THE SIRENA CRUISE

R/V Le Suroit

Ponta Delgada (Azores), May 18th
Brest (France), June, 3rd, 2002.

Cruise Report

Short preliminary version
J. Goslin – Last edited Aug, 30th, 2002

UMR 6538 "Domaines Océaniques"
Institut Universitaire Européen de la Mer
Université de Bretagne Occidentale
29880 Plouzané - France

Report summary

Avant- propos Foreword

La campagne SIRENA est le résultat d'une coopération internationale entre des laboratoires de trois pays, tant au cours de la phase de soumission du projet qu'au cours de la campagne elle-même:

- les laboratoires UMR6538/CNRS à Brest; le Laboratoire de Géophysique Marine de l'IPG Paris and le DASE du CEA à Bruyères-le-Chatel, en France;
- le PMEL/NOAA, à Newport, Oregon aux Etats-Unis;
- le Laboratoire de Géophysique Marine de l'Université de Lisbonne, l'Université de l'Algarve à Faro et l'Université des Açores à Ponta Degada) au Portugal.

La plupart de nos collègues étrangers participant au projet maîtisent bien le Français … même lorsqu'ils étaient soumis aux mauvaises conditions de mer rencontrées dans l'Atlantique Nord au cours de la campagne.Nous avons cependant préféré rédiger ce rapport en Anglais, ce qui permettait d'y inclure directement les contributions de nos collègues américains et nous laisse espérer qu'il sera ainsi plus complètement compris de l'ensemble des membres de l'équipe du projet SIRENA et des personnes extérieures à cette équipe qui souhaiteraient en prendre connaissance.

The planning and achievement of the SIRENA cruise are the result of a cooperation between labs in three countries:

- the UMR6538/CNRS in Brest; the Marine Geophysics Lab of IPG Paris and the DASE of the CEA in Bruyères-le-Chatel, France;
- the PMEL/NOAA, at Newport, Oregon, United States;
- the Marine Geophysics Lab of the University of Lisbon, the University of Algarve at Faro and the University of the Azores at Ponta Degada, Portugal.

Most of our foreign colleagues which took part in the Sirena project got along quite well with French, even while experiencing the excruciating motion of the Suroit in the heavy seas of the North Atlantic …It was however considered preferable to write up most of this report in English, as it will so more easily include the contribution of the US members of the scientific party and in the hope that it will be more fully understandable by all the members of the SIRENA Project Team and by various persons who might want to read it!

Remerciements

L'équipe scientifique embarquée sur Le Suroit pour la campagne SIRENA tient à remercier le Commandant Gilles Ferrand, les officiers et l'équipage pour leur efficacité et leur disponibilité lors de la conduite des différentes opérations à la mer menées durant la campagne.

En particulier, l'équipage de pont s'est très vite affranchi de l'obstacle de la langue (voir ci-dessous au paragraphe III-3, les commentaires généraux sur les opérations de mouillage, rédigés à bord par Chris Fox) et tous les mouillages ont été réalisés très rapidement, malgré les mauvaises conditions de mer qui régnaient lors des quatre premiers mouillages.
Grâce au dialogue toujours facile et efficace entre l'équipe scientifique et l'équipage, qui a permis de modifier "en temps réel" le programme pour l'adapter aux mauvaises conditions météo rencontrées pendant les trois quarts de la durée de la campagne, 95% des objectifs prévus ont pû être atteints.

Nos remerciements vont également à l'équipe technique embarquée de GENAVIR, qui a assuré l'acquisition et l'archivage des données en route. Le sondeur EM300 a confirmé ses performances, même par les grandes profondeurs rencontrées lors des levés de sites.

Des financements de différentes provenances ont permis la réalisation de la campagne Sirena:

- le coût de fonctionnement du navire a été assuré par le Ministère de la Recherche, suite à l'évaluation favorable du projet en 2001 par le Comité Géosciences Marines;
- les coûts de développement, de construction et de mise en oeuvre des hydrophones autonomes ont été couverts par la NOAA;
- les salaires et les frais de missions des membres de l'équipe scientifique ont été payés par leurs pays respectifs (l'Institut National des Sciences de l'Univers et de l'Environnement INSUE a pris en charge ceux des participants français).

Acknowledgments

The scientific party on board *Le Suroit* for the SIRENA cruise wishes to thank Gilles Ferrand, the ship's master, the officers and crew for conducting all cruise operations with great seamanship, efficiency and permanent availability.

In particular, the deck crew quickly overcame the language barrier and all moorings were completed especially quickly (see below in section III-3, the general comments from Chris Fox on mooring operations), in spite of the rather poor weather and sea states encountered during four of the six moorings.
Thanks to the easy and efficient communication between the scientific party and the crew, we were able to adapt the program "in real time" to the poor weather conditions which prevailed during three quarters of the cruise and to reach 95% of the initial objectives.

Our thanks extend to the GENAVIR technical team, who ensured flawless and smooth inflow of along-track data. The EM300 Simrad multibeam confirmed that it could produce good-quality data, even in the deep areas where limited-extension site surveys were conducted before mooring the hydrophones.

Funding from various sources made the Sirena experiment possible:

- the cost of ship time was provided by the French Ministry of Research, after the project had received scientific approval by the "Géosciences Marines" Committee;
- the development of the autonomous hydrophones, their building and deployment costs during the Sirena experiment were provided by NOAA;
- salaries and travel costs were provided to their nationals by the universities and institutions of three countries involved (in France the Institut National des Sciences de l'Univers et de l'Environnement INSUE covered the costs of travels of the French members of the scientific party).

I – General objectives of the SIRENA cruise

Previous cruises on the "Azores hotspot/ridge interactions factory"

Many cruises, ran by various universities or institutions, were devoted in the recent years to study the accretion processes along the Mid-Atlantic Ridge, along a section where this Ridge interacts with the Azores plume. All these cruises (to the exception of the TRIATNORD cruise Goslin et al., 1999) were aimed at sections of the Ridge *south of the Azores.* Moreover, none of these cruises considered the study of the upper mantle structure in a slow ridge/hotspot interaction context as one of its direct objectives.

All of these cruises were part of the "hotspot-ridge interactions" initiatives set within national (such as "Dorsales" in France, "Ridge" in the US) or international ("InterRidge") ridge-study programs. This area of research has been – and still is - very active in the international ridge community and numerous symposia were devoted to it in international meetings (AGU, EUG, AGS).

The autonomous hydrophone technology

The PMEL/NOAA has been developing the technology of mooring autonomous hydrophones (alias "haruphones") in the SOFAR channel for a few years now and has deployed them successfully in the Eastern Equatorial Pacific and in the Central Atlantic. Other deployments are planned in the coming months, in the Gulf of Alaska for example. These deployments have proved the great efficiency of the haruphones for precisely locating low-magnitude earthquakes (as an example, the network deployed south of the Azores was able to record as much as 30 times more earthquakes occurring along the MAR than were recorded by several land stations of the global seismic networks).

For further details on haruphone technology, please link to the web sites:

http://newport.pmel.noaa.gov/geophysics/epr_seis.html

http://newport.pmel.noaa.gov/geophysics/haru_system.html

and read the papers listed below:

Dziak, R.P., and **C.G. Fox** (1999): Long-term seismicity and ground deformation at Axial Volcano, Juan de Fuca Ridge. Geophys. Res. Lett., 26(24), 3641-3644.

Dziak, R.P., and **C.G. Fox** (1999): The January 1998 earthquake swarm at Axial Volcano, Juan de Fuca Ridge: Hydroacoustic evidence of seafloor volcanic activity. Geophys. Res. Lett., 26(23), 3429-3432.

Dziak, R.P., **C.G. Fox**, R.W. Embley, J.L. Nabelek, J. Braunmiller, and R.A. Koski (2000): Recent tectonic of the Blanco Ridge, Eastern Blanco Transform Fault Zone. Mar. Geophys. Res., 21(5), 423-450.

Fox, C.G. (2000): U.S. NOAA underwater acoustic environmental monitoring efforts. Proceedings of the Fifth European Conference on Underwater Acoustics, ECUA2000, M.E. Zakharia, P. Chevret, and P. Dubail (eds.), Lyon, France, 2000, 749-754.

Fox, C.G., and R.P. Dziak (1999): Internal deformation of the Gorda Plate observed by hydroacoustic monitoring. J. Geophys. Res., 104(B8), 17,603-17,615.

Johnson, H.P., H. Hutnak, R.P. Dziak, **C.G. Fox**, I. Urcuyo, C. Fisher, J.P. Cowen, and J. Nabelek (2000): Earthquake-induced changes in a hydrothermal system at the Endeavour Segment; Juan de Fuca Ridge. Nature, 407, 174-177.

