CONSIGLIO NAZIONALE DELLE RICERCHE
ISTITUTO PER LA GEOLOGIA MARINA

PROJECT VOLTAIRE

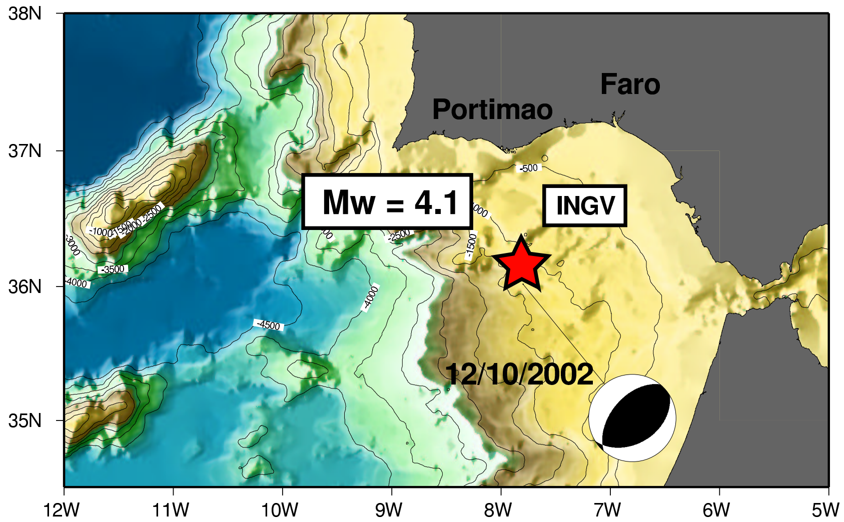
VOLTAIRE 2002 CRUISE REPORT

Joint research project between

Istituto di Geologia Marina (IGM-CNR)
Instituto de Ciências da Terra e do Espaço (ICTE)
Università degli Studi di Bologna (DSTGA-UNIBO)
Università degli Studi di Parma (DST-UNIPR)

REPORT ON GEOPHYSICAL INVESTIGATIONS during CRUISE VOLTAIRE 2002 aboard R/V URANIA

Participating institution: ISMAR-CNR (formerly IGM), CGUL, DSTGA-UNIBO, IGM-Portugal, CIMA-Ualg, IJA-CSIC, UNIBREST, IGME



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VOLTAIRE cruise (**V**aluation **O**f **L**arge **T**sunamis **A**nd **I**beria **R**isk for **E**arthquakes) by N. Zitellini, M. Ligi, L. Matias, M. Rovere & the Shipboard Scientific Parties

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AUTHORSHIP

N. Zitellini, L. Matias and M. Rovere compiled and finalized the main body of this report. All the participants to the cruise contributed to this report with their work and discussions aboard the R/V Urania. When not already noted, most of the maps were produced by the GMT software. The front page figure shows the focal mechanism of the 12/10/2002 earthquake, occurred at sea during the VOLTAIRE 2002 cruise and recorded by the inland Portuguese seismic network.

HOW TO READ THIS REPORT

Section 1 gives background information, together with some technological and scientific issues of the organization and execution tasks. Section 2 claims tha aims and scopes of the project and Section 3 presents the cruise planning, while section 4 summarizes the cruise. Sections 5 provides the technical details for data acquisition and processing, whereas section 6 discuss some results, the on-going data processing and usage, and give concluding remarks. Some data processing procedures that were used in the production of this report along with further technical details and data are presented in Appendix 9.

ACKNOWLEDGMENTS

Many people contributed to the success of the cruise. Firstly, we wish to thank the Captain, Vincenzo Lavadera Lubrano, the first officer Ernesto Violetta, the Chief Engineer Pietro Ciano and the crew of R/V Urania for their great professionalism and big effort in assuring the success of the cruise. The project was funded by IGM-CNR, ICTE and the University of Bologna. We wish to thank also the Núcleo para a Prospecção e Exploração de Petróleo, Ministério da Economia, Dir. João Pacheco and Dra Teresinha Abecassis, to have made us available the TGS-NOPEC dataset in Lisbon; Juanjo Dañobeitia and the UGBO staff in Barcelona for their prompt reaction to our help request; the Real Instituto y Observatorio de la Armada in San Fernando Cadiz, Dr. Jose Martin Davila, who kindly provided us the daily observations through mail, to perform the diurnal variation correction of magnetic anomalies; the Divestco Inc. for their WinPics demo and the Seismic Micro-Technology Inc. for the Kingdom Suite+ demonstration package.

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1 INTRODUCTION

The main goal of the project VOLTAIRE was the study of the active tectonic processes occurring at continental margins of SW Iberia which determine a high concentration of natural hazards linked to seismicity, tsunami generation and large submarine mass wasting. The mitigation of these hazards requires a deep knowledge of the dynamics along margins and surrounding basins, and implies multidisciplinary and high-resolution marine geophysical investigations. The research work is focused on the Southwestern Margin of the Iberian Peninsula, from the eastern border of the Tagus Abyssal Plain to the Guadalquivir Bank. The project has been supported by Italian and Portuguese funding Agencies and represents a further step on a long standing cooperative effort among European institutions for the study of this area.

1.1 The State of the Art

The region off the SW Iberian Peninsula and the Gulf of Cadiz shows an important seismic activity and complicated tectonics. The area encompasses the plate boundary between the Eurasian and African plates which, in the Atlantic, runs from the Azores Islands to the Strait of Gibraltar. Along this line the relative motion is divergent in the Azores, transcurrent in the central segment and convergent East of the Tore-Madeira Rise until the Strait of Gibraltar Strait. In the easternmost sector diffuse compressional deformation is present as testified by scattered seismicity (Fig. 2). Topographic, geoid and gravity anomalies indicate significant deformation in a wide area, either in oceanic and in continental lithosphere. Around SW Iberia the regional stresses are of compressive nature, oriented in NNW-SSE to WNW-ESE direction (Fig. 3). The tectonics of the region is complicated by the presence of a complex ocean bottom topography and the offshore continuation of the inland active faults. The presence of intermediate depth earthquakes (between 30 and 80 km of depth) suggests a complex transition from oceanic to continental domain. Classic rigid plate tectonics theory do not fit this geodynamic regime and it is suggested that new plate boundaries are being nucleated with significant intraplate deformation.

During the Eighties and the Nineties a lot of effort has been devoted by Academic Institutions to understand the geodynamic evolution of the continental margins of the South-western European block. Multichannel seismic data collected in this area (Sartori et al., 1994; Torelli et al., 1997: AR92 lines in Fig. 1) gave a new insight of the tectonic structure of the South-western Iberian margin. One of these seismic lines (AR-9210 in Fig. 1) shows a large compressive structure located offshore Cape San Vincente (Portugal), called Marquês de Pombal, whose motion probably caused the famous 1755 earthquake (Zitellini et al., 1999). Following this discovery the European Community funded the project BIGSETS (Big Sources of Earthquakes and Tsunami in SW Iberia) and an MCS survey (multichannel seismic survey) has been carried out to better investigate this structure (BIGSETS lines in Fig. 1).

The BIGSETS survey confirmed that the Marquês de Pombal is the likely source of the 1755 event (Zitellini et al., 2001). The deformed area, associated to the emplacement of Marquês de Pombal structure, is at least 100 km long, 5 km wide, the maximum up-lift is of about 1100 m and is located where the thrust fault emerges at the surface with a strike of N20E. The BIGSETS survey has shown that beside the Marquês the Pombal, other active, compressive, tectonic structures of regional significance are present: the Horseshoe fault (HSF), the Guadalquivir Bank (GB) and a large hill of tectonic origin (A) (Fig. 1). Besides the Marquês the Pombal structure the other above mentioned tectonic structures are poorly known and the VOLTAIRE campaign was designed to investigate them. This new set of data will point to a re-evaluation of the potential tsunami hazards in this very highly populated area and can constitute a firm basis both for more elaborated geodynamic models in the whole region and to assess seismic and tsunami risk associated with the largest events in Western Europe and North-western Africa.

