Sterna hirondo (off Sherbo Island, Sierre Leone). This area was not previously known to support substantial tern populations and further coastal surveys are necessary to establish the significance of the area.

In addition to Roseate Terns a further 16 species of seabird were recorded (see List). The most widespread and abundant of these was Cory's Shearwater Calonectris diomedea and Pomarine Skua Stercorarius pomarinus. Black Terns though numerous were patchily distributed throughout. Other species were much less common.

The seabird communities of waters on and off the continental shelf differed. Seabirds offshore were both quantitatively fewer and qualitatively different. Cory's Shearwater and Pomarine Skua were largely restricted to shelf areas whilst Leach's Petrel Oceanodroma leucorhoa and Storm Petrel Hydrobates pelagicus were characteristic of deeper waters. A similar distribution was found by Brown (1978) between Senegal and the Cape Verdes archipelago. Tern flocks were encountered erratically both on and beyond the shelf.

In general seabird numbers were low and largely consisted of migrant species which breed to the north (13 out of 17 species and 98% of all individuals). This reflects the scarcity of resident breeding species in the area, a result of few secure nesting sites (Cooper 1984) and may also reflect the attraction of the productive waters of the Benguela upwelling further south (Brown 1978); cool waters typical of upwellings and higher latitudes have higher primary productivity than those of warm tropical areas (Volkovinskii 1974).

List of seabirds recorded

BULWERS'S PETREL Bulweria bulwerii - small numbers recovered off continental shelf between 4°34'N 00°29'W and 4°08'N 335'W.

CORY'S SHEARWATER Calonectris diomedea - widespread throughout when on continental shelf

MANX SHEARWATER Puffinus puffinus - singles at 5°01'N 00°33'W, 5°009'N 00°18'W, 7°17'N 14°24'W.

STORM PETREL Hydrobates pelagicus - small numbers irregularly recorded when off continental shelf

LEACH'S PETREL Oceanodroma leucorhea - small numbers recorded when off continental shelf

RED BILLED TROPICBIRD Phaeton aethereus - single adult 4°49'N 00°45'W

WHITE TAILED TROPICBIRD Phaeton lepturus - single adult 7°35'N 14°06'W

GANNET Sula bassana -three recorded off Dakar

BROEN BOOBY Sula leucogaster - single adult 4°34'N 00°29'W

GREY PHALAROPE Phalaropus fulicarius - singles at 5°10'N 10°25'W, 4°09'N 4°13'W

POMARINE SKUA Stercorarius pomarinus - widespread when on continental shelf

SABINES GULL Larus sabinii - single adult 4°49'N 00°45'W

BLACK TERN Chlidonias niger - widely distributed. One large concentration at 7°30'N 14°06'W

COMMON TERN Sterna hirundo - small numbers north of 05°00'N. Largest gatherings with Black terns at 7°30'N 14°06'W

ROSEATE TERN Sterna dougallii - small numbers with Black and Common Terns at 7°30'N 14°06'W

SOOTY TERN Sterna fuscata - small numbers irregularly recorded between 4°34'N 00°29'W and 3°16'N 3°16'W

BROWN NODDY Anous stolidus - single at 4°34'N 00°29'W

PA

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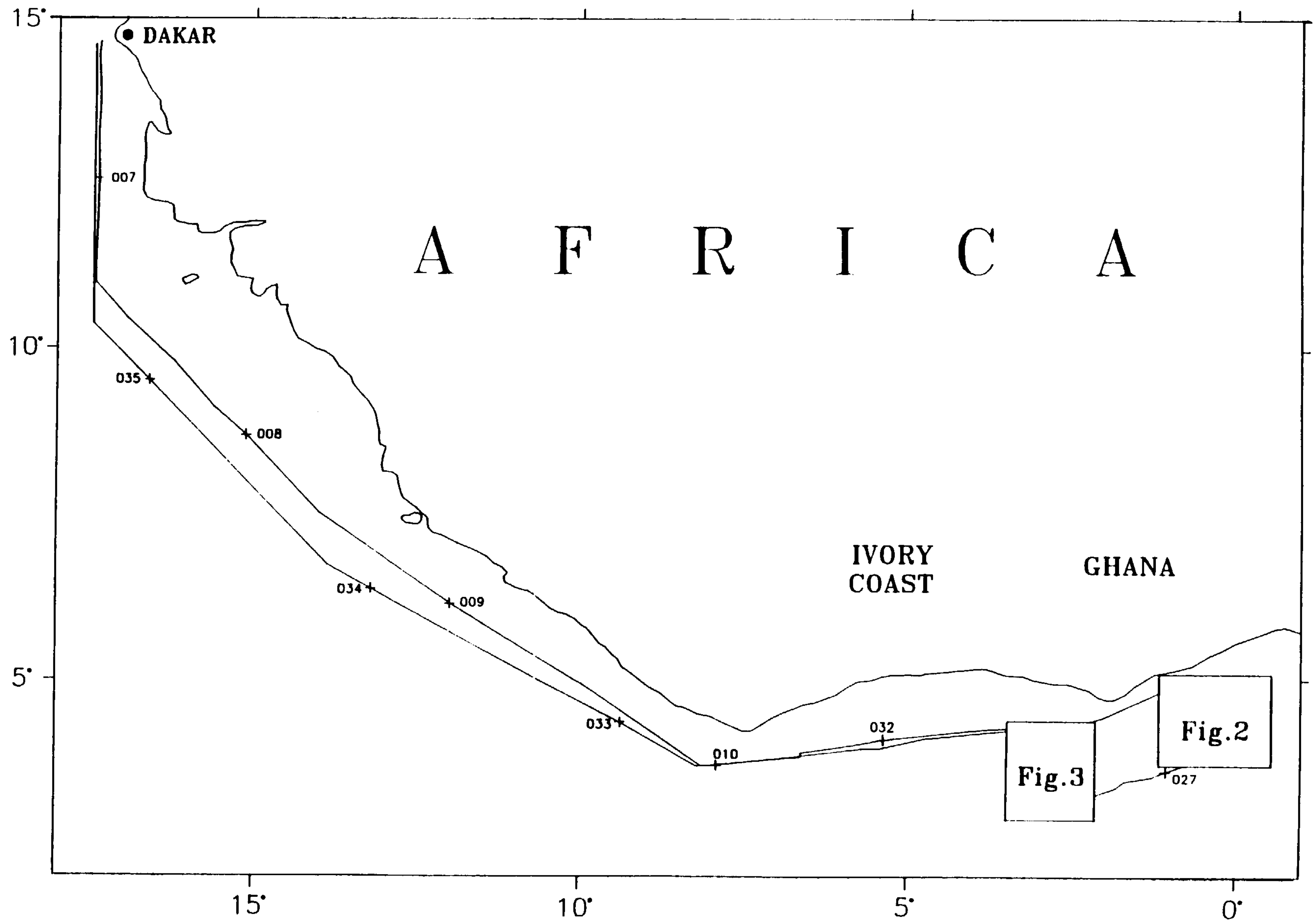

