R.R.S. Charles Darwin

Cruise 64 Report

Objectives

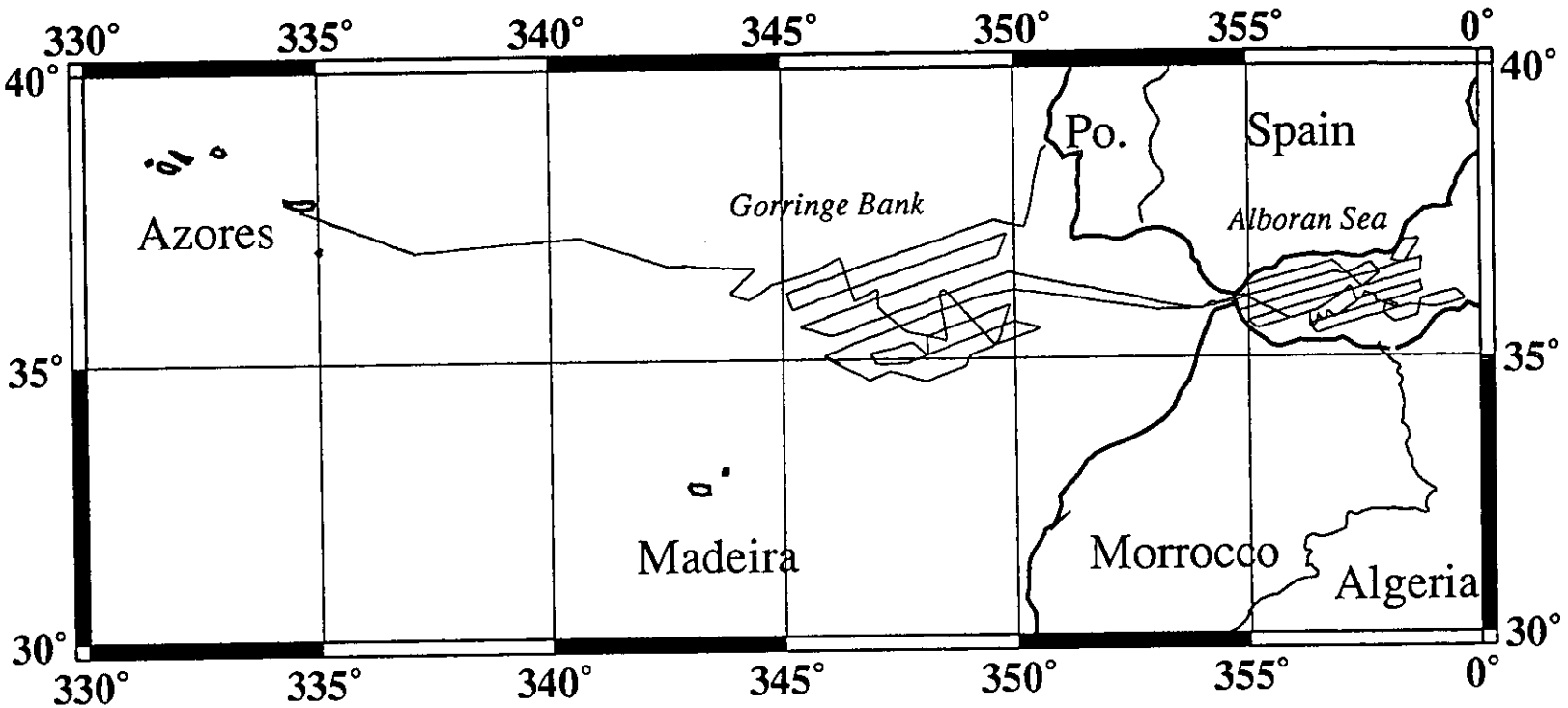
The main objective of the cruise was to obtain GLORIA, seismic reflection profile, gravity and magnetic data along the Eurasian/African plate boundary and to use these data to test current models for the styles of deformation and tectonic processes occuring along this boundary. The cruise was focussed on two areas where plate kinematic studies suggest the two plates are actively converging : the Alboran sea and the Gorringe Bank. Previous geological and geophysical cruises to these regions had determined the geological framework but, they had not been successful in mapping the zones of active deformation. We hope that by acquiring GLORIA together with "high resolution" seismic reflection profile data over a grid of the Alboran Sea and the Gorringe Bank to determine the tectonic fabric in these regions and the relationship that exists between the surface structure mapped by GLORIA and the deep structure imaged seismically.

Geographical Area

Cruise 64 of R.R.S. Charles Darwin began in Lisbon on December 22nd and ended in P. Delgada (Azores) on January 24th. The cruise was divided into two "target" areas : one of the Gorringe Bank region and the other of the Alboran Sea (Fig. 1). Previous studies indicated that these two areas were likely to be localities of active deformation the extent of which could be mapped using GLORIA and other underway geophysical data. During the cruise a total of 9313 km of underway geological and geophysical data were collected over a 32 day period at an average speed (over the ground) of 6.6 knots.

The cruise was broken down in the following way :

1. Transit - Lisbon to Gorringe	1 day
2. Gorringe Bank Survey	15
3. Transit - Gorringe to Alboran Sea	1
4. Transit - Alboran Sea to Gorringe	1
4. Alboran Sea survey	12
5. Transit - Gorringe to Azores (Gloria Fault)	2



R.R.S. Charles Darwin Cruise 64

December 22, 1991 to January 24th, 1992

Figure 1. Location of RRS Charles Darwin Cruise CD 64 in the central east Atlantic Ocean.

Total Transit	5
Total Survey	27
Grand Total	32 days

Sea and Weather conditions.

The sea and weather conditions during the cruise were excellent. There were one or two days of moderate seas with high winds but, these were separated by long spells of slight seas and sunny weather. On no occasion during the cruise did it become necessary to modify the scientific plan because of bad weather.

Personnel

The scientific party comprised of the following :

Prof A. B. Watts	Oxford
Prof. G. K. Westbrook	Birmingham
Dr. J. Collier	Oxford - Seismic Processing
Dr. J. Wilson	IOS - GLORIA Mosaic
Mr J. Campbell	IOS - GLORIA (until Jan 3rd)
Mr. J. Cherriman	IOS - GLORIA (after Jan 3rd)
Miss C. Marr	Oxford - Graduate Student
Miss A. Willet	Oxford - Graduate Student
Mr. P. O'Neill	Birmingham - Graduate Student
Miss R. Campbell	Birmingham - Graduate Student
Mr. C. Rymer	RVS - Air Guns
Mr. M. Davies	RVS - Air Guns
Mr. C. Paulson	RVS - Electronics Technician
Mr. C. Woodley	RVS - Electronics Technician
Mr. A. Fern	RVS - Computing Services

Narrative

The vessel left Lisbon on December 22nd at 12:00 and headed SW to a point on the slope off Portugal (Lat: 9° 45' N, Lon: 37° 20' W) to stream the gear (Fig. 2). Deployment began with the PDR (3.5 and 12 kHz) fish, GLORIA and the 200 m long seismic streamer. The GLORIA was up and running shortly after deployment and successfully imaged a Late Cretaceous/Early Eocene escarpment that French workers had previously mapped using seismic data. A 30 sec repetition rate was used for the GLORIA sonar source and signal levels were pre-set to 24 dB. The