Orcutt, J., E. Bernard, C.-S. Chiu, C. Collins, C. deGroot-Hedlin, R. Dziak, **C. Fox**, W. Hodgkiss, W., Kuperman, J. Mercer, W. Munk, R. Odom, M. Park, D. Soukup, R. Spindel, F. Vernon, and P. Worcester (2000): Long-term observations in acoustics. The Ocean Acoustic Observatory Federation. Oceanography, 13(2), 57-63.

Slack, P.D., C.G. Fox, and R.P. Dziak (1999): P wave detection thresholds, Pn velocity estimates, and T wave location uncertainty from oceanic hydrophones. J. Geophys. Res., 104(B6), 13,061-13,072.

I-I Rationale for the deployment of autonomous hydrophones

Six haruphones were deployed in the SOFAR channel in the North Atlantic during the SIRENA cruise (see the general track map in section III for the locations of the mooring sites). At water depths around 1000 meters, acoustic waves generated in the water column by earthquakes – and by marine mammals - propagate to very long distances with a very low signal attenuation. The moorings are located on both flanks of the Mid-Atlantic Ridge (MAR), north of the Azores, between latitudes 40°N and 50.5°N (that is between the Azores Plateau and a major structural discontinuity south of the Gibbs Fracture Zone).

An haruphone network, similar to the one which was deployed during the SIRENA cruise, has been deployed south of the Azores by the PMEL/NOAA between latitudes 17°N and 35°N. This network has been operating since Feb. 99 and will remain active for one more year from now.

It should be noted in this respect that the Azores Plateau is globally shallower than the SOFAR channel in the North Atlantic, especially as the apex of the SOFAR channel was found to be unusually deep in the area of survey, exceeding 1000 meters at some of the mooring sites. It therefore acts as a "barrier" to the sound propagation of the acoustic waves generated by earthquakes whose epicenters are located south of the Plateau. The existence of such a barrier explains that the haruphone network which is presently operated by PMEL/NOAA cannot observe any of the events which originate south of the Azores Plateau. This problem is the main reason which warranted the SIRENA experiment.

The SIRENA cruise objectives (two main objectives and an ancillary one) are based on a very accurate determination (better than 2 km) of the epicenters of the earthquakes occurring along the Mid-Atlantic Ridge. Such a precise determination will be made possible by the data recorded by the hydrophone network.

The objectives are the following:

I.I.1 - To contribute to the understanding of active processes at the axis of mid-oceanic ridges.

Recent studies of the accretion processes active at the axes of slow ridges, whether based on field studies (e.g. Thibaud et al., 1998) or on the interpretation on analog or numerical models (e.g. Mauduit & Dauteuil, 1996) have promoted the now well-accepted image that spreading results from a succession, in time and space, of magmatic and tectonic episodes. In such an image:

- most of the magma output is focused near the centers of ridge segments (e.g.. Bell & Buck, 1992; Cannat, 1995), consequently resulting in the emplacement of a thick crust, while spreading at segment ends would be mostly tectonic. Focusing of magma output near the segment centers could be the result of the presence of mantle diapirs, or occur during the magma upwelling itself (Magde et al., 1997).
- added to these spatial variations in the magma output, variations in time would also occur: long cooling periods (a few Ma) would separate relatively short “hot episodes” (typically less than a million years, according to Tisseau & Tonnerre, 1995). Tectonic processes would be dominant during the long cooling periods.

If confirmed, such time- and space-variations in the magmatic activity along the axis of the ridge will bear direct consequences on the rheology of the lithosphere and crust, influencing in turn the stress regime and the distribution of deformation, which would be therefore also variable with time and space (see e.g. Dauteuil & Brun, 1996 ; Thibaud et al., 1999).

The above hypotheses, mainly derived from structural and petrological observations, await to be confirmed "directly" by geophysical arguments. For example:

- it has been proposed (Durand et al., 1995) that, near the segment centers, the deformation would occur across a limited number of large faults forming the rift valley walls, while it would be distributed near the segment ends over a greater number of smaller-thrust faults – some of which being found on the ridge flanks at some distance from the active ridge-. But this remains largely an open question, awaiting for a direct observation of the distribution of the seismicity at the segment's scale.
- moreover, while field observations allow to localize the faults and to quantify their total thrust, they bring only indirect arguments on their present activity: which faults are presently active? has this activity lasted for a long time? has it been recurrent along a small fraction of the total number of faults?

Unfortunately, the low magnitude earthquakes occurring at the axes of active ridges very often escape recording by land seismological stations, located too far away from the epicenter locations. It is therefore very difficult (if not outright impossible) to relate the epicenter locations provided by global networks to even major ridge features (such as active segments, transform and non-transform axis discontinuities).

Recently conducted experiments, involving the deployment of haruphone networks, have allowed to pinpoint the location of epicenters with a precision better than 2 km for the earthquakes occurring within the networks and are therefore perfectly fit to reach this first objective.

To reach this first objective, trying to relate seismic activity to small-scale structural features along the ridge axis, the recording of EM300 multibeam bathymetry data over sections of the ridge axis where next to no multibeam data are available in the public domain, is extremely useful. This warranted the "ridge axis survey" (see section IV-2 below).

I.I-.2 - To get some insight into ridge / hotspot interaction processes in the upper mantle

Global geoid grids, derived from satellite-altimetry data, provide information on the upper mantle structure in the medium- to long-wavelengths. On the other hand, the density geochemical sampling of the MAR has recently increased, though this sampling remains largely limited to the North to 45°N (e.g. Goslin et al., 1999 ; Dosso et al., 2000). It has therefore become tempting to try to link mantle heterogeneities (as could be accessed by the two above-mentioned techniques) to accretion processes at the segment's scale, as were derived from surface observations. A first attempt to establish correlations between "surface" and "deep" observables (Goslin et al., 1998) has prompted the need for a high-resolution tomographic model of the upper mantle, allowing to characterize heterogeneities in the upper mantle (uppermost 200 km) at the segment's scale, under the recent domain of the North Atlantic north of the Azores.

It is to be noted that global tomography models, derived from the inversion of teleseismic data recorded at land stations belonging to global networks, represent the only direct information on the distribution of the velocities (and hence, of the densities and temperatures) in the upper mantle. Unfortunately, available recent models (such as those of Ritsema et al., 1999 or of Mégnin & Romanowicz, 2000) do not provide a sufficient horizontal resolution for the upper mantle (their resolution is less than 1000 km for depths shallower than 150 km, and they are not reliable at all in the first 50 km). Moreover, while they compare well enough at longer wavelengths, their global nature itself can induce major differences between them at more local scales.

The inversion of travel-time anomalies of the first arrivals of seismic waves, generated by earthquakes which occur at the mid-Atlantic Ridge axis and recorded by distant land stations, should allow to make significant progress towards the computation of a regional high-resolution model of the upper mantle. Work has begun at UMR6538 (DEA A. Kielius, 2000) to obtain such a model under the North Atlantic, by inverting the travel-time residuals along the raypaths between ridge earthquakes and distant land stations. However, only a small fraction of the earthquakes are of sufficient magnitude to be recorded by a significant number of stations, and therefore precisely localized. In the absence of a independent mean of localization of smaller, more numerous, earthquakes, this brings a tight limitation to the efficiency of the above method. Indeed, inverting land station data simultaneously for the epicenter location and for the upper mantle velocity structure rapidly degrades the resolution of the latter.

Precisely-determined epicenters from the haruphone network will therefore greatly improve the reliability of the inversion in terms of upper mantle structure. Such a high-resolution model will certainly be a major advance towards the understanding of ridge-hotspot interaction processes active in the upper mantle.

I.I.3 - By observing time-variable along-ridge seismicity north of the Azores and by comparing it to the seismicity observed within the Azores archipelago itself, to contribute to the assessment of **the seismic hazard in the Azores archipelago**.

Bell, R.E. & Buck, R.W., 1992. Crustal control of ridge segmentation inferred from observations of the Reykjanes Ridge. Nature, 357, 583-586.

Cannat, M., 1996. How thick is the magmatic crust at slow-spreading ridges ? J. Geophys .R., 101, 2847-2857.

Dauteuil, O. & Brun, J.-P., 1996. Deformation partitioning in a slow-spreading ridge undergoing oblique extension (Mohns Ridge, Norwegian Sea). Tectonics, 15, 870, 884.

Dosso, L., Bollinger, C., Etoubleau, J., Bougault, H. & **Goslin, J.**, 2000 - géochimie de la dorsale médio-atlantique au nord des Açores (40°-45°N). RST Paris, 17-20 avril 2000.

