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Wormley, Godalming, Surrey

R.R.S. "DISCOVERY" CRUISE 16 REPORT

January-May 1967

GEOLOGY AND GEOPHYSICS IN THE RED SEA, GULF OF ADEN AND N.W. INDIAN OCEAN

N.I.O. CRUISE REPORT SERIES: CR 16

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SHIP'S OFFICERS

Mr. R.H.A. Davies	Master
Mr. G.L. Howe	Chief Officer
Mr. J.T. Walker	Second Officer
Mr. R.T. Abraham	Third Officer
Mr. E.C. Agius	Radio Officer
Mr. R.J. D'Souza	Chief Engineer Officer
Mr. K.F. Douglas	Second Engineer Officer
Mr. J. Woodruff	Third Engineer Officer
Mr. G.A.W. Williams	Fourth Engineer Officer
Mr. J.A. Crombie	Junior Engineer Officer
Mr. P.H. Shipway	Junior Engineer Officer
Mr. M. Sprague	Chief Electrical Officer
Mr. M. Robertson	Second Electrical Officer

SCIENTIFIC PERSONNEL

		Leg	1	2	3	4	5	6	
		*	Plymouth	Malta	Massawa	Djibouti	Seychelles	Aden	Suez	Plymouth
A.S. Laughton	NIO		X	X	X	X	X	X	X
D.G. Roberts	NIO		X	X	X	X	X	X	X
E.P. Collins	NIO		X	X	X	X	X		
R. Preston-Smith	NIO		X	X	X	X	X		
J.A. Moorey	NIO		X	X	X				
J.S.M. Rusby	NIO		X						
N.D. Smith	NIO		X						
R. Dobson	NIO		X						
R.H. Edge	NIO		X						
Mrs. P. Edwards	NIO		X						
G. Morrison	NIO		X						
D.H. Matthews	Camb.			X	X	X	X	X	
Miss C. Williams	Camb.			X	X	X	X	X	X
D. Davies	Camb.			X	X				
C. Tramontini	Camb.			X	X				
Mrs. C. Keen	Camb.			X	X				
T. Vertue	Camb.			X	X				
G. Day	Camb.			X					
D.T. Pugh	Camb.						X	X	X
J.R. Cann	BM				X	X			
E.R. Oxburgh	Oxford				X				
R.W. Girdler	Newcastle			X	X	X			
J.S. Tooms	IC						X	X	
G.P. Glasby	IC		X	X	X	X	X	X	X
W.I. Farquharson	BIO		X	X	X	X	X	X	X
Lt. Cmdr. R.I.C. Halliday, R.N.	HD		X	X	X	X	X	X	X
J. Mauchline	SMBA		X						
R.C. Reid	YARD		X						
			16	16	17	11	11	9	7

* For key, see below

NIO	National Institute of Oceanography, Wormley, Godalming, Surrey.
Camb	Department of Geodesy and Geophysics, Madingley Rise, Madingley Road, Cambridge.
BM	Department of Mineralogy, British Museum (Natural History), Cromwell Road, London, S.W.7.
Oxford	Department of Geology and Mineralogy, Parks Road, Oxford.
Newcastle	School of Physics, The University, Newcastle-upon-Tyne, 1.
IC	Department of Applied Geochemistry, Royal School of Mines, Imperial College of Science and Technology, Prince Consort Road, London, S.W.7.
BIO	Bedford Institute of Oceanography, Dartmouth, Nova Scotia.
HD	Hydrographic Department, Ministry of Defence (Navy), Old War Office Building, London, S.W.1.
SMBA	Scottish Marine Biological Association, Marine Station, Milport, Isle of Cumbrae, Scotland.
YARD	Yarrow Admiralty Research Department, Yarrow and Co. Ltd., Scotstoun, Glasgow, W.4.

SUMMARY OF CRUISE INTENTIONS

1. Stability trials of a one third scale model of GLORIA (Geological Long Range Inclined Asdic):- to be made on passage to Malta.

2. North End of the Red Sea and the Gulf of Aqaba:- The central rift of the Red Sea is typified by a positive Bouguer gravity anomaly whereas the Gulf of Aqaba (like the African Rift Valley) has a negative anomaly. A theory of the origin of the Red Sea by the relative movement of Arabia and Africa suggests that the Red Sea south of Sinai has opened by separation and shear, whereas the Gulf of Aqaba results from mainly shear. Seismic refraction stations and further gravity measurements to be made in both areas.

3. Gulf of Aden - main magnetic anomaly:- Selected tracks to establish and map main E-W anomaly.

4. Gulf of Aden - special area studies:-

   (a) Survey and sampling programme in a one degree square in the Central rough zone (Sheba Ridge).

   (b) Survey programme in sediment filled south main trough.

   (c) Dredging and seismic programme on cliffs and flanks of Alula-Fartak trench where gravity measurements have indicated high density rocks near the surface.

5. Gulf of Tadjura and Tadjura Trench:- Survey magnetic and topographic lineations as far as possible in towards Afar depression and to sample exposures on cliffs.

6. Deep crustal structure of Gulf of Aden:- Seismic refraction stations to determine crustal structure and nature and depth of Moho boundary.

7. Eastern approaches to the Gulf of Aden:- Topographic, magnetic and gravity survey to determine the nature of the connection between the central rough zone of the Gulf of Aden and the Owen fracture zone with special reference to the epicentre belt.

8. South end of the Owen Fracture Zone:- Topographic and seismic reflection survey to determine direction of continuity (if any) of the fracture zone and whether the Somali Basin was at one time enclosed. (This project was cancelled due to engine failure).

9. Manganese encrustations and nodules on the Carlsberg Ridge:- Samples obtained in 1963 in area 4c showed variable composition over short ranges. Dredging, coring (gravity and boomerang), grabbing, photography and water sampling planned in relation to topography.

10. Bottom water stability:- Chemical and thermal structure in bottom 200 metres to be studied with closely spaced water bottles and continuous temperature recorder.

11. Water and sediment probe (WASP):- Simultaneous measurement of temperature gradients above and below the sediment-water interface.

12. Red sea bottom water:- Sampling programme of sediment and bottom water in the deep holes along the Red Sea rift (especially in the hot salty holes) for geochemical studies.

NARRATIVE

Leg 1: Plymouth to Malta: 20th - 31st January: 020-031

"Discovery" sailed on January 20th after a delay of one day due to engine trouble on the cranes. After fuelling at Falmouth, we headed south across the Bay of Biscay in a south westerly gale along a track chosen to fill a gap in magnetic data. After being hove-to for half a day we eventually found better weather off the Portuguese coast although a big swell was still running.

In the approaches to Gibralter south of Cape St. Vincent, we started the first towing trials of the $\frac{1}{3}$ scale model of GLORIA in very calm conditions with only a low swell.

After 36 hours of trials we steamed into the Mediterranean in extremely flat seas and made another series of runs with a new towing point on the model. The GLORIA trials were successfully finished on January 30th when we headed for Malta.

Before entering Malta, the Bergen-Nautic ship's log was calibrated on the Malta measured mile.

In Malta the GLORIA trials party disembarked together with all their gear and the Cambridge geophysical party joined the ship.

Leg 2: Malta to Massawa: 1st - 13th February: 032-044

On leaving Malta, we spent three hours completing the log calibration over the measured mile and then set course for Port Said. On the day before passing through the canal, four hours were spent launching some of the new commercially made sonoradio buoys and firing some shots. These revealed several instrumental defects.

Our passage through the canal was prolonged to 36 hours by traffic congestion and when finally clear we anchored in the Gulf of Suez to float the sonobuoy hydrophones. On February 7th we laid sonobuoys for our first seismic refraction line south of the Sinai peninsula. This revealed more instrumental defects and we discovered also that the range of the sonoradio buoys was being severely limited by atmospheric radio noise which increased strongly during the day. Four seismic lines were fired in the same general area in an effort to establish crustal thickness.

Between seismic stations two shore-to-shore gravity traverses were run right across the Red Sea and a profile of sound velocity in the sea was obtained with the Plessey velocimeter. Velocity profiles were subsequently made (to a maximum depth of 1500 metres) at each seismic refraction station. The weather in this area was extremely calm.

At the end of the seismic work it was hoped that we could make some measurements in the Gulf of Aqaba, but clearance from the bordering countries had not yet been obtained so the project was postponed until the end of the cruise. We steamed down the east side of the Red Sea to about 24° N and then made another coast-to-coast section south of Gezt. Zabargad Is. Our passage into Massawa was via the North Massawa channel. We made one transit across the deep trench in this channel and found no appreciable magnetic anomaly associated with it.

In Massawa, the scientific party was conducted on a geological tour of the rift scarp and was entertained in Asmara by Gulf Oil Company of Ethiopia and Mobil Petroleum Ethiopia Inc. Discussions followed on the origin of the Red Sea and the Afar depression.

Leg 3: Massawa to Djibouti: 16th February - 6th March: 047-065

From Massawa, we sailed through the South Massawa channel straight to the Gulf of Aden, encountering strong head winds through the straits of Bab-el-Mandeb and spent four days making six long sections across the Gulf of Aden arriving at the centre of the Alula-Fartak trench.

During the next five days we laid two dan buoys in the axis of the trench and carried out an intensive programme of dredging, photography, and seismic reflection and refraction shooting. Positions were controlled by radar transponders mounted on the buoys.

On 26th February, we left the Alula-Fartak trench (with much more remaining to be done) and after making a section just west of the trench across the central rough zone arrived at the centre of the one degree square (12°-13° N, 47-48° E) chosen for study as representative of the central rough zone (Sheba Ridge) with its NE-SW trending mountains. Two buoys with radar transponders were laid initially to cover a survey grid of lines 5 mile spaced. During the ensuing five days progressively stronger winds and stronger surface currents made the dan buoys drag their moorings and two more were laid. A maximum radar range on the radar transponder of 42 miles was obtained due probably to super refractive conditions of the atmosphere.

During these five days, many attempts were made, with limited success, to dredge rocks from both the NE-SW trending mountains and from the axis of the median rift valley revealed by the survey. A seismic refraction line was shot just south of the central rough zone in the sediment filled main trough.

On the passage back to Djibouti, two seismic refraction lines were fired, one just north of Berbera some thirty miles off the coast. This revealed an excitingly thin crust underlain by a well established 8.2 km/sec., demonstrating that the outer parts of the Gulf of Aden are oceanic in structure. The second seismic station was just south of the Tadjura trench in the region of high magnetic anomalies.