Figure 1 Track chart and work areas for RRS *Charles Darwin* Cruise 55, 6 Jan-5 Feb 1991.

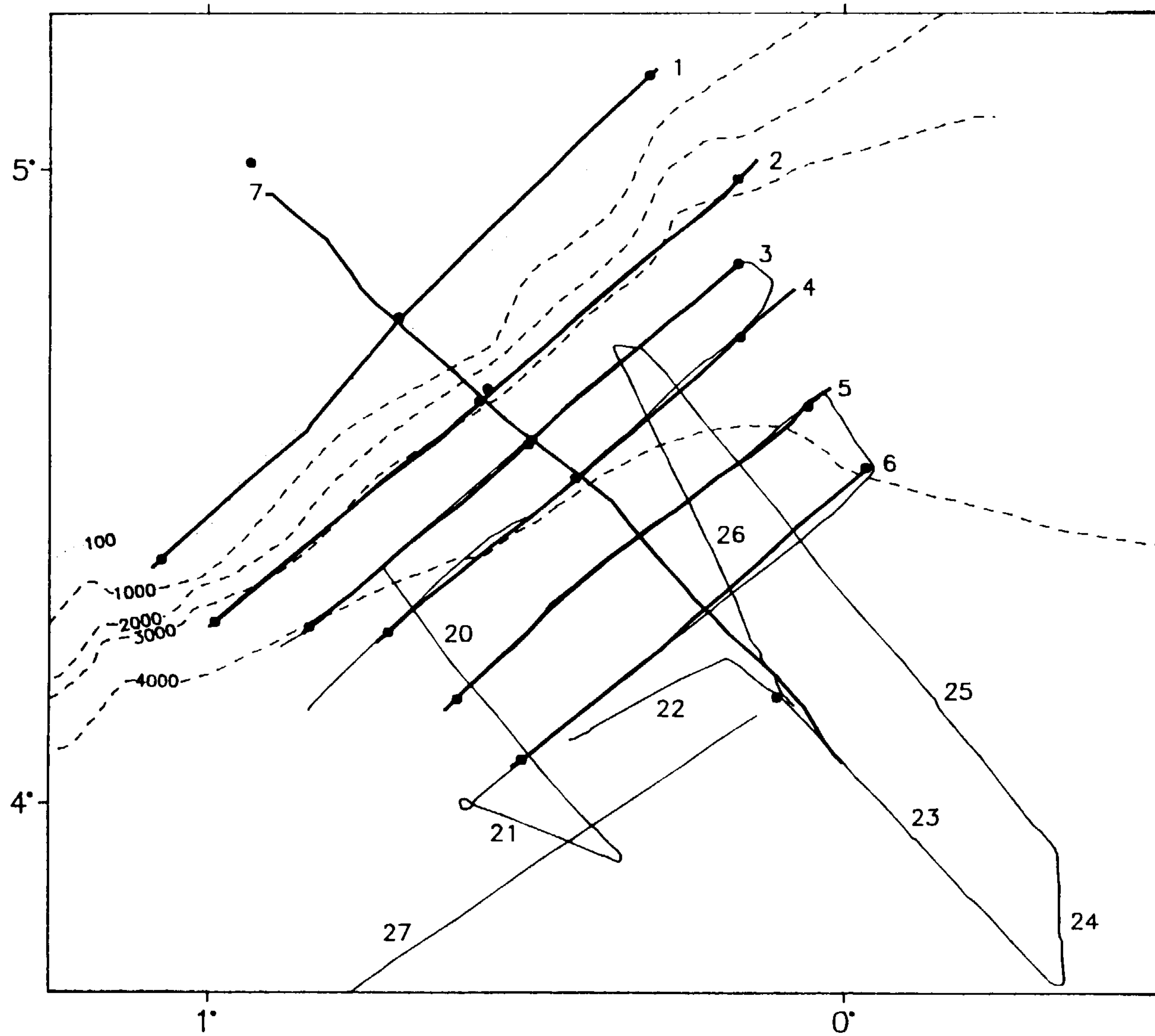

Figure 2 Location of tracks off Ghana (numbered). Thick lines are seismic refraction profiles (with dots showing OBS locations), thin lines are seismic reflections profiles.

