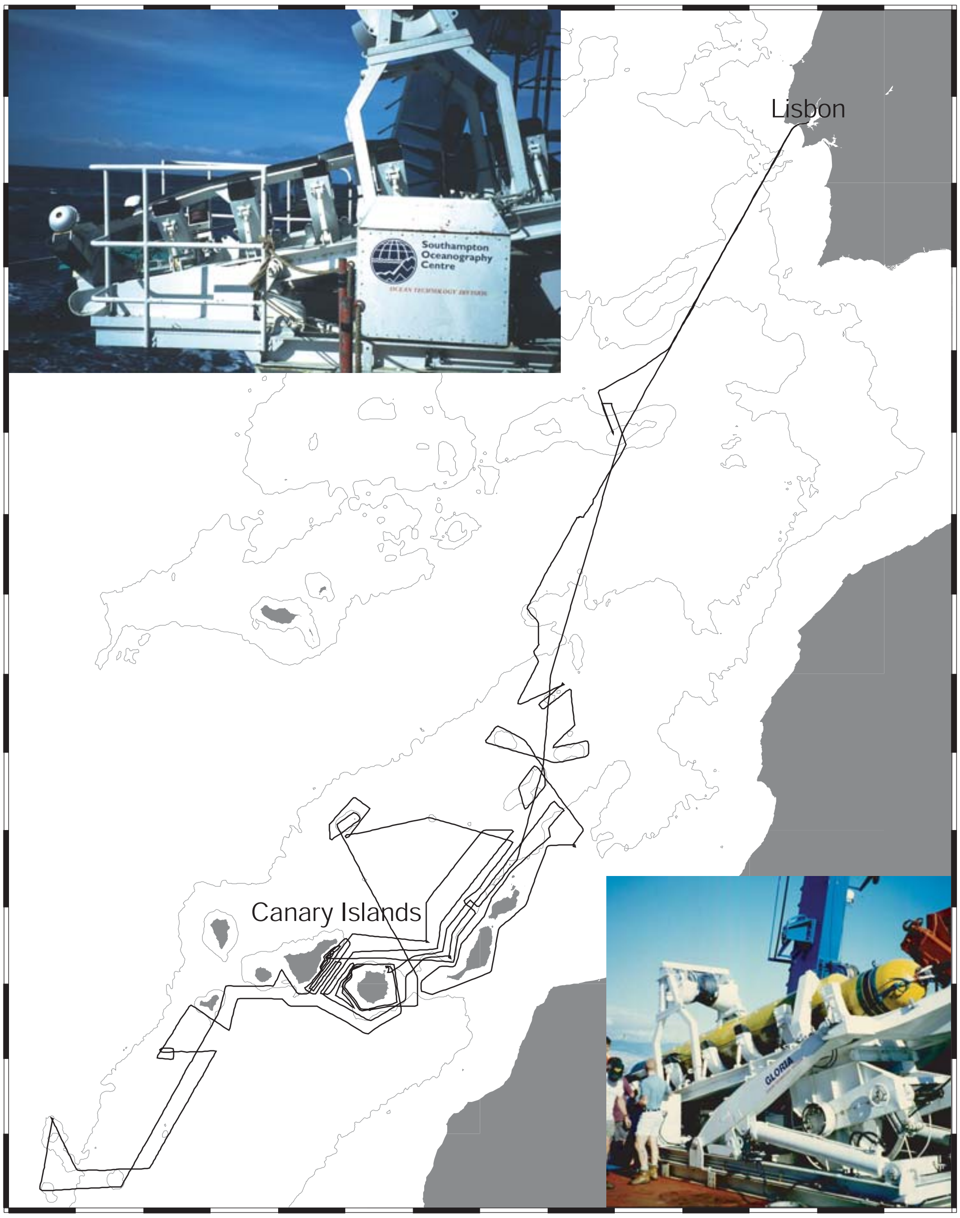
Cruise Report
R.R.S. CHARLES DARWIN Cruise 109

25. Oct. 1997 - 19. Nov. 1997

Lisbon - Lisbon



by

R. Rihm

S. Krastel

and

Shipboard Scientific Party

R.R.S. Charles Darwin CD109 Cruise Report:

R.R.S. CHARLES DARWIN Cruise No.: CD 109

Dates of Cruise: 25/10/97 - 19/11/97

General Subject of Research:

- morphology, structure, origin and evolution of the Canary Island group and adjacent seamounts on the Northwest African continental margin.
- understanding of the constructive and destructive processes during growth of large intraplate volcanic edifices
- estimation of potential hazard of giant landslides

Port Calls: Lisbon/Lisbon

Principal Scientist: R. Rihm

Number of Scientists: 17

Contents

Summary

The research concerns of CHARLES DARWIN Cruise CD 109 were the morphology, structure and origin of the Canary Island group and adjacent seamounts and their evolution on the Northwest African continental margin. The main objective of the cruise was to gain an understanding of the constructive and destructive processes during growth of large intraplate volcanic edifices and an estimate of the potential hazard of giant landslides, which are triggered by volcano flank instabilities and have the potential of creating large tsunamis. The sidescan sonar and bathymetric mapping capabilities of the GLORIA and SIMRAD EM12 systems were used to analyze the dynamic processes that are reflected in the submarine shape of these islands and seamounts. The working area is shown in the track chart (Figs. 1, 2).

