I.O.S.

R V FARNELLA
CRUISES 1 AND 2

19 SEPTEMBER – 5 NOVEMBER 1981

GEOPHYSICAL STUDIES OF THE CONTINENTAL MARGIN ON THE EASTERN EDGE OF THE GRAND BANKS

CRUISE REPORT NO 126
1982

INSTITUTE OF OCEANOGRAPHIC SCIENCES
NATURAL ENVIRONMENT RESEARCH COUNCIL

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Geophysical Studies of the continental margin on the eastern edge of the Grand Banks

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Institute of Oceanographic Sciences
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SCIENTIFIC PERSONNEL

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M L Somers (PSO)	IOS
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L M Parson	"
P R Miles	"
B J Barrow	"
D G Bishop	"
R G Rothwell	"
M R Saunders	"
R F Wallace	"
A R Lewis	RVS
E E Cooper	"
S Jones	"
T Probert	"
A Grant	Canadian Observer

LEG 2

J A Revie (PSO)	IOS
D G Masson	"
L M Parson	"
P R Miles	"
J M Campbell	"
D G Bishop	"
M R Saunders	"
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R F Wallace	"
S Jones	RVS
T Colvin	"
G Knight	"
E Lawson	"

CRUISE OBJECTIVES

The main objectives of Farnella Cruises 1 and 2 were to study the structural and sedimentary processes which have shaped the continental margin to the east of the Grand Banks between 41° and 52°N, and to compare the geological history of this margin with that of its conjugate on the eastern side of the Atlantic.

Prior to the formation of the North Atlantic, the northern part of the Grand Banks margin (east of Flemish Cap and Orphan Knoll, fig. 1) lay adjacent to Porcupine Bank and Goban Spur; the southern part lay to the west of the Iberian margin. A better understanding of the geological history of the Grand Banks margin should therefore give further insight into the geology of the more intensively studied West European margin.

A number of profiles orthogonal to the margin were planned, along which multi-channel seismic reflection, GLORIA, magnetic, gravity and bathymetric data would be collected. Disposable sonobuoys were to be used to obtain velocity data from the thicker sediment sequences.

DGM/LMP

CRUISE NARRATIVE

The ship sailed from Hull at 0930 on Day 262 (19th September). After compass correction, three double runs were made over the measured mile in the Humber estuary to calibrate the EM log. The runs were at 6, 9 and 12 knots. The planned run at 3 knots could not be undertaken because of the strength of the tide. The three double runs enabled a straight line calibration to be deduced with an error within $\pm$ 1.5%. There was also evidence of a 4° misalignment of the log head. The ship left the Humber at 1400 to go north about the British Isles. By keeping well inshore the effect of the severe westerly gales overnight were largely avoided. The ship passed through the Pentland Firth the following afternoon and, after a short stop at Scrabster to discharge the air-conditioning engineer who had sailed from Hull, set course for the Grand Banks.

The trans-Atlantic passage took 6 days at 12 knots with some stops for equipment towing trials and one night of reduced speed, due to Force 10 head-winds. The time was spent in rigging, testing and tuning all the gear and in re-stowing and lashing down the spares and consumables. The passage was often uncomfortable as the ship kept her speed in quite high seas. The effects of vibration were evident on some of the equipment, particularly the GLORIA photographic gear, and this had to be extensively re-mounted.

The idea of making a working traverse of the Mid-Atlantic Ridge was abandoned due to bad weather when the time arrived.

The ship arrived at a station 100 miles short of the start of the first planned survey line at 0800 on Day 269, but after deploying the PES and 3.5 kHz fish the weather had freshened to Force 8 and was increasing. So the ship proceeded at 4½ knots down the run-in line until conditions would permit a launch of GLORIA and the SRP.

The following morning the weather had abated enough to launch GLORIA and the SRP with the 6-channel streamer and the survey commenced at a speed of 6.3 knots.

The 3.5 kHz system was based on the Edo-Western type 515 depresser tow-fish and associated transceiver with the addition of an IOS-produced chirp generator and correlation receiver. Unfortunately, it proved extremely disappointing and it was difficult to detect even the bottom in 4000 m of water. It was eventually concluded that this lack of performance was caused by two factors, the poor sound output (inefficiency) of the type 515 transducer and by the same token a poor performance on reception, and secondly bad gain control on the pre-amplifier. The chirp generator and correlator were shown in shallow water to be working. The results were so disappointing that it was not considered worthwhile to run the system, particularly as it had an apparently intractable interference problem with other pieces of equipment, notably GLORIA and the SRP system.