Durand, C., Gente, P. & Dauteuil, O., 1995. Caractéristiques morphologiques des segments axiaux de la Dorsale Médio-Atlantique. C. R. Acad. Sci. Paris, 320, 411-418.

Goslin, J. & the TRIATNORD Scientific Party, 1999 - Extent of Azores plume influence on the Mid-Atlantic Ridge north of the hotspot. Geology, 27, 991-994.

Goslin, J. , Thirot, J.-L., Noel, O. and Francheteau, J., 1998. Slow-ridge / hotspot interactions from global gravity, seismic tomography and 87Sr / 86Sr isotope data. Geophys. J. Int., 135, 700-710.

Kielius, A., 2000. Structure thermique de la lithosphère et du manteau supérieur sous la dorsale médio-Atlantique déduite de l'analyse des temps de trajets des ondes sismiques (application à la zone TRIATNORD au nord des Açores). U.B.O. juin 2000.

Kong, L. S., Solomon, S.C. & Purdy, G.M., 1992. Microeartquake characteristics of a mid-ocean ridge along-axis high. J. Geophys. R., 97, 1659-1697.

Magde, S.G., Sparks, D.W. & Detrick, R.S., 1997. The relation between buoyant mantle flow, melt migration, and gravity bull's eyes at the Mid-Atlantic Ridge between 33°N and 35°N. Earth Planet . Sci. Lett., 148, 59-67.

Mauduit, T. & Dauteuil, O., 1996. Small-scale models of oceanic transform zones. J. Geophys. Res., 101, 20195-20209.

Mégnin, C. & Romanowicz, B., 2000. The three-dimensional shear velocity structure of the mantle from the inversion of body, surface and higher-mode waveforms. Geophys. J. Int., 143, 709-728.

Ritsema, J., Van Heijt, H.J. & Woodhouse, J.H., 1999. Complex shear wave velocity structure imaged beneath Africa and Iceland. Science, 286, 1925-1928.

Silveira, G., Stutzmann, E., Griot, D.-A., Montagner, J.-P. & Mendes Victor, L., 1998. Anisotropic tomography of the Atlantic Ocean from Rayleigh surface waves., Phys. Earth Planet. Int., 106, 257-273.

Thibaud, R., Dauteuil, O. & Gente, P., 1999. Faulting pattern along slow-spreading ridge segments : a consequence of along-axis variation in lithospheric morphology. Tectonophysics, 312, 157-174.

Thibaud, R., Gente, P. & Maia, M., 1998. A systematic analysis of the Mid-Atlantic Ridge morphology and gravity between 15°N and 40°N : constraints on the thermal structure. J. Geophys. R., 103, 24223-24243.

Tisseau, C. & Tonnerre, T., 1995. Non steady-state of spreading ridges : implications for melt generation and mantle outcrops. In : Mantle and lower crust exposed in ridges and ophiolites. Vissers, R.L.M. & Nicolas, A., eds. Kluwer Acad. Press, 181-214.

Toomey, D.R., Solomon, S.C. & Purdy, G.M., 1988. Microearthquakes beneath the median valley of the Mid-Atlantic Ridge near 23°N : tomography and tectonics. J. Geophys. Res., 93, 9093-9112.

Finally, the haruphones will also record the sounds produced by large marine mammals, thus allowing to evaluate the distribution between various species of whales and to locate major whale herds. This piggy-back experiment on SIRENA is conducted by PMEL, in cooperation with the University of the Azores at Ponta Delgada, as part as an environmental **monitoring program of marine mammals in the world's oceans.**

I-2 Along-track data recorded along transits between mooring sites

Mutibeam soundings, scalar magnetic data and gravity data were recorded continuously along the transits between morring sites and during two dedicated survey (see below section IV).
The EM300 multibeam performed remarkably well, taking into account the poor sea conditions. A fairly long processing work is to be contemplated, to eliminate spurious pings before a reliable DEM can be computed over the ridge axis. Such a processing work was completed onboard for the sites surveys (see figures in section III below).

I-3 Installation of a seismic station on Graciosa Is.

A temporary seismic station was set up on the northern coast of Graciosa Is. (Azores) to operate during the duration of the SIRENA experiment. The station installation was done by J. Perrot and Luis Matias (Geophysics Lab., University of Lisbon) in the days just preceding the beginning of the cruise. The final site selection benefited from the help of F. Piserchia from DASE/CEA, who performed, at Bruyères-le-Châtel, a real-time analysis of the noise spectra recorded at different tentative sites (see section V at the end of this report for the site selection details).

This station will hopefully record T-waves (seismic waves converted from the acoustic waves travelling in the SOFAR channel). The north of Graciosa Is. indeed appears as a good choice for the installation of a T-wave recording station as the slope north of this island is both steep and relatively regular down to depths of the center SOFAR channel

Another possible favorable site would be Corvo Is., offering the additional advantage of "opening" the angle of the network to the Southwest. If logistical problems can be solved, it is contemplated to install a second seismic station on Corvo Is., even if the small size of this island will probably increase the wave noise on the seismic records.

Data from the station "Aero" (named because of its proximity to Graciosa's airfield…) are regularly transmitted and analyzed in Brest and in Bruyères-le-Châtel.

II – List of participants

Members of the SIRENA scientific party

GOSLIN Jean goslin@univ-brest.fr	geophysics	UMR 6538 -Brest
BAZIN Sara bazin@ipgp.jussieu.fr	geophysics/seismology	Lab. Géosciences Marines. IPG Par
BENTO SAN MIGUEL Rita ritasanmiguel@yahoo.com	biology of marine mammals	Univ. of the Azores (Ponta Delgada)
FOX Christopher fox@pmel.noaa.gov	geophysics/acoustics	PMEL/NOAA Newport (Oregon)
LOURENCO Nunõ m15894@fc.ul.pt	qeophysics/tectonics	Geophysics lab. Univ. of Lisbonne
LUIS Joaquim jluis@ualg.pt	geophysics	Univ. of Algarve (Faro)
MATSUMOTO Haruyoshi matsumoto@pmel.noaa.gov	Hydrophone technology	PMEL/NOAA Newport (Oregon)
PERROT Julie Julie.Perrot@univ-brest.fr	geophysics/seismology	UMR6538 – Brest
ROYER Jean-Yves jyroyer@univ-brest.fr	geophysics	UMR6538 -Brest

GENAVIR Team : shipboard science support group

Name, First N	
CAGNA Renaud	Real-time data recording
GUYAVARCH Pierre	‘’
SERVE Henri	‘’

CREW members

Gilles FERRAND	Captain	Erwann TANGUY	Seaman
Gérard BOURRET	Chief Mate	Jean-Michel SIMON	Seaman
Marc SOUCARET	Mate	Louis HNANGANYAN	Seaman
Paul-Henry VIMBERT	Mate	Yvon LE PORS	Chief Oiler
Hervé TALLEC	Chief Engineer	René ROBION	Oiler
Eric COLIN	First Engineer	Jean-Pierre LE CORRE	Electrician
Gérald BENETON	Electronics Officer	Marcel LIQUETTE	Chief Cook
Claude HERVY	Boatswain	Philippe DEBEAUVAIS	Chief Stewart
Viseio TAGATAMANOGI	Able Seaman	Jacques FRIANT	Second Cook
Yann FLOCH	Able Seaman	Franck TERNON	Stewart
Jean-Jacques DONNART	Seaman	Didier AGNERAY	Steward