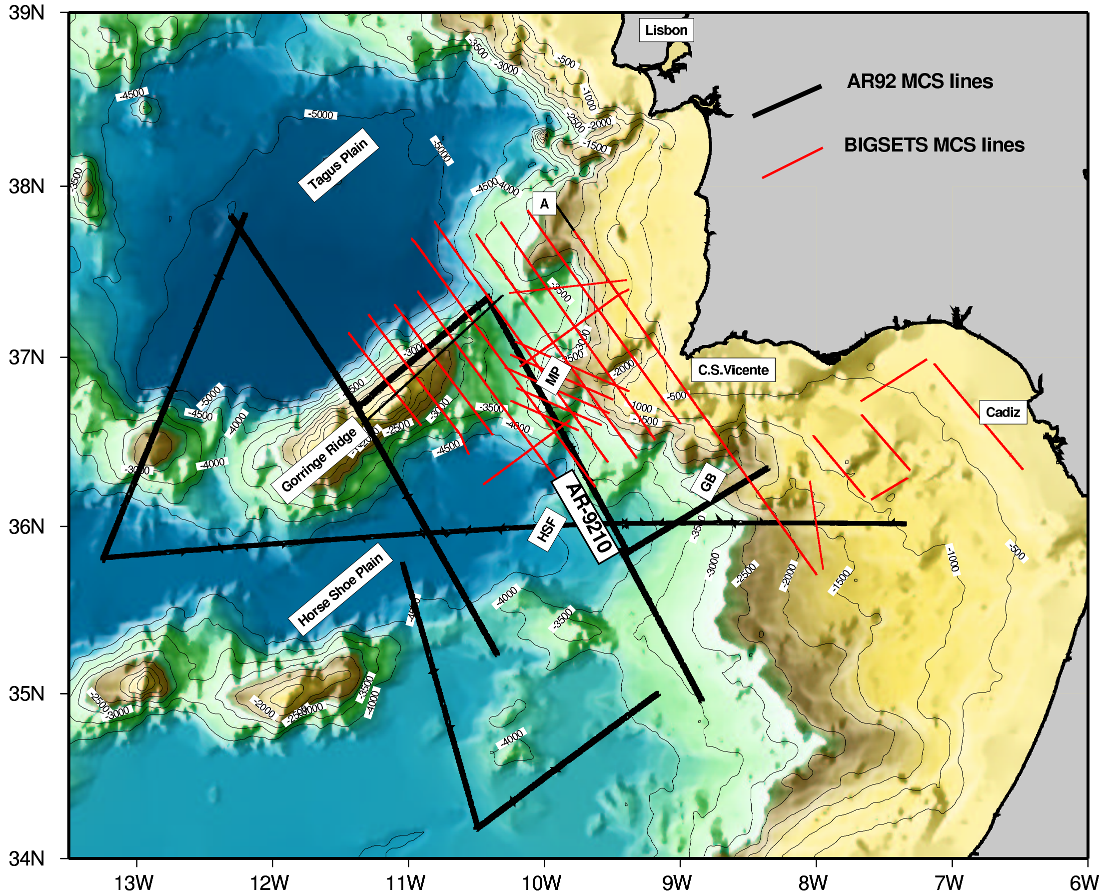

Figure 1: Geographical area setting. Bathymetry contours every 500 m from GEBCO97 Digital Atlas at www.nbi.ac.uk. HSF = Horseshoe Fault; GB = Guadalquivir Bank; MP = Marquês de Pombal; A = submarine hill of tectonic origin. Also shown RIFANO92 and BIGSETS98 MCS lines.

2 AIM OF THE SURVEY

The main objective of the project was the detailed investigation, based on multi-channel seismic reflection profiles, of the most active tectonic structure of SW Iberia, i.e. the southern termination of the Marquês the Pombal, the Horseshoe Fault (HSF) and the Guadalquivir Bank (GB), where these structures accommodate and partition the strain across a wide and diffuse plate boundary zone. In addition, one of the purposes was to enlighten the main pre- and syn-compressional episodes observed at the sedimentary basins and to correlate with the outcropping of morphological structures. By means of the acquired data we will try to determine the 3D tectonic geometry and style of active faults in the Southern Iberian Margin.

In particular, we want to obtain a detailed mapping of the fault/fold pattern associated to: 1) the southernmost tip of the Marquês de Pombal; 2) the Horseshoe Fault (HSF in Fig. 1); 3) the Guadalquivir Bank (GB in Fig. 1); 4) a geological mapping of the possible strike-slip motion between the Gorringe Ridge and the Marquês de Pombal (Fig. 1). Moreover we will try to unfold the neogenic tectonic event to disclose the original structural setting of the Mesozoic and Cretaceous passive margins. To accomplish this goal we plan to merge the pre-existing MCS data, reprocess part of them and reinterpret them jointly. The collection of this MCS data set will greatly help to develop a model of potential geological hazards based on the precise mapping of the trace the active fault/folds with the final goal to assess on the earthquake and tsunami risk at the South West Iberian Margin.

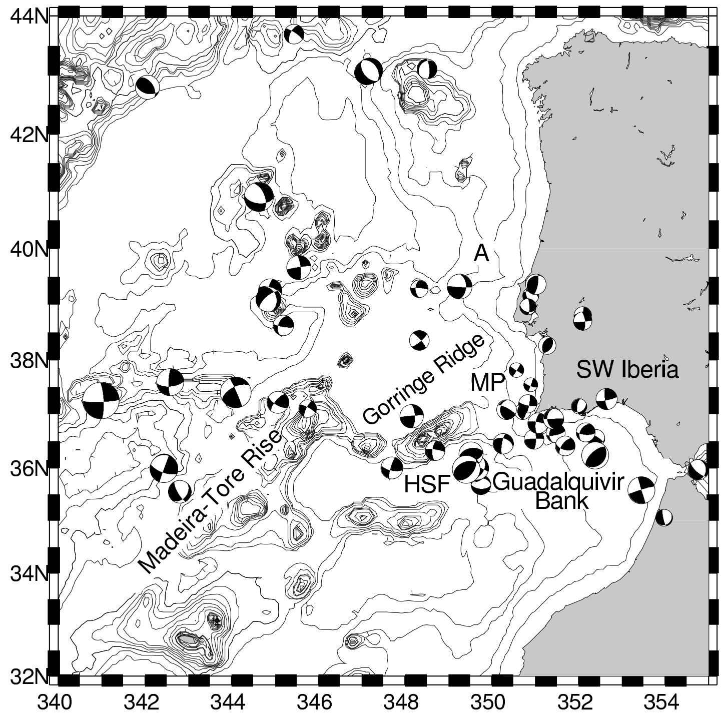

Figure 2: seismicity off W Iberia. Bathymetry from Smith & Sandwell (1997). HSF = Horseshoe Fault; MP = Marquês de Pombal; A = submarine hill of tectonic origin. Focal mechanisms summarize the works by Ribeiro et al. (1996); Borges et al. (2001); Zitellini et al. (2001).

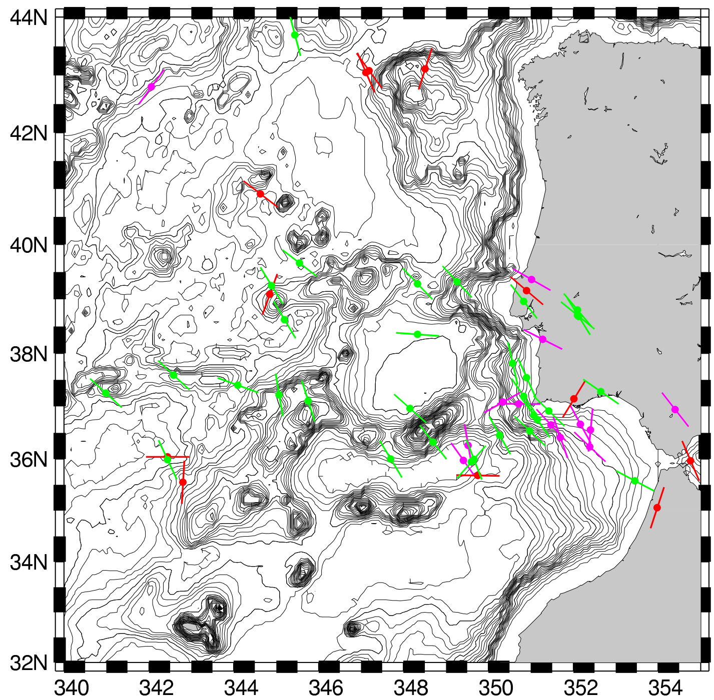

Figure 3: maximum horizontal stress off W Iberia. Bathymetry from Smith & Sandwell (1997). Violet = compressional; red = extensional; green =strike-slip.

3 SURVEY PLANNING

The preparation of VOLTAIRE campaign was carried out in tight collaboration with all the partners involved in the project: IGM-CNR, ICTE, DSTGA-UNIBO, DST-UNIPR, University of Algarve, IJA-CSIC, UNIBREST, IGME. A preparatory meeting was held in Lisbon at the end of June 2002 with all the partners. We discussed the survey strategies based on the available data set: AR92, IAM, BIGSETS, SISMAR and commercial multi-channel seismic lines.

During this meeting it was decided to focus the VOLTAIRE investigation across the Marquês the Pombal - Horseshoe Fault - Guadalquivir Bank structures with additional targets as the NW termination of the accretionary wedge of the Betic-Rif chain and the mud volcanoes that outcrop there. After this meeting, during the first week of July, the maps with the survey planning were submitted to local Portuguese and Moroccan authorities for approval.

Before the start of the campaign, on the first week of October 2002, it has been possible to see the commercial TGS-NOPEC MCS data set. The TGS-NOPEC extended along the whole SW Portuguese continental margin until the depth of 1000 m and helped greatly to select, avoiding useless overlapping, the location of VOLTAIRE MCS lines.

Because the streamer owned by IGM of Bologna showed some dead traces, IGM decided to rent a 48 channel, 600-meters-long streamer from a private company, the Oceansismica - Fugro of Rome. The campaign was carried out on board of the R/V Urania of Italian flag. The R/V Urania departed from the harbour of Livorno on Nov. 21, 2002 with the Italian team embarked and all the equipment for the experiment. In addition to the equipment for MCS acquisition the ship was equipped with facilities for MCS and Chirp processing and interpretation with the aim to either obtain a preliminary interpretation of the data already and the end of the campaign, either to train the young PhD students to geology and geophysics on the field.

During the transit we tested the streamer of Oceansismica. The R/V Urania reached the harbour of Portimão on Nov. 26, 2002 where the non-Italian partners have been embarked. The ship left the harbour on the following day to start the operations. The first day at sea was spent for testing and calibration of the streamer, the GI guns and the acquisition system.

On Friday night, Nov. 28 at about 22.00 GMT, after the acquisition of the first MCS line, we suffered the lost of the whole streamer. The search for the streamer started on the following sunrise. The day after in the early morning we advised the Director of IGM as well the Oceansismica and the Insurance company of the happening. On the same day the personnel of IGM in Bologna started to prepare the IGM streamer for shipment on the following working day (Monday, Dec. 1). The search for the streamer (Fig. 4) was successful and it was recovered on board at around noon time of the 29th of November.