The ship is driven by a controllable pitch propeller directly coupled to a single diesel which can run at a range of speeds. Thus a range of pitches and engine speeds can be used to maintain any required ship speed, but the quietest operation is obtained with the propeller pitch set as near as possible to the full design value. Sustained low engine speed at high pitch was an unfamiliar operating regime for the ship's engineers so it took a few days to find the

lowest sustainable engine speed. It turned out that there was little to be gained acoustically by reducing below 132 r.p.m. and the accumulation of soot in the engine exhaust was not severe at this speed. The DC generator on the shaft could also maintain its output at this speed, so it was not necessary to run a DC auxiliary generator, with a consequent saving of fuel. Most of the first leg was run at 150 r.p.m., but subsequently 132 r.p.m. was always used.

The survey tracks had been laid out on the basis of a later and slower crossing of the Atlantic, so the work started with a theoretical 500 miles in hand on the first leg at a survey speed of 6.3 knots. Provided there were no major upsets to the course of the work, it was planned to use this extra time to take up some track mileage from Leg 2, but it was always necessary to keep in mind the possibility of having to find shelter when the time came to recover the gear. In the event, it proved most efficient to do the outer two N-S legs planned for Leg 2, and these were started on Friday 9th October, after some very successful work on the Mid-Ocean Canyon.

However, before this extra work could be finished the ship suffered a trip on the AC generator, compounded by a loss of hydraulic pressure on the propeller pitch control which caused it to go to full astern; as a final complication, the emergency engine shutdown failed as it required AC power to operate. This incident took place on Sunday 11th October (Day 284) and resulted in damage to the GLORIA cable and the outermost section of the 6-channel SRP array, plus the SRP array depth gauge. At the time the sequence of events was naturally confused, but it was subsequently unravelled and modifications to the emergency engine stop system were carried out to make it battery operated. It was also learned that the pitch control must not be touched in such a situation as this unbalances the ahead and astern pressures, forcing the pitch to full scale. On this occasion an attempt to alter the pitch from ahead to zero resulted in an overrun to full astern. With the modifications and an understanding of what happened full confidence in the ship was rapidly regained.

The SRP array was re-streamed with 5 sections and the survey continued with SRP, magnetometer, gravity and PES, while the GLORIA cable was changed. By the time this had been finished and tested, there was no time for a launch even to tension the cable on the winch drum. The gear was recovered and the ship docked in St. John's at 0730 on Wednesday 14th October.

After bunkering during the forenoon of 16th October, the ship sailed at 1430, with 140 miles to go to the start of the second leg survey plan. GLORIA was launched the following afternoon in winds gusting to Force 6 and poor visibility. The 3.5 kHz, PES and airgun had been deployed during the forenoon. The 2-section IOS streamer was used on Leg 2 as there was less interest in CDP processing on the southern portion of the survey, and work commenced at 7.5 knots. Once again the 3.5 kHz interfered badly with the GLORIA records, and accordingly its use was abandoned.

On Monday, 19th October it was necessary to recover the gear for repairs to the engine which had a freshwater coolant leak on one cylinder. The shutdown lasted from 1216 until 1607 and included further towing trials on the 3.5 kHz fish, which showed it to be behaving very well, even on a non-compliant tow.

On Thursday, 22nd October the PDP 11/CAMAC digitiser and SE 8000 tape recorder were used to take digital GLORIA records for the first time, the system software and hardware interface bar having been completed and adjusted. Subsequently this record was replayed via the same system onto the Raytheon Line Scan Recorder and a record as good as the original was reproduced, making an auspicious start to the GLORIA digital era.

By 2100 on Friday, 30th October (Day 030) the Grand Banks survey was complete including a box survey of the Newfoundland Seamounts. Course was then set towards the Mid-Atlantic IPOD sites with GLORIA, PES and magnetometer streamed, the SRP and 3.5 kHz having been recovered. For this period the speed was increased to 10 knots, though in worsening weather the speed over the ground was less. On Saturday morning, in worsening weather and with a tropical storm in the vicinity, the magnetometer and GLORIA were recovered, so that in the event of good weather there would be more time on the IPOD sites, and if the weather got worse, it would still be possible to get to Ponta Delgada in time.

GLORIA was launched for the IPOD site survey at 0700 on Monday 2nd November, (Day 306). The first site was boxed at 8 knots, and the survey was completed at 2015 on Tuesday, 3rd November by making 10 knots between sites. All the gear, including PES, was then recovered and the ship set course for Ponta Delgada, docking at 1000 on Day 309.

MLS/JAR

GLORIA OPERATIONS

The vehicle was first launched at 1030, ship's time on Day 270, in position 50°N 42°W. The conditions were very close to the limit for launching, but no trouble was experienced, and the system was transmitting by 1310. With the exception of course changes there was only one shut down of 12 hours duration during the next 14 days. This was to work on the analogue tape-recorders which had been giving synchronisation troubles on replay. During this shut down a reversed section sonobuoy station was run. For the whole of the period the tape replays caused anxiety, although only half of one tape proved irrecoverable. In all, on Leg 1, 42 tapes of 8 hours each were recorded with a track distance of over 2000 miles. The 2-second FM pulse with a 40-second repetition rate was used throughout and the returns were processed in the digital correlators first tried on Discovery Cruise 123.