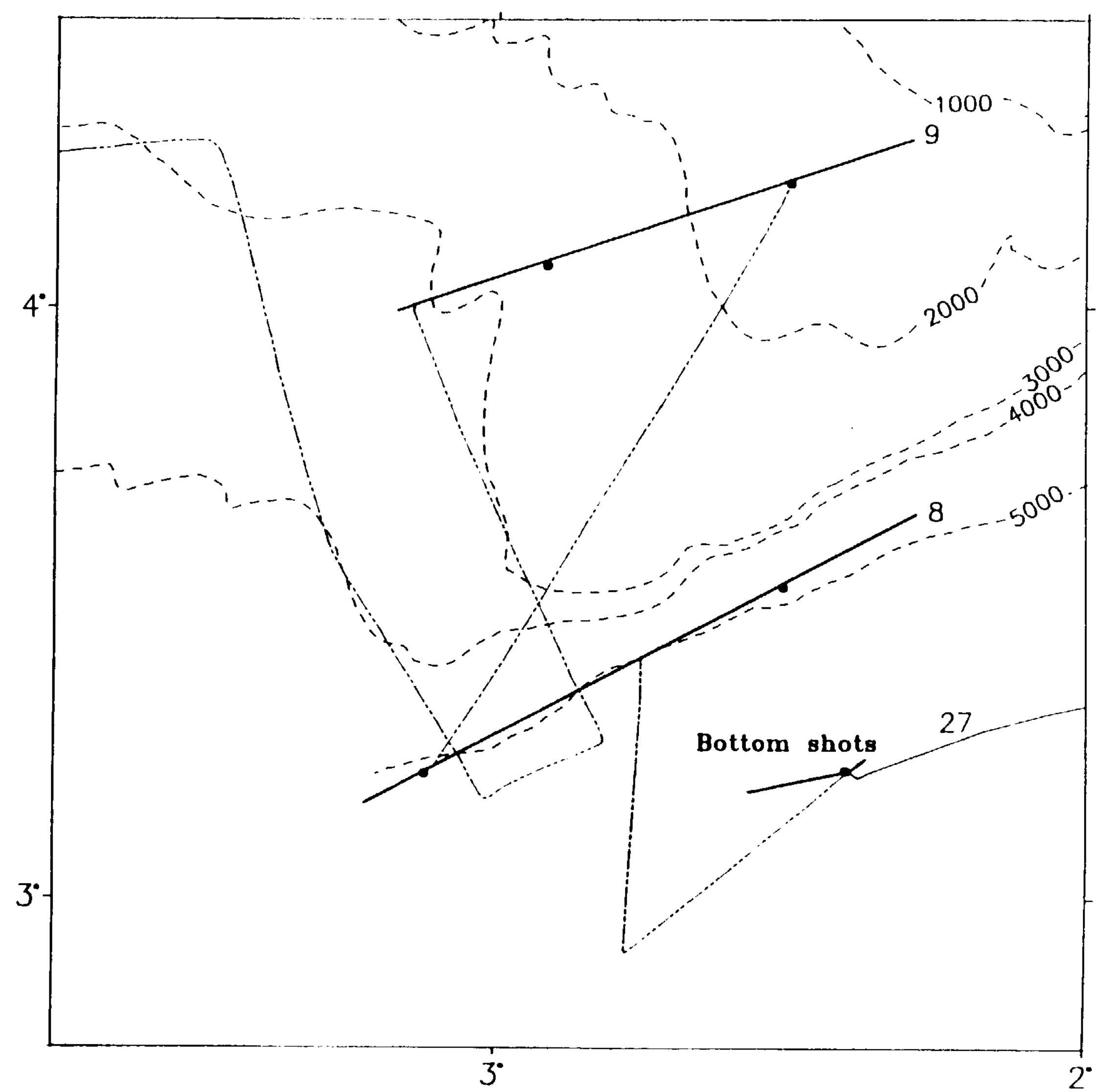

Figure 3 Location of tracks close to the Ivory Coast-Ghana Ridge (numbered). Thick lines are seismic refraction profiles (with dots showing OBS locations), line 27 is a reflection profile, dashed lines denote bathymetry/gravity profiles with some magnetics.