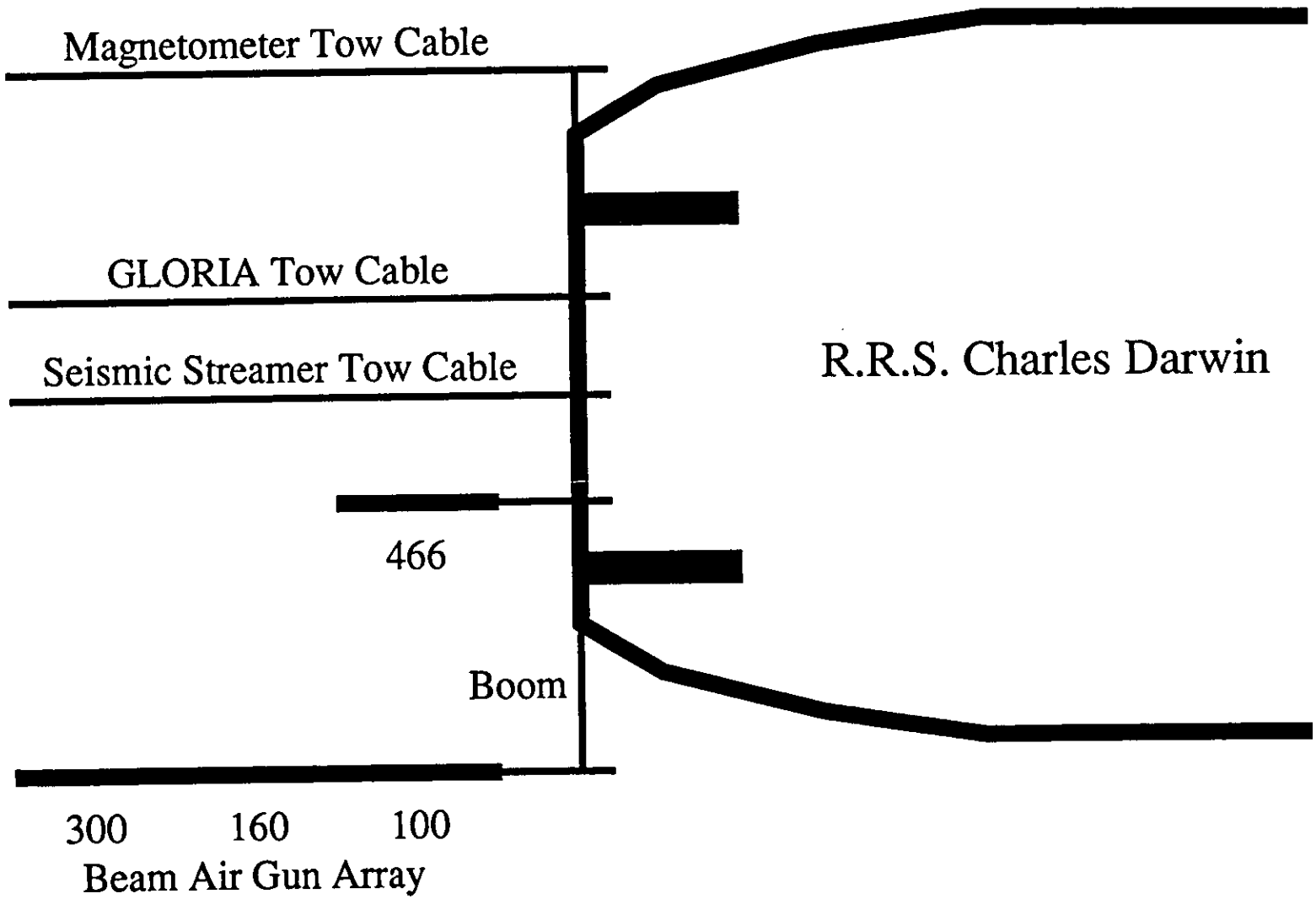


Figure 2. Configuration of underway geological and geophysical gear off the stern of the vessel during CD 64.

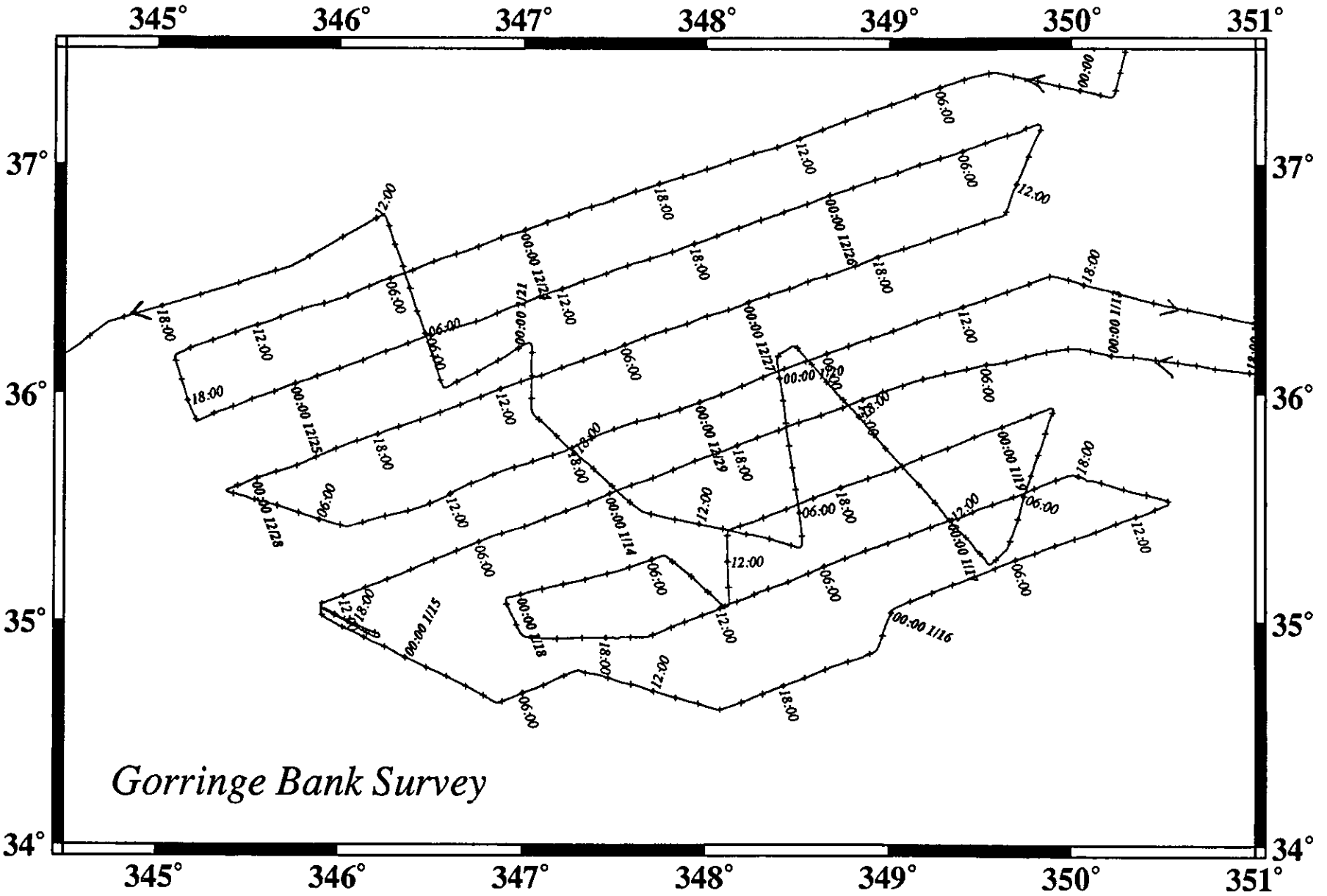


Figure 3. Detailed ship track plot of the *Gorringe bank* survey area. The track has been annotated every 6 hours and at every 24 hour interval the month and day are given. The tick marks are 1 hour intervals along the track.

air gun deployment was delayed because of a faulty seal on one of the 3 beam guns (300, 160 and 100 cu.in) and so the magnetometer was put out next. By 0230 on December 23rd the beam guns and the 466 cu.in "single" gun were ready for operations and at 0400 we began the first of the four NE-SW trending survey lines (Line # 1) planned in the Gorringe Bank area (Fig. 3).