The PPAs in the Portakabin provided the usual crop of trips, but they were not a serious problem. One of the main causes was that the lamp and photocell which detect fan rotation were getting dirty in the damp atmosphere when a following wind blew exhaust fumes forward over the ship. Cleaning the surfaces would invariably cure a particular amplifier for at least several days. The short circuit trips were always re-settable and were due to the drive level to the amplifiers requiring careful setting up. As the cruise went on, and particularly on later legs, the trip problem was almost completely overcome.

Another problem caused by poor atmospheric conditions was poor contact (at the millivolt signal level) on the resolver slip-rings and in the steering changeover relays. This chassis is only protected by a dust cover and, over 4 years of operation, enough tarnish had accumulated on the contact gold plating to give intermittently poor contact, resulting in partial and sometimes total loss of signal, mainly, as it happened, on the port side. This type of intermittent problem is particularly difficult to diagnose. It will be treated by re-building the beam steering in an air-tight box fitted with a desiccator.

Trouble was experienced with interference from the 3.5 kHz high resolution SRP. This was eventually traced to a fairly obscure earth loop. However, since the performance of the 3.5 kHz was so poor as not to warrant running it regularly, it was not normally a problem.

On one occasion it was necessary to replace the A/D converter on one of the correlator boards. Otherwise, the correlators behaved extremely well, but the wide dynamic range of the signals handled brought its own problems in the compression circuits feeding the tape recorders, and both the AGC amplifiers and the 'linear' amplifiers could benefit from modification. The AGC amplifier has a little too much forward gain control and time constants which are too short. This makes it a remarkable edge detector, but obscures large area target variations.

GLORIA operations on Leg 1 were brought to an abrupt halt by the mishap to the ship described in the cruise narrative. When recovered, the cable had the familiar damage in the immediate neighbourhood of the vehicle. The cable change was effected without incident on Day 285, but it was necessary to rig an awning over the vehicle on its launcher to dehumidify the junction box before closing up, and it was not possible to launch the system before St. John's to tension the new cable on the winch drum.

Operations on the second leg started with a launch on Day 290 in poor conditions, but in spite of the untensioned cable the vehicle got cleanly away. The same 2-second pulse every 40 seconds was used, as on Leg 1. Leg 2 was punctuated by two vehicle recoveries. The first on Day 292 was to allow the ship's engineers to change a freshwater cooling pipe on the main engine and resulted in 3 hours down time, and the second was for the passage from the end of the Grand Banks survey to the IPOD site survey area.

The main problem on Leg 2 was an apparent beam widening on the Starboard side which was very difficult to pick out. In fact, the real cause, which was not diagnosed until the start of the next leg, lay in the beam-steering resolver gearbox, where the control transformer was found to have slipped and one of the resolvers was misaligned. Unfortunately it is not known exactly when the trouble arose - indeed the effect was not serious on the rather featureless Grand Banks terrain. It could have recurred late in Leg 1, when the port resolver slip-rings were cleaned.

On day 301 the GLORIA digital recording era started when the PDP 11/CAMAC and SE 8000 digital tape deck were brought into operation alongside the analogue recorders. There had been a trial run previously and the recorded tape had been successfully replayed via the same system onto the Raytheon Line Scan Recorder,

but from this point on digital tape recordings were regularly made during the rest of the Farnella cruise. However, only tapes 1, 2 and 3 belong to Leg 2.

GLORIA was recovered at 2130 on Day 307, at the end of the IPOD site survey, to enter Ponta Delgada the following day.

The analogue tape count for both Legs 1 and 2 was 89.

MLS/JAR

SRP

A highly successful cruise, with 4600 nautical miles of seismic reflection data having been logged, without any breaks due to instrumental failure. During the first leg of the cruise, the RVS 6-channel hydrophone was used with a 300 cubic inch airgun and wave shape kit (WSK). Although the WSK produced a higher resolution record, it was at the expense of output energy and hence penetration; it also intermittently caused the airgun to jam open, particularly at pressures above 1400 PSI, although only on a few occasions did this affect the quality of the records. The only major break in the records occurred during Leg 1, when the ship lost power. The gun and array were recovered shortly after, whereupon the sixth active section and depth sensor were found to be irreparably split. The leg continued with 5 active sections and no depth sensor.

During Leg 2 the IOS 2-channel array was used with a 300 cubic inch airgun plus WSK.

Data was displayed using one Raytheon and 2 EPC recorders. The EPC recorders were used to display a live monitor (15-80 Hz band pass filter) and a digital monitor (50-100 Hz band pass filter). The Raytheon was used to display various filter band widths, these being varied depending on the sub-surface geology. A full wave rectified, rather than the normal half-wave rectified signal was used in this display. On almost every occasion, the Raytheon recorder, with its superior scanning head, produced a much better record than the EPC recorders.