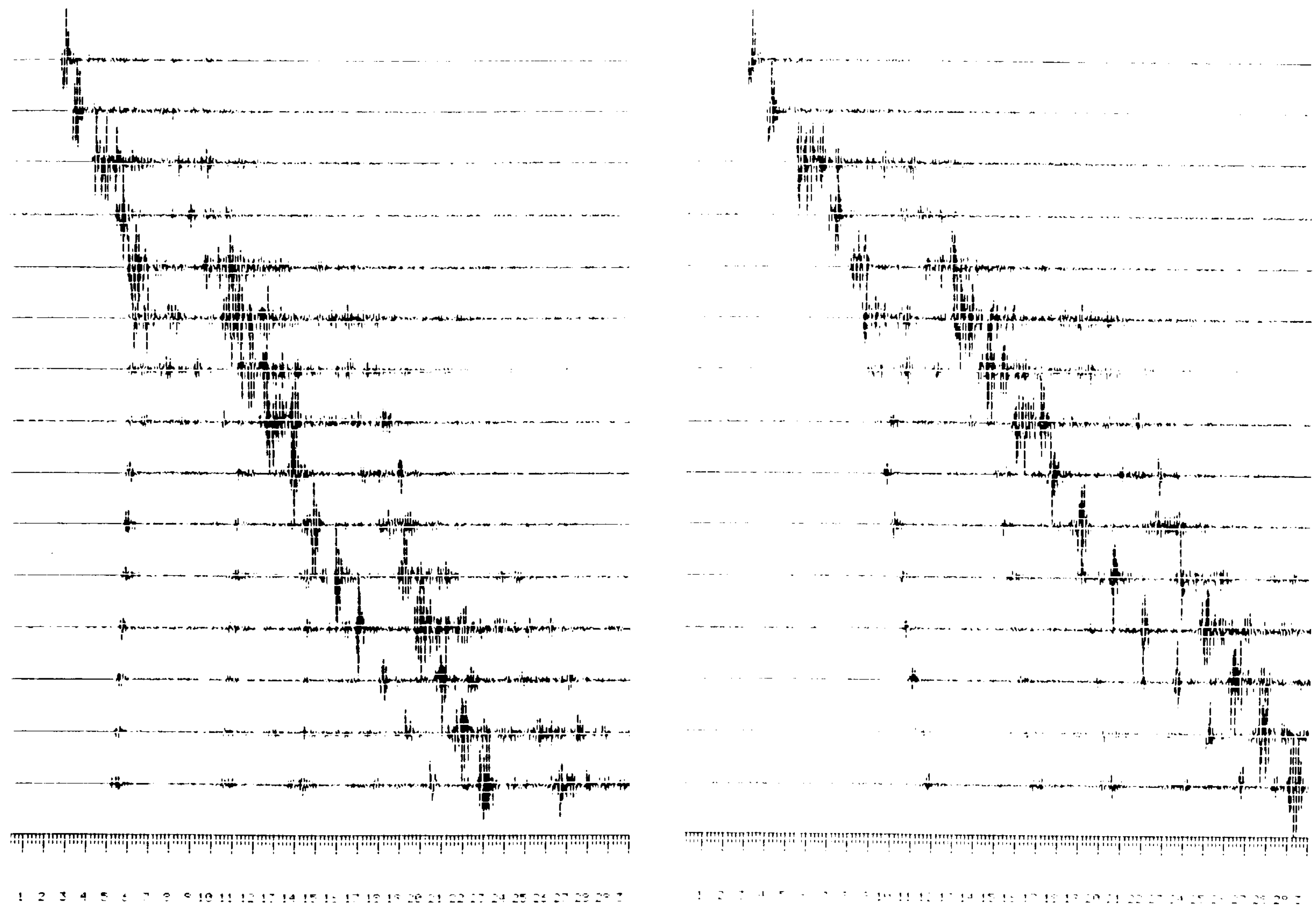

Figure 4(a) Example of a vertical geophone record section produced by the TRACES program. Vertical scale is travel-time in seconds. Every tenth trace is plotted. (b) Same data as in (a) presented with travel-times reduced to 6 km s^{-1} and filtered from 4 to 20 Hz in the first 20 seconds.