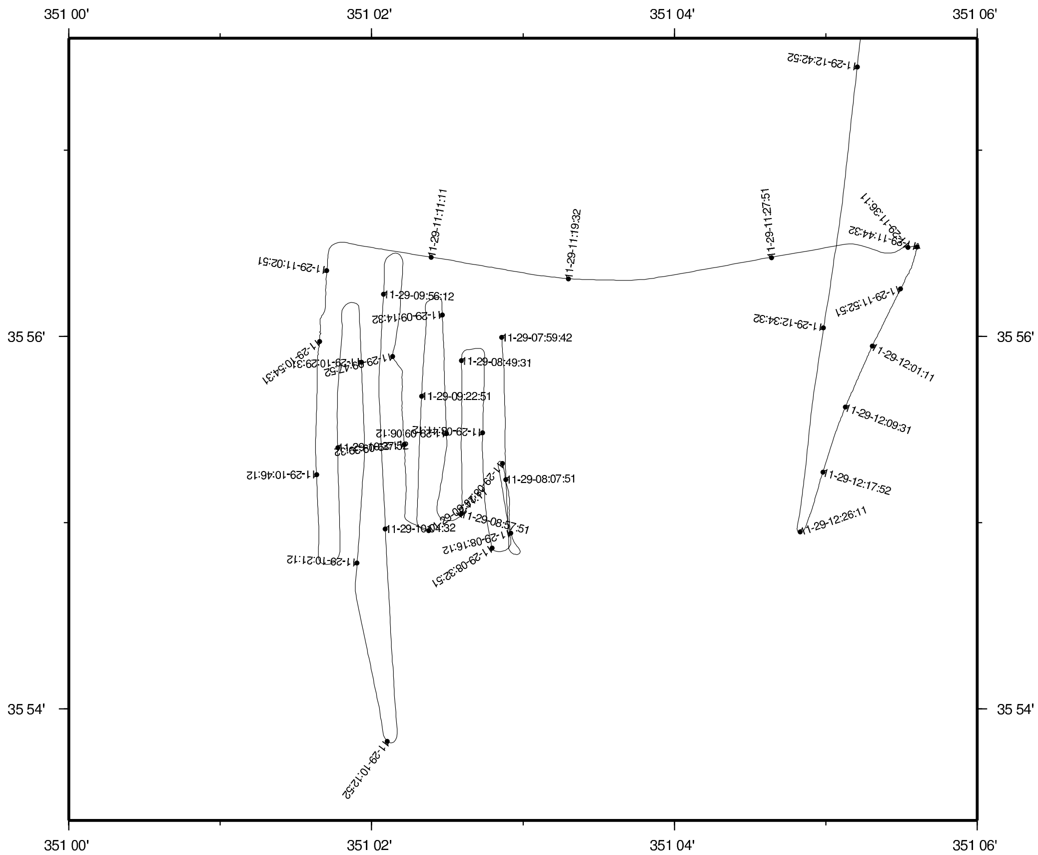

Figure 4: navigation tracks during the searching of the streamer, lost at sea during acquisition.

On November 30th the ship stopped nearby Lagos to allow the repairing of the Oceansismica streamer. The damaged stretch section was replaced and the cable was fixed by the end of Saturday 30th. Two birds (Digicourse), out of four, were out of service. Our Spanish colleagues were alerted and ready to ship three replacements. Here we wish to thank them for their effort, kindness and prompt reaction. We show up for the request over the weekend and they were ready to deliver the Digicourse we needed, during the following Sunday.

Unfortunately, on Saturday night, just after the deployment of the streamer for the first test, we found out that the streamer had a second failure at the replaced stretch section. We could not repair the cable anymore for lack of a further stretch section.

The IGM streamer was shipped from Bologna on the following Monday and reached the harbour of Portimão on Thursday Dec. 5. From Monday to Thursday the R/V Urania performed magnetic survey across the Gorringe Bank and the Ampère - Coral Patch Seamounts and two chirp survey to identify coring sites, one across the Portimão Canyon and one along the continental slope South of Cape San Vincente.

In the first place the target was a marked unconformity of probable Miocene age (Mauffret et al., 1989), in the second place the target was a lower sequence underneath the regional Miocene unconformity. The Portimão Canyon was selected for coring and two cores were performed along the canyon. On Thursday afternoon, the IGM streamer was embarked on board and the Oceansismisca streamer was shipped back to the owner in Rome. During the following night the IGM streamer was controlled for functionality.

On Friday 6th at 13.00 the ship left the harbour of Portimão and reached the working area at 15.00 to start the second MCS line. The weather in the following days was variable, sometimes with very rough wind and sea waves. As a consequence the survey was suspended a couple of times with the recovery on board of the streamer and the GI guns array. On Dec. 10 an earthquake of 4.1 of magnitude occurred (frontpage figure) in our study area. The focal mechanism obtained by the INGV indicates a reverse fault with a clear NW-SE compression. On Dec. 12 the Portuguese authorities restricted until Dec. 16 the working area because of military operations. The MCS acquisition ended on Dec. 16, at 01.30 GMT because of rough sea. The equipment was recovered on board by 04:30 GMT and we lead the ship towards Portimão half day in advance because the forecast was foreseeing very rough sea in the following hours.

The acquisition survey ended officially with the arrival of R/V Urania in Portimão on Dec. 16, at 13:00. On Dec. 17, part of the scientific staff disembarked and on Dec. 18 the R/V Urania left the harbour of Portimão at 13:00 with destination Naples. The ship arrived in Naples on the evening of Sunday, Dec. 22. The following day all the equipment was disembarked and shipped to Bologna. On Dec. 24 all the equipment was stored at IGM institute.

4 SUMMARY OF OPERATIONS

SHIP: R/V URANIA
START: 2002-11-20 PORT: Livorno
END: 2002-12-23 PORT: Napoli
SEA/OCEAN: Atlantic Ocean
LIMITS: NORTH 38:00 SOUTH: 33:30 WEST: -12:00 EAST: -6:00
OBJECTIVE: MULTICHANNEL SEIMIC PROFILES
COORDINATING BODIES: IGM-CNR BOLOGNA (ITALY) ICTE LISBOA (PORTUGAL) DSTGA BOLOGNA (ITALY) DST PARMA (ITALY)
PARTICIPATING BODIES: CGUL, Université de Brest, CSIC, IGM-Portugal, IGME, CIMA-Ualg, Università di Urbino.
CHIEF OF EXPEDITION: Nevio Zitellini (IGM-CNR)
CONTACT: Nevio.Zitellini@igm.bo.cnr.it
DISCIPLINES: MULTICHANNEL SEISMIC REFLECTION
WORK DONE: 1111.1 km of multichannel, 1469 km of magnetic and 1260 km of CHIRP SBP acquisition, 2 coring sites.

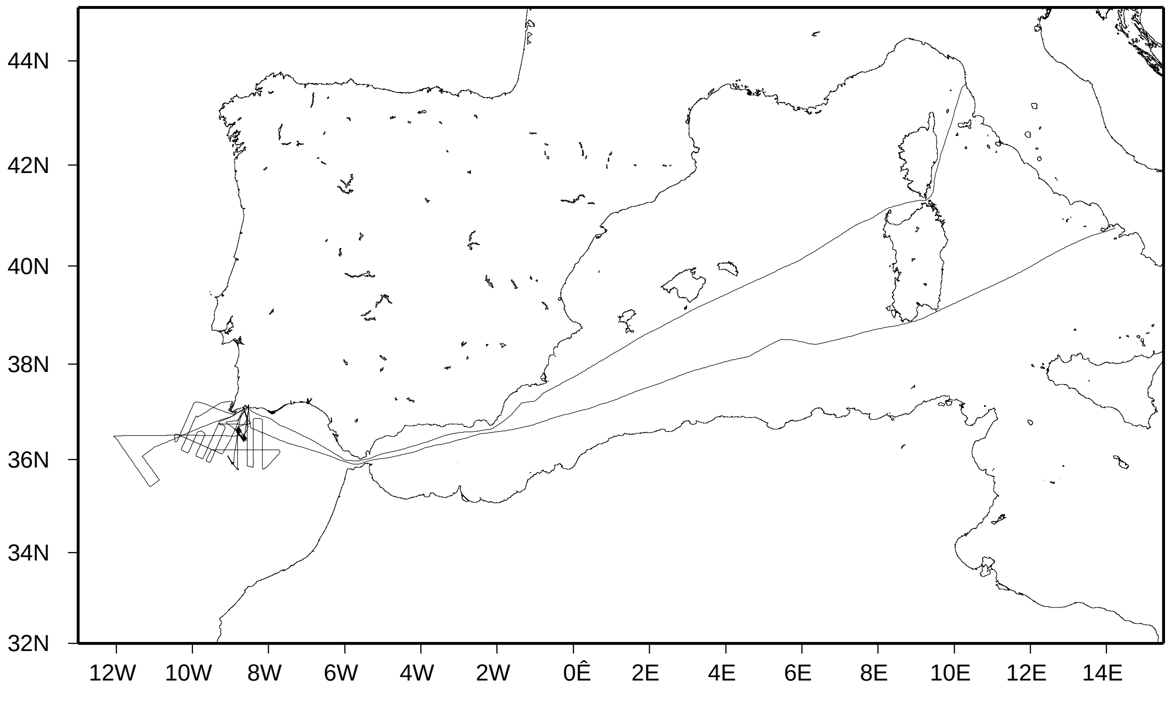

Figure 5: overall ship tracks for cruise V2002.