All SRP data was continuously logged in digital form for further playback and processing.

DGB

COMPRESSORS AND AIRGUNS

The compressors gave little trouble throughout the cruise, during which they were operated for a combined total of 800 hours. All faults recorded were electrical: the freshwater pump motor on the IOS compressor failed due to an accumulation of dirt on the brush gear, and the first contact breaker coil burnt out, causing the compressor to trip. The latter fault was temporarily rectified by fitting a coil from another contact breaker, and the compressor gave no further trouble.

The airguns, which were nearly new at the beginning of the cruise, gave little trouble, except for occasional leaks which prevented the gun from sealing. On average, each gun was run for five days between services.

RW

MAGNETOMETER

The Barringer magnetometer performed well after initial earthing problems. A fault was discovered on one of the fish cables, but this was subsequently repaired.

SJ

GRAVIMETER

The gravimeter was well sited on the forward port side of the laboratory, approximately on the centre line of the ship. Unfortunately, the Farnella is a 'stiff' ship, resulting in higher accelerations than are normally experienced on other ships in similar sea conditons. This resulted in a noisy, but acceptable, record. Overall, the meter performed well throughout legs 1 and 3.

Gravity base stations were established at Hull and St. John's, although a land gravimeter was not available. The calculated drift rate of +0.25 m gal per day was rather high, but within acceptable limits. Crossing tracks allowed a check on gravimeter accuracy on thirteen occasions. Average errors were 2.27

m gal for Leg 1 and 3.66 m gal for Leg 2 (no drift corrections applied).

SJ

DISPOSABLE SONOBUOY STATIONS

Nine sonobuoy stations were successfully occupied during the cruise. Two further buoys failed to transmit useful data. In the Newfoundland Basin, two stations were positioned to form a reversed refraction profile oceanward of the three reversed profiles occupied during Discovery Cruise 111. Five stations were shot using a 1000 m^3 airgun, the remainder with a 300 m^3 airgun. Ship speeds varied between 4.5 and 6 knots.

The only persistent equipment problem was the ever present earthing difficulty on the jet-pen recorder input panel. This was temporarily rectified by removal of the panel from the recorder. In addition, a sporadic failure in the delay system occasionally upset record continuity. It was also noticed that pen-time marks/sweep speed could suddenly alter, a few minutes after switching on the recorder.

The new clamp for the sonobuoy receiver aerial is a great success, taking only minutes to secure the aerial in position. It should be usable on a wide range of support diameters.

PRM

DATA LOGGING AND PROCESSING: LEG 1

With only one previous short cruise, during which data logging and processing requirements were minimal, this was the first major geophysical cruise for the new PDP 11/34 - based "G2" offline processing system, which replaces the old IBM 1130 computer. Raw data was logged and filtered by the PDP 11/04 - based "Minilogger" system, and tapes transferred from this to the G2-system on a daily basis.

Data logging

After incorporating the E/M Log calibration data deduced from measured-mile runs outside Hull, logging began on a regular basis on Day 265. The first problem to arise was a noticeable degradation of the raw gravity data after processing by the filtering software. At first it was felt that the extremely rough weather during the first week was contributing to this, although when the weather subsided the problem remained very clear. Superficial attempts to cure the problem by altering the spike-limits proved fruitless, and by this stage it was felt better to enter the raw data (which is already filtered over a 4-minute period at the gravimeter) directly into the processing system, rather than repeatedly stopping the logger to rebuild the filtering programs, each stoppage meaning a loss of minimum of 20 minutes' data due to the nature of the filtering process. This problem has been rectified in Barry in the meantime, and corrected software will be installed in St. John's.

The only other problems experienced were attributable to the tape-decks and associated hardware, which have always been the weakest link in this system. The data tape for Day 271 contained extensive patches of "- l " s and lower case "w" s. Quite how this data got through the read-after-write checking procedure is unclear, and subsequent testing of the deck off-line failed to reproduce the fault. This particular deck was not used again, and the worst faults from the other deck were two bad 20 minute data blocks on Days 281 and 285. In all cases the navigation data could be interpolated since no course changes were made at the critical times.

The Satellite Navigation system is still receiving very poor signals on the 150 MHz channel. This problem has been present since the system was first installed in Hull at the beginning of the last cruise, and was originally attributed to the proximity of the ship's VHF aerial. This was moved during the period in port between cruises, but unfortunately did not improve the situation. Although good position fixes were still obtained, they were not quite as frequent as could be expected, and it is hoped that further investigation of the problem in St. John's will enable it to be solved before the ship moves South into the Equatorial regions.

Data Processing

On Day 275 the Calcomp 1039 drum-plotter failed, with serious damage to the drum drive gear. Inspection of the main coupling gear revealed that 51 of the 256 teeth had been stripped off, and the rest were extremely fragile. Although some measure of success was achieved in effecting repairs, fears as to how long it would last were totally set aside when, during investigation of a subsequent fault with the pen drive on the same day, accidental, but irreparable, damage was done to the optical encoder of the pen-carriage motor. It has been arranged for a Calcomp engineer to visit the ship in St. John's, and hopefully all will be made good very quickly.