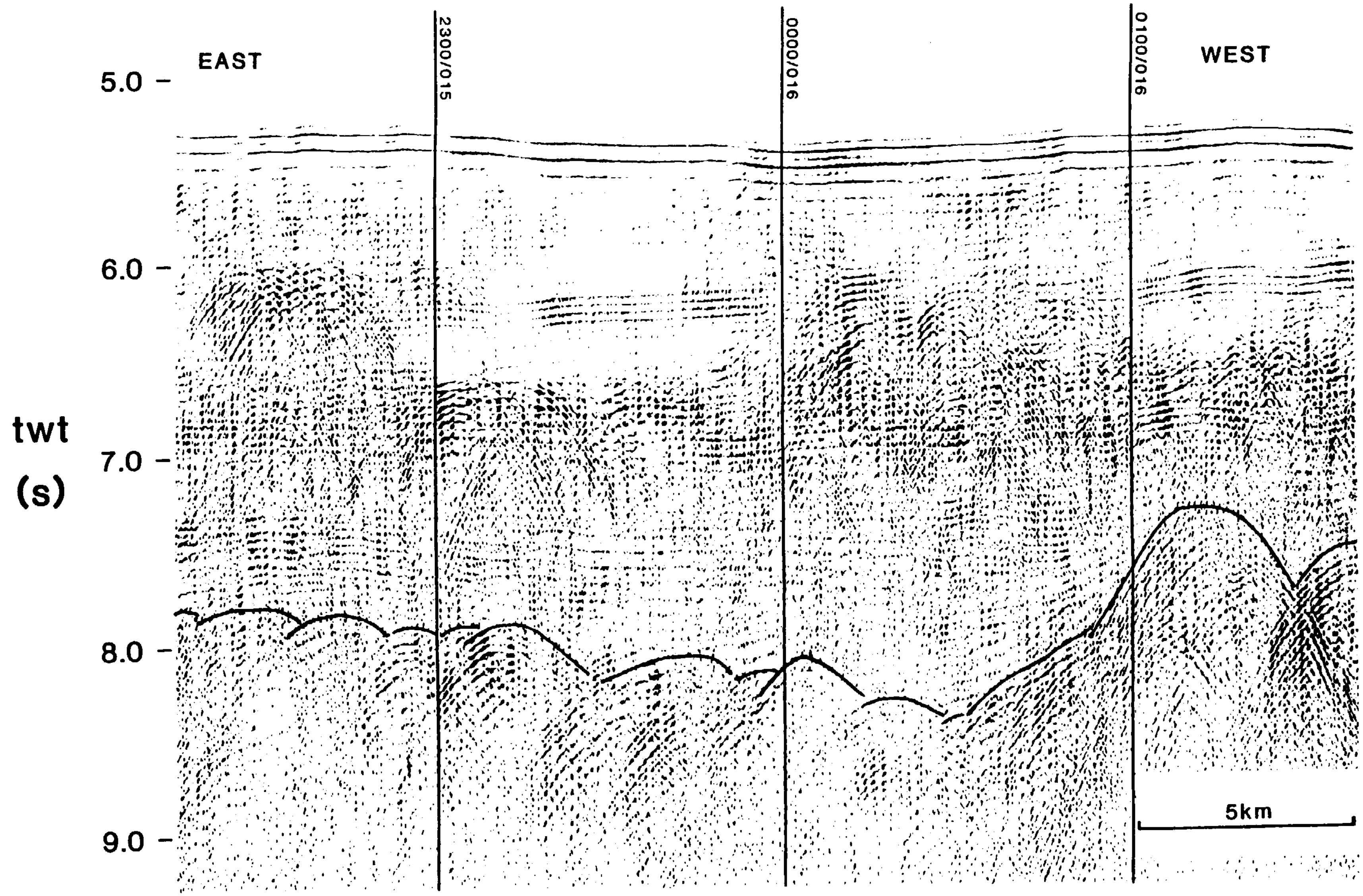

Figure 5 Example of a seismic reflection profile from the Guinea Basin.

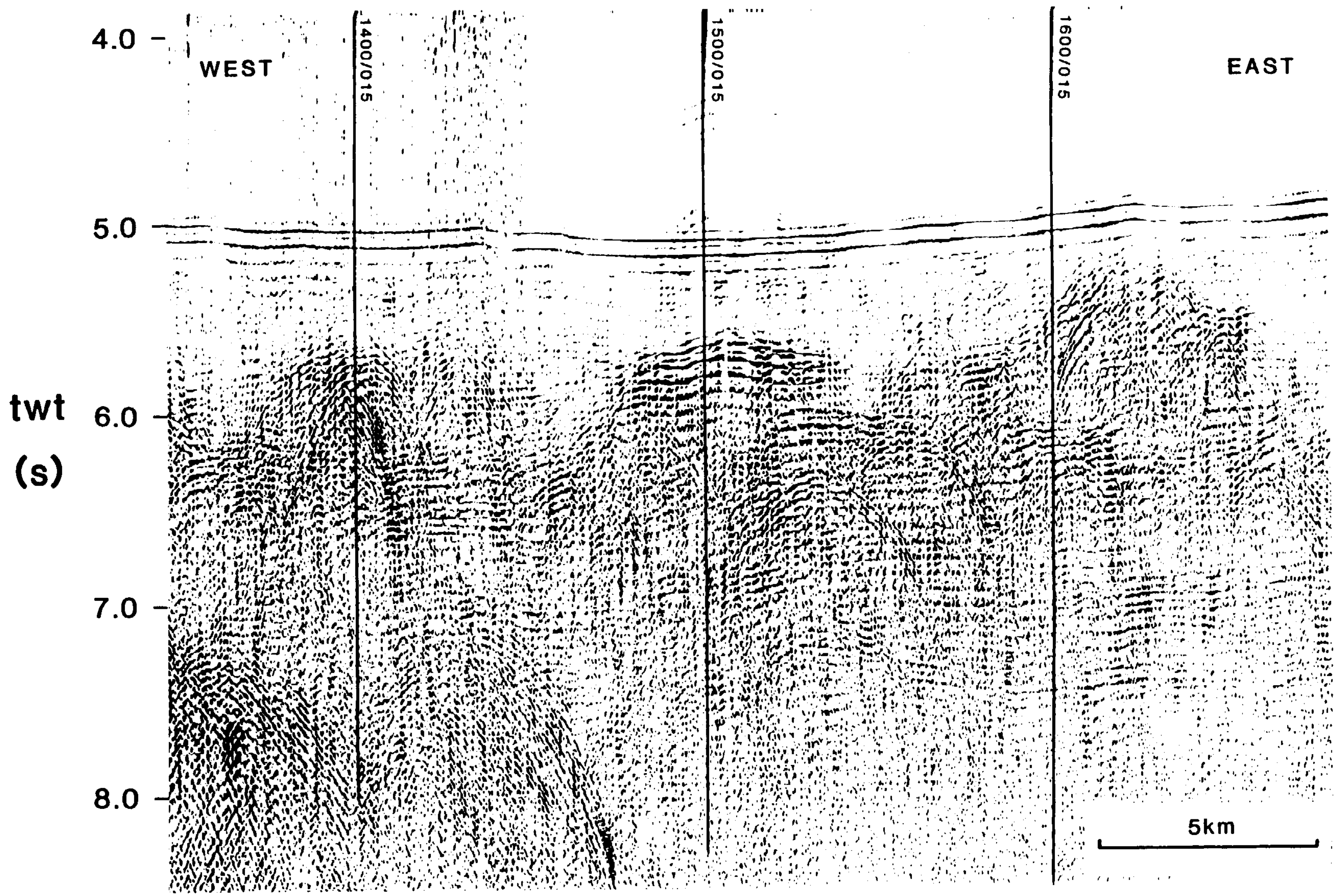

Figure 6 Example of localised highly reflective intrasediment events seen in some parts of the Guinea Basin.