III- Cruise operations

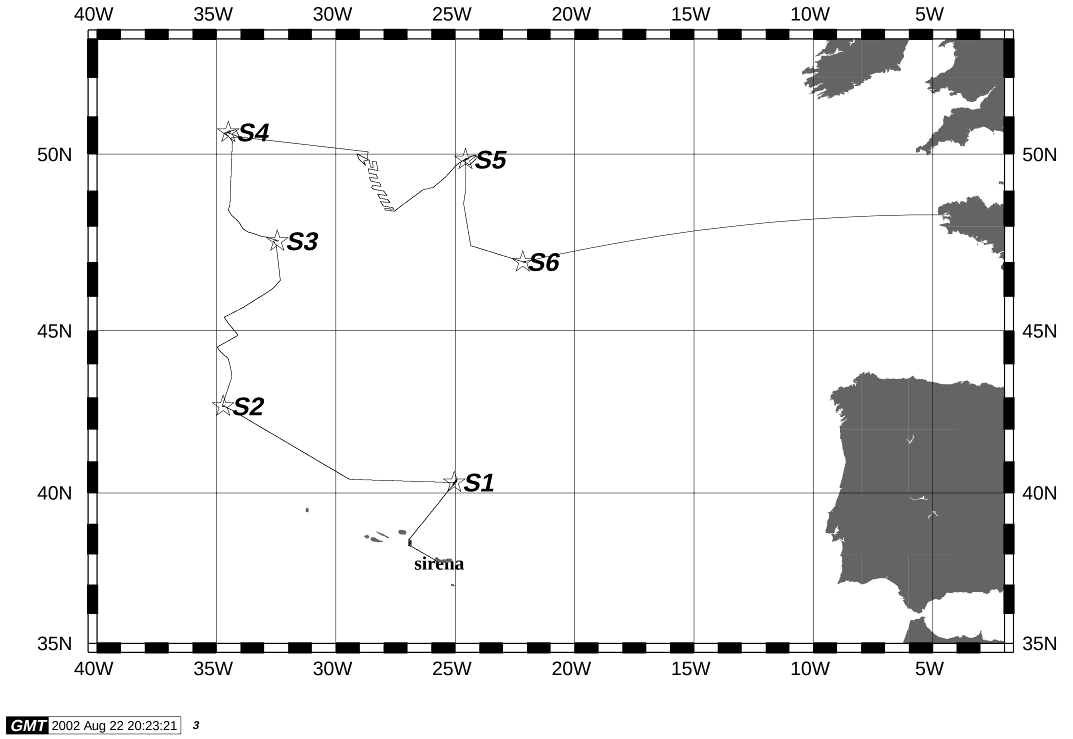

Figure III-1-1: *Le Suroit*'s tracks during the SIRENA cruise

Just after sailing from Ponta Delgada, 6 hours were devoted on the night of June 18th to conduct a limited-extension 100%-coverage multibeam survey SE of Terceira Is. (Azores) (see below section IV-1) and 3.75 days were devoted to a wide-spaced survey of the ridge axis between sites S4 and S5 (see section IV-2 below).

III.1 Short cruise log

(Hours are GMT)

Day 1 - Saturday, May, 18th, 2002
- left Ponta Delgada (Azores) at 11:30 and sailed W-NW towards **bathymetric survey ESE of Terceira Is.**
- begin survey at 18:00. Finished survey at 24:00 and begin transit towards deployment site S1. SW wind 7 to gale 8 during the night.

Day 2 - Sunday, May, 19th, 2002
- transit towards S1 in strong 7/8 SW wind

- begin surveying possible deployment site at 12:43 by running reciprocal profile. The ship strongly pitches in 4-5m waves
- buoy and hydrophone in water at 17:00. Length of mooring: 2300 m.
- anchor dropped at 18:05 (**Site S1: 40°20.259'N, 25°02.233'W**)
- start of hydrophone ranging by pinger at 19:00. No signal from acoustic release (noisy conditions due to the poor sea state and pinger too close to the ship's propeller). Stop trying to range at 21:32.
- start transit to site S2 at 22:30

Day 3 - Monday, May, 20th, 2002
- transit to site S2, through point at 40°26'N, 29°26'W (just south of the TRIATNORD '98 survey). Northwesterly wind 28 to 33 kts, backing west in the afternoon. Strong pitch.

Day 4 - Tuesday, May, 21rst, 2002
- continuing transit to site S2. Strong northwesterly wind 35 kts with strong gusts. Waves 5 to 6 m. Speed reduced to less than 5 kts during most of the day because of extremely severe pitch.

Day 5 - Wednesday, May, 22nd, 2002
- wind decreases during the night. Speed increased to 10.5 kts. Able to maintain a speed above 9 knts to site S2, in spite of sustained high seas.
- buoy and hydrophone in water at 17:40. Length of mooring: 3000 m.
- anchor dropped at 18:27 (**Site S2: 42°43.022'N, 34°43.366'W**).
- start of hydrophone ranging by pinger at 19:305. Only a few pings from acoustic release . Mooring probably receded ENE towards buoy by 1km. Stop trying to range at 21:35
- start transit to site S3 at 21:49

Day 6 - Thursday, May, 23rd, 2002
- continuing transit to site S3. Wind slightly coming down to force 6 after mid-day. Ship rolls heavily in still heavy seas (4 to 5 m waves from the NW. The master decides to tack about the direct course to avoid even heavier roll.

Day 7 - Friday, May, 24th, 2002
- begin bathymetry survey at site S3 at 12:22. Going with the wind and reducing speed to 6 kts allows to get good multibeam image.
- float in water at 14:08
- anchor dropped at **site S3 (47.°35.596' N; 32°27.258'W)** at 15:00.
- start ranging at 16:00
- stopped ranging at 17:53. Unreliable ranges due to strong ship motion and loud noise on the pinger. En route towards site S4. Wind is up again between 32 and 36 kts again and the Suroit rolls heavily. Dishes and unsecured chairs fly by!!!

Day 8 - Saturday, May, 25th, 2002
- transit to site S4. Wind down to force 6 . Calmer seas in the afternoon allow to sail direct course towards site S4

Day 9 - Sunday, May, 26th, 2002
- begin magnetic survey (to pinpoint chron13) and bathymetry to hunt for a deployment site at 00:38.
- 09:01 float in the water
- 10:21 dropped anchor at **site S4 (50°34.529N, 34°29.998W)**. Course 190.

- - lost EG&G pinger while trying to range hydrophone (pinger line got caught in the ship's screw while trying to hold the ship on station). Bentos pinger continues to refuse to receive any usable signal when deployed from either side of the fantail.

- start eastward transit towards the MAR axis along a flow-line at 15:35

Day 10 - Monday, May, 27th, 2002
- begin **survey of the ridge axis** at 10:30. Force 7 wind makes it difficult to design a track plan to avoid excessive ship motion. "Compromise" tracks are preferred: when the ship sails close-hauled, it pitches heavily and speed has to be reduced quite a bit to keep the multibeam image correct; everything is much more comfortable (for the EM300 and for those on board...) when the Suroit sails before the wind on reciprocal profiles.

Day 11 - Tuesday, May, 28th, 2002
- continue survey of the ridge axis southwards. As the ridge axis is now oriented north-south, it becomes somewhat easier to sail east-west profiles.

Day 12 - Wednesday, May, 29th, 2002
- continue survey of the ridge axis southwards. The westerly wind picks up again and the ship pitches heavily on the westward profiles. The ship's speed has to be drastically reduced (down to 4 kts or less at times) along some of these to keep an interpretable signal on the multibeam. The ridge axis survey covers latitudes between 50°N and 48°20'N
- start transit towards waypoint WP5 (start of the search for a good spot to deploy hydrophone #5).
- Arrive on WP5 at 23:55

Day 13 - Tursday, May, 30th, 2002
- search for a flat spot to deploy by passing over three deeps and running a mag survey to locate anomaly 13.
- 08:30 float is over the side
- 09:24 anchor dropped at **site S5 (49°51.253 N; 024°34.443 W)**
- 11:00 tried to range the release with Benthos box. In spite of flat seas and reduced ship movement, no success, even when position over the estimated anchor location!!!
- 12:13 stopped to try to range S5 and depart for S6 (through waypoints SM4, SM6 & SM7). Between SM7 and S6, follow a flow-line.
- wind picks up from the East to 16 kts in the afternoon (if it stays there we will be sailing against the wind for the return transit: many people on board the Suroit start to consider this weather situation as both exceptional and totally unfair!).

Day 14 - Friday, May 31rst,, 2002
- start deployment at site S6. Buoy in the water at 12:30
- anchor dropped at 13:04 at **site S6 (47°00.020N; 22°10.040W)**
- magnetometer deployed at 14:01. Start return transit to Brest

Day 15 - Saturday, June 1rst,, 2002
- on transit to Brest. Light westerly to northwesterly wind (6 kts) at last! Three whales are seen at very short distance at the ship's bow (a few meters) after breakfast. BarBQ party on the fantail to celebrate the Chief Engineer’s retirement: Sirena has really been a windy last cruise indeed…).

Day 16 - Sunday, June 2nd, 2002
- on transit to Brest.

Day 17 - Monday, June 3rd,, 2002

- pilot on board at 08:00
- docked in Brest at 08:30

III-2 The autonomous hydrophones developed by the PMEL/NOAA

The instruments which were deployed have been developed by the PMEL/NOAA in Newport (OR).