The lack of a hard-copy plotter was a severe set-back, but the software was quickly modified to allow track-plotting on the Tektronix VDU terminal, and in combination with inspection of data derived from the corrected navigation, such as course and speed-made-good, it was thus still possible to critically evaluate each satellite fix, and produce listings of 'final' 2-minute positions and associated data for the entire cruise. All position and data limits have been noted, and production of final track-charts and data profiles should be accomplished very quickly on return to Barry.

During the cruise, many unforeseen problems arose with the processing software, which were largely due to taking a rather too literal approach to transferring the old IBM 1130 programs to the PDP 11/34, which will now hold up to 28 days' data on disc, as opposed to the original 5. Gradually, after the 14-day point was passed, one program every day would fail due to problems with 'scratch-file' storage, and then after the 20-day point, every program on the system failed due to one key subroutine. These problems have now all been dealt with, and many new utility programs have been added, so that this system is now both very reliable and very easy to operate.

ARL/EBC/TEP

DATA LOGGING AND PROCESSING: LEG 2

The PDP 11/04 Mini-Logger continually recorded navigational and magnetic data. At the start of Leg 2 some new software was used to record gravity, but this

corrupted other recorded data and was soon abandoned. Instead, 4-minute values from the gravimeter were entered into the processing system. Likewise, 6-minute depths from the PES were typed by hand.

Data Processing

Logged data was transferred to the off-line processing system once a day. Following a service call in St. John's, the Calcomp Plotter was repaired and used extensively throughout the cruise to provide many 'hard copy' charts.

Navigational plots were produced for use with GLORIA data. Annotated track plots, profiles along the track and profiles against distance run were provided daily.

SATELLITE NAVIGATOR

Following the installation of a new satellite navigator aerial at St. John's, the problem of only acquiring single channel fixes was cured and the unit performed well.

TC/GK/EL

Magnetic Anomaly Data

During Cruises 1 and 2, concern was expressed relating to the apparent negative bias (by 200-300 γ) of the calculated magnetic anomalies. An error in the IGRF coefficients used in the processing software was suspected. This has been checked using the standard reduction program on the NERC Honeywell, which shows that the anomalies are correctly reduced to IGRF 1975.

MRS

PROJECT REPORT

Throughout cruises 1 and 2, exceptionally good weather conditions prevailed,

allowing some 4,600 nautical miles of geophysical profiles to be completed. With the exception of Days 284 and 285, when the GLORIA vehicle was out of action due to cable damage, GLORIA, seismic reflection, gravity, magnetic and bathymetric data were recorded at all times.

GLORIA DATA

A complete mosaic of GLORIA sonographs for the Grand Banks continental margin has been compiled, covering an area approaching 500,000 km^2 (Figure 3). Over much of the survey area, however, little was seen beyond a range of 15 km, possibly because of the adverse affects on propagation of severe temperature stratification in the water column. The orientation of the majority of the profiles orthogonal to the margin was also not ideal for GLORIA operations, but was dictated by the need to obtain seismic, gravity and magnetic data across the margin. However, excellent sonographs were obtained in certain areas, particularly on two sections of the north-west Atlantic mid-ocean canyon, on an area of rough topography on top of Orphan Knoll, and in the Newfoundland Basin, where a series of canyons can be followed from the shelf edge to the abyssal plain. Sonographs of the mid-ocean canyon between $47^{o}N$ and $49^{o}N$ indicate that the available bathymetric maps are inaccurate, with the axis of the canyon misplaced by up to 10 km from its true position. Minor areas of mud-waves and sediment lineations have also been identified, often associated with sediment drifts identified on seismic reflection profiles.

SEISMIC REFLECTION PROFILES

During Cruise 1, seismic reflection profiles were obtained using the 6-channel array and a 300 m^3 airgun towed at a speed of 6.5 knots. On Cruise 2, the 2-channel IOS array was used so that this part of the survey could be conducted at the higher speed of 7.5 knots. Comparison between airguns with and without a wave-shape-kit (WSK) showed that the increase in resolution generated by the WSK far out-weighed the slight loss of penetration which also resulted. WSKs were therefore used during most of the cruise. Data was replayed on both EPC and Raytheon recorders, with the better resolution being provided by the latter.

Twenty-two profiles orthogonal to the margin were occupied between 41°N and 52°N, giving a comprehensive cover of SRP data. Additional lines parallel to the margin provide cross-correlation between these profiles. The prominent 'mid-Cretaceous' erosion surface widely identified on the Grand Banks has been identified at the landward end of most profiles from Flemish Cap southward. A small sedimentary basin containing folded sediments underlies this unconformity on the north-west flank of Flemish Cap and superficially resembles similar basins known from the Grand Banks area. Post mid-Cretaceous sedimentation has deposited 2 to 4 seconds (two-way time) of sediment on the continental slope and rise, with a general increase in thickness southward. Sediment drifts and unconformities in the upper part of the section are evidence for bottom-current controlled sedimentation during the Tertiary.