1 Research Objectives

More than 90% by volume of a volcanic island (and all of a seamount) is under water, and the morphology and thus the dynamic evolution of such islands are poorly known. Current bathymetric maps do not adequately describe the underwater geometry of the volcanic islands and the seamounts off the Nortrhwest African continental margin and give little information on structural and sedimentological processes. We mapped the submarine portions of the Canary Islands and the adjacent seamounts north and south, using GLORIA (Fig. 3), to assess the morphological expression of the major processes which have shaped them. Foremost was to document and recognize large erosional scarps, the presence of which was suggested by the currently available general topographic maps, and to identify megaslides, similar to those mapped using GLORIA around the Hawaiian Islands and which form a fundamental part of the evolution of these islands (Moore et al., 1989). Huge pieces (up several thousand km^3) in volume have periodically broken off the various Hawaiian Islands, with detached blocks several km across being left on the lower slopes of the islands, and more distal debris flows and turbidites that may extend more than 200 km from the island. Such landslides also generate major tsunamis which pose a huge hazard to the coastal areas of oceanic islands. The Canary Islands are densely populated and are especially vulnerable to such big events. One gigantic slide has recently been found off Hierro Island in the western Canary Islands (Canary Slide, Masson et al., 1992), and indication for a large flank collapse has been found off the NW coast of Tenerife (Watts and Masson, 1995), but not much has up to now been known about the occurrence and frequencies of such landslides at the eastern side of Tenerife, around Gran Canaria, at the eastern Canary Islands and at the numerous seamounts of the region.

The Canary Islands are one end member type of oceanic islands having been built on thick sediments on top of the ocean crust and being characterised by much longer lifetimes (>15 Ma) compared to the Hawaiian Islands (1 to 3 Ma). Sedimentation and large mass wasting events along the continental slope form the long-term dynamic framework into which the large volcanic islands have grown since the early Miocene. This situation is quite different from the evolutionary framework of the Hawaiian Islands, but it is typical along several thousand kilometres off the Northwest African margin.

Cruise CD 109 was thematically connected with the follow-up cruise POS 206, a reflection seismic mapping cruise of the German R/V POSEIDON led by Dr. F. Theilen of the geophysics department of Kiel University. The geographical targets of POS 206 were defined by the GLORIA records of CD 109; the objective was to map some selected landslides in 3 dimensions and study their internal structure.

The objectives of the combined evaluation of these data sets are:

- Estimation of the total mass of selected landslide features and 3-dimensional visualization.