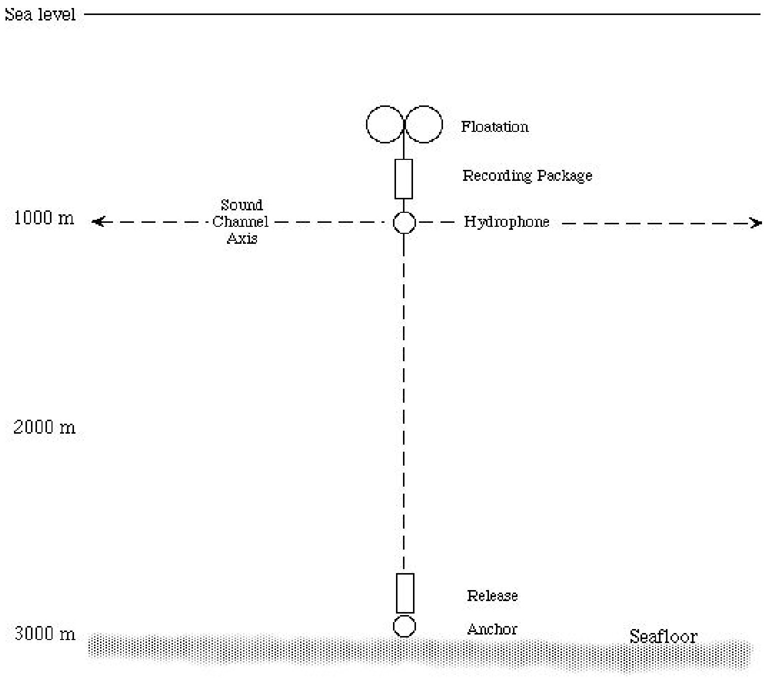

Figure III-2-1: *Schematics of the hydrophone moorings used during the SIRENA cruise*

The SIRENA cruise will be followed up by a second cruise during which the instruments will be retreived. If possible, that is if a third final recovery cruise can be organized, this second cruise would become a turnover cruise, during which the instruments would be serviced and re-deployed at the same sites, following data media retrieval and power supply change.

The recovery/turnover cruise SIRENA-ROM (SIRENA- Recovery Or Maintenance) is, for the time being, planned on NERC R/V Discovery from Sept, 11th to Oct, 5th, 2003. Ship time for SIRENA-ROM is scheduled in the framework of an exchange of ship-time between European Oceanographic Institutions (IFREMER and NERC).

III-3 Deployment particulars

Comments on Hydrophone Deployments on SIRENA
Christopher Fox, NOAA/PMEL
2 June 2002

The deployment of six digital hydrophone moorings from N/O/ Le Suroit during SIRENA was completed successfully with only a few difficulties. *Le Suroit* performed exceptionally well, thanks to the competent and professional officers and crew. Despite its relatively small size, the ship is highly capable with great maneuverability and a well designed after deck for mooring operations. The deck department and bosun deserve special recognition for their smooth operations, accomplishing the entire deployment in only about one hour for a typical 3500 m mooring. The ship handling from the bridge was outstanding as was the coordination with the fantail operations. The scientific support was also excellent, with quality multibeam

and sound speed products to aid in site selection and a state-of-the-art computer network onboard. There were no mechanical failures during the cruise and the food and steward services were superb.
This vessel is a real credit to IFREMER and France.

The only failure during the operation was our inability to accomplish acoustic ranging on the anchor releases to define a precise position of the mooring. It is unclear the source of failure, but was almost certainly due to problems on the U.S. side of the operation. Several new pieces of hardware and software were in use and one of these could be the source of the problem. Also, the relatively rough seas may have generated excessive acoustic noise in the frequency band of interest. Also due to the rough seas, the ship was required to perform more active maneuvering to remain on station and this may have put more sound in the water. Finally, the inability to stop the rotation of the ship's primary screw both introduced noise and resulted in the loss of one ranging hydrophone that was caught in the screw. We plan to check out all of the possible software/hardware sources of failure in the coming year and will be able to derive precise positions on the next cruise prior to releasing the current moorings to the surface.

The final caution deals with the ship's size and sea state during this year's operation. Although we were successful, conditions were marginal for deployment. The sea states were not particularly high (3-4?) and would have been no problem from a larger ship. More importantly, if this cruise had involved either recovery or servicing (recovery and redeployment) of the moorings, as will be the case next summer, it is not clear that we would have been successful due to sea state. The inability to stop the main screw would also present a real danger to the recovery operation. I would recommend, if possible, the use of a larger vessel and a delay in operations to a later weather window to ensure success next year.

Additional comments on Hydrophone Acoustic Ranging on SIRENA
Haruyoshi Matsumoto, NOAA/PMEL
2 June 2002

Due to unexpected hardware/software problem with a new Benthos acoustic surface unit, none of the mooring positions were determined using the long baseline acoustic ranging method. However, based on our past experience, we are certain that all the mooring positions were about 1/7 to 1/10 of the total cable length behind the ship where the anchor was dropped. In 2002, we will have three more hydrophone deployment cruises. We will be better acquainted with the new acoustic ranging system and anticipate no difficulties locating the acoustic releases in the next turn-around (recovery) cruise scheduled in 2003.

Data logging parameters (apply to all):

Sampling speed	-	250Hz
Data size	-	2 byte (12-bit resolution)
Number of hard disks	-	3 (8GB each - 24GB total)
Gain	-	switch setting of "0"
Anti-aliasing filter	-	110 Hz
Program name	-	noaalogger2 version 1.5 (6/29/2002)

All hydrophone's hardware were checked normal with nominal power consumptions. The instruments are expected to record the acoustic signal continuously for 1.5 years.

DEMs computed after the site surveys conducted near sites S1 to S6 are shown below the deployment summary, on pages 20 to 26.

1st deployment ***Site S1 (40°20.259'N, 25°02.233'W)***

Hydrophone name - H26
Date - 5/19/2002 18:05 GMT
Anchor drop position - 40°20.259'N, 25°02.233'W
Ship course - 252 degrees
Cable length - 2300 m (1000m Vectron, 1000m VLS, 200m VLS, 100m VLS)
Bottom depth - 3357m
Acoustic release - Benthos 1045

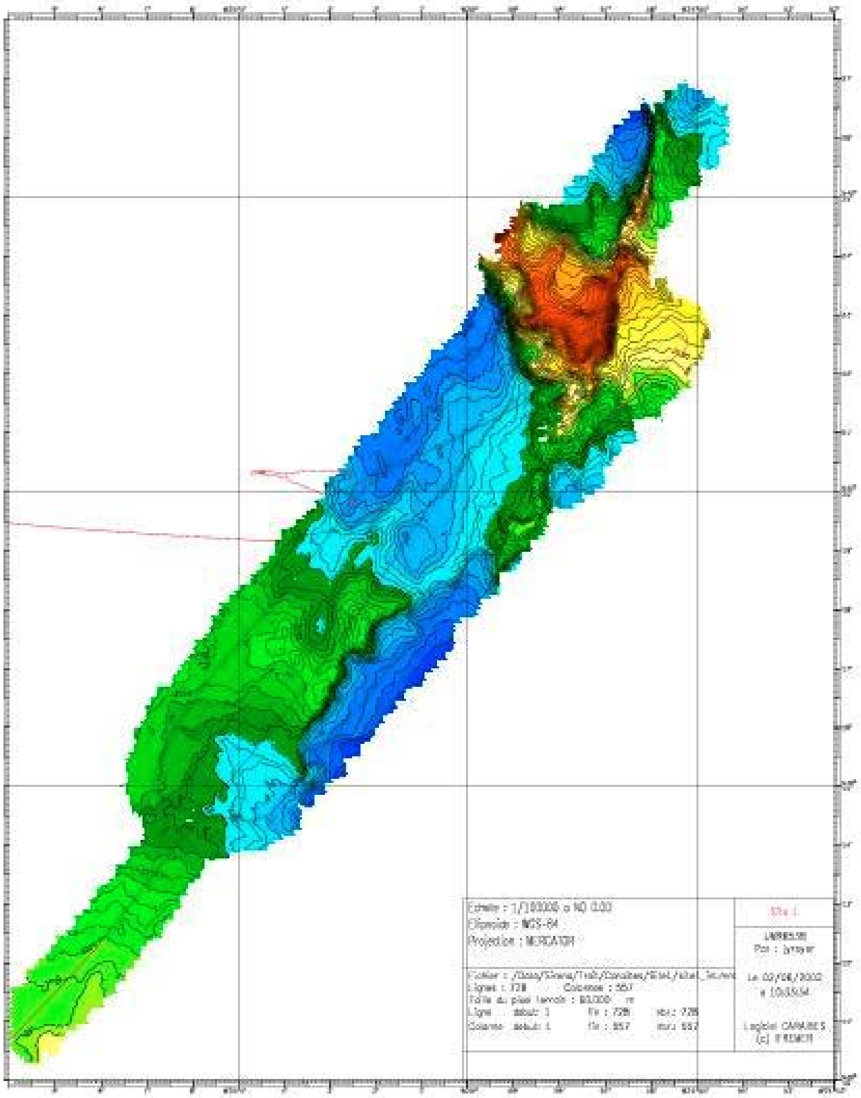

Figure II-3-1: *EM300 site survey near site S1. Mooring was deployed while sailing SW and the anchor therefore probably receded 500/600m towards the northeast from the anchor splash point.*