Weather conditions were excellent and by 1542 on December 24th we had completed Line # 1. The line was run in the Tagus abyssal plain near the foot of the north flank of Gorringe Bank where French workers had sampled ultrabasic (serpentinites) and gabbroic rocks. Several bright reflectors were obtained on GLORIA from the steep north flank of the bank. The Tagus abyssal plain was characterized by a persistent pattern of wavy reflectors which were identified by J. Wilson as interference effects due to sub-bottom penetration of GLORIA's transmission pulse. To the west of Gorringe Bank, several NE-SW trends were noted in the GLORIA data and at about 1400 we crossed a small seamount with a pattern of channels that radiated out from the summit.

Line # 1 was completed at 1542 and we had just begun a short "dog leg" to Line 2 when it was found that one of the guns on the beam was not firing and had to be repaired. The beam was brought in at 1600 and it was not until 2154 that the repairs could be made and all the guns were back in the water.

The second line, Line # 2, was offset about 12 miles from Line 1 so as to to insure adequate overlap for the GLORIA mosaic. At 0540 on December 25th the vessel crossed a deformational structure that showed up on the seismic profile as a possible thrust. Line # 2 continued over the north flank of Gorringe where there were numerous very bright targets on GLORIA but, before reaching the end of the line there was further trouble with one of the beam guns. The airguns were worked on during much of the next day (December 26th) and were not deployed again until 2100.

The third line, Line # 3, was begun at 1300 and crossed the south flank of Gorringe Bank, quite close to the crest of the Ormonde and Gettysburg "seamounts". The upper slopes of the south flank of Gorringe are characterized on GLORIA by numerous channels which connect into a few large ones at the foot of the bank. The rest of the line was run along the horseshoe abyssal plain. At 0200 on December 28th the line was completed

Line # 4 was begun at 0706 on December 28th and was completed by 1600 on December 29th.

After completing Line # 4, the air guns were brought in and the vessel steamed at 10 knots towards the second target survey area : the Alboran sea (Fig. 4). Before passing through the Straits of Gibraltar, GLORIA was shortened because of the possibility of shallow uncharted depths, especially around the "sill" area between Tarifa and Tangier. A quite spectacular GLORIA image was obtained in the Straits with very bright returns indicating outcrop of Betic basement rocks. Both coastlines were partly visible on the record. After passing Europa Point GLORIA was lengthened and the first of the Alboran Sea lines (Line # 11) was begun at 2310 on December 30th. Unfortunately, the guns were not ready for operation until 0405 the next morning because two of the beam guns had again failed to seal. By 1015 on December 31st, however, all guns (including the single gun) were operating satisfactorily.

Line # 11 crossed the north flank of Djibouti Bank and the south flank of Chella bank. Several strong reflections were observed in the GLORIA data from these banks which magnetic anomaly data indicate are probably made up of volcanic rocks. At 0540 on January 1st it was decided to break off the line and image the seafloor of the NE part of the Alboran sea around the Abubacer ridge as far north as the Polomares Canyon. The ridge was of a different texture on the GLORIA data than either Djibouti or Chella banks indicating that it probably was a region of Betic basement outcrop. The Polomares canyon was very well imaged by GLORIA and several meandering channel systems were clearly seen. The track around the ridge was completed at 1910 and Line # 11 re-joined. Line # 11 was then extended to the steep escarpment that separates the east Alboran basin from the Algerian basin.

Once Line # 11 was completed it was decided to proceed to Gibraltar to exchange the IOS GLORIA personnel. The line crossed to the SE of Chella bank and was run approximately parallel to the Spanish continental slope. The slope is known from commercial drilling data on the shelf to comprise of a thick sequence of Neogene sediments that formed as a result of an early to mid-Miocene rifting event. Several normal faults were imaged on the seismic reflection profiles. Some of them were imaged by GLORIA - indicating that a form of extension may be occuring in the basin at the present day.

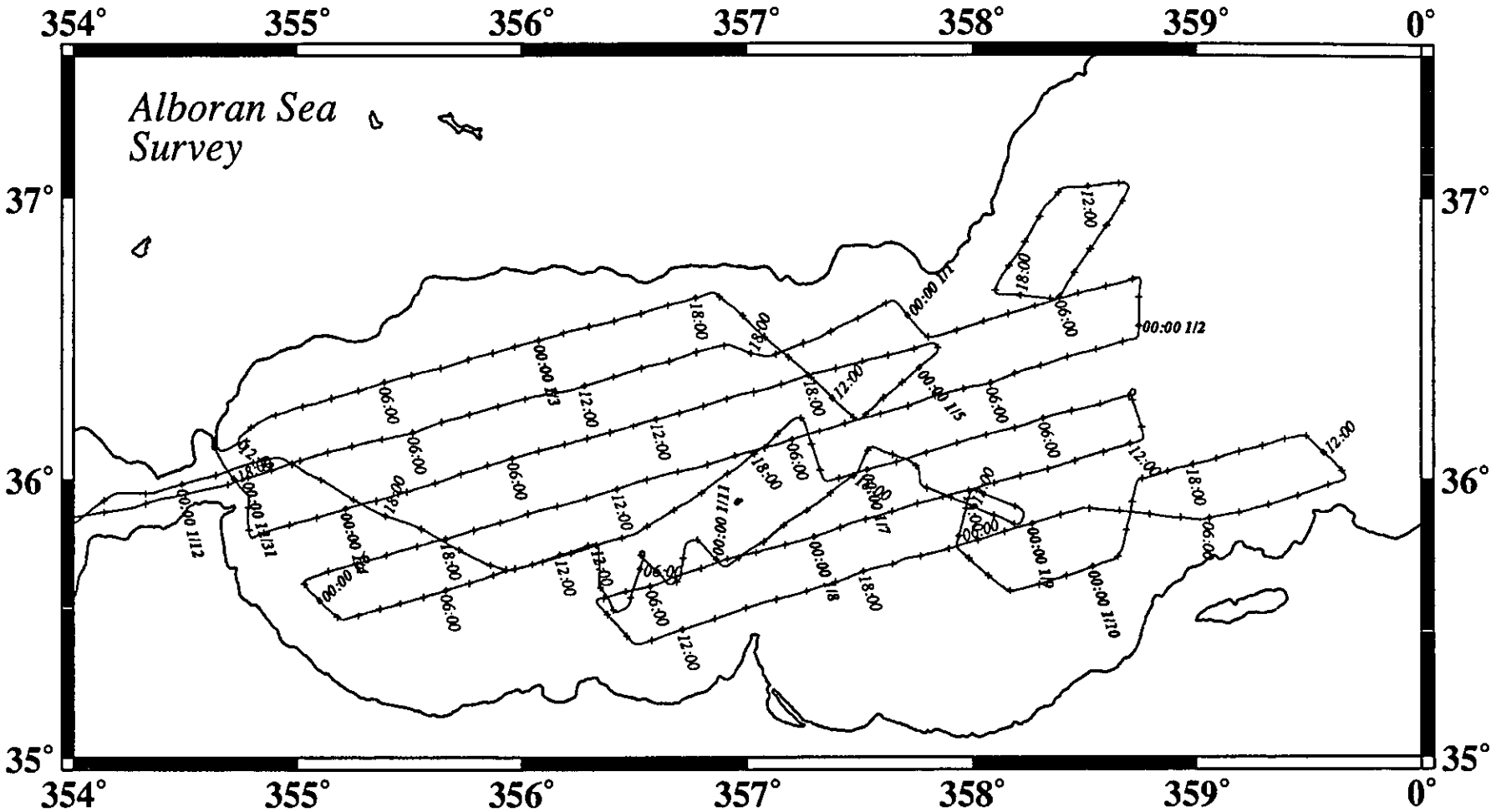


Figure 4. Detailed ship track plot of the *Alboran Sea* survey area. Symbols as in Figure 3.