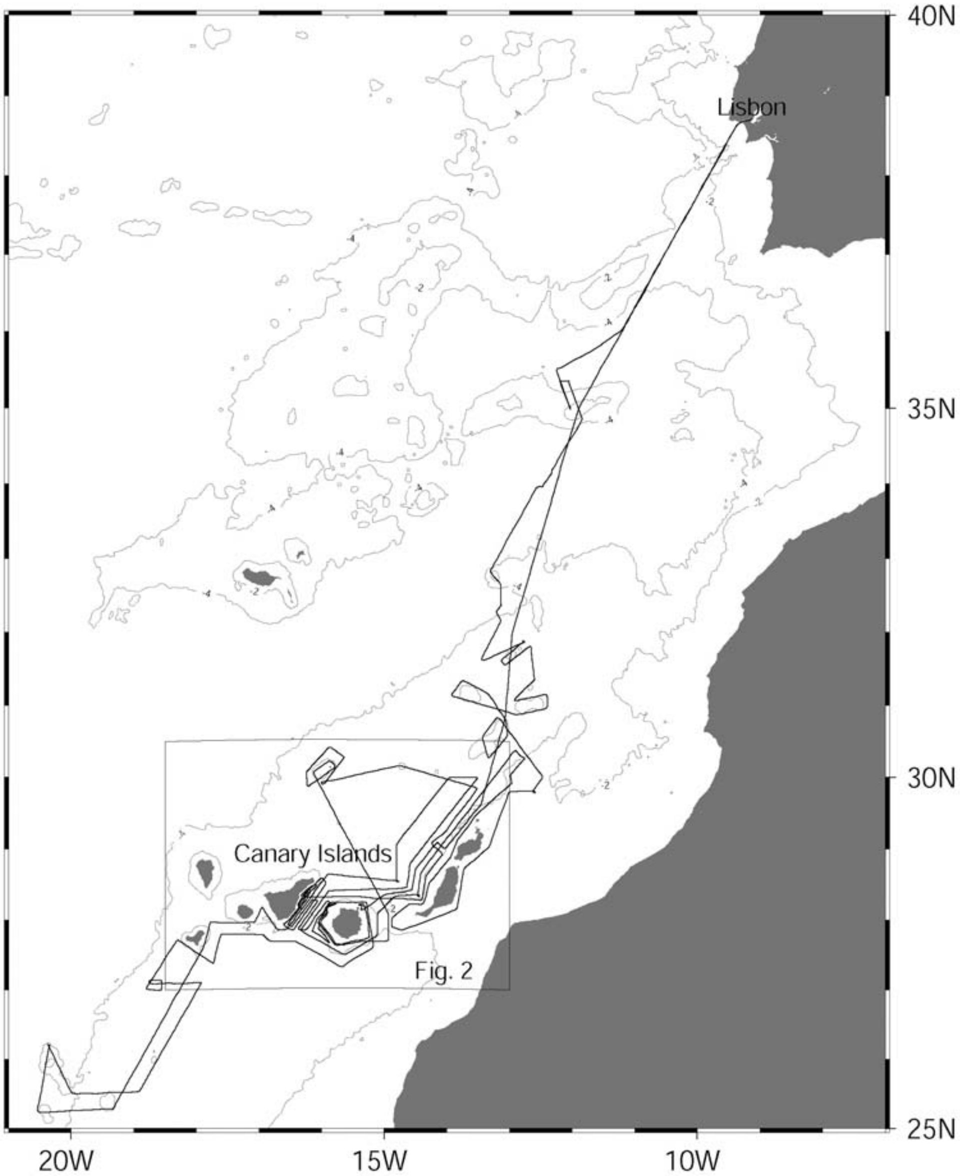


Fig. 1: Trackchart of cruise CD109

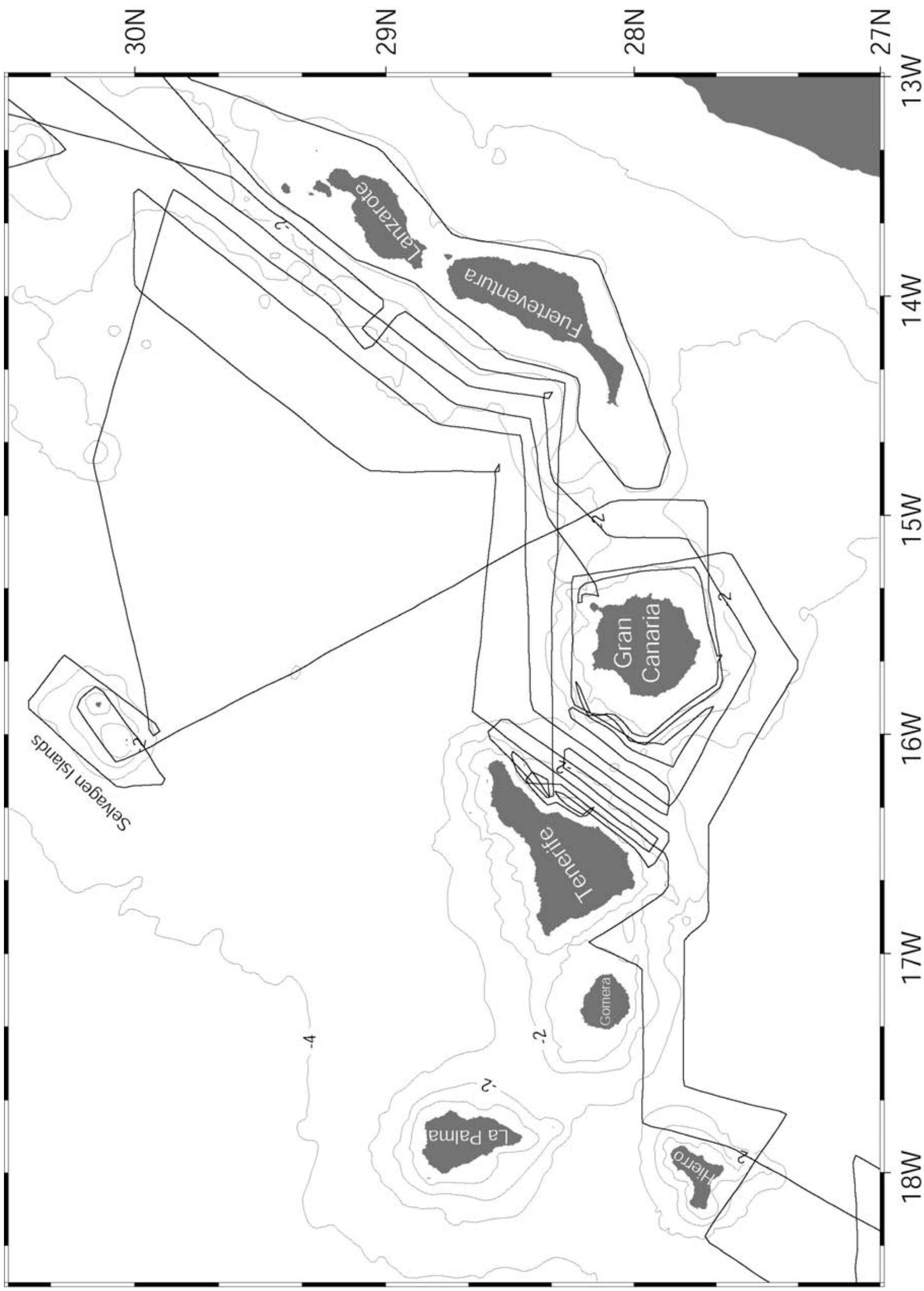


Fig 2: Trackchart in the area of the box in Fig. 1

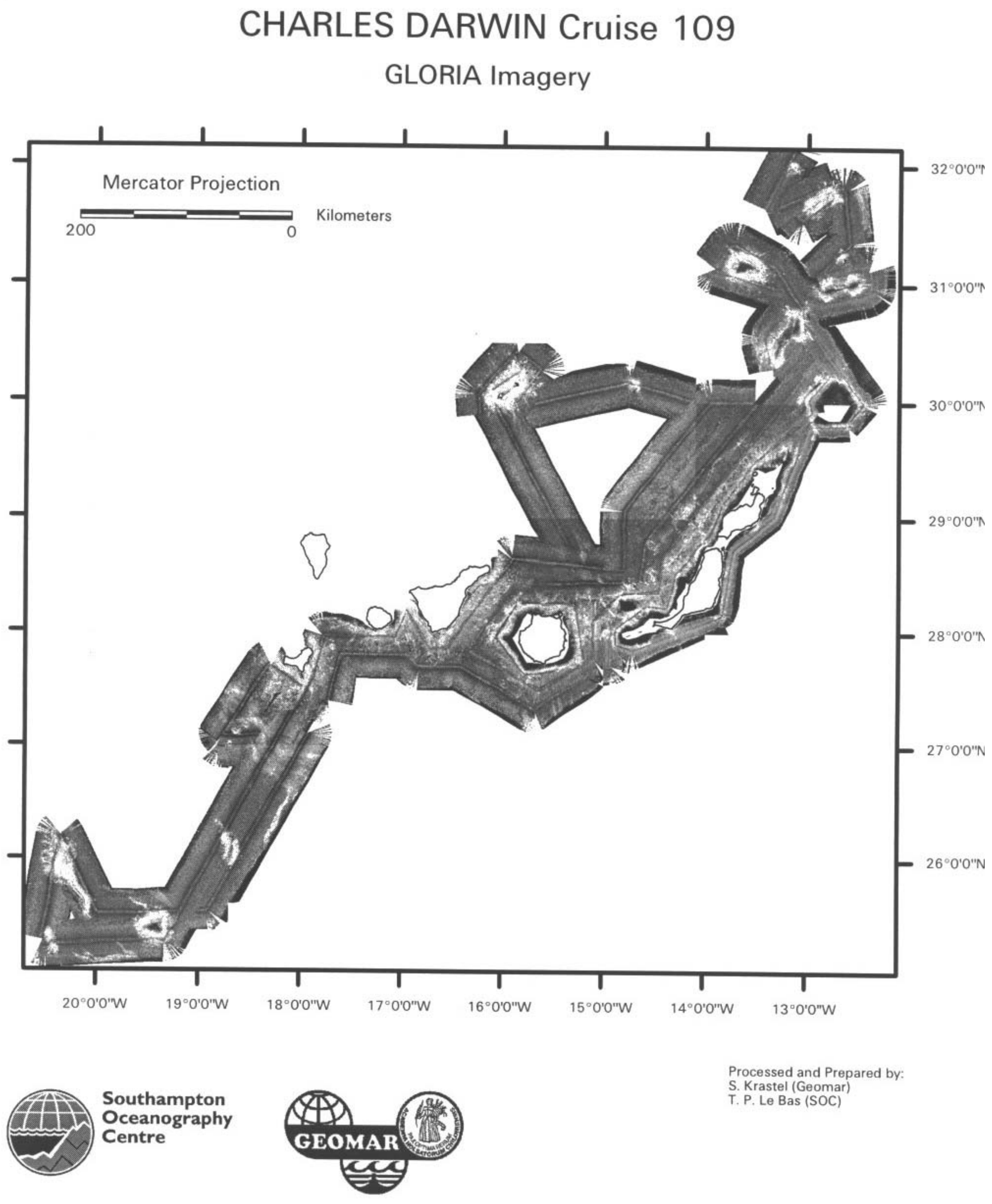


Fig 3: GLORIA Imagery of Cruise CD109

- Evaluation of size and frequency of large landslides off the islands and seamounts of the NW African volcanic province and estimation of the risk for the coastal population of the Canary and Madeira Islands and NW Africa due to tsunamis triggered by such mass wasting events.
- High resolution compositional, temporal, structural and sedimentological analysis of a large volcaniclastic apron surrounding an intraplate volcanic island system and of the more distal abyssal plain sediments.
- Calculation of sediment budgets for the growth, evolution and unroofing of the volcanic edifices of the area.

2 CHARLES DARWIN Cruise Participants CD109

2.1 Scientific Crew

Rihm, Roland (PSO)	GEOMAR
Alibes, Barbara	Univ. Barcelona
Arensmeier, Jens	GEOMAR
Beney, Martin	S.O.C
Bishop, Derek	S.O.C
Campbell, Jon	S.O.C
Jacobs, Colin	S.O.C
Jones, Jeff	S.O.C.
Knight, Gareth	S.O.C
Krastel, Sebastian	GEOMAR
Kröger, Kerstin	GEOMAR
Le Bas, Tim	S.O.C
Morgenstern, Sabine	GEOMAR
Paulson, Chris	S.O.C
Pfeiffer, Tom	GEOMAR
Rosenkranz, Christina	Univ. Hamburg
Whittle, Steve	S.O.C

GEOMAR	GEOMAR Research Center, Kiel University, Wischhofstr. 1-3, 24148 Kiel, Germany
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Univ. Barcelona	GRC Marine Geosciences, Faculty of Geology, University of Barcelona, Campus des Pedrables, E-08071 Barcelona

2.2 Ship's Crew

Plumley, R.C.	Master
Newton, P.W.	C/O
Warner, R.A.	2/O
Mitchell, J.W	3/O
Rant, B.N.	ETO
Mc Gill, I.G.	C/E
Greenhorn, A.	2/E
Slater, G.	3/E
Lutey, W.D.	E/E
Lewis, T.G.	CPOD
Wyness, M.J.	POD
Squibb, M.	SG1A
Thomson, I.N.	SG1A