2nd deployment ***Site S2 (42°43.022'N, 34°43.366'W)***

Hydrophone name	-	HS6
Date	-	5/22/2002 18:27 GMT
Anchor Drop position	-	42°43.022'N, 34°43.336'W
Ship course	-	235 degrees
Cable length	-	3000 m (1000m Vectron, 2000m VLS)
Bottom depth	-	3976 m
Acoustic release	-	Benthos 1051

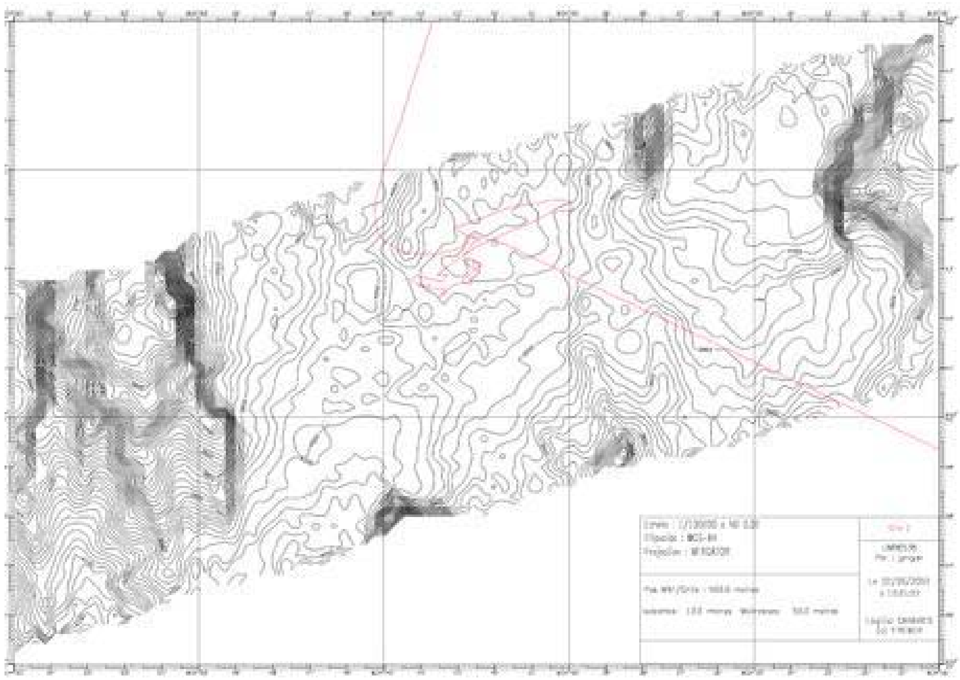

Figure II-3-2: *EM300 site survey near site S2. Mooring was deployed while sailing S/SW and the anchor therefore probably receded 600/800m towards the north/northeast from the anchor splash point.*

3rd deployment **Site S3 (47.°35.596' N; 32°27.258'W)**

Hydrophone name	-	H19
Date	-	5/24/2002 15:00 GMT
Anchor drop position	-	47°35.596'N, 32°27.258'W
Ship course	-	254 degrees
Cable length	-	3400 m (1000m Vectron, 2000m VLS, 200m VLS, 200m VLS)
Bottom depth	-	4442m
Acoustic release	-	Benthos 1046

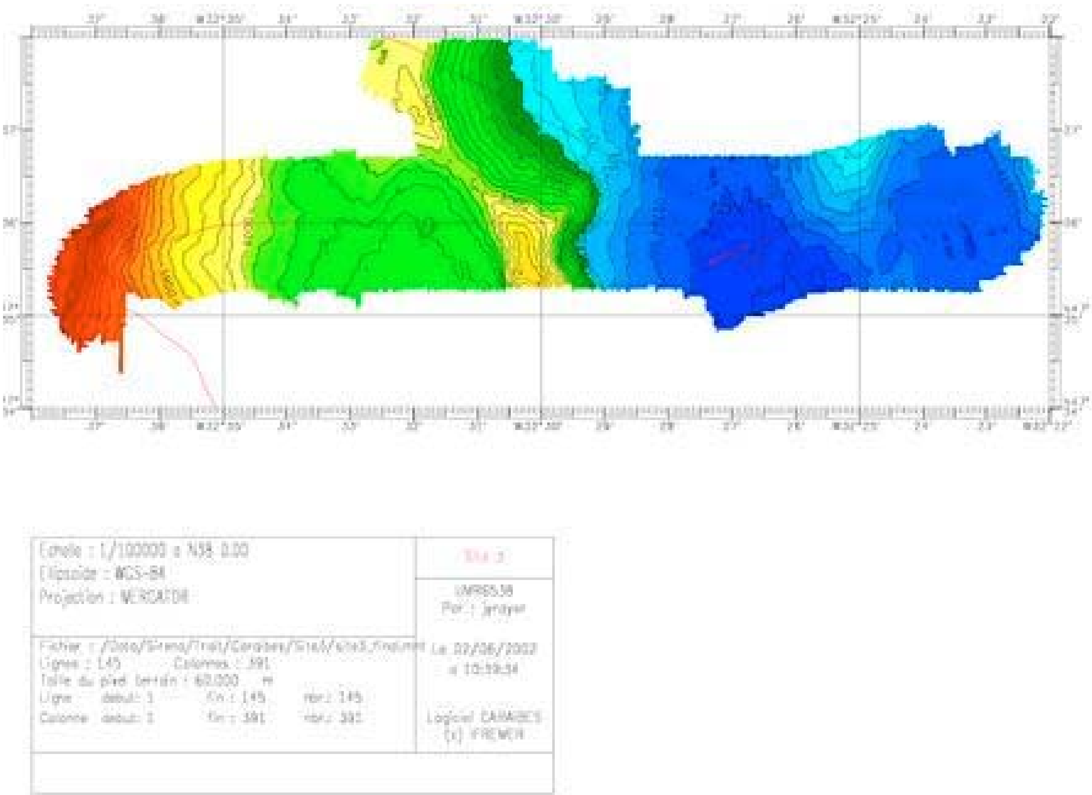

Figure II-3-3: *Merged EM300 and cable-laying multi-beam survey track near site S3. Mooring was deployed while sailing S/SW and the anchor therefore probably receded 700/800m towards the north/northeast from the anchor splash point.*

4th deployment Site S4 (50°34.529N, 34°29.998W).

Hydrophone name	-	HS8
Date	-	5/26/2002 10:21 GMT
Anchor drop position	-	50°34.529'N, 34°29.998'W
Ship course	-	209 degrees
Cable length	-	3500 m (1000m Vectron, 2000m VLS, 500m VLS)
Bottom depth	-	4200 m
Acoustic release	-	Benthos 1048