On the passage into Djibouti zig-zag crossings were made of the entrance to the Gulf of Tadjura to map the magnetic trends.

While at Djibouti, a rock collecting expedition was made by motor boat westwards along the Gulf to examine the Aden volcanic series rocks and to collect oriented specimens for palaeomagnetic studies.

Leg 4: Djibouti to Seychelles: 9th - 27th March: 068-086

On leaving Djibouti, we steamed on a zig-zag survey westwards into the Gulf of Tadjura as far as daylight would allow, then left and shot a seismic line to reverse the one shot just before arriving at Djibouti. In spite of the departure of our number one seismic team at Djibouti, the line went very smoothly.

During the following day we laid a small dan buoy in the Tadjura trench and attempted twice without success to dredge rocks from the cliff. A final seismic line was shot in the area of maximum magnetic anomaly in the central zone giving an extremely well established 7.2 km/sec.

On 12th March (071), after two more crossings of the median anomaly, we arrived back at the median valley in the one degree square survey. A dan buoy was laid and a small closely spaced survey was made to control the dredging. Two camera stations, four dredge stations and a seismic reflection profile were made within this small area.

The final area for special study in the Gulf of Aden was chosen as a 30 mile square in the south main trough, SE of the one degree square. The aim was principally to determine the nature and trend of the magnetic anomalies (± 100 gamma) found away from the central rough zone and to obtain by seismic reflection profiling, a section of the basement beneath the sediments. A survey was made around a dan buoy, running N-S legs of 30 miles separated by 2 miles. In a comparatively flat region of the magnetic field, a pattern of courses was steered through a point to determine the magnetic heading correction of R.R.S. "Discovery" in these latitudes. The data was confused by the rather large daily variation experienced. Two seismic reflection profiles were shot with the air gun across the area and to the central rough zone and these revealed, amongst other things, small hills of an outcropping "transparent layer". On the small chance of sampling this layer, we dredged but without success.

The remainder of this leg, from 16th March (075) was concerned with surveying the Sheba Ridge east of the Alula-Fartak trench and out to the Owen Fracture Zone. Previous data was very sparse and showed only slight indications of a median magnetic anomaly and a median valley. The line of earthquake epicentres suggested these should be there. Eleven sections across the rough zone showed both median valley and associated magnetic anomaly running down as far as the Wheatley deep.

An unsuccessful attempt was made to make a reflection profile across the partly filled trench east of the Owen Fracture Zone before we steamed south across the Carlsberg Ridge on passage to the Seychelles.

At the Seychelles drilled and oriented rocks were collected from Mahé and Silhouette Islands for palaeomagnetic studies.

Leg 5: Seychelles to Aden: 30th March - 14th April: 089-104

Left Seychelles by Dennis Island and set course via slight deviation to area 4c in the foothills of the Carlsberg Ridge. This area had been surveyed by H.M.S."Owen" in 1962, and in 1963 R.R.S. "Discovery" dredged a collection of manganese nodules and crusts, and took bottom photographs. Using the Owen Chart as a base, a dan buoy (and transponder) was laid and a series of dredge hauls were made on the large mountain in the south and on the E-W ridge in the centre of the area. Large quantities of manganese encrusted rock and manganese nodules were obtained. Underwater photographs were taken across the features, patterns of boomerang corers were laid, two grab samples and one core were taken. Four stations of water bottles were made, some for geochemical analysis in relation to manganese deposition and some, together with temperature gradient measurements, for bottom water stability problems.

The first dan buoy stayed anchored for 5 days in a surface current of 0.8 kts. (measured by surface float) but broke adrift when the current increased to 1.5 - 2.0 kts. A second buoy stayed for only 12 hours before breaking adrift. The third laid was a streamlined dan buoy without pellets which survived.

The work in area 4c was completed on 8th April and we steamed westwards towards the south end of the Owen Fracture Zone.

On 9th April, a third engine failure reduced the engine room to standby machinery only to keep two engines going and consequently the remaining scientific programme had to be cancelled and the ship headed to Djibouti for repair and inspection. On the way we were diverted to Aden where better facilities existed.

On passage, we stopped in the Somali Basin for two stations of WASP (water and sediment probe). These were the only lowerings possible for this new equipment in our curtailed programme. One succeeded and one failed.

During these stations, we launched a towed fish containing an experimental electromagnetic log which eventually can record both longitudinal and transverse speed of the ship when mounted rigidly to the hull.

In the Gulf of Aden we made one more south to north crossing before entering Aden. In Aden the gravimeter was closed down.

Leg 6: Aden to Plymouth: 18th April - 6th May: 108-126

The condition of the engines required us to proceed to Plymouth for repairs at the earliest opportunity and this meant that the Red Sea bottom water project and the Gulf of Aqaba seismic refraction project (now agreed to in principle by the bordering countries) had both to be cancelled. Time was allowed for two stations on passage. The first was a core and heat flow in Discovery hot salty hole. The second was a water bottle station, with a free running camera at the bottom, in Atlantis II hole.

We arrived at Suez on 23rd April, left Port Said on 25th April and steamed direct back to Plymouth with minor deviations of track to fill in gaps in magnetic and topographic detail.

PROJECT REPORTS

1. GLORIA model trials

A third scale model of the proposed long-range sonar vehicle was carried on the passage to Malta. During this leg, the model vehicle was towed twice to determine its hydrodynamic stability, first in the Atlantic near Cape St. Vincent and later off Sicily. It was towed at various depths down to a maximum of 600 feet at a ship speed of 6 knots. Perturbation runs were also carried out to investigate the vehicle's response to longitudinal and transverse pulses in the towing cable. Accelerometers and gyros measured the surge, sway, heave and yaw of the ship at the towing point and similar instrumentation monitored the heave, roll, pitch and yaw of the vehicle.

The instrumentation worked well and a great deal of information was obtained on the hydrodynamic performance of an underwater vehicle coupled by cable to a moving towed point. Both analogue and digital records were kept, the latter to be used for spectral analysis and coherence determinations by computer at a later stage.

The launching and recovery techniques for 1000 feet of faired cable were experimental and were designed to test the system for the full scale vehicle. 50 feet sections were handled one at a time on the end of the main warp using Kellum grips (sleeves of wire braid) permanently fitted on the wire.

2. Red Sea

Four seismic refraction lines were fired south east of the Sinai peninsular using the new Bradley sonoradio buoys. Three of these were successful and the fourth was abandoned due to instrumental troubles. Stations 6205 and 6208 form a reversed pair of some 38 miles in length. Station 6209 was fired during the night to avoid

high atmospheric radio noise and a range of 48 miles was achieved. Radio signals were still good at this range and the line was stopped only by the presence of land ahead. The velocity structure in the water was observed on a velocimeter station to the bottom. The relative positions of these four lines and the movement of the buoys was difficult to establish on account of the strong surface currents, generally to the north, and the hazy visibility. The seismic data listed in Table I showed that in this area the structure was continental as found by Drake and Girdler (Geoph. J. 8 473-495 1964) i.e. a 4.4 km/sec layer underlain by one of about 6 km/sec.

Two coast to coast traverses were made across the Red Sea through the seismic stations in order to give gravity data for their interpretation. The steep cliffs bordering the coastline were found to be further inshore than the charts suggested. No median rift valley was found and the magnetic anomalies over the central region did not exceed ± 150 gamma. A second crossing of the Red Sea at about latitude 24° N showed the median rift with three inner rifts, associated with anomalies of ± 200 gamma.

In the north Massawa channel, a traverse of the deep valley which appears to form an extension of the Gulf of Zula to the north showed no anomaly greater than 50 gamma.

On the passage home the Red Sea water and sediment sampling programme was cancelled due to engine failure. Two stations were made, one in each of Discovery and Atlantis holes. In Discovery hole a heat flow measurement was attempted using the **corer.** Due to the limitation on time available, a buoy was not laid and strong currents drifted us to the side of the hole. The **corer** penetrated only a few feet before hitting a hard layer, damaging the probes. However, a heat flow value was obtained. In Atlantis hole, a water bottle cast near the bottom was planned to see if the increase in the temperature of the 56° C water reported by Woods Hole Oceanographic Institution was continuing. Unfortunately the two special thermometers borrowed from Woods Hole for the purpose failed to function. A free running camera was suspended at the bottom of the cast in the hope of photographing material lying on the discontinuities. None was observed, although on two frames the compass is partly obscured by turbid water.

On the approach to these holes, horizontal stratification of the water was observed on the echo sounder in another hole in position 21° 06.2'N 38° 08.2'E, the boundary being at 2486 metres.

3. Gulf of Aden

(a) Gulf of Tadjura and Tadjura Trench

A survey in the Gulf of Tadjura and in the approaches to it was designed to track the E-W magnetic anomalies typical of the west end of the Gulf of Aden. The major negative anomaly which lies over the Tadjura trench at 44° E runs into the coast north of Djibouti and in the Gulf another negative anomaly was found, of about 700 gamma.

Rocks of the Aden volcanic series were collected from cliffs on the south shore of the Gulf for palaeomagnetic studies. Raised beaches, especially noticeable along the north shore, suggested recent uplift of the area.

Two attempts at dredging the cliffs of the Tadjura trench at 44.5° E were successful only in bringing up mud. An examination of the E/S records indicated that there were few outcrops. The flatness of the sea bed either side of the trench suggested that the cliffs would be largely sedimentary.

(b) One degree square on Sheba Ridge (12°-13°N, 47°-48°E)

The name "Sheba Ridge" has been given to the central rough zone of the Gulf of Aden and it extends from the mountains associated with the Tadjura Trench in the west to the Owen Fracture Zone in the east, a total length of 800 miles. It is divided into the East Sheba Ridge and the West Sheba Ridge by the Alula-Fartak trench which displaces its axis by about 100 miles. The term "Ridge" is used, although it contains valleys deeper than the sediment basins either side, as well as hills, since it is linked generically with the Carlsberg Ridge and hence with the mid-oceanic ridge system.

A one degree square was chosen for special study in the region of Sheba Ridge where the NE-SW mountains were well developed and where there was a suggestion of a median valley. Using two anchored dan buoys with radar transponders for navigation, ten 60 mile N-S lines about 5 miles apart were surveyed and numerous cross tracks linked these lines together.