Perkins, J.R.	SG1A
Buffery, D.G.	SG1A
Bridge, A.M.	POMM
Staite, E.	SCM
Lynch, P.A.	CHEF
Swenson, J.J.	M/STWD
Mingay, G.	STWD
Dillon, C.V.	STWD

3 Description of the used technical systems

3.1 GLORIA - Sidescan sonar system (J. Campbell)

The GLORIA long-range sidescan sonar system (Somers et al., 1978) has been used to map geological features on the seafloor for more than 25 years, in all of the world's major oceans. It uses an 8m long fish towed on 400m of armoured cable. The two sonar arrays are each 5.3m long and comprise 60 transducer elements arranged in two rows. The arrays are inclined at 20° to the vertical, and have beamwidths of 3° in the horizontal and 30° in the vertical planes. The system transmits a 2s pulse every 30s, giving a maximum range of 22.5km per side. The frequencies used are 6.3kHz on the starboard side and 6.8kHz on the port. The pulse employs a 100Hz swept frequency chirp, yielding a BT product of 200. The peak electrical power transmitted is 5kW per side.
The images produced by the system have a range resolution of 50m and an along-track resolution of 125m to 600m depending on the range. The range of the imaging system is approximately 5 times the water depth. The image data has a dynamic range of 12 bits and is archived on Exabyte tapes and CDs.
In recent years the GLORIA system has been upgraded to provide bathymetry data as well as imagery [Le Bas et al, 1996]. By measuring the difference in phase between signals arriving at the upper and lower rows of transducers, it is possible to calculate its arrival angle and combining this with the travel time gives the target's depth and range. The signal processing algorithms to achieve this are still being refined, but the system appears to be capable of measuring depth with a vertical accuracy of 100m and a positional accuracy of 250m.