A preliminary examination of 'basement' character shows typically rough 'oceanic basement' at the eastern end of many survey lines, and block faulted 'basement' of continental aspect to the west. However, the boundary between the two basement types is transitional rather than sharp, and seismic profiles alone cannot be used to define the continent-ocean boundary.

MAGNETIC ANOMALY DATA

Magnetic anomaly data was processed and displayed as profiles along track throughout the cruise. In the northern part of the study area a number of magnetic anomalies recorded over suspected oceanic crust could be correlated with basement 'highs' identified on the seismic reflection profiles. In some cases, these features could be correlated between adjacent tracks. A large amplitude anomaly was consistently recorded over the continental slope and rise, landward of which a clear decrease in anomaly amplitude is apparent.

On the southern part of the margin, the prominent 'J' anomaly, with total amplitudes of up to 900 γ, was crossed on three occasions. Landward of this feature, a persistent series of low amplitude margin parallel anomalies were observed.

The continued streaming of the magnetometer during the passage from the Grand Banks to the Azores provided a useful continuous profile from the continental margin to the active mid-Atlantic Ridge.

DGM/LMP

TABLE 1: SONOBUOY STATION LIST

STATION	DAY	TIME	LAT (N)	LON (W)	WATER DEPTH (m)	AIRGUN VOLUME	AREA
1	276	1254	49 25.2	46 45.7	2927	1000	NW Flemish Pass
2	276	1553	49 21.0	47 01.1	2807	1000	NW Flemish Pass
4	278	0732	48 40.8	41 35.4	4345	300	NE Flemish Cap
5	285	1624	47 25.0	44 38.2	200	300	Flemish Cap
6	294	1917	45 38.0	43 22.0	4676	1000	N Newfoundland Basin
7	298	0212	44 33.5	45 39.5	4061	1000	NW Newfoundland Basin R))
8	298	0453	44 22.0	45 35.5	4237	1000	) NW Newfoundland Basin R)
10	299	1805	44 18.0	46 39.2	3925	300	Newfoundland Basin
11	302	0819	42 50.0	46 34.5	4285	300	SW Newfoundland Basin