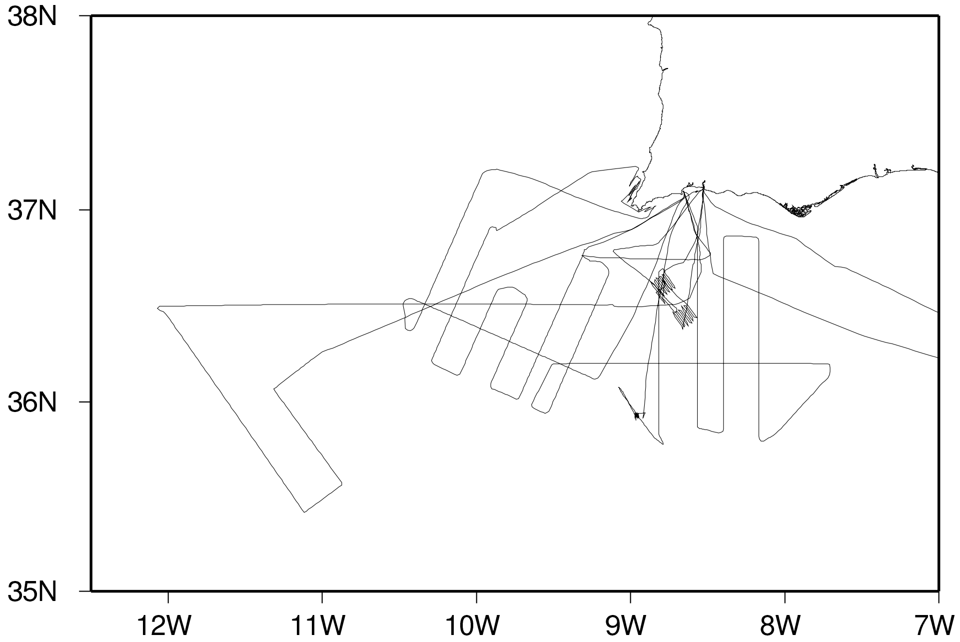

Figure 6: MCS/SBP tracks for cruise V2002.

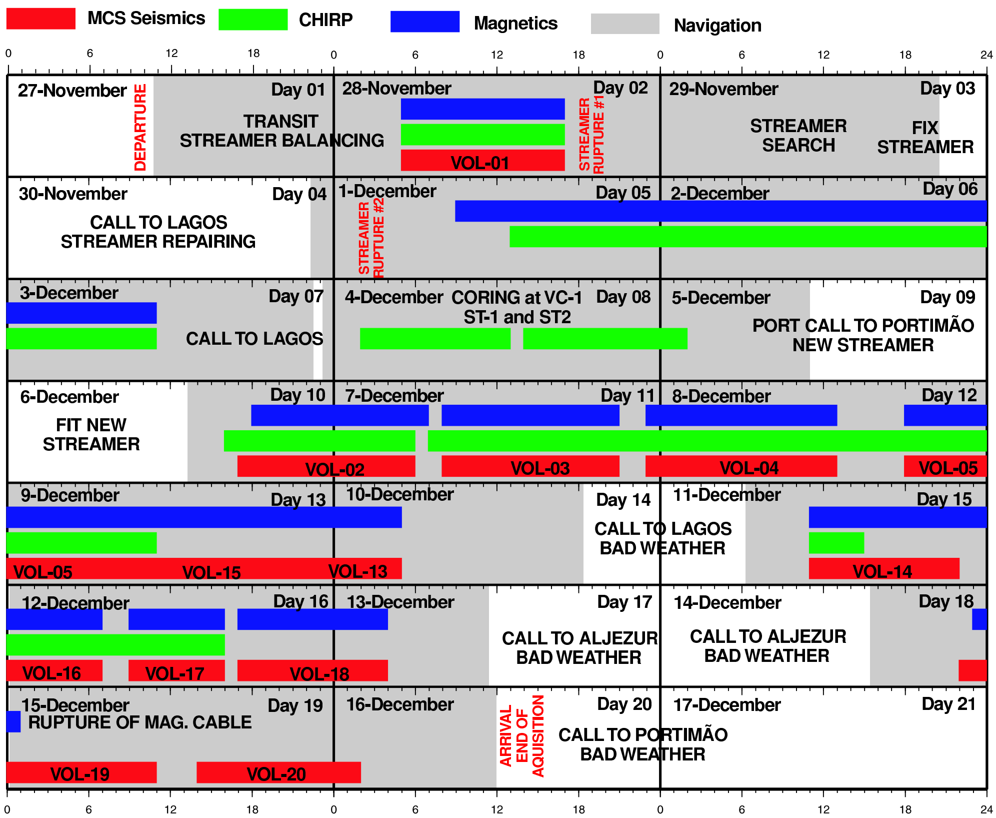

Figure 7: summary of operations at sea.

5 MATERIALS AND METHODS

The cruise was was performed aboard the R/V Urania, leased to CNR and operated by SO.PRO.MAR of Fiumicino.

Figure 8: R/V URANIA

5.1 Positioning and Navigation

The Navigation system NAVPRO V5.6 by Communication Technology of Cesena was used. The positioning sensor was the FUGRO 3000L 12 channel GPS receiver, with a OMNISTAR DGPS Satellite link by FUGRO. The integrated system used a Robertson model Skr82 gyrocompass, and was used for navigation and sensor data logging, other than for the fixed distance seismic shot control.

The instrumental offsets are presented in Tab. 1 and in Fig. 9.

WHAT	X	Y	Z asl
VESSEL Zero Offset	0.00	0.00	0.00
POS 1 ANTENNA	1.40	4.80	15.0
ECHO 12	-1.85	5.50	-3.50
ECHO 33	1.85	5.50	-3.50
CHIRP	-0.95	-5.50	-3.50
MAG	-3.90	-240.0	3.0
GI-GUN ARRAY	3.90	-50.0	-6.0
ACTIVE 1	0.00	-110	-10.0

Table 1: navigation offsets (m) on R/V Urania for NAVPRO. Positive directions are X:starboard, Y:ahead, Z:up. Point of ZERO offset VESSEL (0,0) is located on the ship's main mast behind the command brifge. POS1 = primary positioning system of main GPS antenna.

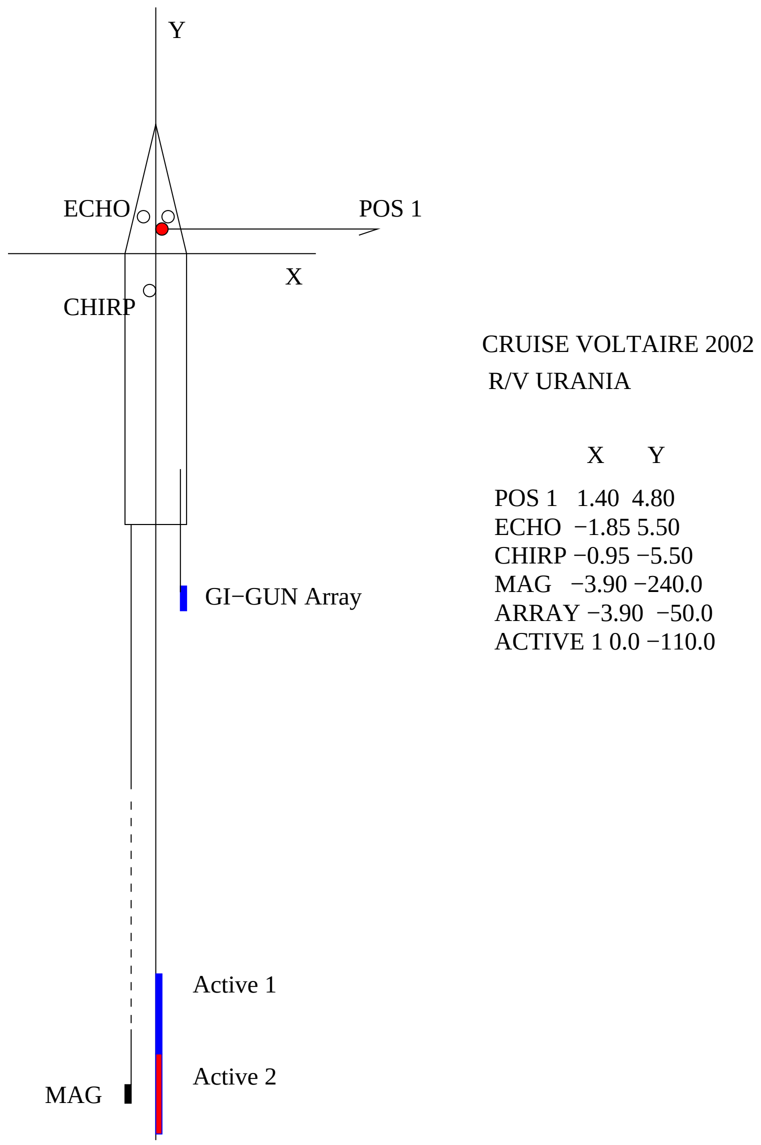

Figure 9: Instrumental Offsets on R/V Urania for cruise V2002

The water depth was measured by two ATLAS-KRUPP DESO 25 (the speed of sound was set to 1500 m/sec). The total magnetic field was measured by a model G-811 GEOMETRICS proton-precession magnetometer, deployed at a depth of 3 m.

The model ADU-2 ASHTECH attitude measurement system and models OS-75 and WHM-3000 RDI ADCP current meters provided additional high quality positioning data, such as heading and speed, that were recorded on separate logging systems.

5.2 Bathymetry

The bathymetry was acquired with the Ship's ATLAS RUPP DESO 25. The water speed of sound was set to 1500 m/s. Digitised data were recorded by NAVPRO after correction for draught. Analogic data were recorded at the range 0-5000m. The model ADU-2 ASHTECH attitude measurement system and models OS-75 and WHM-3000 RDI ADCP current meters provided additional high quality positioning data, such as heading and speed, that were recorded on separate logging systems.