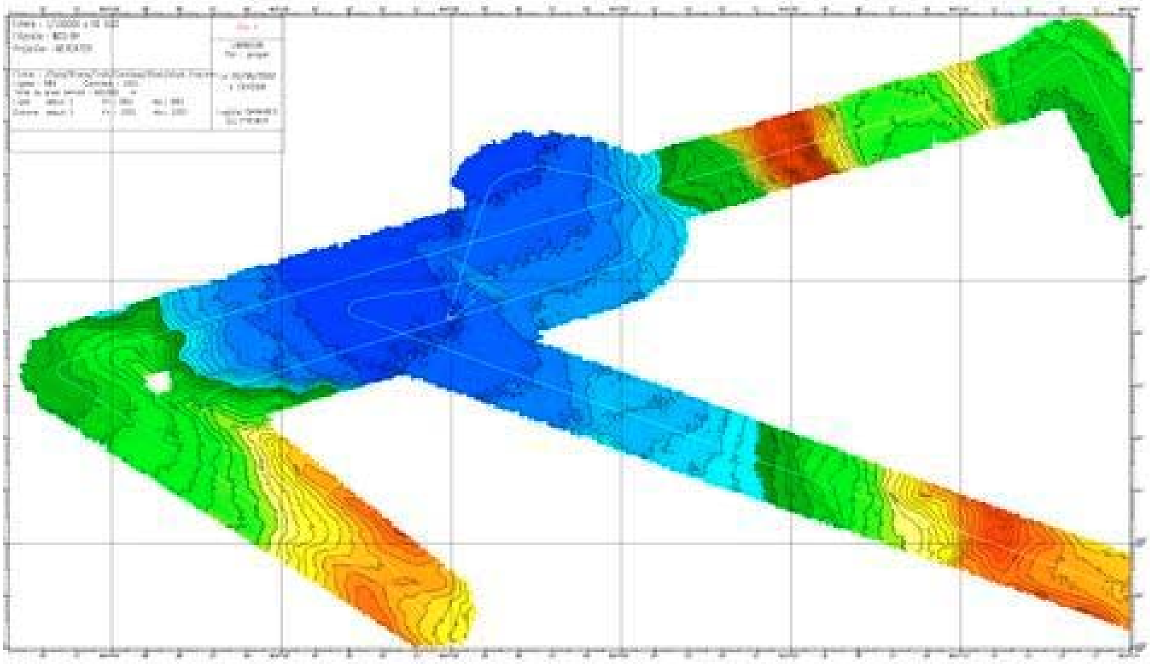

Figure II-3-4: EM300 site survey near site S4. Mooring was deployed while sailing W/SW and the anchor therefore probably receded 700/800m towards the northeast from the anchor splash point.

5th deployment Site S5 (49°51.253 N; 024°34.443 W)

Hydrophone name - HS5
Date - 5/29/2002 09:22GMT
Anchor drop position - 49°51.253'N, 24°34.443'W
Ship course - 240 degrees
Cable length - 3400 m (1000m Vectron, 2000mVLS, 200mVLS, 200mVLS)
Bottom depth - 4200m
Acoustic release - Benthos 1050

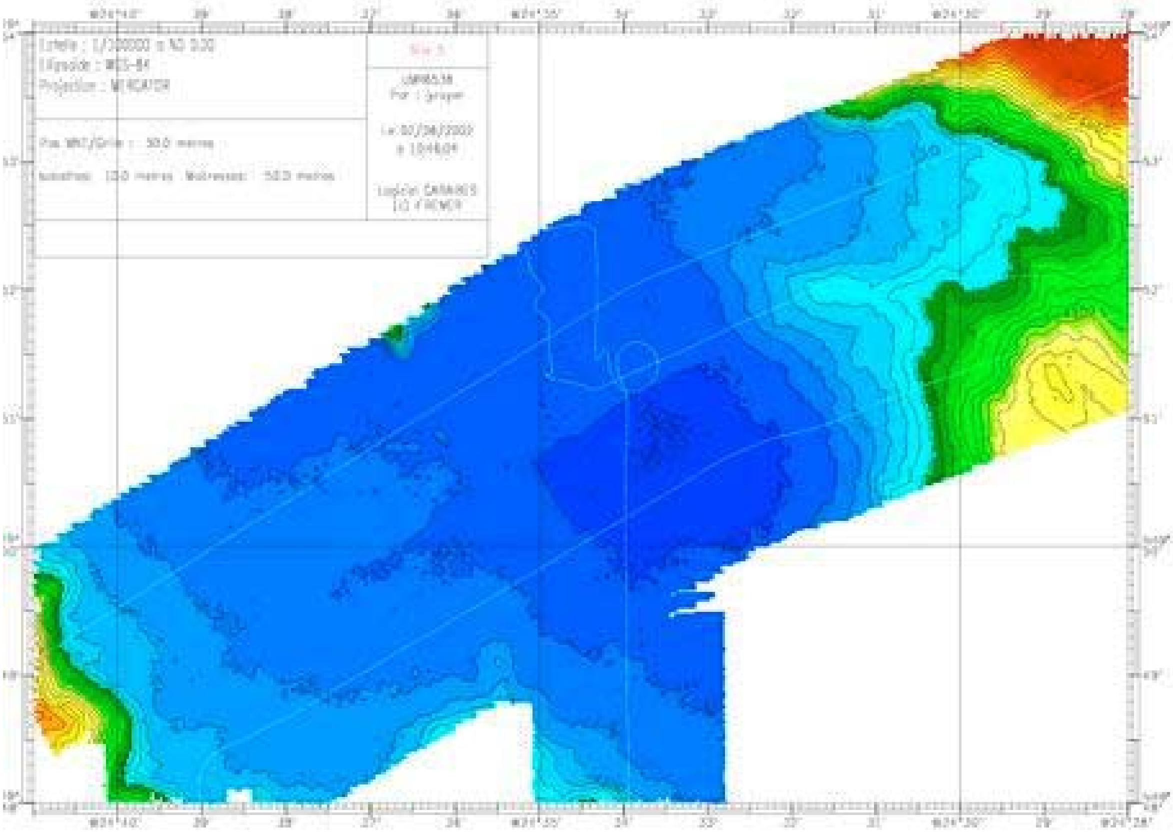

Figure II-3-5: EM300 site survey near site S5. Mooring was deployed while sailing W/SW (strong surface current about 1 kt) and the anchor therefore probably receded 700/800m towards the north/northeast from the anchor splash point.

<u>6th deployment</u> **<u>Site S6 (47°00.020N; 22°10.040W)</u>**

Hydrophone name - H30
Date - 5/31/2002 13:01:45 GMT
Anchor drop position - 47°00.020N, 22°10.040W
Cable length - 3300m(1000mVectron, 1000mVLS,1000mVLS, 1000mVLS, 100mVLS,100mVLS,100mVLS)
Bottom depth - 4294m
Acoustic release - Benthos 1023

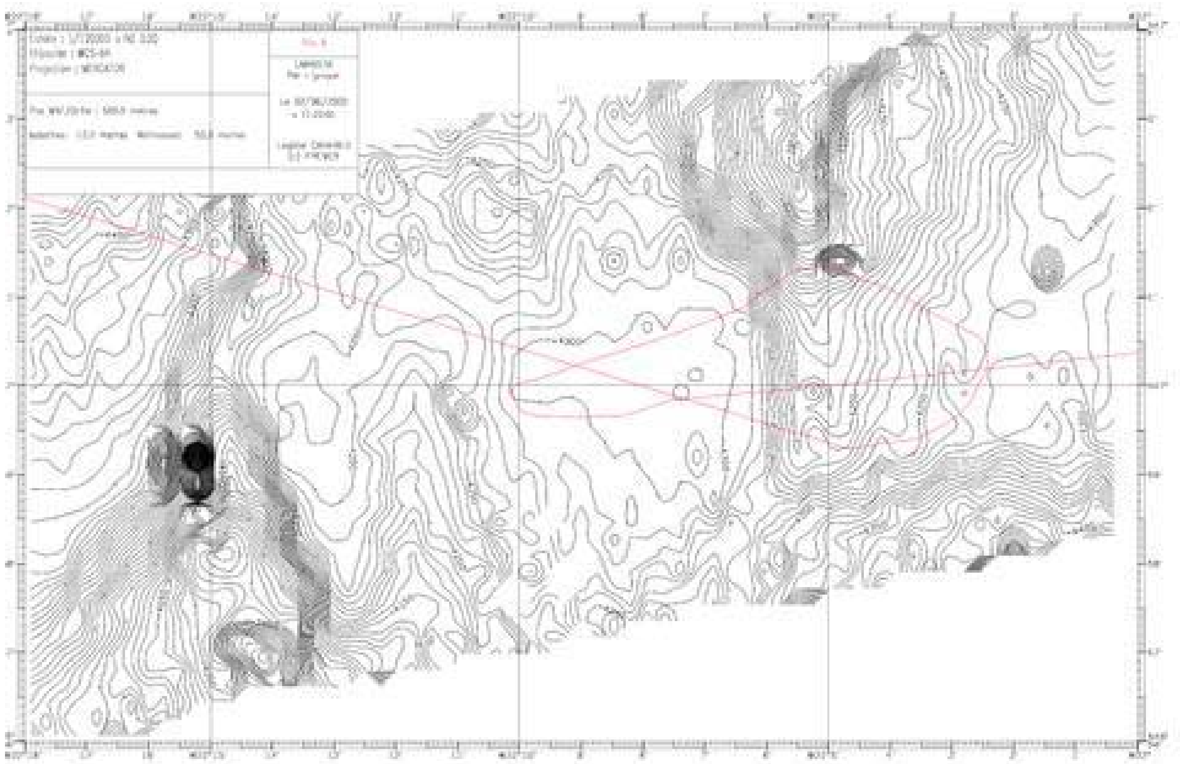

Figure II-3-6: Cable-laying multi-beam survey near site S6. Depths were checked with EM300 before deployment. Mooring was deployed while sailing S/SW (strong surface current about 1 kt) and the anchor therefore probably receded 700/800m towards the north/northeast from the anchor splash point.