The vessel arrived off Europa point, Gibraltar at 1200 on January 3 and all the gear was pulled in. We then proceeded to a point just outside the harbour breakwater and anchored. A small boat met the vessel and J. Campbell left the ship and J. Cherriman joined. Two radar technicians also boarded the vessel in order to repair the port radar on the bridge. It had been planned to pick up an Algerian and Moroccan observer in Gibraltar. However, we had already been informed by RVS that the Algerian observer could not take part in the cruise because of "internal difficulties in his country". Also, the agent in Gibraltar had not received any word from the Moroccan observer. The vessel therefore raised anchor at 1800 and steamed across the Straits to a point just west of Cueta to stream the gear. The gear was deployed by 2200 and Line # 13 of the Alboran Sea was begun.

Line # 13 crossed the west Alboran basin and then proceeded east into the Alboran channel between the Djibouti bank and the north flank of the Alboran ridge. At 0100 on January 4th a diapiric structure was crossed that was similar to structures that had been identified previously by Shell and Amoco workers. The line was continued to a point south of Avenzoar bank. At 2250, just after the course change to re-join line # 12. the 300 cu.in gun failed and so the beam gun array had to be brought in. By 0423 on January 5th the guns were on again and line # 14 begun.

Line #14 began in the Alboran channel just to the north of the Alboran ridge. Between 0500 and 0600 a number of fault structures were crossed which appear to be of extensional origin. The faults had previously been imaged on R/V CONRAD multichannel seismic reflection profile 825. The faults were not imaged by GLORIA but, several "offsets" were observed in the basement outcrop pattern in the region. The line continued past the north flank of the Alboran ridge to off the Moroccan coast.

After a short connecting leg, line # 15 was began at 0100 on January 6th off the Moroccan coast. Diapirs were noted on the seismic reflection profiles at 0330 and 0430 which appear to be part of a broad belt of structures trending parallel to the Moroccan margin. It is not presently clear whether the diapirs are of salt or clay origin. At 1440 it was decided to cross the Alboran ridge on its northern flank in order to determine more information on the faulting observed the previous day. Subsequently, the faults were identified and by connecting individual fault traces it appears that they are normal faults that trend approximately NW-SE. This trend is similar to the trend of

the Habibas escarpment to the SE and may indicate that they are part of a major thoroughgoing fault system. Line # 15 was extended from the faulted region across the El Monsour "seamount" towards the Algerian basin.

Line # 15 was completed at 0900 on January 7th but, the approach of another ship prevented the vessel from making the necessary course change to join a short connecting line. As a result a turn to port was made and the line was then resumed.

Line # 16 was begun at 1130. The line extended across El Monsour seamount to the southern flank of the Alboran ridge and crossed the "pull apart" basin - described earlier by French workers. Unfortunately, the GLORIA record was not very clear when the basin was crossed at 1815. It was noted that at similar times in other parts of the Alboran sea that the GLORIA record was also poor and J. Wilson speculated that it may be the result of a "plankton blanket" that descends at dusk and scatters GLORIA's acoustic energy.

At 2330 one of the two seismic compressors had to be serviced, resulting in a loss of power to the beam guns. Full power was resumed at 0130 on January 8th.

The line continued past the southern flank of the Alboran ridge where some evidence of slumps were seen in the GLORIA data. At about 0630 a bright reflector was observed on the GLORIA data which subsequent seismic reflection profiles showed to be a deformational (topographic) ridge. This was the first evidence that the deformation patterns observed on the southern flank of the ridge may be visible in the GLORIA data.

Line # 16 was completed at about 0815 and Line # 17 begun at 1030. From about 1200 a strong, continuous reflector trending ENE-WSW could be seen in the GLORIA data in the continental slope region off Morocco. The feature could be traced for more than 25 km along the ship track and we speculate that it is an extension of fold/fault structures in Morocco. At about 2200 we reached the pull-apart basin but, again its outline could not easily be seen in the GLORIA data.

The end of Line # 17 was reached at 0200 on January 9th and since sufficient time remained we decided to extend the line to the ENE so as to cross the Habibas escarpment at a high angle. By 0600 we were in sight of the coast of Algeria and so decided to run a line parallel to the coast for about 50 km. The GLORIA

data along the line was quite spectacular and numerous channels were observed. Individual channels in the vicinity of the coast were quite narrow but, they tended to coalesce into large fan-shaped bodies on the continental slope.

Although the vessel had been operating in Algerian waters quite safely to this point there was some uncertainty on board about our status especially since we were unable to complete the rendez-vous with an Algerian observer in Gibraltar. We therefore decided to cut short the Algerian margin profile and at about 1100 headed out towards the Algerian basin.

A line was then run from the Algerian basin back to the south Alboran basin that included two additional crossings of the Habibas escarpment. The seismic reflection line showed most clearly a feature shown by the other lines crossing the western margin of the Algerian basin ; a roll-over anticline on a normal fault caused by eastward gravitational sliding of sediments into the Algerian basin, with compressional deformation of the sediments at the foot of the slide farther east in the basin. The seismic data also showed a significant amount of deformation along the Habibas escarpment with a large thickness of sediments terminating abruptly against the acoustic basement.

The vessel then proceeded to the southern flank of the Alboran ridge where a previous R/V Conrad multichannel reflection profile had shown a zone of deformation at about lat 35° 42' N and lon 3° 20' W. At 0200 on January 11th it was decided to make 5 additional crossings of the region with the small channel system in order to map the lateral extent of the deformation. The first crossing was mid-way between the Conrad lines # 825 and 824 and did not reveal any structure but, the next four lines all showed a well developed tectonic fabric which appears to be compressional in origin. The third and fourth lines were especially useful as they crossed a bright reflector that had been previously identified in the GLORIA data. The feature on GLORIA corresponded on the seismic profile to the zone of deformation which locally is associated with a topographic high. It seems likely, although we could not prove it, that the zone of deformation continues ESE to the Moroccan coast.

The 4 short lines over the south flank of the Alboran ridge were completed by 1200 and so it was decided to repeat some of line # 15 which had been missed because of gun failure. After completing about half of the line it was decided to complete the work in the Alboran Sea and head for the Straits of Gibraltar. A

speed over the ground of about 10 knots was obtained and we arrived at the entrance to the Straits at about 2100.

The passage through the Straits was, with the help of Radio Tarifa, again free of incident and at 0000 on January 12th we decided that the water depths were sufficient to lengthen the GLORIA tow cable. The vessel then proceeded to a point just to the south of the line we ran on the way in to the Straits. Several large canyons were visible on the GLORIA image but, we saw no evidence for a major thrust fault that had been proposed by Maldanado (Granada Univ.) to cross our line at about 1930.

At 2040 we reached the Gorringe Bank survey area. The seismic streamer and guns were subsequently deployed and Line # 5 begun at 0200 on January 12th. At 2100 the vessel crossed the north flank of Ampere seamount where an undulating reflector was noted near the base of slope. The line continued across the valley between Ampere and the Madeira-Tore rise where there was evidence for recent deformation on the 3.5 kHz record.