5.3 Multichannel Seismic

The seismic source employed an array of two SODERA-SSI's, model GI-GUN guns (Fig. 10). The guns were set to the harmonic configuration of 210 c.i. each, with medium ports, and were fired and syncronized by the IGM gun controller, a system capable of controlling up to four guns.

We used the Teledyne Mod. 24500, 12.5 m group interval, 48 channel streamer, that was hired by FUGRO/OCEANSISMICA of Rome (Fig. 11). The shot distance was set to 50 m, thus attaining a 600% fold coverage. The streamer depth was set to 9 m by three depth controllers and a model DIGISCAN 293A modem by DIGICOURSE. The Oceansismica streamer, after failure, was replaced by the IGM streamer owning the same characteristics.

The analog data were input to the model STRATAVISOR NX GEOMETRICS controller, that digitized and recorded the data in the SEG-D/8048 (demultiplexed format). The sampling rate was set to 1 ms, record lenght to 12288 ms.

The data were processed on board by the Paradigm's FOCUS 2-D software. The processing sequence was conventional up to the time migration for the totality of, including: resampling to 2 ms, editing of the traces, shot delay removal, amplitude recovering, predictive deconvolution, sort, velocity analysis every 200 CMPs, NMO correction, stack, band-pass filter and time migration using stacking velocities reduced of 10%. The seismic data were also interpreted by means of two softwares, made us available in demo copies by Divestco Inc. and Seismic Micro-Technoilogy Inc.: respectively WinPics and Kingdom Suite+.

Figure 10: picture of the GI guns during their deployment at sea, taken by S. Carluccio.

Figure 11: picture of the Teledyne streamer during deployment at sea, taken by S. Carluccio.

5.4 Sub-bottom Profiler

We used ship's DATASONIC DSP-661 Chirp 2 Profiler 4SBP. Trigger rates varied from 2 to 3 seconds, the chirp length was set to 120 ms. Data were displayed on an EPC 9600 and recorded on Magneto-optical disk in SEG-Y format.

5.5 Various

The datum was set to WGS84 and the UTM projection (zone 29) was chosen for navigation and display and data acquisition. The time zone was set to the UTC. The positioning maps and bathymetric images were done with GMT (Wessel & Smith, 1995).

The computing center used two INTEL based PC running the SUSE 8.1 GNU-Linux O.S. and two SUN workstation running SOLARIS 8. Two additional PC running the WINDOWS 2000 OS were used for running additional seismic interpretation and processing packages. One of the Linux boxes served disk space in the NFS and SAMBA program suites. The CHIRP SBP data were processed with IGM's SEISPRO software by Luca Gasperini. The maps were plot on the onboard HP A4/A3/A0 deskjet printers. Photographs and videos were taken by an Olympus Camedia Mod. C2005L.

6 RESULTS

In this section we will present the data acquired and some very preliminary processing and interpretation, with the aim of showing their quality and of addressing their potential and importance in the whole processing sequence. As explained in Section 5, during the cruise we have acquired:

1. a grid of MCS lines, to define the regional tectonics;
2. a detailed grid of high resolution CHIRP-SBP profiles to examine recent deformations;
3. a grid of magnetic data;
4. two cores to investigate the stratigraphy of the area.

6.1 Magnetic Survey

A total of 17 magnetic profiles were acquired during the Voltaire cruise, comprising a total length of 1469 km for 162.2 acquisition hours. The acquisition was interrupted at the beginning of profile VOL19 due to cable problems that could not be solved in due time to allow the acquisition of the last profile, VOL20, that was also lost. Details on routines and scripts used to process the data are given in Appendix.

Normally the total field values were stored in the navigation files 1 point every 10 seconds. A few missing lectures were discarded during the decoding of these files (program nav03m.f).

The first processing step is to correct for the International Reference Field (IGRF). To perform this we used the program geonew.c and the file .igrf with the field parameters needed to correct for the year 2000. Information required is latitude, longitude, year, month and day. The program mag01.f prepared the input file for processing by geonew. Then the IGRF field and the anomalous field were computed and appended to the original .mag profile by program mag02.f For quality control we produced plots for the field recorded and the IGRF2000 correction using the script plota-brut.csh.

To perform the diurnal variation correction we used the daily observations at the Real Instituto y Observatorio de la Armada in San Fernando Cadiz, kindly provided trough mail by Dr. Jose Martin Davila, Jefe Seccion Geofisica/Head Geophysical Department. The Observatory coordinates are (WGS-84 GPS): 36º 29'50" N, 006º 07'10" W, H= 77.74m. These data was available for processing onboard on a weekly basis up to the 3rd December as a time series 1 point every 60 seconds. To obtain the diurnal variation at the ROA observatory we converted the time series to the magnetic profile format used in Voltaire with program roa01.f. Then we used the same procedure as before (mag01, geonew and mag02) to obtain the diurnal anomaly at ROA. Finally the onboard corrected anomaly was obtained by subtracting the ROA anomaly using program roa02.f.

To evaluate the contribution of the new magnetic data to the knowledge of the area we compared the anomaly obtained to the one predicted from the compilation published by Verhoef et al. (1996). For the profiles acquired latter than the 3rd December a simple shift was applied to make a better correspondence with the Verhoef et al. (1996) compilation. A synthesis of these data is shown in Fig. 12.

In many profiles the Voltaire data confirms the data already compiled and published. However, in some places, like South of the Guadalquivir Bank, at the top of the Gorringe bank and the magnetic quiet zone near the coast, the new profiles show a considerable difference and thus make a significant contribution to the knowledge of the crust magnetic susceptibility variation. It seems that the SW Iberia is bordered by a strong positive magnetic anomaly from South the Guadalquivir Bank to the eastern border of the Tagus Abyssal plain. This may correspond to a major crustal change from thinned continental crust to transitional crust. Voltaire results also show that the top of the Gorringe bank merits a high resolution magnetic compilation and that the weak anomalies near the coast must be better constrained.

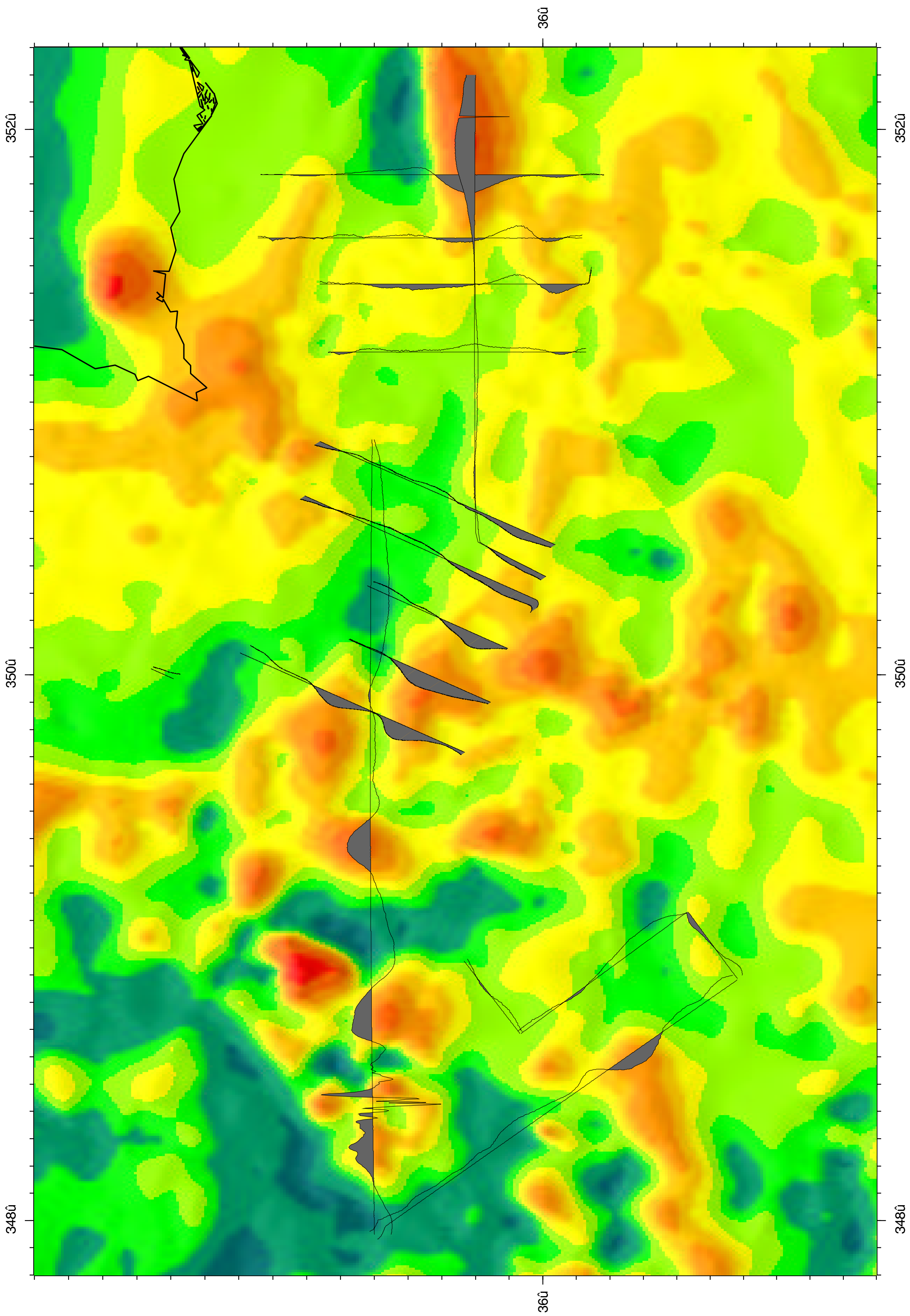

Figure 12: comparison between magnetic anomaly obtained during on board acquisition and Verhoef et al. (1996) compilation.