R = reversed line

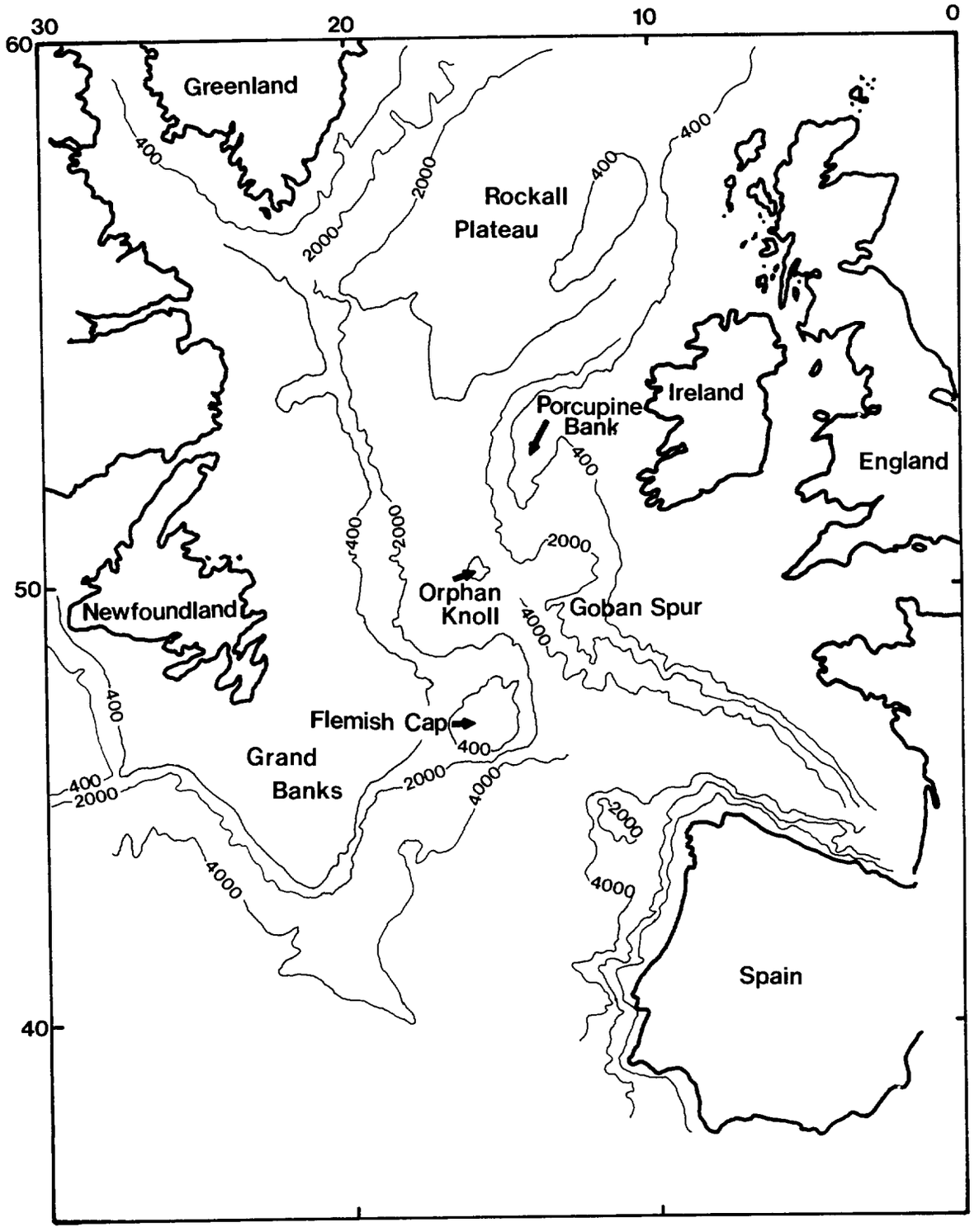

Figure 1: Continental reconstruction for the North Atlantic area after Kristofferson (Earth Planet. Sci. Lett., 38 (1978)). Greenland, North America, Spain and the Rockall Plateau have been rotated with respect to Europe, the position of which is fixed. Bathymetry in metres.