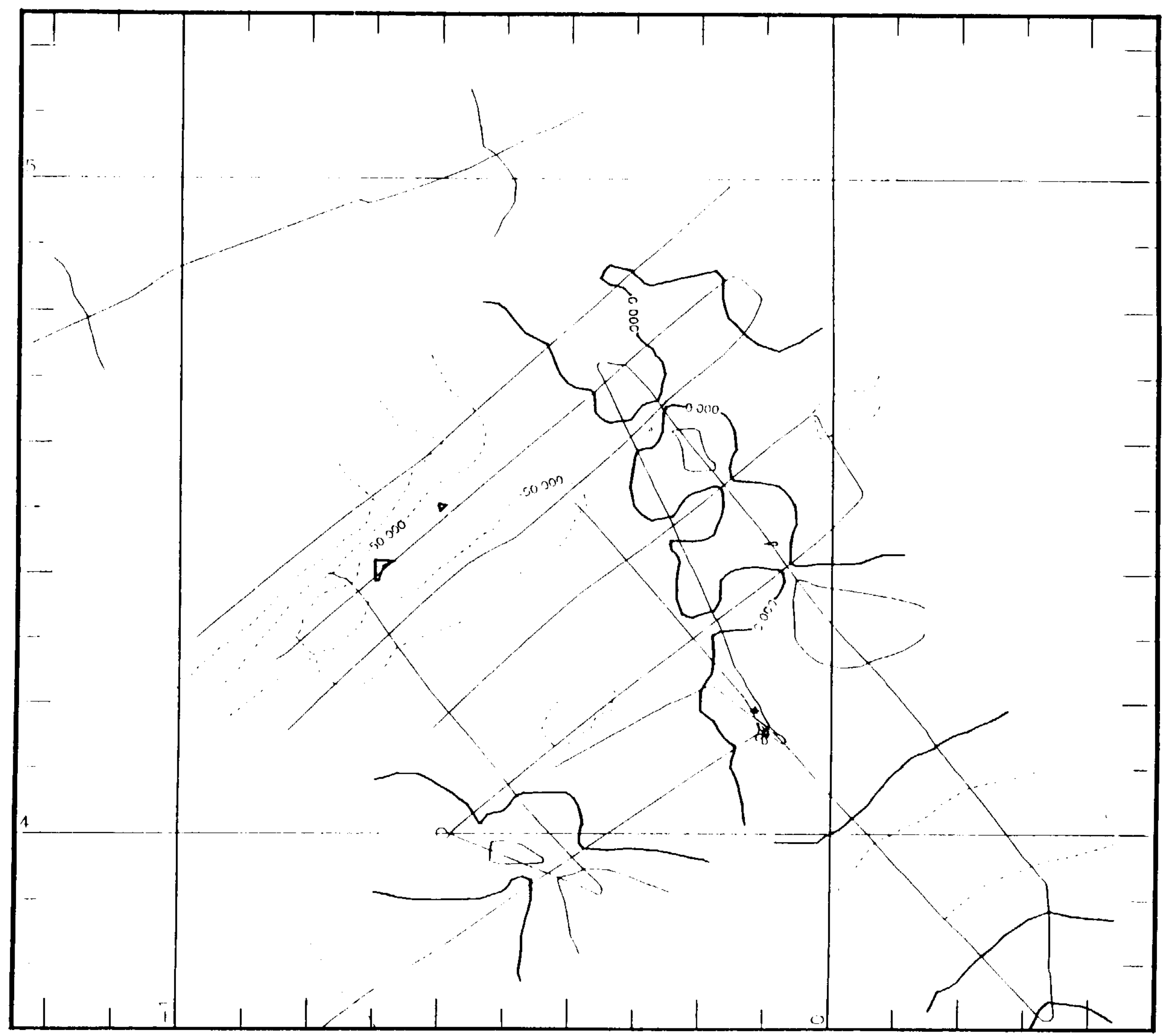

Figure 7 Magnetic anomaly chart for the region off Ghana. Contour interval is 50 nT.