6.2 CHIRP survey and Coring

During the Voltaire cruise more than 1260 km of CHIRP data have been acquired, for more than 149 hours. These data were used to survey the coring site VC-1 (actually sampled by the cores ST-1 and ST-2) and the potential coring site VC-2, both along the seismic line BS-07A (Fig. 13). Fig. 14 shows the location of all lines acquired. Fig. 15 and Fig. 16 show the location of the two coring sites in respect to bathymetry.

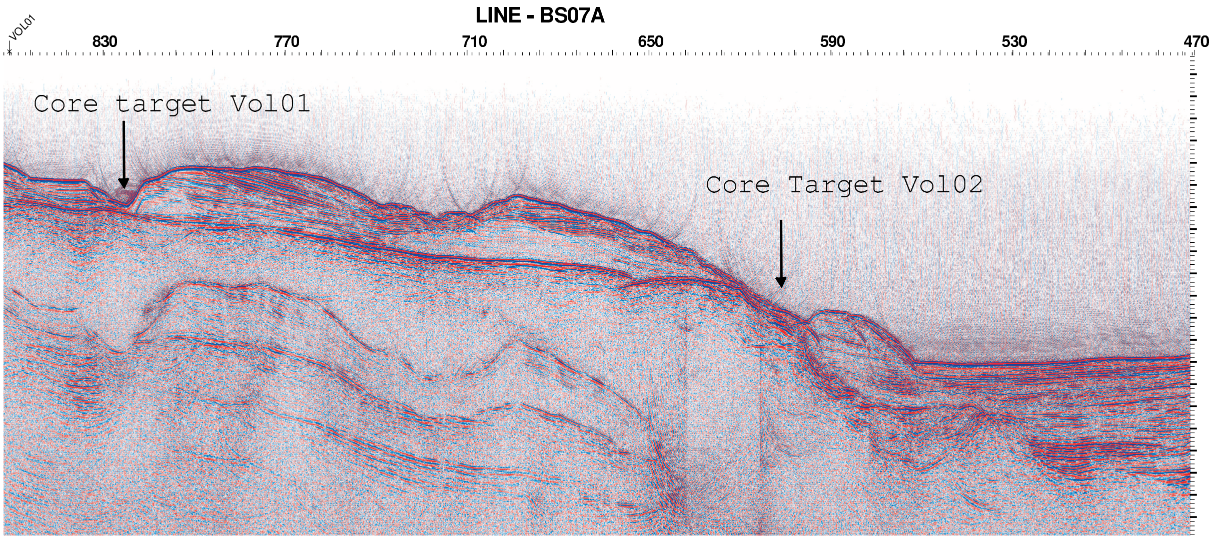

Figure 13: line BS07A, acquired during the survey BIGSETS in 1998, showing the location of coring site VC-1 (VOL01) and the potential VC-2 (VOL02).

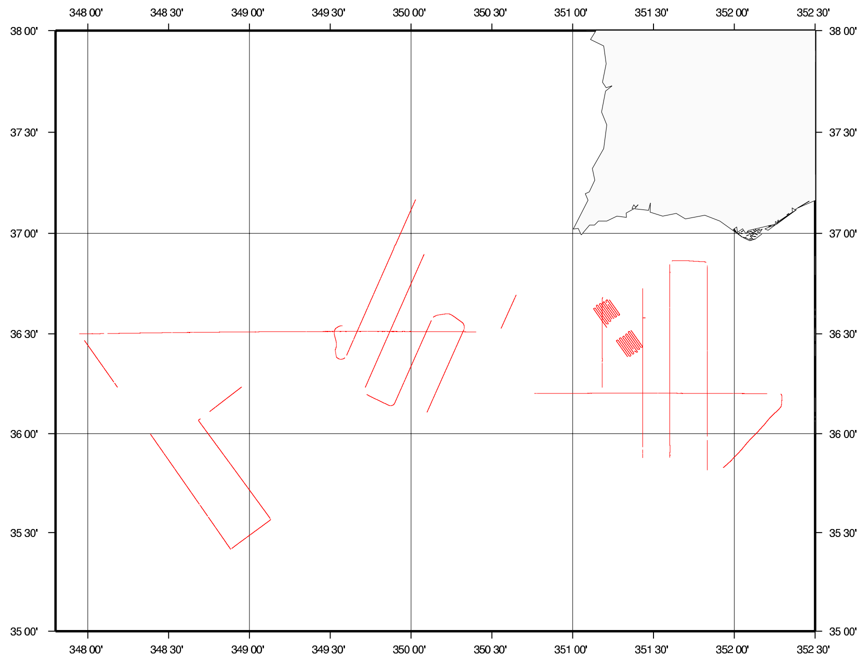

Figure 14: overall of total CHIRP acquisition.

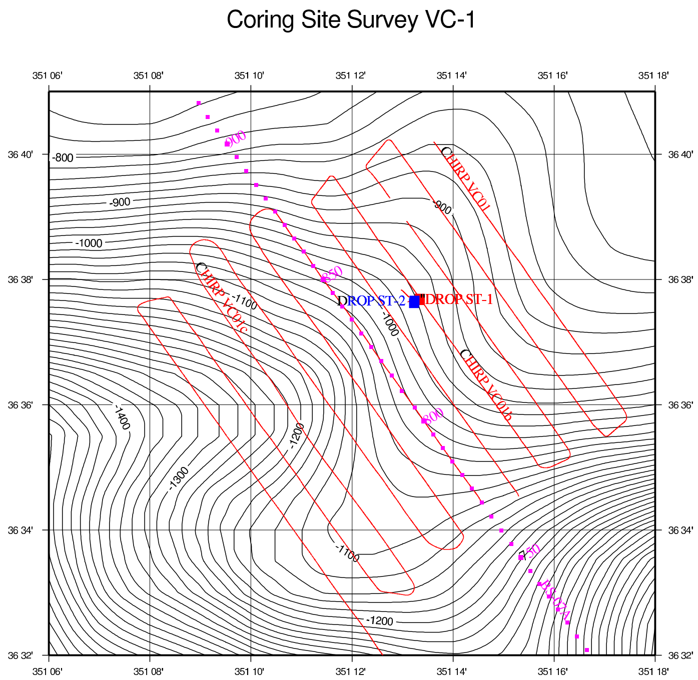

Figure 15: location of the coring site VC-1 and bathymetry of the area.

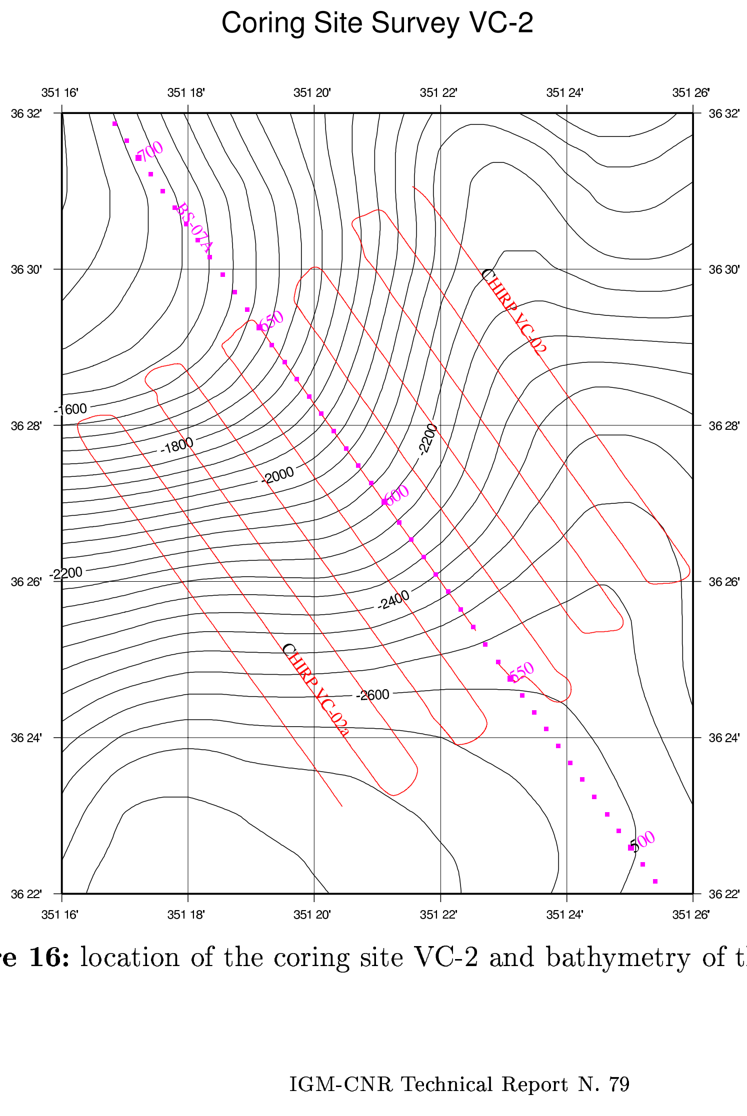

Figure 16: location of the coring site VC-2 and bathymetry of the area.