At 1328 on January 14th it was decided to shorten the streamer, because of concern that the depth of the streamer was too deep and was producing an unduly prominent sea-surface ghost on the seismic records. Unfortunately, as the streamer was being wound in the restraining ropes on the stern caught the conductor cable between the hydrophones and the drum and was badly chafed. The cable appeared to be cut as well as stretched so it was decided not to repair it on deck but, replace it with the spare that was carried on board. By 1630 the spare conductor cable had been connected to the hydrophone and the drum and we recommenced seismic profiling. However, while the conductor cable was being replaced we had lost valuable seismic data from the valley where there was evidence for recent deformation so a reciprocal course was made back to the end of Line # 5, thereby repeating the short track segment between lines # 5 and 6.

By 0000 on January 15th we were close to the shallowest point linking the Madeira-Tore rise and Ampere seamount and Line # 6 was begun shortly thereafter. The rest of the day and most of the following day was spent in the Seine abyssal plain following the south flank of Ampere and Coral Patch seamounts where there was surprisingly little evidence for recent deformation. Both Ampere and Coral Patch seamounts were associated with high amplitude free-air gravity anomalies. However, it was noted that while Coral Patch correlated with high amplitude magnetic anomalies, Ampere did not. The line then proceeded across the

Seine abyssal plain and crossed a small ridge that links the Madeira-Tore rise complex to the Gibraltar continental margin.

Line # 7 was begun at 1800 on January 16th in the Horseshoe abyssal plain. At 0200 on January 17th we had reached the east flank of Coral Patch seamount and began a run across its northern flank. Between 1000 and 1600 a number of NE-SW trending ridges on the port side GLORIA record were noted. A few of the ridges continued across the record to the starboard side suggesting a tectonic origin.

After completing line # 7 it was decided to cross into the region between Ampere and Coral Patch and then begin line # 8 by running a survey line into the deformational structures identified the previous day to examine whether they were folds or basement ridges. At 0719 on January 18th, just as we began the approach to the deformation features, the 300 cu in gun on the beam stopped firing. However, the deformational features were characterized by a thin sedimentary layer overlying the basement which could be easily defined in the seismic profile. It was therefore decided to leave the air guns operational and repair them once the survey line was completed. By 1523 we had finished the line and the beam was brought in.

Line # 8 was continued across the Horseshoe abyssal plain in order to determine whether the deformational structures continued to the NE. Since the beam was still not ready it was decided to deploy the single 466 cu in air gun in order to get some penetration. At a towing speed of 8 knots the single gun provided useful data and good enough penetration to define the thickness of the "olistostrome unit" and in places the depth to basement. At 2240 an abrupt 15 m offset in the bathymetry on the 3.5 kHz record was noted which correlated with a fault on the seismic reflection profile. The nature of the offset suggests recent deformation and we speculate that it is due to earthquake activity which most compilations show is concentrated in this part of the east Horseshoe plain.

Shortly after mid-night on January 19th a series of short profiles were begun in order to cross at a high angle some of the deformational structures that were previously observed during the survey. Three regions were targeted. These included the southwestern flank of Gorringe bank, the southern flank of the unnamed seamount west of Gorringe and, the southern flank of Josephine seamount The lines were begun at 1200 and were completed by 1040 on January 21st.

At 1040 it was decided bring the guns in and complete the remaining part of the Gorringe bank survey at 8 knots with a GLORIA profile that extended from the southern flank of Josephine seamount to the complex ridge and trough topography of the Madeira-Tore rise. The line was run parallel to the GLORIA lines of the Gorringe bank survey and was designed to be long enough so as to cross the predicted plate boundary trace based on the RM2 and NUVEL 1 global models.

The lines were completed at about 0000 on January 22nd at which time it was decided to proceed to the Azores by following the trace of the Gloria fault which previous surveys had shown to be the transform segment of the combined Eurasian/ African plate boundary. We attempted to follow one side of the trough that characterizes the transform fault in this region but, this proved difficult in the absence of swath bathymetry data. However, the GLORIA data appeared of very high quality and it is clear from the records that we were reasonably successful in following the trace of the fault.

After reaching 22^{o} 59' W lon at 1604 on January 23rd it was decided to retrieve GLORIA and the remainder of the underway gear. By mid-night all the gear had been stowed and the vessel then proceeded to Ponta Delgada, Azores. Cruise 64 ended successfully at 0700 on January 24th.

Equipment

The main items of equipment used during the cruise were :

1. GLORIA Mark II side scan sonar vehicle and launch gantry.

2. SAQ 1 "Single-channel" digital seismic data acquisition system.

3. Air-gun array of 4 Bolt 1500-C guns consisting of 3 guns on the beam (300, 160 and 100 cu in) and a single 466 cu in gun.

4. Geomechanique hydrophone streamer configured as follows :

Element	Length
Tow cable	160 m (from stern)

Spring section	25 m
Weight section	10 m
Active section 1	50 m
Active section 2	50 m
Active section 3	50 m
Active section 4	50 m
Spring section	
Trail rope	

5. Lacoste-Romberg Model S40 and Model S84 seagravity meter systems. (Model S40 was mounted mid-ships and S84 off-axis in the photography room).

6. Varian proton precession magnetometer

7. 12 and 3.5 kHz Precision Depth Recorders

8. GPS and transit satellite navigation systems

Comments on Equipment Performance (GKW and ABW)

Airgun array

The airgun array of a 466 cu.in chamber towed singly, and 300, 160 and 100 cu.in. chambers on longitudinally towed beam, was designed to give a peak-to-bubble ratio of about 7 when towed at a depth of 7.5 m. In practice, the towing depth of the guns on the beam was about 7.5 m when towed at 6.2 knots, but the single 466 gun towed more shallowly by about 1 m. Variations in towing speed and sea state caused the guns to vary in their depths by about 1 m either side of their mean depth. An increase in speed of 0.5 knots would cause the guns to rise by 0.8 m (a decrease of 0.5 knots would cause the sinks to sink by 0.8 m).

Unfortunately, there were numerous failures of the airguns during the cruise (see narrative), and some of these must be attributed to insufficiently careful preparation of equipment before it was put on the ship as well as errors in on-board preparation. Several components were faulty or worn. In one case, the top housing of a gun would not fit snugly on to the main housing with the standard clamps and the modified clamps required had not been put on the ship.