The survey confirmed the existance of a well defined median valley characterised by a negative magnetic anomaly. The valley cuts across the NE-SW mountains and also across the valleys in between. Although individual parts of the median valley are elongated E-W or ESE-WNW its continuity is disrupted by a series of left-lateral displacements. At these places its magnetic anomaly is substantially reduced. North and south of the median valley a series of tilted fault blocks were identified parallel to it and dipping away from its axis.

The NE-SW mountains have no appreciable magnetic anomaly although in one place magnetic E-W ridges were mapped on top of one of these mountains. Five dredge hauls (6223 to 6227) were made in this area only two of them yielding rocks. These were weathered basalts, dolerite and manganese encrustations.

Of six dredge hauls in the median valley (6230, 6231 and 6242 to 6245) four produced fresh basalts and pillow lavas. Two camera stations which drifted across the bottom and side of the valley showed only two rock outcrops out of a hundred photographs, showing that although the echo-sounder records a rough bottom, the valley is covered by recent sediments.

An airgun seismic reflection profile across the median structure from north to south started over a basement outcrop, crossed a flat sediment pond ($\frac{1}{2}$ second thick) which joined on to the median valley without a retaining sill, indicating the youthfulness of the valley. Basement outcrops and tilted blocks were seen in the valley and on its walls.

(c) 30 mile square survey in south main trough

The survey area was chosen over the sediment covered main trough south of Sheba Ridge, with the principal aim of delineating the magnetic anomalies in this province. Fifteen lines of 30 miles were run N-S and separated by 2 miles. Navigation was by radar transponder from one anchored buoy. The survey linked up with the SE corner of the one degree square survey.

The topography showed sediment basins at different levels connected by interplain channels and separated by low relief (100 fathoms) ridges trending NE-SW.

The magnetic anomalies, ± 200 gamma, trended WNW-ESE with elongation ratios of about 4 to 1. This trend is parallel to the sections of the median valley anomaly between displacements.

Two seismic reflection profiles were made from the base of the continental slope to the hills of Sheba Ridge. At the south end of the profile, layered sediments (turbidite sequences?) lie on a basement more than 1 second below the surface. The basement rises to a (faulted?) high and the turbidites wedge out against a transparent layer. The transparent layer is dissected with valleys infilled with layered sediments. Some outcrops of the transparent layer were seen. Further north the turbidites alternate with basement hills and ponded sediments.

An unsuccessful attempt was made to dredge the outcrop of the transparent layer.

(d) Alula-Fartak Trench

Numerous crossings by ships on passage through the Gulf have established the general topography of the Alula-Fartak trench so no attempt was made to survey it. Two sections of the trench 20 miles apart were studied, a dan buoy being laid in the centre of each section. Five dredgesstations (6210 - 6213 and 6216) were made in the southern section, three of these being from the east cliff and two from the west cliff. Both top and bottom of the cliffs were dredged. On the east side indurated mud and siltstones were found near the top and basalts and dolerites (metamorphosed?) were found lower down. A terrace near the bottom was interpreted as a slump. A camera station (6214) down this cliff showed the rounded and slab-sided sedimentary rocks near the top and the more angular basalts nearer the bottom. In spite of the steepness of the slope, most of it was sediment covered. On the west side of the trench only sedimentary rocks (indurated mudstones, siltstones and sandstones) were obtained. On the northern section, a dredge station on each side (6221 and 6222) gave the same pattern.

At station 6213, a specimen of Neopilina was dredged. This is thought to be the first known occurrence in the Indian Ocean of this rare mollusc.

None of the hard rocks obtained from the cliffs of the trench appeared to have a density as high as that suggested by the interpretation of gravity data. The latter may well be masked by slumping from higher levels.

Essentially continuous seismic reflection profiles were obtained across each section. On the east side of the trench complex layering overlies a basement at 1 second depth. On the west side more uniform layering (turbidite) covered a basement less than $\frac{1}{2}$ second down. No structure was observed in the axis of the trench.

Two seismic refraction lines were shot parallel to the trench on either side. These will be discussed below in section (f).

(e) Topographic, magnetic and gravity sections

West of the Alula-Fartak Trench, some ten sections across the Gulf of Aden were made for gravity and magnetic interpretation. These were chosen to fill in gaps in the magnetic coverage already available. A preliminary examination of these crossings combined with earlier data have lead to the following conclusions:-

(1) The median valley, starting as the Tadjura trench in the west, can be followed with only little interruption to $46\frac{1}{2}^{0}$ E; it can

be identified as displaced sections through the one degree square and probably therefore through the other regions of NE-SW mountains to $50\frac{1}{2}^{o}$ E. From here a well defined valley runs into the Alula-Fartak trench with a trend WNW-ESE.

(2) Throughout its length, the median valley is associated with the median negative magnetic anomaly which is similarly displaced between $46\frac{1}{2}^{o}$ and $50\frac{1}{2}^{o}$ E. The amplitude of the median anomaly is largest at about 46^{o} E where it is 2100 gamma from peak to trough. Where it is displaced, the amplitude is considerably reduced. The positive anomalies to the north and south of the median anomaly can be traced over most of its length but further from the axis correlation is more difficult. In the western half of the Gulf considerable anomalies ($\pm$ 300 gamma) parallel to the axis, were found right up to the coastlines.

The median anomaly, as well as the median valley, is truncated by the Alula-Fartak trench. East of the trench both the median valley and anomaly can be identified leading immediately out of the trench further to the north. The displacement along the trench is 112 miles, the trends of the median structure near the trench being 100^{o} from the trend of the trench between.

East of the Alula-Fartak trench, eleven crossings were made of the East Sheba Ridge. A median valley and magnetic anomaly were initially predicted on the basis of the epicentre belt. The first eight crossings showed a well developed negative magnetic anomaly associated with a median valley. On the three south eastern crossings the magnetic anomaly was much reduced in amplitude although the median valley was clearly developed.

These results indicate the continuity of the seismically active median structure of the Carlsberg Ridge into the Gulf of Aden NW of the Owen Fracture Zone. There is evidence of an additional displacement (transform fault?) of 40 miles of the East Sheba Ridge along a line joining West Socotra and Kuria Muria Bay.

Recontouring of the topography and the magnetics of the East Sheba Ridge shows a marked lineation parallel to the median structure which curves southwards at its eastern end. Near the Owen Fracture Zone the topographic lineation is crossed by large non-magnetic ridges that run parallel to the Fracture. These however are cut by the median valley which ends immediately east of the Owen Fracture Zone ridges in Wheatley Deep.

(f) Seismic refraction stations

Eight seismic refraction lines were shot in the Gulf of Aden. At each station we layed four of the sonoradio buoys recently bought from Bradleys Ltd., London. Shots were fired between 2300 and 0400 because experience showed that this time was most free from radio interference. Meaningful arrivals were obtained out to a maximum range of 52 seconds, or 80 kms. (Station 6239). At each station a Plessey velocimeter was lowered to obtain a profile of the velocity of sound in water to a depth of 1500 m. or to the bottom.

The provisional seismic results are tabulated below. Of the eight stations, three indicated normal oceanic layering (6218, 6228, 6233). The pair of reversed lines on the E side of the Alula-Fartak trench gave a well defined layer 2 of 5 km/sec and upper mantle of 8.1 km/sec, but the intermediate layering was difficult to identify. Two stations (6235 and 6239) showed unusual layers of 4.0, 6.4 and 7.2 km/sec.

Table I

Provisional results of seismic refraction stations

Station	Locality	Layer velocities km/sec
6205	N. end of Red Sea	4.3 5.8
6206	ditto	4.3
6208	ditto	4.5
6209	ditto	4.4 6.3
6215	Gulf of Aden E of Alula-Fartak trench.	5.0 8.3
6218	W. of Alula-Fartak trench.	5.0 * 6.9 8.5 *
6219	E of Alula-Fartak trench (reversal of 6215).	5.0 6.1 * 7.9
6228	South flank of Sheba Ridge.	6.9
6233	30' north of Berbera.	5.2 * 6.7 7.8
6235	10' south of Tadjura trench.	4.0 6.4 7.2
6236	Reversal of 6235.	5.7 6.9
6239	Over median anomaly, Sheba Ridge, SE of Aden.	4.0 6.4 7.2

Note:- * Indicates uncertain result.

4. Palaeomagnetic rock collection in the Seychelles

Whilst in the Seychelles, a portable rock drill lent by Mr. T.A. Reilley of the Dept. of Physics, University College of Nairobi, was used to collect rock specimens for palaeomagnetic work. Specimens were taken from two dykes exposed on the foreshore near Sunset Cafe, NE Mahe. A second suite of specimens was taken from the Tertiary microsyenite exposed at Pointe Vareur near La Passe, Silhouette Island and from the main syenite outcrop near La Passe. The specimens were sent to Mr. Reilley for examination.

5. Manganese project in area 4c (south flank of Carlsberg Ridge)

Dredge hauls made in area 4c by R.R.S."Discovery"in 1963 Cruise 2 revealed the existance of two chemically distinct populations of manganese nodules within a very small area. The aim of the current project was to study in more detail some of the environmental characteristics which might lead to these differences by studying variations in the composition and redox properties of the bottom waters and sediment and by making a more extensive study of the nodules themselves.

The topography of area 4c had been established in 1962 by a buoy controlled survey by H.M.S."Owen". Elongated mountains and valleys run parallel to the axis of the Carlsberg Ridge. Two areas were chosen for investigation. The large massif in the SW corner of the area had been the site of three dredge stations and two camera stations in 1963. The central ridge (20' X 3') had not previously been sampled or photographed, although two camera stations had revealed nodules on a similar feature to the SE. The central ridge showed a distinct contrast in topography and aspect to bottom currents to the SW massif and was examined for this reason.

In all 12 dredge stations were attempted each with both a rock dredge and a sediment dredge on the same chain. In 9 stations manganese encrustations and rocks were collected and in 11 stations sediment (sometimes with manganese deposits) was collected. In only 5 hauls were there appreciable quantities of nodules and these tended to be concentrated on the central ridge. The failure to obtain substantial quantities of nodules on the SW massif was surprising in view of the abundance indicated by underwater photographs.

Two grab stations were successful in obtaining sediment, the first also gave what is possibly a unique sample of 10 nodules in the sediment with which they are in contact on the sea floor.

Boomerang corers were used to obtain closely spaced core sequences. Due to instrumental problems only 7 cores were obtained from 21 corers launched. One gravity core was taken. The cores will be studied for trace element distribution.