Operational Problems:
The GLORIA towfish was launched on the morning of day 300 but recovered shortly afterwards when it was discovered that the transmit/receive changeover relays in the towfish were stuck in the transmit position. The towfish electronics package was removed and checked before the problem was eventually traced to the tow cable. This had been re-

spliced shortly before leaving SOC and it seems likely that the splice was not completely watertight, causing the impedance between adjacent cores in the cable to fall dramatically. The remainder of day 300 was spent replacing the tow cable with one of the two spares.

Early on day 301 the towfish was re-deployed and after testing the system, logging commenced at 0842. Data were then logged continuously until 0930 on day 318 without any significant problems.

On days 315 and 316, pulses of noise were observed on the records for periods of a few hours. This noise was probably caused by the towfish snagging a fishing line, which then tapped against the transducers as it was dragged along. When the towfish was recovered there were indeed several long-lines caught around it. Some noise was also produced by a fault in the 3.5 kHz system that resulted in some of the transmission signal getting into the ship's earth and hence other instruments. This fault was rectified at 0030 on day 318.

Images for the on-board mosaics were produced on a 200 dpi, 256 grey-level thermal printer. The rugged topography found in parts of the survey area, sometimes made it impossible to get a perfect slant-range correction in the near range region. Some improvement was obtained by adjusting the correction program parameters, but a different approach is needed in the future to resolve this problem.

Phase difference bathymetry data were also recorded throughout the survey, and considerable effort was put into improving the signal processing algorithms for converting the raw phase data into range/depth points.

Two minor problems were experienced with the data logging; very occasional incorrect time values in the headers, and dropped data blocks during the daily file transfer operation. Neither of these problems is new, and fixes exist for both.

3.2 3.5-KHz High resolution profiling system (C. Paulson)

The 3.5-KHz profiling system is made up of four major components: Raytheon Line Scan recorder, Transceiver, Correlator and Towed Fish.

Swept Signals of between 3 kHz and 4 kHz and 28 ms length triggered by the line scan recorder are transmitted to the Towed fish via the Transceiver. Received signals are passed through an all pass filter which delays the low frequency end of the swept pulse until the high frequencies have caught up, to produce a pulse length of 1 ms which is shaped before being filtered further and being recorded.

In this way ‘chirped’ signals provide the way to produce enough acoustic energy to enable transmission through water in depths exceeding 1500 m.

Operational Problems:

Flashing of the ‘Load Mismatch’ Light and loss of transmit pulse, indicated some progressive failure in the tow cable or slip ring assembly; this was eventually traced to water ingress into the winch slip-ring unit which was cleaned and re-assembled with no further fault problems.

3.3 SIMRAD EM12S-120 Multibeam echo sounder (C. Paulson)

The Simrad EM12S -120 is a low frequency 13kHz Multibeam echo-sounder with full ocean depth capability. It has an angular coverage of 120 degrees with a swath width of up to 3.5 times the ocean depth. For regular sampling of the seabed the beam spacing of the 81 beams is set to being equidistant horizontally to enable the postprocessing system to handle the data easily. Bottom detection is at the beam centres by phase measurement (interferometric principle). Typical accuracies are 0.25% of ocean depth, reduced to 1% in areas of steep slopes.

The transmission sector is stabilised both for roll and pitch with the reception sector stabilised for roll with attitude information provided for by a Hippy 120C vertical reference unit. A calibration run around Coral Patch Seamount calculated the pitch and roll offsets of the VRU at the beginning of the cruise.

Optimum beam pointing is attained by measuring the sound velocity of the surface water using an OTS sound velocity probe mounted inside a tank containing pumped surface water.

Soundings require an accurate measurement of sound velocity, this is done by using an Applied Microsystems Ltd SVP16 self recording sound velocity probe deployed from the starboard gantry whilst the ship is ‘hove to’.

Two measurements were made on CD108 for use both on that cruise and CD109; these were at:

36° 06.9' N 12° 05.5' W (Gorringe Bank / Gettysburg Seamount)
27° 54.7' N 18° 07.2' W (Hierro)

The first profile was used for surveys around Coral Patch, the second profile was used for surveys around the Canaries archipelago. Expendable bathythermograph probes (XBT) were shot daily and converted to sound velocities to check on any divergence from the installed profile.

Operational Problems:

Silt whilst alongside in Lisbon and marine growth fouling whilst surveying around the Canaries necessitated cleaning of the tank and OTS sound velocity probe on two occasions. This fouling caused ‘null’ readings to be fed to the EM12 beam pointing software allowing erroneous soundings to be recorded, the surface sound velocity value was entered manually whilst maintenance to the probe was undertaken.

The logging stopped on 3 occasions and had to be restored by resetting the LAN 1 Port between the Bottom detection unit and the Operator Unit, this was due to the logging system receiving sonar imaging messages of the wrong length in areas of shallow water. This was avoided by ensuring the Operator Unit was continuously in AUTO mode in areas of varying topography.

Fortunately on two of the occasions the data lost was either on a turn or where coverage already existed. On the other occasion the line was repeated.

Loss of outer beams in areas of depths in excess of 3500 metres with speeds greater than 8 knots was traced to a faulty transmitter transducer module in the array causing an overall power reduction of around 5% and resultant loss of coverage. This is not serviceable outside of a dry dock.

3.4 Computing report (M. Beney)

General:

On the cruise the primary role for the computing system was to provide navigation for subsequent integration with the swath data from the EM12. Although the EM12 system reads positions from a GPS receiver, the central computer system reads positions from 3 GPS receivers and uses the speed and heading of the ship to determine the accuracy and hence acceptability of the fixes before generating a final position. The GPS receivers logged were an Ashtech GG24, a Trimble 4000 and a Decca Mk53G.

The Ashtech GG24 receiver collects data from both the Russian Glonass and American GPS satellites and produces a more accurate position. As a consequence of the increased number of satellites available from the two systems the amount of downtime when a position cannot be computed is significantly reduced. However as the two systems are not fully compatible it is necessary for one more satellite to be visible to the receiver than is required with just the one system. The Trimble 4000 uses the American satellites only as does the Decca Mk53G.