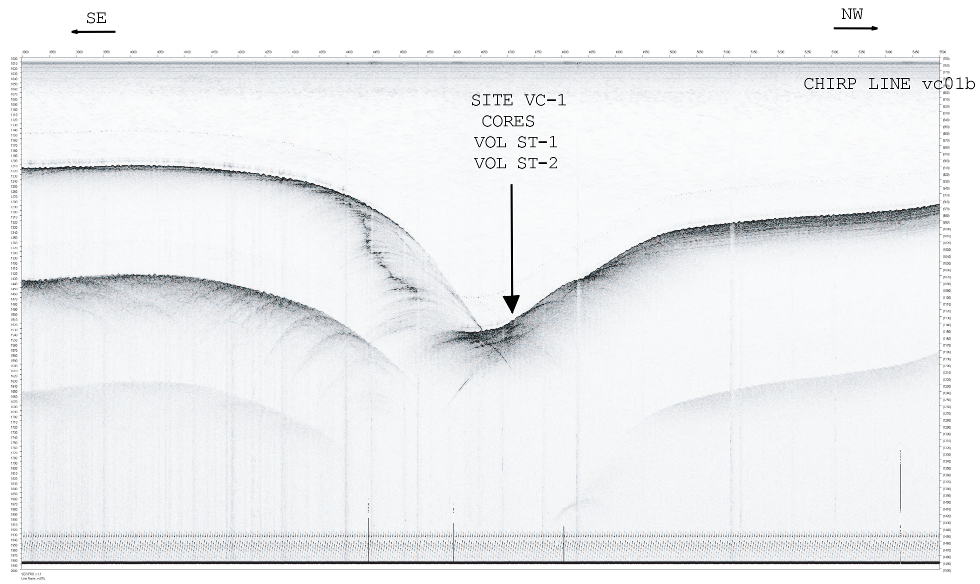

Figure 17: location of coring site VC-1, stations 1 and 2 along the corresponding CHIRP profile.

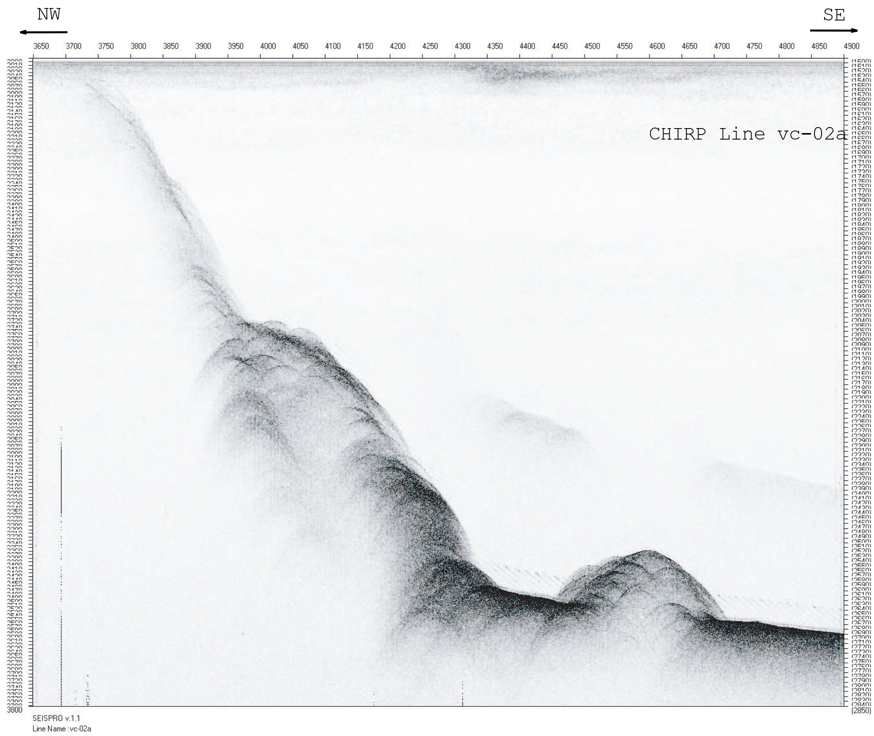

Figure 18: location of the potential coring site VC-2, along the corresponding CHIRP profile.

Some of the CHIRP lines provided also excellent images of different geological features:

1. A mud volcano (Fig. 19).
2. A possible gas pocket (Fig. 20).
3. One active fault south of Albufeira (Fig. 21).
4. Beautiful images of actual sea-bottom erosion at 54x vertical exaggeration (Fig. 22).

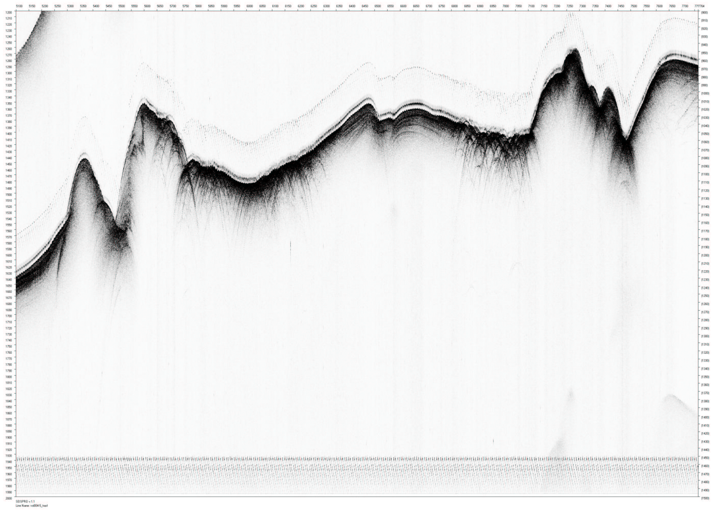

Figure 19: example of mud volcanoes, recorded during CHIRP acquisition.

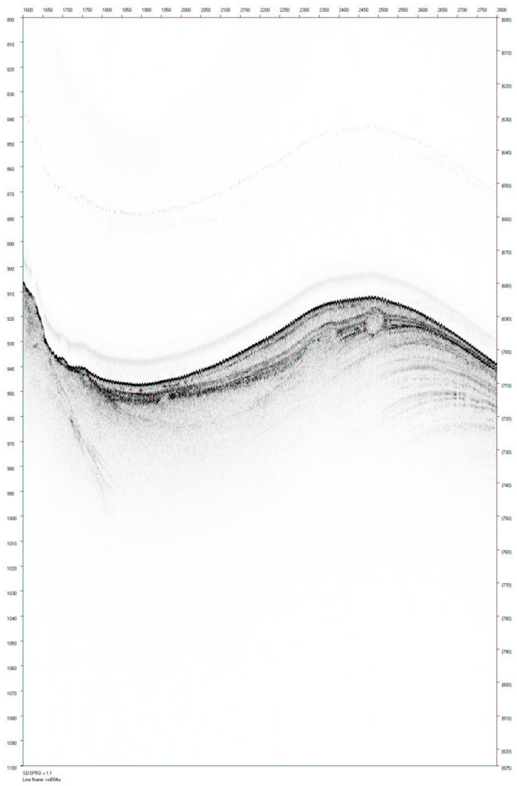

Figure 20: example of possible gas pocket, recorded during CHIRP acquisition.

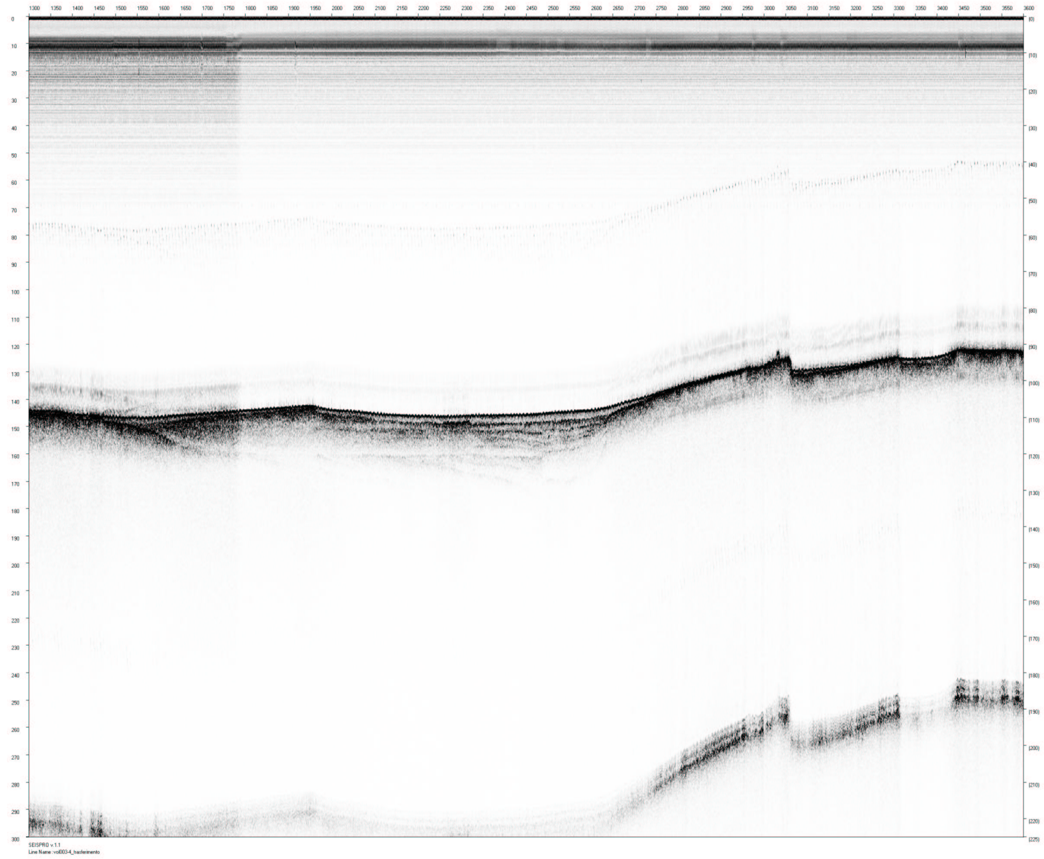

Figure 21: the Albufeira fault, recorded during CHIRP acquisition.