IV –Along-track data

The initial planning of transit lines between sites had to be largely modified because of the prevailing bad weather and strong westerly winds.

This plan included:
- a 100%-coverage survey SE of Terceira Is (see below section IV-1).
- three long transits between sites S1 and S2, S6 and S3, S4 and S5 respectively, along the flow lines of the opening of this section of the North Atlantic;
- multi-beam surveys of the Ridge's axis where two of the transects crossed the ridge axis, that is 46°N and 50°30'N respectively.

Of these three objectives, only the third could be completed on the first day of the cruise, before the weather started degrading very rapidly en route towards site S1.
Three days were needed to head into the wind from site S1 to site S2, therefore lowering the probability to achieve the two other long transects without risking to impair the major objective of the cruise, that is the successful mooring of the six haruphones.
Finally, the general cruise plan lead to conduct the ridge-axis survey from the northernmost section of the cruise, after four moorings had been completed successfully.

IV - 1 the "Azores Plateau survey"

The exact geometry of the Africa/Eurasia boundary within the Azores Archipelago is poorly known. However seismicity data indicate that part of this major structural feature runs between the islands of Saõ Miguel and Terceira.
This section of the plate boundary, known as the Terceira Ridge, consist of several deep troughs and linear ridges. Some of these ridges were studied during a TOBI side-scan survey (AZORRE 98 cruise), sail by *R/V* Urania within the framework of a cooperation between the SOC, the IGM/Bologna and the University of Algarve at Faro. A more detailed study of the high located SE of Terceira Is., which limits the Hirondelle Basin to the South, was performed during the Azorre 98 cruise. TOBI images show that this area is intensively fractured and shows a complex morphology, with a dominant 140°N structural trend.

A bathye metry survey, to be used as a framework for the interpretation of TOBI images, and to allow the quantification of the fault distribution, was planned during the SIRENA cruise.

This survey was performed on May, 18th, from 18:30 to 24:00, in fair sea conditions. Five N-S, 12-mile long lines were sailed, allowing a 100% coverage of a 370 km^2 area. Tis area covers roughly 40% of the TOBI mosaic. Due to the favorable sea conditions during the survey, the global quality of the EM300 multibeam data is good. Some limited editing was nevertheless conducted on board to delete erratic echoes.

Following this edition, a DEM was produced, with a 60-m grid spacing (see figure below).

***Luis, J. F.**, J. M. Miranda, A. Galdeano, P. Patriat , Constraints on The Structure of the Azores Spreading Center from Gravity Data. Marine Geophysical Research, 20, 157-170, 1998.*

***Lourenço, N**, J. M. Miranda, **J. F. Luis**, A. Ribeiro, L.A. Mendes Victor, Madeira, J & H. D. Needham, Morpho-tectonic analysis of the Azores Volcanic Plateau from a new bathymetric compilation of the area. Marine Geophysical Research, 20, 141-156, 1998.*

*Miranda, J. M., L. A. Mendes Victor, J. Z. Simões, **J. F. Luis**, L. Matias, H. Shimamura, H. Shiobara, H Nemoto, H. Mochizuki, A. Hirn, J. C. Lépine, Tectonic setting of the Azores Plateau deduced from a OBS survey. Mar Geophys Res, 20, 171-182, 1998.*

***J. Freire Luis**, J.M. Miranda, A. Galdeano, P. Patriat, J.C. Rossignol and L.A. Mendes Victor. Azores Triple Junction evolution since 10 Ma from an Aeromagnetic survey of the Mid-Atlantic Ridge. Earth and Planetary Science Letters 125, 439-459, 1994.*

***Luis J. F., N. Lourenço**, J. M. Miranda, J. L.Gaspar and G. Queiroz. A Submarine Eruption west of Terceira Island (Azores Archipelago). Interridge News. Vol 8: Nº1: 13-14, 1999.*

*Ligi M., N. C. Mitchell, M. Marani, F. Gamberi, D. Penitenti, G. Carrara, M. Rovere, R. Portaro, G. Centorami, G. Bortoluzzi, C. Jacobs, I. Rouse, C. Flewellen, S. Whittle, P. Terrinha**, J. Freire Luis and N. Lourenço**. Giant Volcanic Ridges Amongst the Azores islands. Fall Meeting of the American Geophysical Union, 1999.*

*Ligi M., N. C. Mitchell, M. Marani, G. Carrara, F. Jacobs, **N. Lourenço, J. F. Luis**, D. Penitenti, R. Poraro, M. Rovere, P. Terrinha. Tectonic control on the growth of giant Volcanic Ridges in the Azores. XXV EGS, Nice, 2000.*

***Lourenço N., J. Luis,** M. Miranda, M. Ligi, and the AZORRE 99 Team. Linear Volcanic Ridges in the Azores: preliminary characterization from TOBI data. 3º Simpósio da Margem Ibérica Atlântica, Faro, p 197, 2000.*

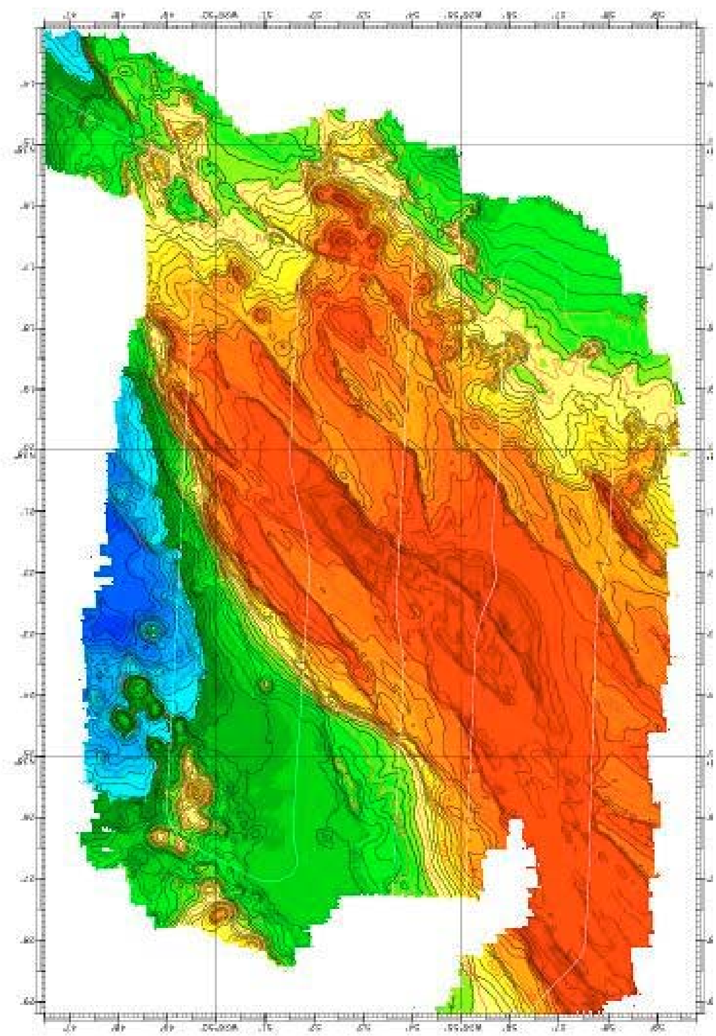

Figure IV-1-1: *Topography of the Terceira Ridge surveyed during the SIRENA cruise*

IV - 2 the "ridge-axis survey"

A multibeam survey was sailed between mooring sites S4 and S5. The axis was crossed for the first time around 50°5'N on May, 27th, 08 :00 GMT and the survey proceeded southwards till May, 29th, around 12 :00 GMT (see tracks below).

While all eastward tracks, sailed before the wind, allowed to record, while westward profiles were sailed with a very heavy ship pitching. Data recorded along the two sets of tracks are therefore of very unequal quality.
The data from both sets cannot therefore be readily merged before quite some "swath cleaning "work is completed on the westward-going profiles. This work is an absolute pre-requisite before a DEM can be produced.

Data recorded along the eastward courses nevertheless produce a clear picture of the Ridge's rift valley and walls and will be a very useful tool to locate the earthquake epicenters with respect to these structural features.
Finally, it should be noted that the persistence of poor weather till the ridge-axis survey was almost completed and we had to sail towards site S5 made this survey very slow. Only 1°40' degree in latitude was surveyed, thus leaving a gap of around 2°20' degrees between the northernmost profile sailed by S. Mello and the southern most ridge crossing sailed during the Sirena cruise.