The accuracy claimed for each of the systems is summarised below:

GPS	25 metres
Glonass	8 metres
GPS + Glonass	7 metres

Navigation processing:
The GG24 Glonass receiver was chosen as the primary navigation aid. The data output from this receiver is known to produce erroneous values when it cannot compute a position and these were initially filtered out by parsing the logged data file into another file. This was done online.
A graphical editor was used to examine the trace of the Latitude and Longitude values. When the receiver switches between satellite constellation, a spike or offset are normally produced. Spikes were removed and offsets were effectively smoothed by removing the data at the time of these errors. (In practice we do not remove data but reduce it in status. Every data value logged is automatically given a quality status and subsequent processing will only use data which has a status value greater than or equal to the minimum value set by the operator. Hence data removed from one set of processing is still available in the future.)
For each second of the navigation window which was set at 10 seconds for this cruise, the speed and heading were resolved to provide a Northerly and Easterly component. These components were averaged for the window period and the averaged values written to a file.
Starting from a known position the Northerly and Easterly components are used to generate a dead-reckoned position at the next satellite position fix at or after the end of the current navigation window. This satellite position is compared with the dead-reckoned position and if the difference in position is less than the maximum set by the operator, the satellite position is accepted. From the difference in positions, a corrected speed (speed made good) and heading (course made good) is computed and any interim positions at the navigation window interval are generated. The resultant values are written to file.
With the current state of technology and the availability of satellite positions every second, the positions generated in the output file are in the main a subset of the input file.

Depths processing:
The depth from the centre beam of the EM12 swath system was extracted and transferred to a file on the central computing system. The graphical editor was used to remove spikes.
During two short periods when no depth data was available from the EM12, values were read from the paper printout of the 3.5 kHz system. These depths were uncorrected values and were subsequently processed using Carter corrections to produce corrected depths.

Outputs:
The final navigation file, at a 10 second interval, was transferred to the EM12 swath processing system and the positions integrated with the swath data.

A combined navigation and depths file was produced at a 2 minute interval (in dxfmt format and made available for inclusion in the Gloria processing.

A combined navigation (including speed made good and course made good) and depths file was produced at a 1 minute interval in ascii.

4 Onboard Processing of GLORIA (T. Le Bas)

4.1 Swath Bathymetry from GLORIA (Principles)

The basis of swath bathymetry is the accurate measurement of an angle and a time for a reverberation returning from the seafloor. In hull-mounted multi-beam systems a number of pre-defined angles are well known, corresponding to the individual beams, and the time of arrival of the seabed echo along each beam has to be measured. This method requires a large cross-track aperture which is not available in the towed vehicle systems deployed to acquire side-scan images. Here, the only way to measure swath bathymetry is to infer arrival angles as a function of time from measurements of the phase differences between signals arriving at two or more closely spaced rows of receivers. The slant range is known from the time elapsed and thus ground range and depth can be calculated using the angle of arrival. Accuracy of the data is critical on the phase difference. At far range accuracy in phase difference is critical as a small error in angle creates a large error in depth. Errors can eminate from a variety of sources.

There are two problems to be overcome in measuring swath bathymetry by phase difference methods. In the first place the limited aperture means that small perturbations (e.g. due to noise) in the wavefront are fully reflected in differences in measured arrival angle, instead of being averaged over a large aperture. In the second place any attempt to alleviate this problem by using a larger aperture leads inevitably to the ambiguities which arise when the phase difference exceeds 360°.

In applying the method to the GLORIA system it was necessary to use the existing arrays which are spaced more than three quarters of a wavelength apart rather than the maximum unambiguous value of half (Le Bas et al., 1996). The GLORIA system uses a linear FM pulse of 2 seconds duration which also leads to some complications (and advantages) in the processing. Sonar waves returning from the seafloor in a different direction and reflecting off the sea-surface interfere with the main incoming wave front. This alters the phase difference measurement and can lead to considerable mis-calculation, especially for shallow towed vehicle such as GLORIA. Modelling the surface reflection is difficult, as the extra distance travelled by a surface reflection is several wavelengths (Somers et al., 1978). Sea noise also interferes with the returning wave front causing relatively small errors, though the deeper the vehicle the quieter the environment. The broad vertical beam pattern of a side scan bathymetry system receives noise constantly. If the spacing between the two receiving arrays is more than one wavelength the noise at each array becomes statistically independant. Ambiguity in the conversion of phase difference to arrival angle is also possible. If the array spacing exceeds half a wavelength the phase difference can exceed 2. Thus the same phase shift can signify different azimuths. Following the data carefully with a predicted model will remove most of the ambiguity. Data from shadow zones must also be flagged as bad because there is no useful data to be gained. The magnitude of such returns are inevitably small and thus can be used as an indication of bad data.

4.2 Processing and archiving of GLORIA and Swath Bathymetry data

A network of SUN workstations (One SunSparc 20 and two SunSparc Classics) was established onboard with two separate arms: one for logging and the other for processing. One machine was set up as gateway between the two sides. In this way any load on the processing network would not affect the routine logging. This was found later to be essential. All the machines were set up in stand-alone mode and running PC-NFS for communication to PCs.

The processing and archiving of the GLORIA imagery and GLORIA bathymetry was done separately but using similar techniques. The data from the GLORIA console are recorded in one hour data files either for the imagery or FFT (Fast Fourier Transform) I and Q values. Each hourly imagery datafile is about 250kB compared with about 47Mb for the hourly FFT datafiles. At the end of each day these files were then transferred from the logging machine to another disk ready for archive and processing. A problem arose because the transfer used so much bandwidth of the network that the logging occassionally was interrrupted and thus data lost. For each daily transfer about 48 blocks (1024 bytes) were lost, equating to about 4 pings of swath bathymetry. Several methods of transfer were attempted and the most successful was to transfer each of the hourly FFT file separately with a small pause (of 60 seconds) between files. A processing routine was created that handled all the daily transfer and processing functions.