Of two stereo-camera stations, one on the SW massif showed only one picture of a manganese encrusted outcrop in 45 pictures of sediment. The other station consisting of a drift from the top to near the bottom of the south side of the central ridge, showed sediment and rock outcrops near the top and manganese nodules near the bottom.

Five water bottle stations were made to sample the water close to the sediment, but bottle failure limited the number of samples in the bottom 100 m. Preliminary results of eH, pH, salinity, dissolved oxygen and silicate analyses are compatible with an Antartic origin for the bottom water.

A seismic reflection profile of 27' was made across the area perpendicular to the strike of the ridges and showed two basins of sediment

without turbidites, seperated by basement outcrops on abyssal hills. The section is similar to a typical section across the foothills of the mid Atlantic Ridge.

6. Bottom water studies

As an extension of the near-bottom water stability programme carried out in the NE Atlantic on "Discovery" Cruises 10 and 11 (1966), three water bottle stations were made in an enclosed trough in area 4c. Bottles were spaced at 5 metre intervals in the bottom 40 metres and accurate temperature gradients were determined using a modified Cambridge heat flow recorder. Salinity, oxygen and silicate determinations were made on the water samples obtained, and on samples obtained from two intermediate depth bottle stations. These stations were made in collaboration with the manganese project.

An experiment to monitor temperatures in the bottom water and in the sediments simultaneously was performed on the Somali abyssal plain using the water and sediment probe (abbreviated WASP). Unfortunately only one successful station of this type was completed before the scientific programme was terminated.

7. Gravity measurements

Continuous gravity measurements were made with the Graf Askania sea gravimeter from Malta, on the outward passage, to Aden on the return passage. Base station calibrationsand links to the world network were made in Malta, Massawa, Djibouti and the Seychelles. At Aden the ship lay at a buoy so no calibration was possible. A Worden gravimeter was used to connect Massawa to Djibouti via Asmara by air.

Notes on new instrumentation used during cruise.

1. Radar transponders

Two Decca-Alpine radar transponders were kindly lent by the Hydrographic Department of the Ministry of Defence (Navy) for trials on anchored buoys. Two standard angle projectors and one wide angle projector were tried for comparison.

The dan buoys and associated battery cases and framework designed for use with Sea-Fix equipment on cruise 11 of "Discovery" in 1966, were

modified to take radar transponders. These were mounted 9 feet above water level and powered by 12 volt Varley batteries rated at 160 AH, housed in 4 cylinders below the buoys. A measured mean current drain of 620 ma, while under constant surveillance by the ships radar, would give an expected life of 10 days.

Ten separate layings of radar transponder buoys were made during the cruise as tabulated below. The lining up procedure recommended by Decca was carried out before the first few layings but was later found to be unnecessary owing to the ample tuning available on the radar. A Kelvin-Hughes 14/12 radar was used for all the trials. Launching and recovery techniques were straightforward although more protection is necessary for the projector on top. The wide angle projector was smashed during recovery. The batteries were well up after the maximum lay of 5.2 days.

The maximum range of 42 miles obtained was doubtless a freak condition to abnormal super refraction. A reliable range of 22 miles was obtained on most occasions. However super refractive conditions are well known for the Gulf of Aden, and similar ranges may not be obtained in the Atlantic. No noticeable difference was seen between the performance of the wide angle and standard projectors. In spite of the rough sea condition and considerable swing of the buoy, a 42 mile range was obtained with the standard projector.

D/B	Duration	Maximum range and weather
I (W.A.) Gulf of Aden.	0700/052 - 1830/055 3.5 days	15.2' - 23.1' Wind 8 kts. waves 1 ft.
II (W.A.) Gulf of Aden.	2215/055 - 0905/057 1.5 days	17.0' - 21.0' Wind 10 kts. waves 1-2 ft.
III (W.A.) Gulf of Aden	1047/058 - 2207/060 2.5 days	20.1' - 32.0' Wind 12 kts. waves 2 ft.
IV (S) Gulf of Aden	1300/058 - 1000/059 0.9 days	20' - 32' Wind 12 kts. waves 2 ft.
V (S) Gulf of Aden	0250/061 - 1541/062 1.5 days	29' - 42' Wind 27 kts. waves 6 ft.
VI (S) Gulf of Aden	1920/062 - 0845/063 0.7 days	>4.1'
VIII (S) Gulf of Aden	0130/071 - 1530/072 1.6 days	>10.8'
IX (S) Gulf of Aden	2030/072 - 2100/075 3.0 days	13.5' - 25.8' Wind 4 kts. sea calm.
X (S) Indian Ocean	1140/091 - 1600/096 5.2 days	24.3' Wind 8 kts. waves 1-2 ft.
XI (S) Indian Ocean	2005/096 - 1507/097 0.8 days	8.9'

Notes:- WA = Wide angle projector.
S = Standard projector.
>41' = Ship not taken to maximum range.

2. Velocimeter

A prototype velocimeter was loaned by Plesseys for sea trials. The velocimeter, of a "sing-around" type, was lowered on the midships electrical cable to a maximum depth of 1500 metres and gave faultless performance. Six profiles were obtained, one from each seismic station.

3. Varian proton magnetometer

A Varian proton magnetometer was run on the cruise and records were obtained throughout. Twice the towed fish was attacked by sharks but with only superficial damage. The control console suffered from overheating and it was necessary to run it with the cases partly open. A progressive deterioration of the potentiometer slide wire(?) in the recorder reduced the accuracy of the record on the return passage.

A heading correction pattern was steamed near D/B IX in the Gulf of Aden, using two magnetometers at 600 and 200 feet respectively. Inputs were exchanged twice within three minutes of steaming through a fixed point on eight different headings. The accuracy of the determination of the heading correction coefficients was reduced by the large daily variation encountered during the run. The observed heading effect is shown in Figure 5.

4. Two component electromagnetic log

As part of the development of a two component EM log for installation through the hull of Discovery, trials were made with the log attached below a towed tadpole fish. A trial with a new cast head proved unsatisfactory but results were obtained from the old head before it flooded.

5. Sonoradio buoys

New sonoradio buoys,purchased from Bradley's Ltd., London, were tried for the first time. The radio range obtainable from the small sonobuoys was considerably greater than expected (due to superrefractive conditions and low atmospheric noise at night). Radio triggering problems prevented the internally recording buoys from being used at all.

6. Boomerang corers

Boomerang corers were used for the first time in Discovery. Various teething troubles were experienced. To avoid damage to the spheres on launching it was found necessary for the corer to enter the water vertically (an inclined launching ramp was used) and for the spheres to be cushioned from the paddles. The line joining the paddles was broken when the corer was in the water by a rip cord attached to the ship. The ship was stopped for launching.

The lights in the floats could be seen at 3 miles and recovery was made easier by using a platform over the side near to the water surface. A buoyant recovery line was used attached to the floats.

The core length was limited (to about 26") by a restricted water flow through the top valve. Minor modifications possible on ship board resulted in increased length of core and the manufacturers are now redesigning the valve.

Only 7 cores were obtained from 21 launchings. The failures were attributed to sphere damage, resulting from bad launching techniques, insecure core catchers and attack by fish before recovery. (Fish teeth were found embedded in a broken core liner).

Dan Buoy Positions.

Area	D/B	Type	Position	Laid (Zone C)	Recovered	Comments
Alula-Fartak Trench	I	Transponder	13°55.0'N 51°41.4'E	0700/052	1830/055	
" "	II	Transponder	14°19.9'N 51°57.6'E	2215/055	0905/057	
One degree square, Sheba Ridge.	III	Transponder	12°49.7'N 47°27.0'E	1047/058	2207/060	Adrift after 1000/060.
" "	IV	Transponder later Passive.	12°24.2'N 47°36.1'E	1300/058	1015/063	Transponder buoy replaced by small D/B on same moorings. 1000/059.
" "	V	Transponder	12°28.4'N 47°38.8'E	0250/061	1541/062	Adrift after 0600/061.
" "	VI	Transponder	12°34.2'N 47°38.6'E	1920/062	0845/063	Adrift soon after laying.
Tadjura Trench	VII	Passive	11°59.5'N 44°30.5'E	1006/069	1855/069	
One degree square, Sheba Ridge.	VIII	Transponder	12°35.0'N 47°36.9'E	0130/071	1530/072	
30 mile square.	IX	Transponder	11°51.2'N 48°12.6'E	2030/072	2100/075	
Area 4c, Carlsberg Ridge	X	Transponder	2°55.7'N 59°52.2'E	1140/091	1600/096	Dragged to 1100/092. Adrift after 0900/096
" "	XI	Transponder	2°59.2'N 60°05.5'E	2005/096	1507/097	Adrift after 0900/097
" "	XII	Passive	2°59.7'N 60°04.7'E	1715/097	1205/098	Streamlined D/B.

Key to Station List and Station Summary

		No. of Stations
SS	Surface Seismics (Refraction).	12
SRP	Seismic Reflection Profile (Airgun).	8
V	Velocimeter.	6
RD	Rock Dredge.	32
CD	Conical Dredge.	(11)
SUC	Stereo Underwater Camera.	6(+1)
SC	Surface Current (Buoy and drogue).	1
BC	Boomerang corer.	5
C	Corer.	1
CHF	Corer and heat flow.	1
WB	Water Bottle.	2
WBTG	Water Bottle and Temperature Gradient.	4
G	Grab.	2
WASP	Water and Sediment Probe.	2
UCF	Uncorrected fathoms (800 fms/sec).	
CF	Corrected fathoms.	
CM	Corrected metres.	