Hydrophone Streamer

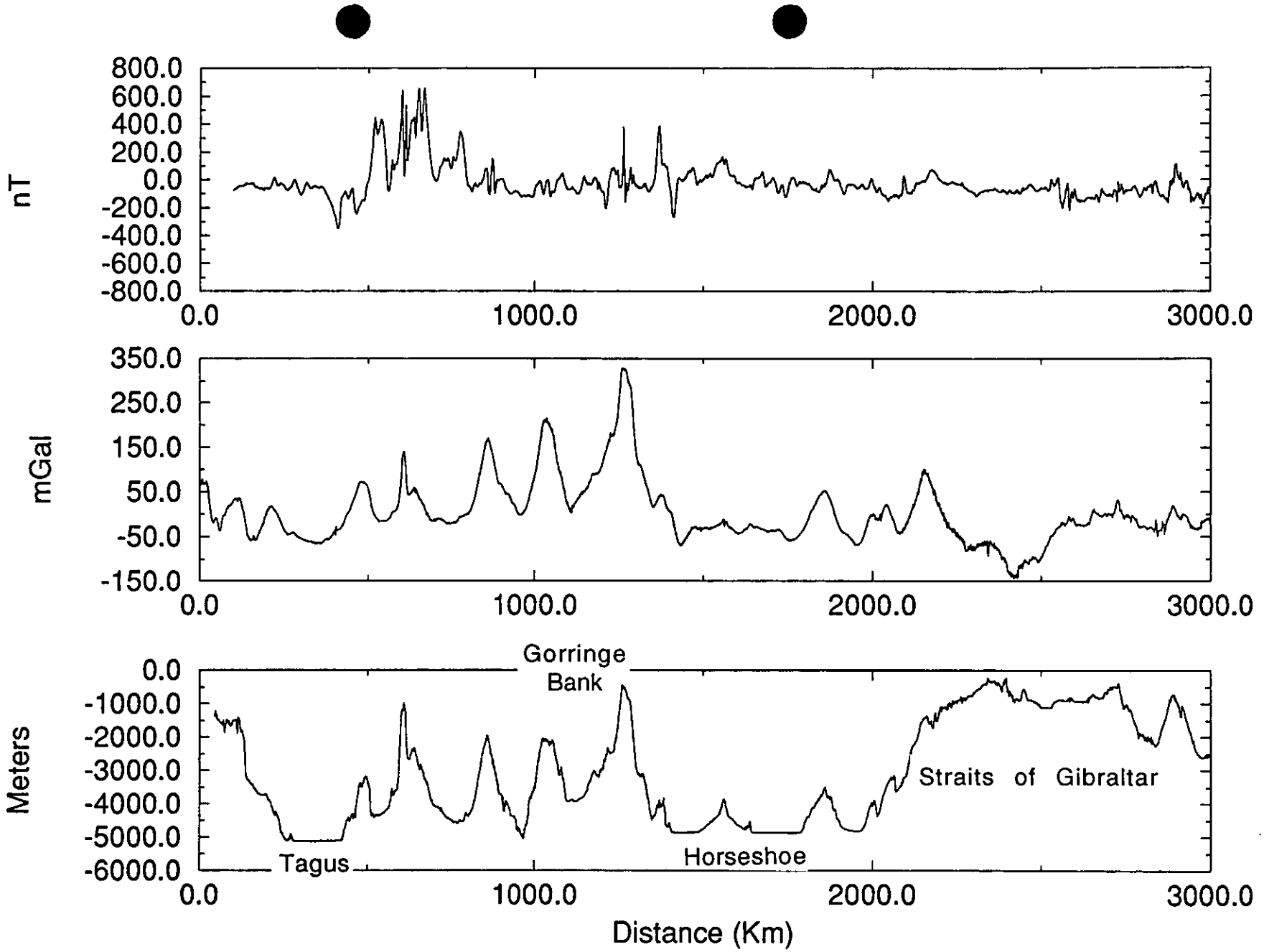
The streamer performed well in having low noise, but it was towed too deeply, because the depth sensors that were requested at the pre-cruise meeting were not provided and the depth of tow could not be continuously monitored. From inspection of the seismic records obtained in shallow water, where the seabed multiples could be used to determine the geometry of the seismic system, the depth of tow of the streamer was found to be 33 m, four times greater than desired. The expected delay of the streamer ghost is about 44 ms, which corresponds to the second prominent "event" seen beneath the seabed on the seismic record of Fig.7, broadening the effective source signature.

GLORIA

The GLORIA II system worked well flawlessly the cruise. The system was operated continuously throughout the cruise, except for a short interuption while personnel were exchanged in Gibraltar.

Gravity and magnetics

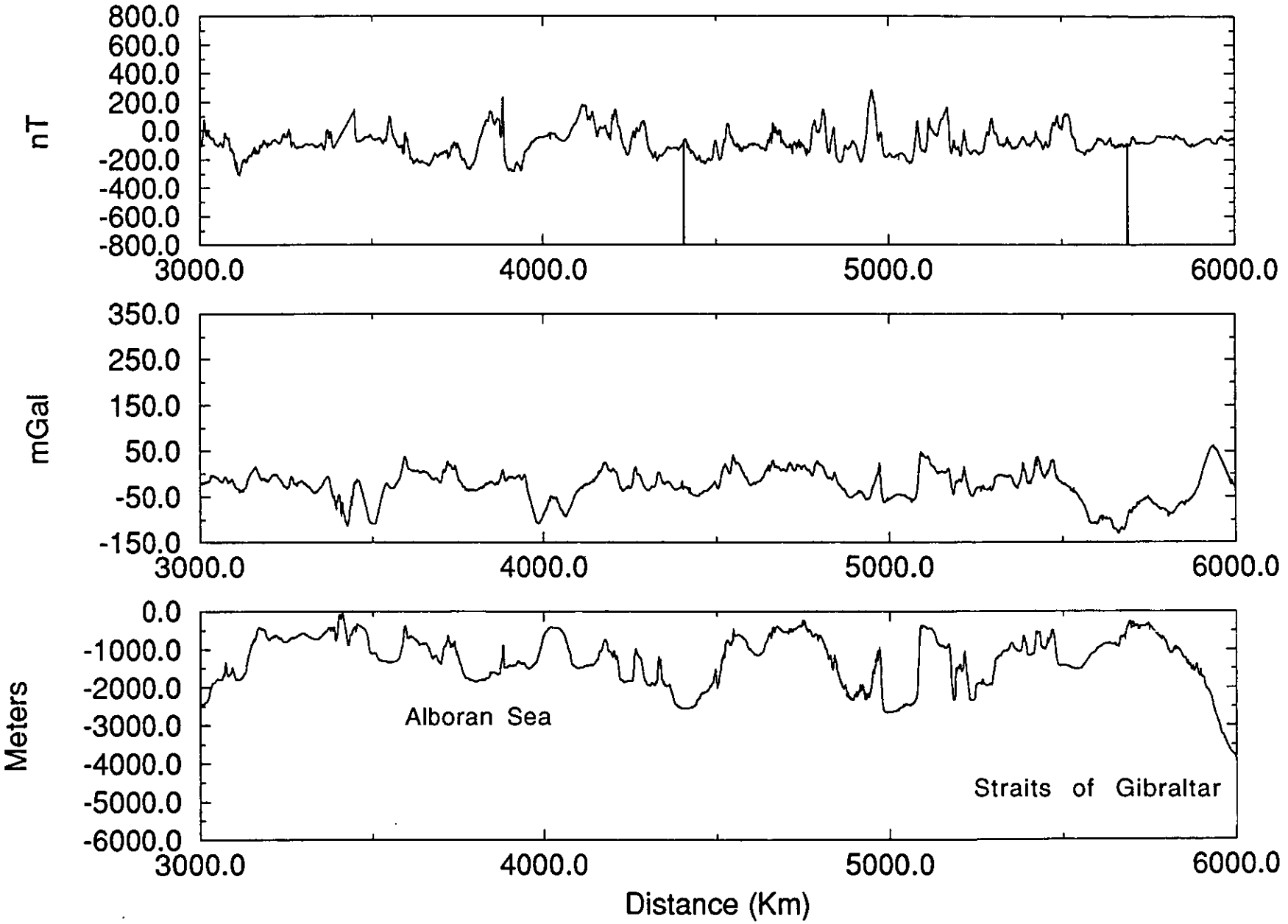
The gravity and magnetic systems worked flawlessly during the cruise.



a)