Once the data had been transferred, three archive exabytes were created for the day's data. In this way the raw data are kept and, if required, any processing can be redone. In addition the data were transferred to the processing machine for analysis. A processing routine was created that handled all the daily transfer of data and processing functions.

4.3 GLORIA Imagery for Shipboard Mosaic

There are several stages to processing:

- Concatenate hourly data files into 6 hour data files (for ease of processing and reducing the number of files)
- Convert the format of the data from PC binary data to NetCDF imagery=(.cdf).
- The data was collected in with 12 bit A/D converters. As all processing, display and hardcopy is done with 8 bit data; the data was logarithmically reduced using the usual conversion formula.
- The navigation (via the GLORIA GPS receiver) was extracted and put into a separate datafile.
- Bathymetry data points were then added to the header information on each ping of the imagery.
- Using a flat bottom assumption a slant-range correction was applied making the across-track resolution equal to 50 metres.
- No shading correction was applied at this stage.
- A combination of low pass and high pass filters were applied to remove dropout errors.
- An anamorphic correction was applied thus making each pixel 50m by 50m. For a speed of 8 knots this gives an along track stretch of 3 times.
- A very small low pass smoothing filter was applied to remove the blockiness sometimes seen after anamorphic correction.
- A linear contrast stretch was then applied to the imagery: 0-0 200-255 255-255
- The data was output to file ready for printing on the Raytheon printer (attached to a PC)
- The data was then transferred to the PC and scaling instructions given and the 4 passes printed.

4.4 GLORIA Digital Mosaic Processing

This processing was done separately to the daily processing and was only attempted when all data had been collected for a particular area. The main survey area was divided into eight areas. This was done to reduce the size of the final mosaics (typically about 15Mb).

In addition some different processing steps were applied:

- The vehicle heading was corrected using the latest IGRF.
- A constant shade correction was applied to each segment of data.
- No anamorphic correction was applied as the geographical registration does this automatically
- Filtering of the geographically registered imagery to interpolate between pings. A linear contrast stretch was also applied - the two end points being the 2 s.d points on the grey scale histogram for each image. The adding together of separate segments of data was done using ERDAS Imagine. Final map output was also done using ERDAS Imagine.

4.5 GLORIA Swath Bathymetry

The first requirement of GLORIA swath bathymetry is a reliable velocity profile of the water column. This was extracted from the XBT data and a rayplot diagram plotted. A binary table of angle, time, depth and range was created. It was decided that only one profile would be used at present. Secondly, as the GLORIA swath bathymetry system is affected by surface reflections, a bias curve is required for both port and starboard arrays. To create this curve a piece of seafloor is required with a relatively flat bottom of known depth. An area was chosen and the bias required for each array calculated. Having these correction files and the rayplot dataset, the data can then be processed to produce range and depth imagery. The output datafiles (.bat) were in NetCDF format exactly compatible with the imagery datafiles except the pixel values now represent depth rather than backscatter intensity. In addition, a phase magnitude is recorded and stored in a separate file (.mag).

The CD-ROM archive contains the imagery data (hourly binary files and 6 hourly NetCDF files), the bathymetry data (6 hourly NetCDF files) and the phase magnitude data (6 hourly NetCDF files). All the correction files are also included.

5 Diary of CD109

October 25 - November 19, 1997, Lisbon - Lisbon

Oct. 25	10:00	Departure Lisbon for bunkering.
	16:00	Departure bunker station, heading for Coral Patch Seamount.
Oct. 26		Test of swath bathymetry system (at Coral Patch Seamount). Start of swath bathymetry mapping.
Oct. 27	8:30	Deployment of fish for 3.5 kHz subbottom profiler, start of 3.5 kHz recording.
	11:00	Deployment of GLORIA. Error in recording system detected, no sonar signal available. GLORIA back on board and examined. Short circuit in cable - needs to be exchanged.
	17:00	GLORIA cable exchange.

		During cable exchange heading for WP (waypoint) 1 near "Seamount 1" with speed of 8 Kn (Profile N1).
Oct. 28	4:00	Depth to "Seamount 1" only 617 m, i.e. some 50 m shallower than in bathymetric maps.
	8:30	Redeployment of GLORIA, working OK.
	8:42	Start of GLORIA recording. Mapping Profiles N2 - N8 (North of Canary Islands).
	20:00	Informal meeting on the Why?, the What? (R. Rihm) and the How? (T. Le Bas) of the cruise.
Oct. 29		Mapping profiles N8 - N15 (North of Canary Islands).
Oct. 30		Mapping profiles N15 - N21 (North of Canary Islands). GLORIA shipboard mosaic started.
Oct. 31		Mapping profiles N21 - 28 (East of Lanzarote and Fuerteventura (**E**ast **C**anary **R**idge: ECR)). no landslides, some recent lava flows.
Nov. 1		Mapping profiles 28 - 39 (West of ECR). Indication for large slides off westcoast of S Fuerteventura.
Nov. 2		Mapping profiles 40 - 45 (West of ECR). Indication for NNE striking fault west of Lanzarote Slides off S Fuerteventura are of significant size ("Hawaiian type debris avalanche").
Nov. 3		Mapping profiles 40 - 50 (around Gran Canaria). Little volcano detected E of Gran Canaria. Indication for sediment flow systems S of Gran Canaria, direction to SW. Hijo de Tenerife (little volcano found on METEOR cruise 24) re-encountered in channel between Tenerife and Gran Canaria. The channel is filled with debris mainly from Tenerife.
Nov. 4		Mapping profiles 51 - 54 (West of ECR). Fault off Lanzarote verified, length is approx. 24 km. Debris avalanche off S Fuerteventura extends some 34 km off the coast, largest blocks of >1km diameter; sediment coverage approx. 15 m. Slump off ECR near the waterstrait between Fuerteventura and Lanzarote continuing as debris flow (> 100 km off the coast).
Nov. 5		Mapping profiles 55 - 60 (South of Tenerife and Gomera). Large blocks from Tenerife in channel between GC and TF up to 1 km in diameter. S and SW coast of Tenerife, SE and S coast of Gomera and E coast of Hierro show a variety of landslide deposits.
Nov. 6		Mapping profiles 61 - 63 (southern area, Saharan seamounts). Not much indication for large scale sediment transport. Three of the four mapped seamounts show a peculiar ridge-like feature, appearing to propagate NW or SE, respectively. Distal facies of turbidite current