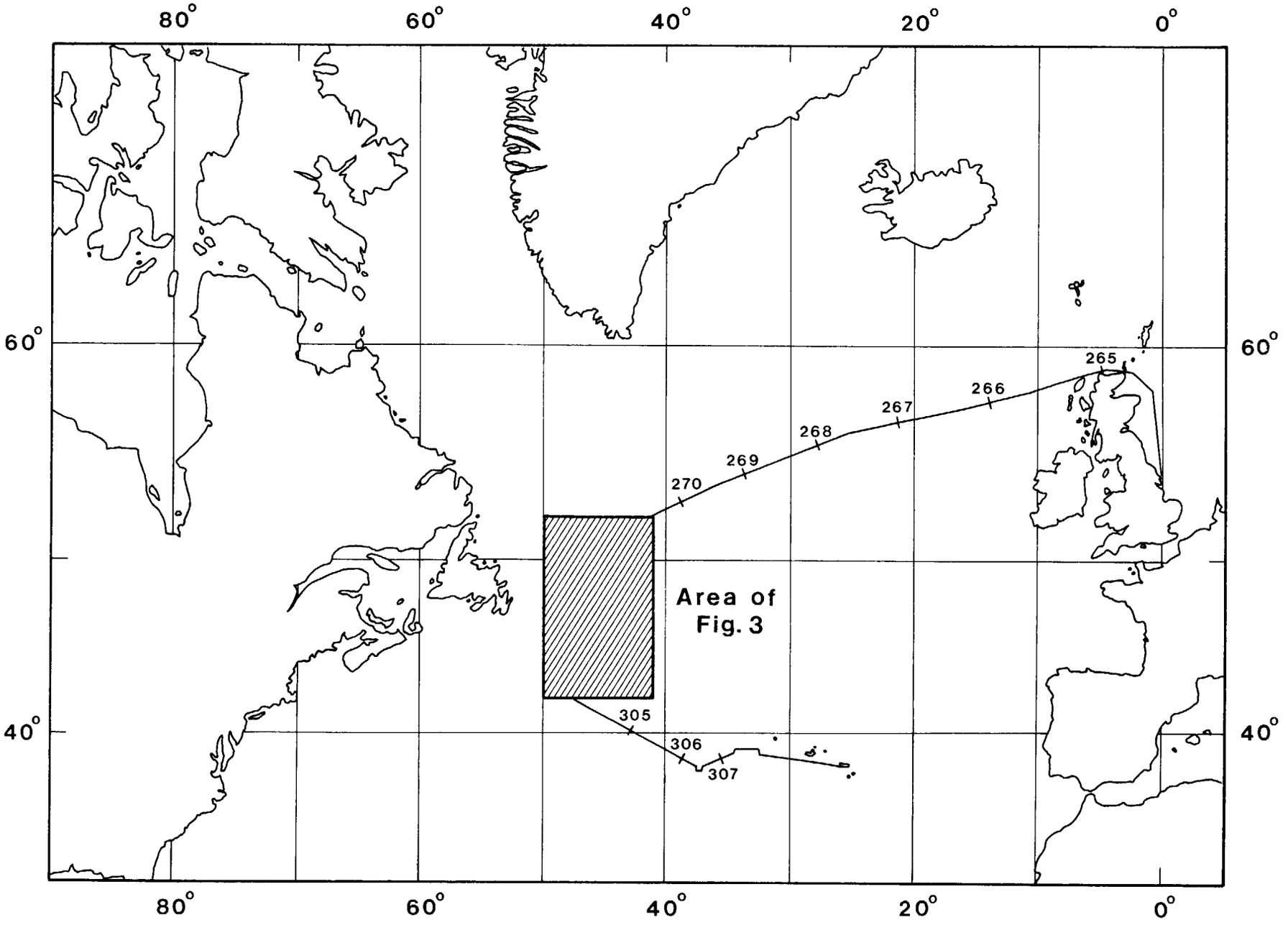

Figure 2: Map of North Atlantic showing location of detailed study area and passage tracks.

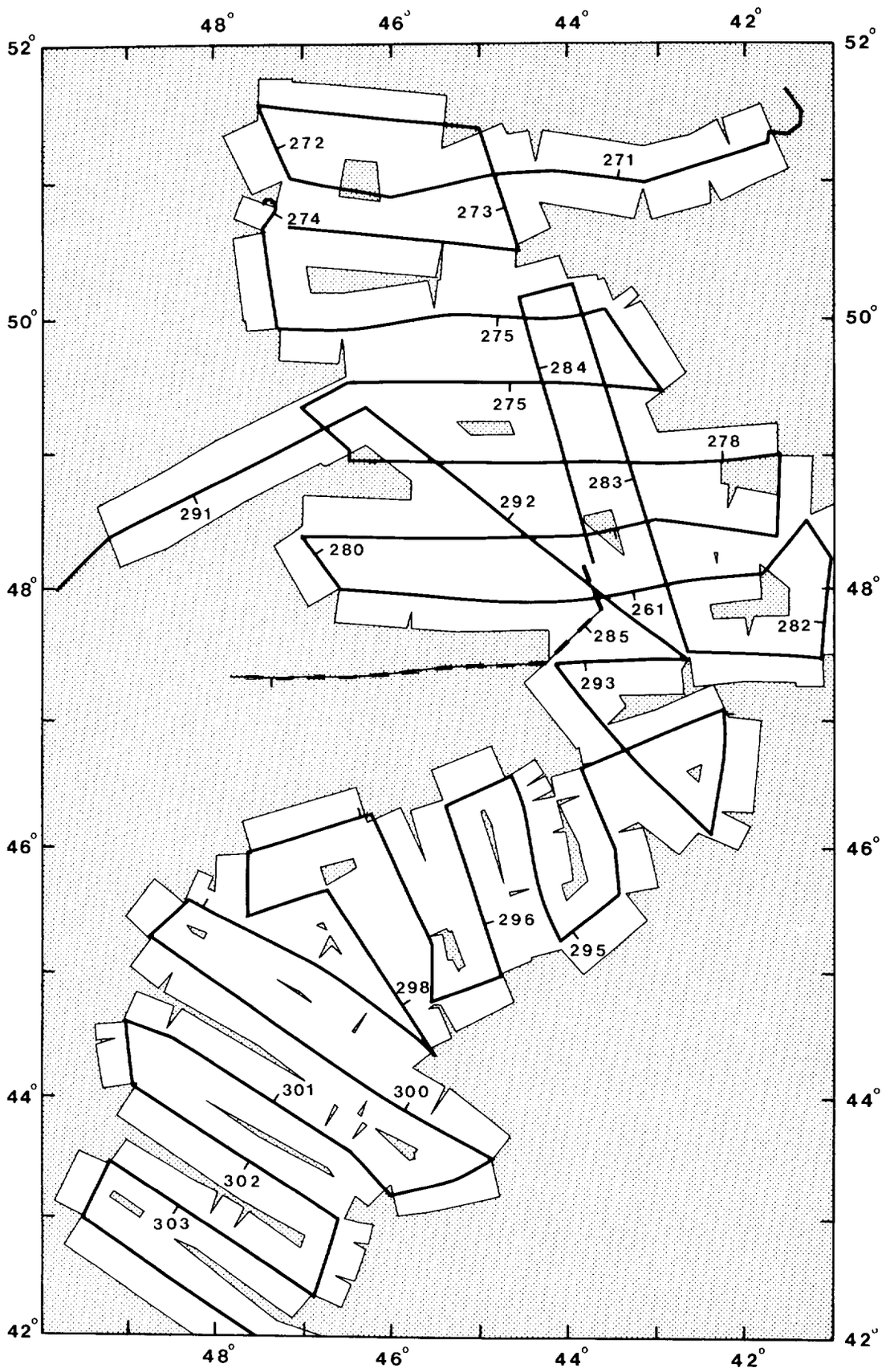

Figure 3: Track chart for detailed study area. Unstippled areas show GLORIA coverage.