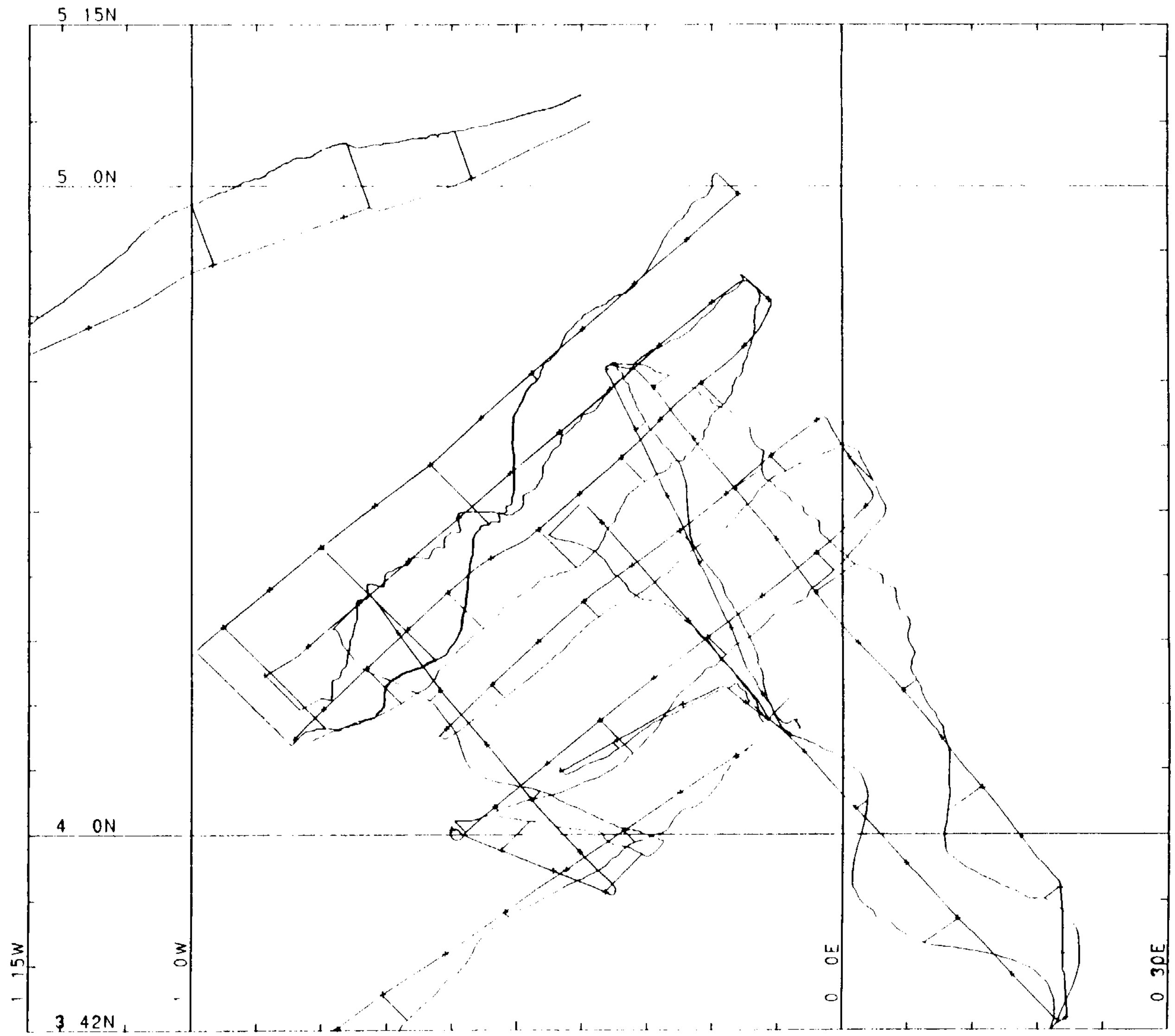

Figure 8 Magnetic anomalies plotted along track for the area indicated in Figure 7. The crosses denote hour-marks along the tracks.

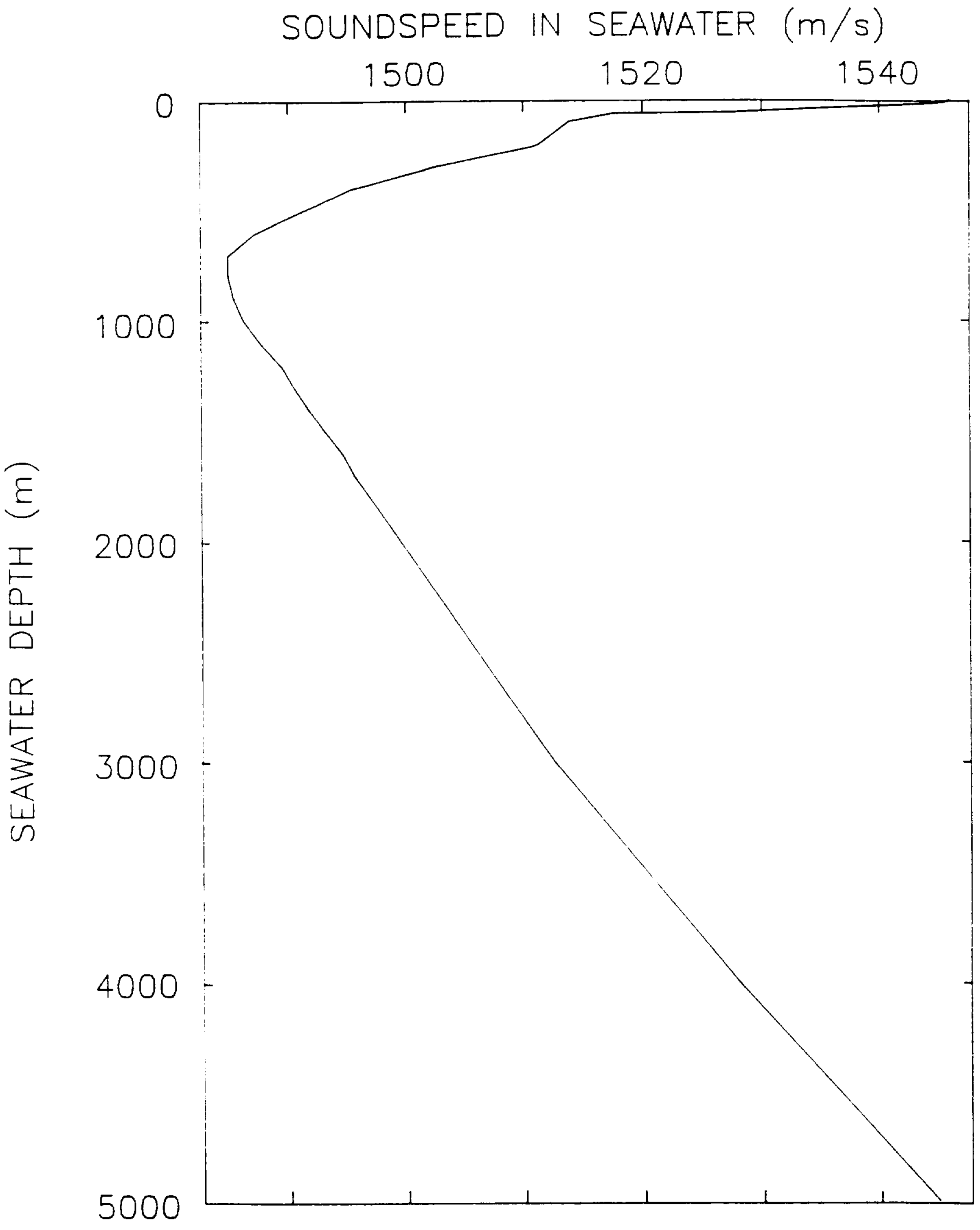

Figure 9 Representative soundspeed/depth profile in the Guinea Basin incorporating XBT data acquired during the cruise.