	and/or debris flows S of Paps and Endeavour seamounts, probably from African continental margin.
Nov. 7	Mapping profiles 63 - 68 (Saharan Seamounts).
Nov. 8	Mapping profiles 68 - 69 and Las Hijas Seamounts. Las Hijas Seamounts, 90 km SW of Hierro identified as very young features. Two volcanic cones, the small one has a conical shape, 4 km diameter and 600 m height, the larger one has 11 km diameter at its foot, 1.6 km elevation above seafloor and shows a ridge-like feature off the NE flank, directing towards a third edifice which is about 3 km across and 400 m high and probably is another small volcano. No indication for mass wasting events can be identified at these seamounts. No indication of sediment was found on either of Las Hijas Seamounts, which might be regarded as the next member of the Canary Islands group to grow like Loihi in the Hawaiian Chain.
Nov. 9	Mapping profiles 69 -76 (South Canary Basin). Major debris avalanches identified both SW and SE off Hierro.
Nov. 10	Mapping profiles 77 - 84 (around Gran Canaria). Many debris blocks between Tenerife and Gran Canaria. Sediment flows N of Gran Canaria
Nov. 11	Mapping profiles 84 - 90 (Selvagen Islands).
Nov. 12	Mapping profiles 91 - 94 (Selvagen Islands to ECR). Selvagen Islands are completely surrounded by debris avalanches, which are older (deeper buried) than those off the larger islands.
Nov. 13	Mapping profiles 95 - 105 (West of ECR and North of Gran Canaria).
Nov. 14	Mapping profiles 105 - 109 (between Gran Canaria and Tenerife).
9:30	End of GLORIA recording. Recovery of GLORIA.
11:00	Continuation of bathymetric mapping along E coast of Tenerife.
Nov. 15	Continuation of bathymetric mapping between TF and GC.
Nov. 16	Continuation of bathymetric mapping South and East of GC.
13:00	Disembarkation of 6 scientists (Las Palmas, Gran Canaria). Continuation of bathymetric mapping West of Fuerteventura. Transit to Lisbon.
Nov. 19 16:00	Arrival Lisbon.

6 Preliminary Results

During CD 109 more than 100 profiles with some 7.000 km total length were obtained with GLORIA side-scan sonar and SIMRAD EM-12 swath bathymetry. Three shallow water target areas were covered with SIMRAD only in order to obtain complete bathymetric coverage for follow-up sampling and reflection seismic work. Some 130.000 km^2 of seafloor were mapped with GLORIA and some 55.000 km^2 were covered by the EM12 multibeam system. Together with the earlier mapped areas in the region of the West Canaries (Masson et al., 1992) a nearly complete side-scan sonar dataset for the Canary Islands and adjacent seamounts is now available.

Major goal of the cruise was to identify large slumps, debris avalanches and flows and other mass wasting features on the flanks of the volcanic edifices and to map their extension.
We identified a large number (> 10) of debris avalanches with blocks of up to 1 km or more diameter transported downslope further than 20 km off the coast. Some debris flows could be traced > 150 km off the coastline. The most numerous and youngest landslides were detected around Tenerife and the young western Canaries, but some, possibly older slides were also detected on the slopes of the older islands of the East Canary Ridge (Fuerteventura and Lanzarote), Gran Canaria and around the Selvagen Islands. The seamounts north and south of the Canaries in contrast did not show any evidence for large mass wasting features.
The ages of the avalanches were roughly determined by their sediment coverage indicated by the 3.5 kHz records and using approximate values for sedimentation rates as indicated by ODP drilling around Gran Canaria (Leg 157, Schmincke, Weaver, Firth et al., 1995). The youngest events are very recent (no sediment coverage). The oldest detectable debris flows in areas where sedimentation rates are low, e.g. around the Selvagen Islands, may be as old as 5 Ma. Older events may be hidden by too thick sediment cover.
Further features relating to the dynamic evolution of the volcanic edifices, i.e. growth and destruction of the seamounts and islands, could be identified in the GLORIA map, such as

a) recent or very young lava flows near the coastlines of Fuerteventura, Gran Canaria and Tenerife,
b) young volcanic cones, two of them in the channels between Gran Canaria and her neighbour islands Tenerife and Fuerteventura, two of them some 90 km SW of Hierro, which were named Las Hijas Seamounts and may represent the next Canary Island in an early deep water stage of growth, and
c) a fault of NE to NNE orientation with a length of 24 km and a maximum vertical offset of 200 m. The North Lanzarote Fault is located 100 km off and parallel to the coast of Lanzarote.

7 Concluding Remarks

CHARLES DARWIN cruise CD 109 was the first example of an international research cruise on a British research vessel led by a German principal scientist based on the trilateral agreement of ship exchange. G. Kortum provided great logistical help to make this cruise happen.
Our thanks go to all funding institutions, especially EU (HCM EASSS program, ERBCHGECT930029) and BMBF (03G0530).
The success of our work very much depended on the close cooperation with Captain Plumley and his crew, especially in view of our frequent change of program reacting to features detected in online recordings. Working with such professionals was a very good experience.

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