Stations occupied - 6205 - 6278

R.R.S. "DISCOVERY"

STATION LIST - CRUISE 16

Station No.	Type	Date	Day No.	Time From	Time To	Lat. Long.	Lat. to Long.	Depth Range UCF to UCF	Depth Range CF to CF	Depth Range CM to CM	Comments.
RED SEA				(Zone B)							
6205	SS	7 Feb	038	0600	1544	27°26.5'N 34°36'E	26°56.5'N 35°04'E	444 - 580	467 - 611	853 - 1117	Shots to 34 miles along 150°.
6206	SS	8	039	1430	2225	26°55.5'N 35°10'E	27°15.5'N 35°00'E	550 - 440	579 - 462	1059 - 846	Line abandoned after 22 miles due to instrumental troubles.
6207	V	8/9	039/040	2235	0006	27°01'N 35°12'E	- -	480 -	505 -	923 -	Velocity profile to bottom.
6208	SS	9	040	0908	2058	26°51.5'N 35°08'E	27°28'N 34°48'E	656 - 435	691 - 457	728 - 836	Shots to 41 miles along 330° (reversal of Stn. 6205).
6209	SS	10	041	0104	1110	27°08'N 35°08.5'E	27°50.5'N 34°43'E	455 - 270	478 - 284	875 - 518	Shots to 48 miles along 330°.
ALULA-FARTAK TRENCH - GULF OF ADEN				(Zone C)							
6210	RD	21	052	1042	1630	13°55.5'N 51°39.5'E	13°56.1'N 51°38.7'E	2190 - 1600	2250 - 1650	4100 - 3000	Well indurated mud stones, siltstones and sandstones. (12 spec.) (West lower slope).
6211	RD	21	052	1745	2204	13°56.1'N 51°38.5'E	13°56.5'N 51°37.4'E	1450 - 1200	1490 - 1230	2700 - 2250	Poorly consolidated mudstones, siltstones and sandstones. (88 spec.) (West upper slope).

Station No.	Type	Date	Day No.	Time From	Time To	Lat. Long.	to Lat. Long.	Depth Range UCF to UCF	Depth Range CF to CF	Depth Range CM to CM	Comments.
ALULA-FARTAK TRENCH - GULF OF ADEN (contd.) (Zone C)											
6212	RD	21/22	052/3	2300	0609	13°53.8'N 51°44.8'E	13°52.8'N 51°45.6'E	2500 - 2200	2550 - 2270	4720 - 4140	Mud, (large sample), (East lower slope).
6213	RD	22	053	0705	1312	13°50.5'N 51°46.5'E	13°50.1'N 51°47.1'E	2100 - 1600	2160 - 1650	3950 - 3000	Basalts, dolerites (metamorphosed?), siltstones (soft or more indurated) (32 spec.) (East upper slope).
6214	SUC	22	053	1654	2136	13°49.7'N 51°46.8'E	13°51.2'N 51°45.7'E	1550 - 2200	1592 - 2265	2911 - 4142	20 stereopairs. (East slope).
-	SRP	22	053	2200	2310	13°50.3'N 51°46.6'E	13°47.8'N 51°50.3'E	1900 - 940	1951 - 963	3568 - 1762	(East side of trench).
6215	SS	23	054	0021	1235	13°46'N 51°55'E	14°29'N 52°19'E	1300 - 750	1334 - 772	2440 - 1412	Shots to 50 miles along 030° (East side).
6216	RD	23	054	1323	1855	13°53.4'N 51°44.4'E	13°53.5'N 51°45.0'E	2550 - 2200	2630 - 2270	4800 - 4140	Basalts, dolerites (metamorphosed?), moderately indurated sediments, mud. (115 spec.) (East lower slope).
6217	SUC	23	054	2023	2340	13°57.0'N 51°37.0'E	13°57.0'N 51°37.6'E	1500 - 1790	1541 - 1840	2818 - 3364	61 stereopairs. (West upper slope).
6218	SS	24	055	0108	1055	14°11'N 51°32'E	14°46'N 51°53'E	900 - 814	926 - 837	1693 - 1531	Shots to 42 miles along 030°. (West side).
-	SRP	24	055	1122	1752	14°12.8'N 51°39.4'E	13°55.7'N 51°47.6'E	740 - 2550	759 - 2628	1388 - 4806	(West side of trench).
6219	SS	24/25	055/6	2349	1010	14°10'N 52°10'E	13°33'N 51°43'E	1216 - 1080	1249 - 1110	2284 - 2029	Shots to 45 miles along 210° (reversal of 6215) (East side).
6220	V	25	056	1042	1307	14°13'N 52°06.6'E	- -	1170 -	1202 -	2198 -	Velocity profile to 1500m.

Station No.	Type	Date	Day No.	Time From	Time To	Lat. to Long.	Lat. Long.	Depth Range UCF to UCF	Depth Range CF to CF	Depth Range CM to CM	Comments.
ALULA-FARTAK TRENCH - GULF OF ADEN (contd.) (Zone C)											
6221	RD	25	056	1437	1916	14°19.5'N 51°58.3'E	14°19.5'N 51°59.5'E	2400 - 2100	2470 - 2160	4520 - 3950	Basalts, dolerites (metamorphosed?), mud. (11 spec.) (East slope).
6222	RD	25/26	056/7	2028	0138	14°22.3'N 51°56.9'E	14°22.7'N 51°56.1'E	2300 - 2000	2370 - 2050	4330 - 3760	Hard and soft siltstones, mud. (8 spec.) (West slope).
-	SRP	26	057	0250	0600	14°27.4'N 51°46.9'E	14°13.7'N 52°10.0'E	970 - 2350	994 - 2419	1817 - 4423	(Across trench).
ONE DEGREE SQUARE - CENTRAL ROUGH ZONE (SHELL RIDGE) - GULF OF ADEN (Zone C)											
6223	RD	1 March	060	0312	0436	12°46.3'N 47°22.5'E	12°45.1'N 47°22.2'E	530 - 450	550 - 465	1000 - 850	No specimens. (On NE-SW ridge).
6224	RD	1	060	0506	0617	12°43.9'N 47°21.7'E	12°43.5'N 47°21.7'E	680 - 560	700 - 580	1280 - 1060	Weathered basalts, manganese crusts (6 spec.) (On NE-SW ridge).
6225	RD	1	060	0717	1015	12°48.8'N 47°21.6'E	12°47.2'N 47°21.5'E	900 - 700	930 - 720	1700 - 1320	No specimens. (On NE-SW ridge).
6226	RD	1	060	1143	1437	12°44.7'N 47°26.1'E	12°46.8'N 47°25.1'E	1040 - 720	1070 - 740	1950 - 1350	Weathered basalt (?) or dolerite(?). (3 spec.) (On NE-SW ridge).
6227	RD	1	060	1505	1800	12°42.2'N 47°24.2'E	12°43.0'N 47°23.0'E	1000 - 530	1030 - 550	1880 - 1000	No specimens. (On NE-SW ridge).
6228	SS	3	062	0000	1125	12°03.3'N 48°01.0'E	12°12.5'N 48°37.0'E	1204 - 938	1237 - 965	2262 - 1764	Shots to 37 miles along 074°.
6229	V	3	062	1125	1200	12°13.2'N 48°02.5'E	- -	1206 -	1239 -	2266 -	Velocity profile to 1500m.

Station No.	Type	Date	Day No.	Time From	Time To	Lat. to Long.	Lat. Long.	Depth Range UCF to UCF	Depth Range CF to CF	Depth Range CM to CM	Comments.
ONE DEGREE SQUARE - CENTRAL ROUGH ZONE - GULF OF ADEN (contd.)											
				(Zone C)							
6230	RD	3/4	062/3	2157	0144	12°35.0'N 47°40.1'E	12°36.1'N 47°41.1'E	1320 - 1100	1350 - 1130	2480 - 2070	Mud. (1 spec.) (Median valley).
6231	RD	4	063	0227	0739	12°33.9'N 47°37.0'E	12°36.2'N 47°38.6'E	1430 - 1340	1470 - 1380	2690 - 2510	Fresh pillow lava fragment (1 spec.) (Median valley).
WEST END OF GULF OF ADEN				(Zone C)							
6232	V	4	063	2223	2252	10°56'N 45°22'E	- -	734 -	756 -	1382 -	Velocity profile to 1350m.
6233	SS	4/5	063/4	2252	0925	10°56'N 45°22'E	10°50'N 44°39'E	734 - 650	756 - 670	1382 - 1225	Shots to 42 miles along 261°.
6234	V	5	064	1952	2010	11°45'N 43°56'E	- -	278 -	287 -	525 -	Velocity profile to 500 m.
6235	SS	5/6	064/5	2100	0619	11°44.0'N 43°57.5'E	11°48.2'N 44°39.8'E	278 - 486	287 - 503	525 - 921	Shots to 32 miles along 087°.
6236	SS	9/10	068/9	2250	0800	11°48.6'N 44°36.0'E	11°44.0'N 43°57.1'E	468 - 288	485 - 298	886 - 544	Shots to 41 miles along 264°.
6237	RD	10	069	1030	1442	11°58.1'N 44°31.6'E	- -	770 - 640	790 - 660	1450 - 1200	Mud. (1 spec.) (Tadjura trough).
6238	RD	10	069	1500	1810	11°56.7'N 44°32.4'E	- -	640 - 520	660 - 540	1200 - 980	Mud and mudstone (1 spec.) (Tadjura trough).
6239	SS	10/11	069/070	2306	1016	11°54'N 45°29'E	12°01'N 46°04'E	456 - 800	472 - 830	864 - 1518	Shots to 45 miles along 081°.
6240	V	11	070	1045	1118	12°01.5'N 45°12.5'E	- -	608 -	630 -	1153 -	Velocity profile to 1100 m.

Station No.	Type	Date	Day No.	Time From	Time To	Lat. to Long.	Lat. Long.	Depth Range UCF to UCF	Depth Range CF to CF	Depth Range CM to CM	Comments.
ONE DEGREE SQUARE - CENTRAL ROUGH ZONE - GULF OF ADEN											
				(Zone C)							
6241	SUC	12	071	0730	1015	12°33.6'N 47°36.4'E	12°35.4'N 47°35.6'E	1440 - 1350	1479 - 1385	2778 - 2534	62 stereopairs. (Median valley).
-	SRP	12	071	1115	1450	12°45.0'N 47°34.5'E	12°29.5'N 47°36.0'E	1028 - 1438	1057 - 1477	1932 - 2700	
6242	RD	12	071	1546	2037	12°32.7'N 47°37.5'E	12°37.0'N 47°37.9'E	1420 - 1200	1460 - 1230	2670 - 2260	Boiler slag (1 spec.) (Median valley).
6243	RD	12/13	071/072	2120	0110	12°33.1'N 47°39.2'E	12°35.8'N 47°39.9'E	1360 - 1200	1400 - 1230	2550 - 2260	Platy lava fragments sideromelane tuffs etc. (c.30 spec.) (Median valley).
6244	RD	13	072	0149	0540	12°33.5'N 47°27.5'E	- -	1420 -	1460 -	2670 -	Fresh basalt (1 spec.) (Median valley).
6245	RD	13	072	0605	1042	12°33.2'N 47°28.4'E	- -	1420 - 1340	1460 - 1380	2670 - 2510	Pillow lava fragment (1 spec.) (Median valley).
6246	SUC	13	072	1125	1449	12°34.8'N 47°40.1'E	12°35.6'N 47°38.3'E	1200 - 1234	1233 - 1267	2255 - 2318	42 stereopairs. (Median valley).
50 MILE SQUARE - SOUTH MAIN TROUGH - GULF OF ADEN											
				(Zone C)							
-	SRP	15/16	074/075	1536	0006	11°43.4'N 48°17.2'E	12°34.5'N 48°16.2'E	1283 - 990	1315 - 1014	2405 - 1854	
-	SRP	16	075	0328	0730	12°06.3'N 48°13.8'E	11°42.6'N 48°14.2'E	1086 - 1158	1112 - 1186	2033 - 2168	
6247	RD	16	075	1657	1946	11°57.4'N 48°14.0'E	- -	1130 - 1080	1160 - 1110	2120 - 2030	Mud. (1 spec). (Outcrop of transparent layer).