Figure 5. Topography (lower panel), Free-Air Gravity Anomaly (middle panel), and Magnetic Anomaly (upper panel) along ship tracks. **a)** 0-3000 km along track, **b)** 3000-6000 km along track, **c)** 6000-end of cruise. Prominent features crossed are indicated

b)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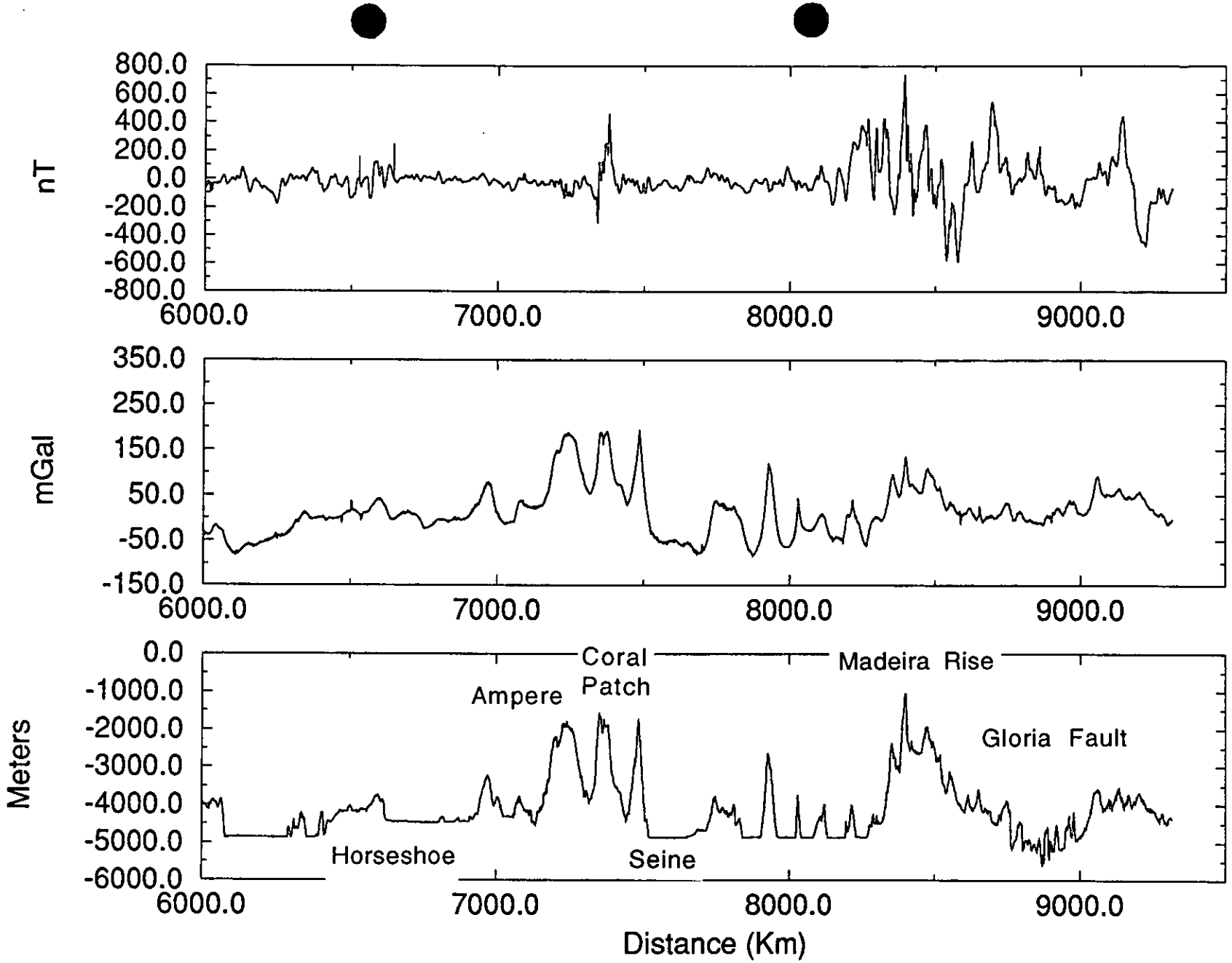
c)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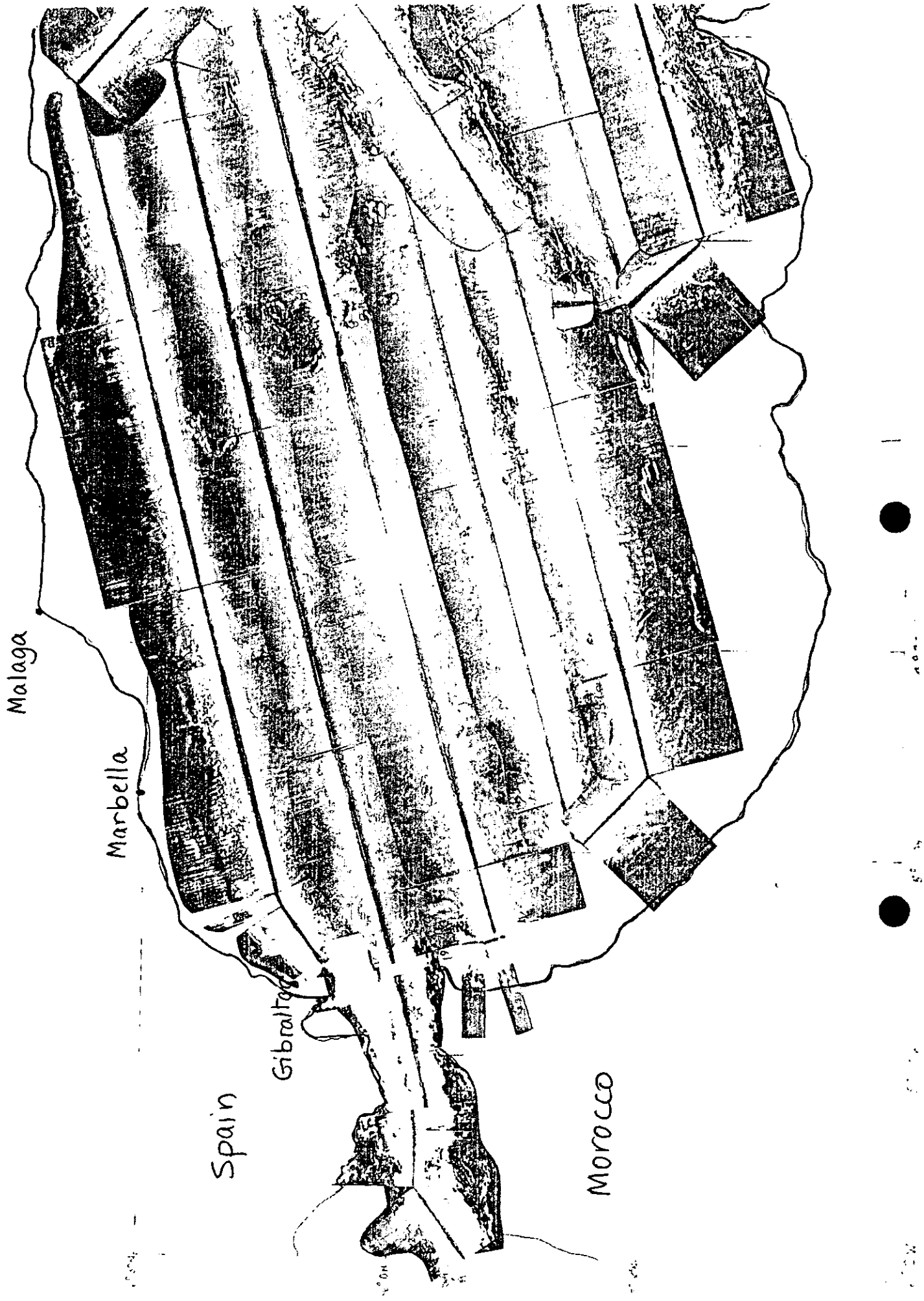
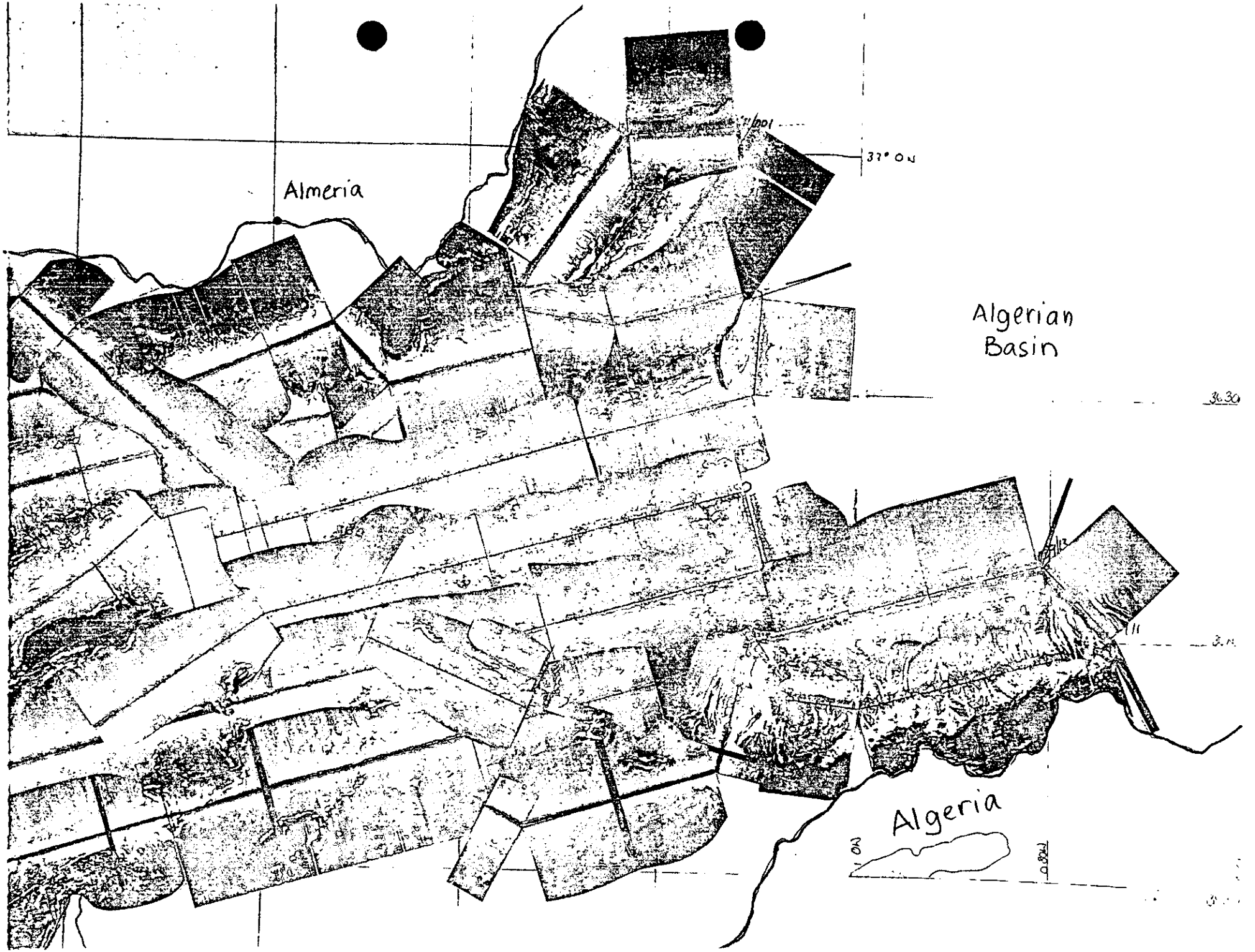