TABLE 1

DOBS DEPLOYMENTS

Line No	DOBS	Latitude	Longitude	Corrected depth/m	Laid	Recovered	Comments
1	055 WDOBS1	5°09.08'N	0°18.49'W	73	1340/011	1715/012	
	111 DDOBS1	4°46.20'N	0°42.06'W	72	1704/011	2116/012	
	165 WDOBS2	4°22.92'N	1°04.50'W	162	2020/011	0124/013	
2	056 WDOBS1	4°59.05'N	0°10.04'W	2878	1515/013	2147/014	
	112 DDOBS1	4°38.04'N	0°34.38'W	3041	1829/013	0215/015	leak found on recovery
	215 WDOBS2	4°17.13'N	0°59.39'W	3294	2146/013	0658/015	
3	165 WDOBS2	4°16.51'N	0°50.47'W	4001	0932/016	1211/018	
	111 DDOBS1	4°33.96'N	0°29.94'W	3656	1216/016	1620/018	
	215 WDOBS4	4°50.99'N	0°09.97'W	3607	1629/016	0035/019	released on timer after failure of transponder to respond
4	055 WDOBS1	4°16.34'N	0°43.12'W	4177	0728/016	1001/018	
	056 WDOBS3	4°44.05'N	0°09.73'W	3813	1431/016	2201/018	
5	056 WDOBS1	4°09.71'N	0°36.46'W	4442	0931/020	0532/022	
	111 DDOBS1	4°37.51'N	0°03.40'W	3979	1624/020	1152/022	
6	215 WDOBS2	4°04.00'N	0°30.50'W	4562	1109/020	0300/022	
	055 WDOBS3	4°31.59'N	0°02.01'E	4010	1447/020	1436/022	
7	055 WDOBS1	4°09.93'N	0°06.37'W	4404	2207/023	1104/026	
	111 DDOBS1	4°30.63'N	0°25.32'W	3995	0108/024	0628/026	
	215 WDOBS2	4°34.34'N	0°29.54'W	3720	0242/024	0402/026	
	056 WDOBS3	4°38.26'N	0°34.07'W	3323	0432/024	0125/026	
	112 DDOBS2	4°45.91'N	0°42.02'W	86	0645/024	2255/025	released on timer
	165 WDOBS4	5°00.59'N	0°56.09'W	29	0852/024	2011/025	released on timer
btm shot expt	056	3°13.00'N	2°23.96'W	5074	1400/027	0142/028	
8	165 WDOBS1	3°31.60'N	2°30.90'W	4674	1858/028	1547/029	
	055 WDOBS2	3°12.02'N	3°08.84'W	4892	2258/028	2219/029	
9	215 WDOBS1	4°13.00'N	2°30.20'W	1438	0441/030	2002/030	
	165 WDOBS2	4°04.08'N	2°55.99'W	2587	0721/030	2354/030	

TABLE 2

SEISMIC REFLECTION PROFILES

Line No	Start	End	Length (km)	Source (ins^3)	Comments
2	0327/013	1400/013	120	2 x 300 1 x 300 @ 9m 1 x 300 @ 16m	from 0327 to 1016 from 1016 to 1051 from 1051 to 1400
3	0841/015	1727/015	100	2 x 300	speed reduced from 6.0 kts to 5.6 kts at 0921 to improve signal:noise ratio
4	1910/015	0530/016	80	2 x 300	
5	2300/019	0706/020	80	2 x 300	
6	1325/019	2106/019	80	2 x 300	
20	0419/019	0914/019	65	2 x 300	
21	0954/019	1325/019	30	2 x 300	
22	1718/022	1930/022	28	2 x 300	
23	1930/022	0148/023	105	2 x 300	
24	0148/023	0401/023	23	2 x 300	
25	0401/023	1507/023	120	2 x 300	
26	1507/023	2027/023	70	2 x 300	
27	1343/026	1256/027	270	2 x 300	2017 stopped firing on one gun. Stopped on both for 4 mins at 2026. Repaired air leak. Started firing on both at 2116.

TABLE 3

AIRGUN ARRAY

Line No	Start	End	Length (km)	EM Log (kts)	Comments
1	0026/012	1440/012	120	3.5 - 4.0	Brake failure on umbilical winch while deploying beams. Only 7 guns deployed until 0230 while a leak was repaired in gun 8 (single 1000 ins^3). Shot interval 2 minutes.
2	0158/014	1740/014	120	3.75	Shot interval 2 minutes. Broken chain found on 1000 in^3 gun on inwardmost beam. Hanging by air hose.
3	2100/016	1330/017	100	4.0 - 4.25	Air leak repaired on one gun on completion of line (broken solenoid). Shot interval 2 minutes.
4	1634/017	0500/018	80	3.5	1714/017 - 3 shots missed on all 8 guns 1905/018 - 3 shots missed. Shot interval 2 minutes.
5	2006/020	0944/021	80	4.5	Shot interval 2 minutes.
6	1300/021	2310/021	80	3.5	Shooting interrupted at 1626 due to fractured pipe on one compressor. Shooting continued at 4 min intervals from 1636 to 2102 while compressor repaired. Otherwise shot interval 2 minutes.
7	2200/024	1730/025	140	4 - 5	Gun no. 6 not always firing - losing pressure. GPS proving to be unreliable - possible errors of up to 1 mile. At 1500 2 x 1000 in^3 guns brought from 28 m to 20m astern due to shallow water depth. Shot interval 2 minutes.
8	0306/029	1200/029	80	4.75-5	Shot interval 2 minutes.