Station No.	Type	Date	Day No.	Time From	Time To	Lat. Long.	to Lat. Long.	Depth Range UCF to UCF	Depth Range CF to CF	Depth Range CM to CM	Comments.
OWEN FRACTURE ZONE											
-	SRP	23 Mar	082	1336	2000	12°05'N 57°52'E	11°50'N 58°16.5'E	1970 - 2472	2024 - 2546	3701 - 4656	No records.
*AREA 4c - CARLSBERG RIDGE				(Zone C)							
6248	SC	1 Apr	091	1300	1403	2°55'N 59°55'E	-	- -	- -	- -	Surface current 0.8 kts. in direction 277°.
6249	RD & CD	1	091	1534	2000	2°43.5'N 59°54.6'E	2°44.1'N 59°53.8'E	2130 - 2106	2189 - 2161	3998 - 3952	40 manganese encrustations and glob. ooze.
6250	BC	1	091	2040	2223	2°44.5'N 59°53.7'E	-	2160 -	2217 -	4055 -	25 in. core of glob. ooze.
6251	BC	1/2	091/2	2255	0148	(i) 2°45.4'N 59°53.2'E	-	2150 -	2207 -	4036 -	(i) and (ii) pretriggered and liners liberated at surface. (iii) to (vi) faulty launching technique resulted in cracked spheres and implosions. No recoveries.
						(ii) 2°45.8'N 59°53.2'E	-	2060 -	2113 -	3865 -	
						(iii) 2°46.2'N 59°53.2'E	-	1960 -	2010 -	3676 -	
						(iv) 2°46.6'N 59°52.9'E	-	1868 -	1914 -	3501 -	
						(v) 2°47.2'N 59°52.8'E	-	1805 -	1848 -	3380 -	
						(vi) 2°47.6'N 59°52.6'E	-	1734 -	1775 -	3246 -	
6252	RD & CD	2	092	0239	0852	2°45.8'N 59°51.7'E	2°46.9'N 59°51.7'E	2043 - 1979	2099 - 2029	3833 - 3718	2 lb coated rocks. Numerous fragments of encrustation of ½ lb and 1 lb nodule and glob. ooze.

* Positions in Area 4c relate to the grid on the chart drawn by Cmdr. Haslam from soundings made by H.M.S."Owen" 1962 - 1963. On the basis of 8 star fixes by two observers during April 1st to 8th 1967, 1.5' should be added to the latitude to obtain true geographical locations.

Station No.	Type	Date	Day No.	Time From	Time To	Lat. Long.	to	Lat. Long.	Depth Range UCF to UCF	Depth Range CF to CF	Depth Range CM to CM	Comments.
AREA 4c - CARLSBERG RIDGE (contd.)												
6253	RD & CD	2 Apr	092	0926	1442	2°49.0'N 59°51.7'E		2°46.9'N 59°51.7'E	1909 - 1892	1957 - 1940	3579 - 3547	Numerous fragments of manganese encrustations and some rock fragments. 8 Mn nodules. Glob. ooze.
6254	SUC	2	092	1622	2114	2°49.3'N 59°52.2'E		2°50.1'N 59°52.5'E	1850 - 1915	1899 - 1967	3472 - 3597	45 stereopairs.
6255	BC	2/3	092/3	2120	0400	(vii) 2°54.2'N 59°53.2'E		- -	2460 -	2532 -	4630 -	(vii) Glob. ooze in core catcher.
						(viii) 2°52.5'N 59°53.1'E		- -	2137 -	2193 -	4011 -	(viii) 27 in. core of glob. ooze.
						(ix) 2°51.4'N 59°52.4'E		- -	2060 -	2113 -	3865 -	(ix) 27 in. core of glob. ooze.
						(x) 2°50.9'N 59°51.1'E		- -	1860 -	1906 -	3578 -	(x) Faulty assembly, no core.
6256	RD & CD	3	093	0450	0948	2°49.3'N 59°51.5'E		2°51.4'N 59°51.1'E	1936 - 1916	1988 - 1968	3636 - 3598	Numerous fragments of manganese encrustations, 1 rock fragment (palagonite) and glob. ooze.
6257	RD & CD	3	093	1106	1557	2°46.6'N 59°46.6'E		2°46.8'N 59°45.6'E	1873 - 1785	1923 - 1831	3516 - 3348	Numerous fragments of manganese encrustation; some on palagonite. Glob. ooze.
6258	WBTG	3/4	093/4	1712	0920	2°54.4'N 59°45.6'E		- -	2485 -	2559 -	4681 -	Station prolonged because of lack of steam to raise wire.

(vii)

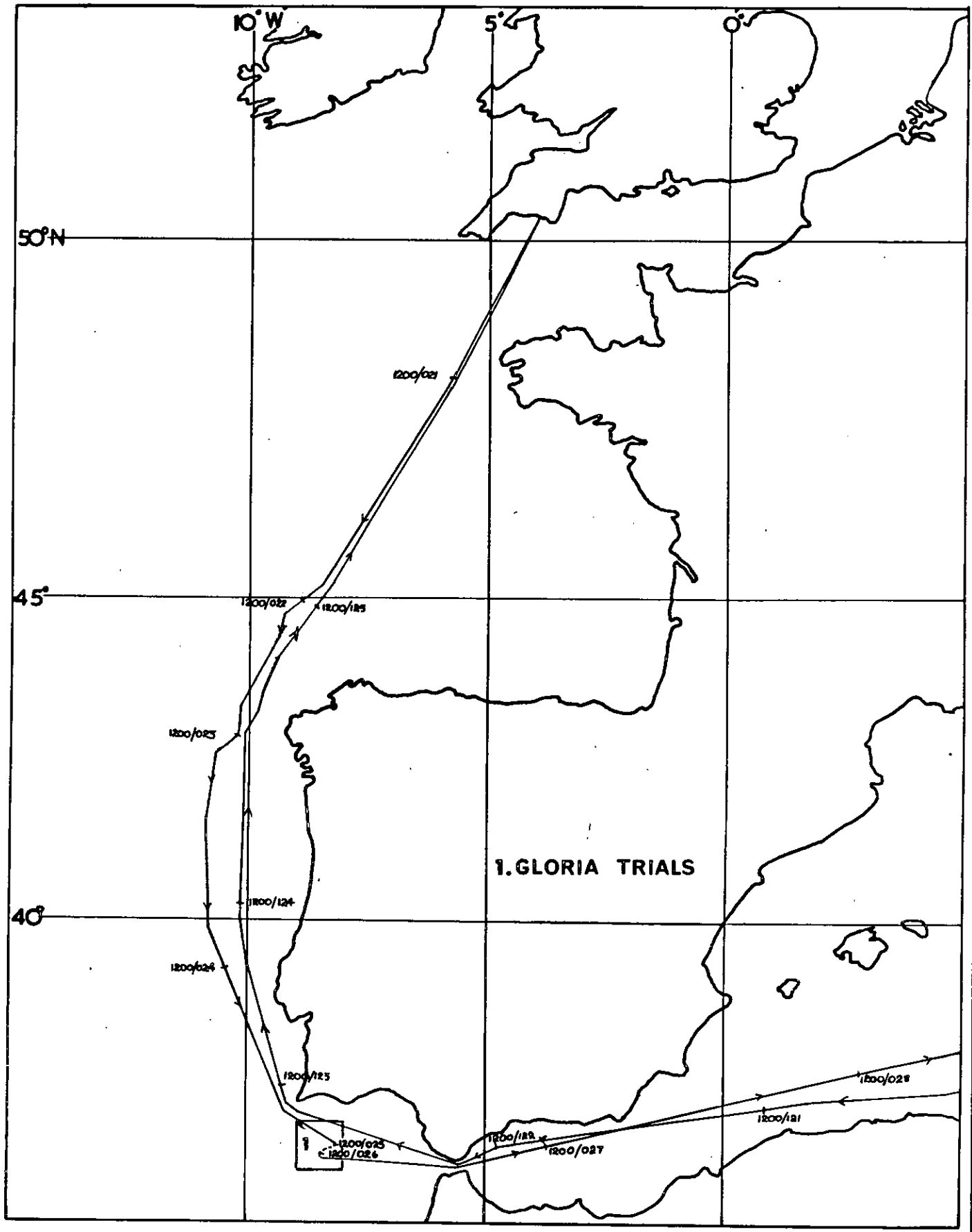
Station No.	Type	Date	Day No.	Time From	Time To	Lat. Long.	to Lat. Long.	Depth Range UCF to UCF	Depth Range CF to CF	Depth Range CM to CM	Comments.
AREA 4c CARLSBERG RIDGE (contd.) (Zone C)											
6259	RD & CD	4 Apr	094	1038	1445	2°50.6'N 59°58.2'E	2°51.6'N 59°52.5'E	2100 - 2043	2155 - 2090	3941 - 3839	Glob. ooze in CD. RD empty.
6260	RD & CD	4	094	1507	2002	2°47.5'N 59°58.2'E	2°47.6'N 59°58.9'E	1909 - 1888	1957 - 1935	3579 - 3539	Glob. ooze in CD. RD empty.
6261	BC	4	094	2025	2335	(xi) 2°46.2'N 60°02.1'E	- -	1933 -	1982 -	3625 -	(xi), (xii) and (xiii) attacked by fish and core liner destroyed.
						(xii) 2°45.8'N 60°02.3'E	- -	2024 -	2076 -	3797 -	
						(xiii) 2°45.0'N 60°02.5'E	- -	2220 -	2280 -	4163 -	No core.
						(xiv) 2°44.1'N 60°02.3'E	- -	2316 -	2380 -	4352 -	(xiv) 24 in. core glob. ooze.
						(xv) 2°42.3'N 60°02.8'E	- -	2340 -	2405 -	4398 -	(xv) 22 in. core glob. ooze.
6262	WB	5	095	0017	0305	2°41.7'N 60°04.8'E	-	2450 -	2523 -	4614 -	
6263	RD & CD	5	095	0412	0940	2°45.5'N 60°02.3'E	2°46.2'N 60°02.7'E	2120 - 1948	2073 - 1997	3979 - 3653	59 Mn nodules. Numerous fragments of Mn encrustations; some on palagonite. CD burst.
6264	RD & CD	5	095	1020	1624	2°45.5'N 59°59.7'E	2°46.2'N 59°59.8'E	2278 - 2084	2343 - 2138	4285 - 3911	1 fragment of Mn encrustation. Glob. ooze.
6265	WBTG	5	095	1836	2127	2°57.8'N 60°09.6'E	-	2479 -	2553 -	4669 -	
6266	WBTG	5/6	095/6	2204	0050	2°59.8'N 60°07.7'E	-	2520 -	2596 -	4748 -	
-	SRP	6	096	0405	0810	3°05.2'N 60°13.8'E	2°51.3'N 59°51.4'E	2520 - 1870	2596 - 1920	4748 - 3510	
6267	SWC	6	096	1038	1420	2°55.9'N 60°03.0'E	2°56.3'N 60°04.8'E	1957 - 2123	2010 - 2182	3676 - 3990	105 stereopairs.