Figure 6. Example of the shipboard GLORIA mosaic for the Alboran sea.


Almeria
Algerian
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Algeria

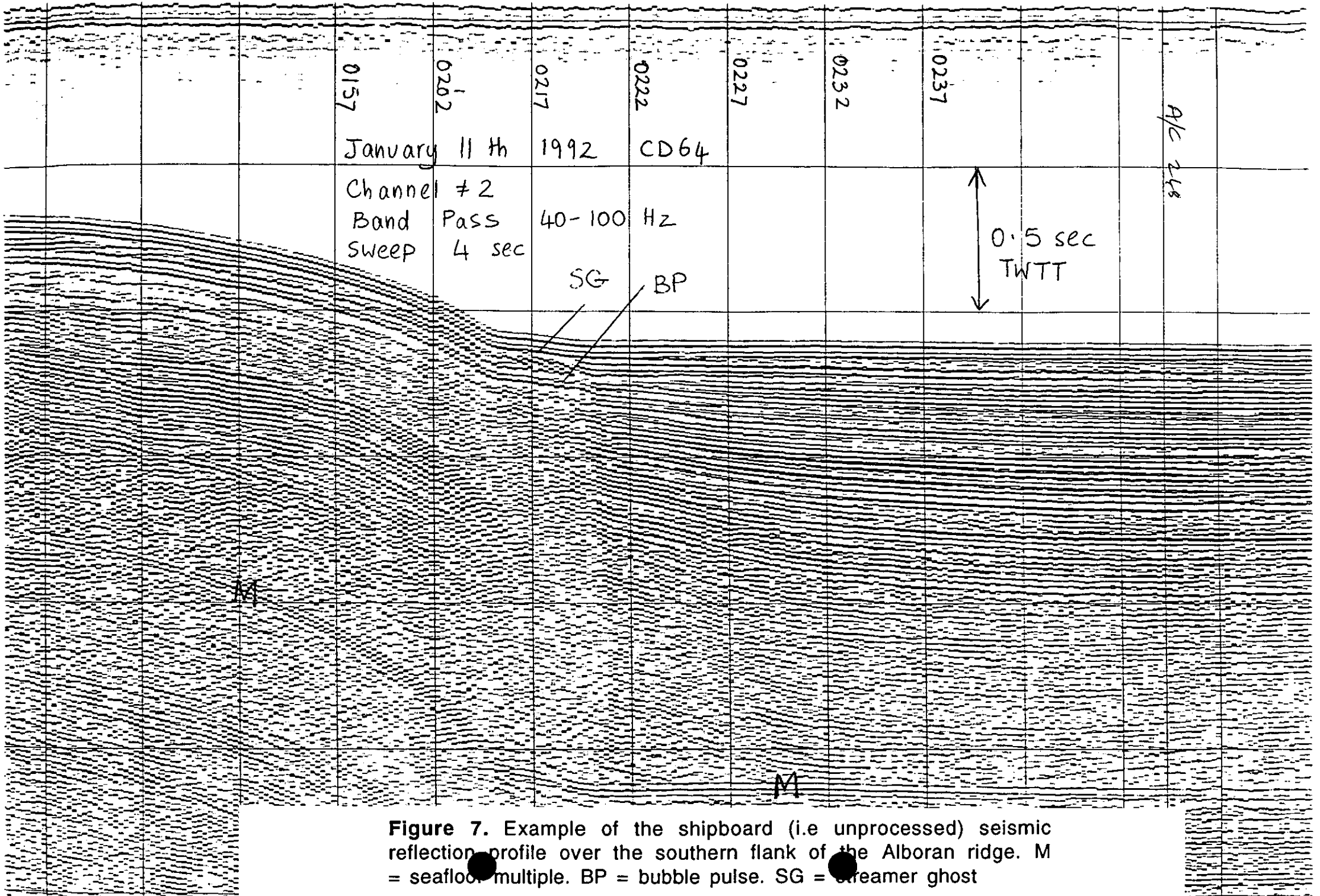

Figure 7. Example of the shipboard (i.e unprocessed) seismic reflection profile over the southern flank of the Alboran ridge. M = seafloor multiple. BP = bubble pulse. SG = streamer ghost