Station No.	Type	Date	Day No.	Time From	Time To	Lat. Long.	Lat. to Long.	Depth Range UCF to UCF	Depth Range CF to CF	Depth Range CM to CM	Comments.
AREA 4o CARLSBERG RIDGE (contd.) (Zone C)											
6268	BC	6/7	096/7	2225	0121	(xvii) 2°55.9'N 60°02.7'E	-	2226 -	2286 -	4181 -	(xvii) and (xix) core catcher made up to replace those lost at Station 6261 failed and core lost. (xviii) 32 in. core of glob. ooze. (xx) 30 in. core of glob. ooze (modified valve used on all these corers.) (xvi) failed to surface.
						(xviii) 2°56.1'N 60°03.2'E	-	2122 -	2178 -	3983 -	
						(xix) 2°56.3'N 60°03.7'E	-	2056 -	2109 -	3854 -	
						(xx) 2°56.2'N 60°04.1'E	-	2016 -	2072 -	3781 -	
						(xvi) 2°56.1'N 60°04.7'E	-	1946 -	1995 -	3694 -	
6269	RD & CD	7	097	0238	0835	2°56.5'N 60°02.3'E	2°56.5'N 60°03.3'E	2267 - 2092	2329 - 2147	4259 - 3926	More than 160 Mn nodules $<\frac{1}{2}$ - 4 ins. diameter, Mn. encrustations, palagonite and glob. ooze.
6270	WBTG	7	097	1000	1333	3°01.7'N 60°01.9'E	-	2531 -	2608 -	4769 -	
6271	G	7	097	1926	2144	2°57.6'N 60°02.0'E	-	2200 -	2262 -	4137 -	Glob. ooze and 10 Mn nodules on surface.
6272	G	7/8	097/8	2220	0027	2°57.1'N 60°02.1'E	-	2240 -	2304 -	4213 -	Glob. ooze.

Station No.	Type	Date	Day No.	Time From	Time To	Lat. Long.	Lat. to Long.	Depth Range UCF to UCF	Depth Range CF to CF	Depth Range CM to CM	Comments.
AREA 4o CARLSBERG RIDGE (contd.)				(Zone C)							
6273	RD & CD	8 Apr	098	0215	0730	2°54.8'N 60°02.8'E	2°55.1'N 60°04.0'E	2231 - 2076	2291 - 2130	4189 - 3895	35 Mn. nodules, 8 fragments of Mn. encrustation and 2 fragments of palagonite. Glob. ooze.
6274	C	8	098	0758	1135	2°57.5'N 60°00.9'E	-	2362 -	2428 -	4441 -	9 ft. core of glob. ooze. Mn. encrustation in core catcher. Barrel and jaws bent in on two sides.
SOMALI BASIN				(Zone C)							
6275	WASP	10	100	0934	1228	7°15'N 53°58'E	- -	2702 -	2789 -	5101 -	Station successful (two probes not working).
6276	WASP	10	100	1445	1743	7°30'N 53°55'E	-	2700 -	2787 -	5097 -	No result.
RED SEA				(Zone B)							
6277	CHF	21	111	0700	0844	21°16.4'N 38°01.9'E	-	1070 -	1131 -	2068 -	Only one probe penetrated - corer stopped by hard rock layer. (Discovery hole).

(x)

Station No.	Type	Date	Day No.	Time From	Time To	Lat. Long.	to	Lat. Long.	Depth Range UCF to UCF	Depth Range CF to CF	Depth Range CM to CM	Comments.
RED SEA (contd.)				(Zone B)								
6278	WB/SUC	21 Apr	111	0944	1117	21°21.0'N 38°03.9'E	-		1080 -	1142 -	2088 -	WBs in hot salty layers. Thermometer failure in 56°C. water. Camera on continuous running. (Atlantis hole).



R.R.S. DISCOVERY
Cruise 16 January – May 1967

Figure 1

NOON POSITIONS
& DAY NUMBERS

Passages to and from Indian Ocean

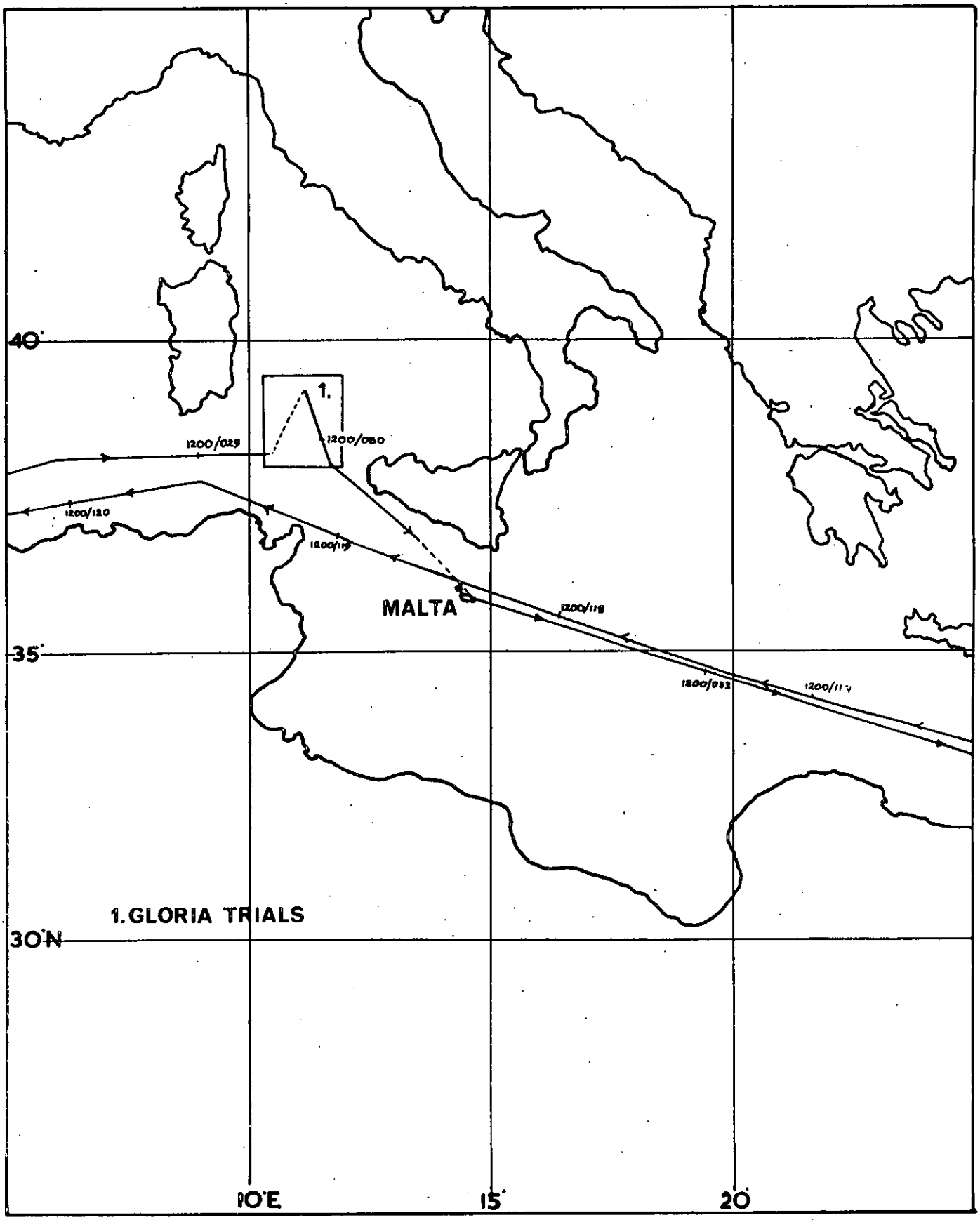

40°
35°
30°N
10°E
15°
20°
1.
1200/029
1200/050
1200/120
1200/118
1200/093
MALTA
1. GLORIA TRIALS

Figure 2

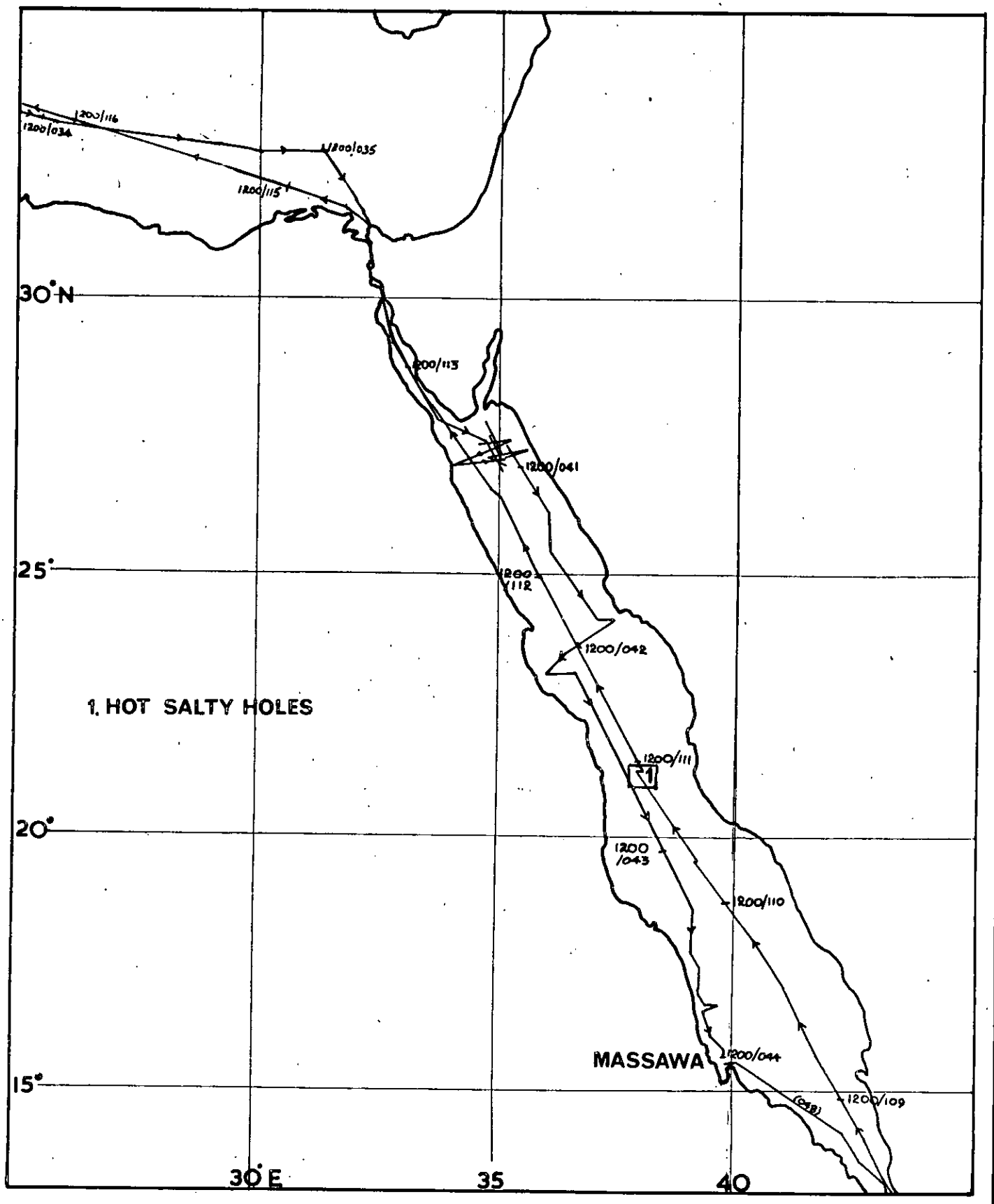
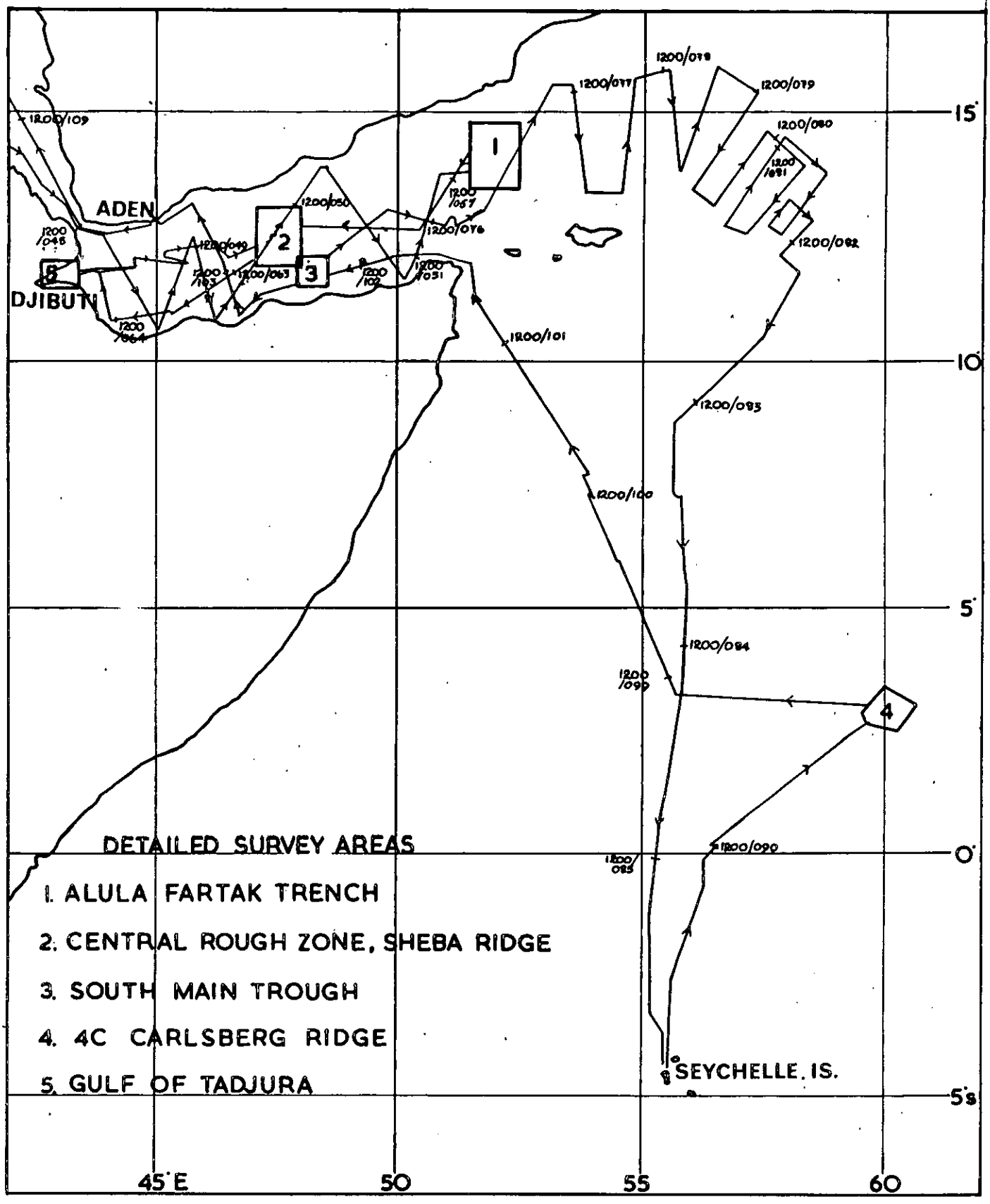

1200/116
1200/034
1200/035
1200/115
30°N
200/113
1200/041
25°
1200/112
1200/042
1. HOT SALTY HOLES
1200/111
1
20°
1200/043
1200/110
MASSAWA
1200/044
15°
(048)
1200/109
30°E
35
40

Figure 3



R.R.S. DISCOVERY
Cruise 16 January – May 1967

Figure 4

NOON POSITIONS
& DAY NUMBERS

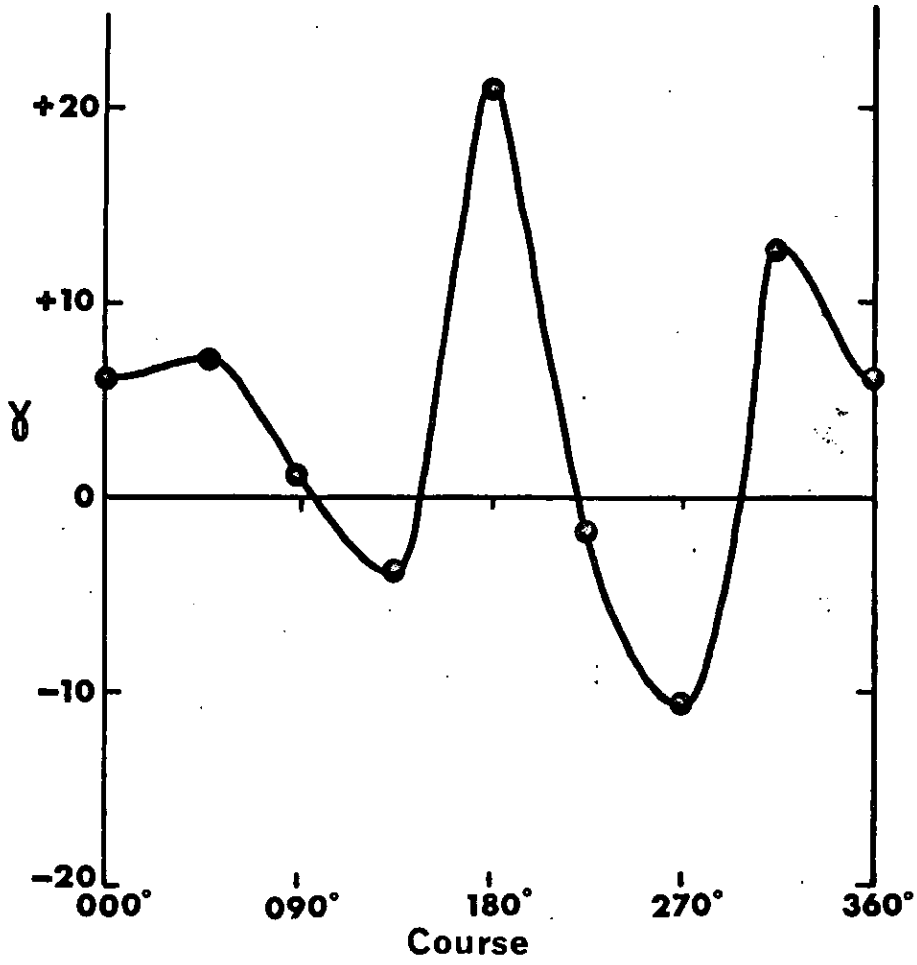


Fig.5 Magnetometer heading effect determined at 11°51′N 48°13′E, dip 8°N. Fish at normal stay, 560 ft from stern. Correction to be subtracted from observed field to give true field.