Figure 22: examples of sea-bottom erosion.

6.3 MCS Survey

During the Voltaire cruise, 1111.1 km of MCS data were acquired, for a total of 132.6 hours of active shooting. The Voltaire lines are shown in Fig. 23s. In Fig. 24 is presented one oh the MCS lines acquired, time migrated by means of Disco/Focus Paradigm Inc. software and displayed by means of WinPics Divestco Inc. software.

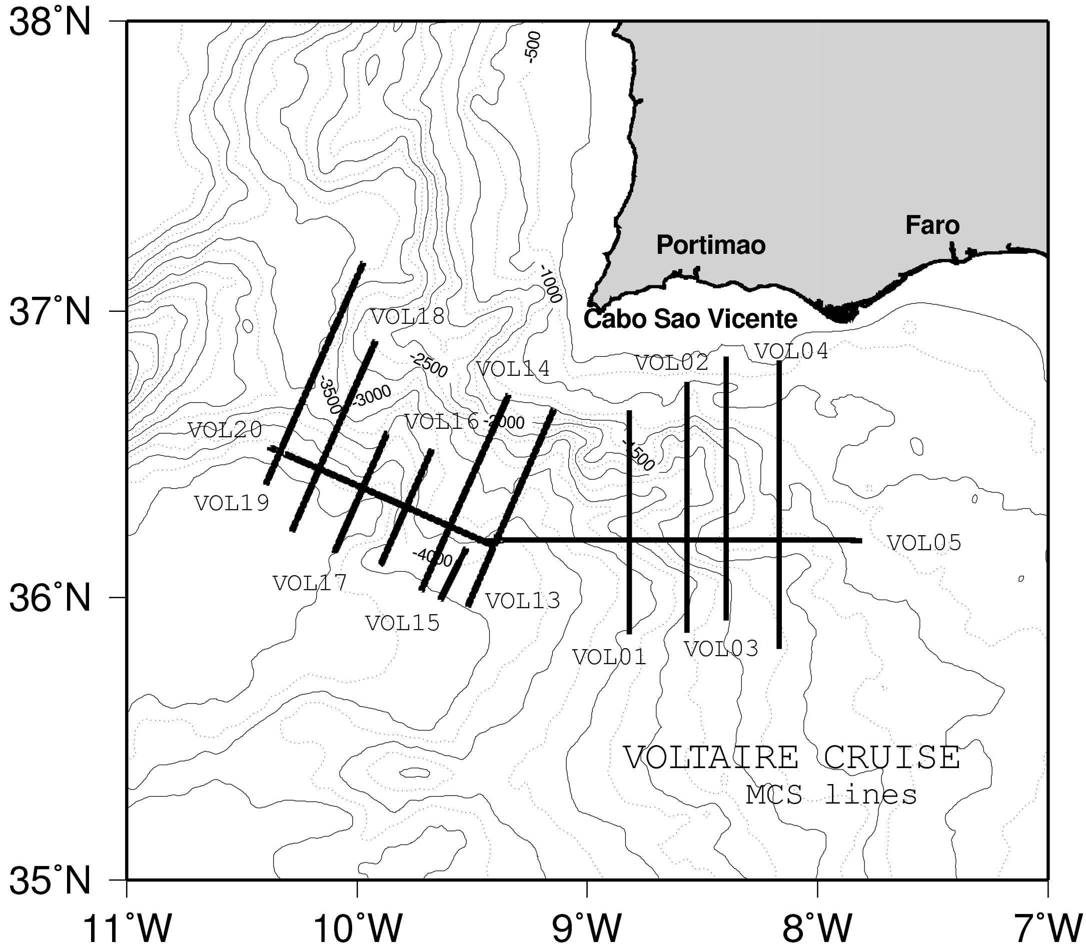

Figure 23: work areas and MCS track lines for cruise V2002.

During the cruise we performed quality control on the shooting interval for MCS which is the critical parameter defining the geometry. The software installed on board allowed to shoot at the constant spacing of 50 m. To perform this the time interval was varied to account for differences in the ship velocity. Using the navigation files the program nav01.f extracts the relevant information for the shots and outputs a label file used for gmt plotting. The same navigation file is explored by vnafdkm.f program to output a navdiff.dat file where we have in different columns the time interval between shots, the distance interval and the average ship velocity between shots estimated from the previous 2 values.

As the shooting time is recorded only to the second, a small fluctuation is observed in the time interval (and consequently a corresponding variation in velocity) that is not real, but due only to rounding. As it can be seen by the example shown in Fig. 25, Fig. 26 and Fig. 27 (prepared by the navdiff.csh script) we obtained a very stable shooting interval and the differences in velocity were well compensated by symmetrical differences in the shot time interval. Compared to other recent academic MCS surveys we must stress that the VOLTAIRE shooting system performed extremely well.

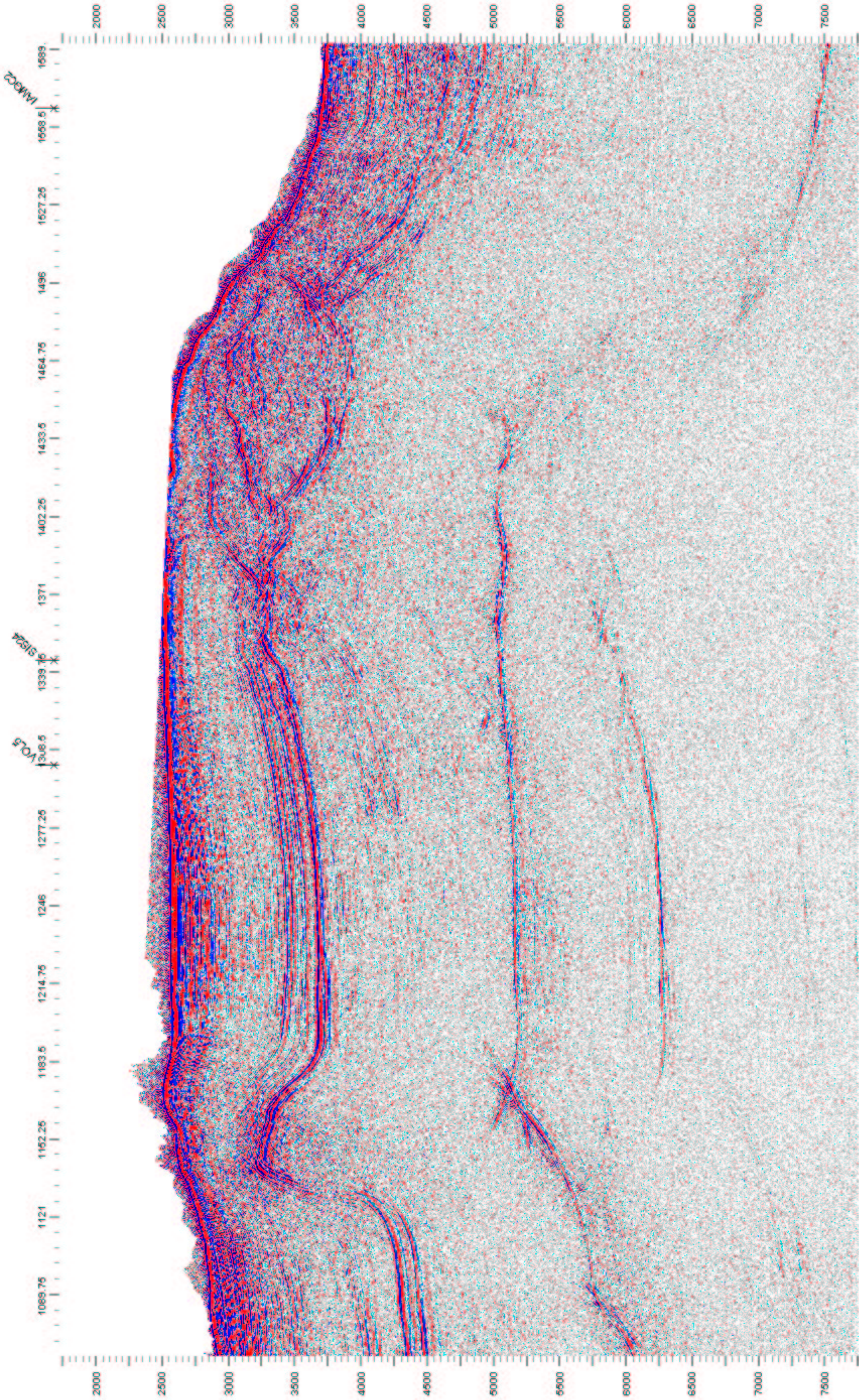

Figure 24: time migration of MCS line VOL02, displayed by WinPics.

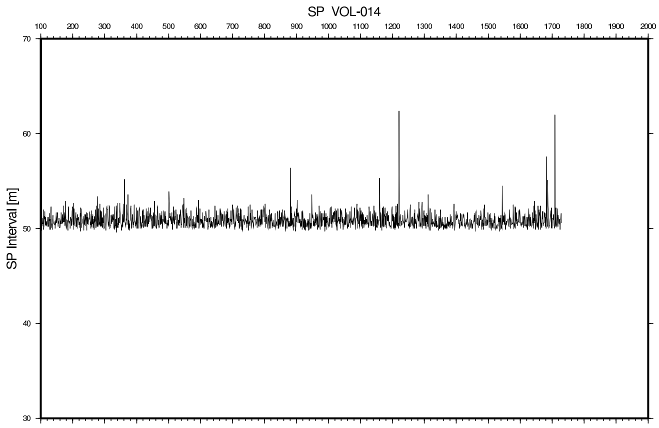

Figure 25: quality control on MCS shooting acquisition, based on shot point interval.

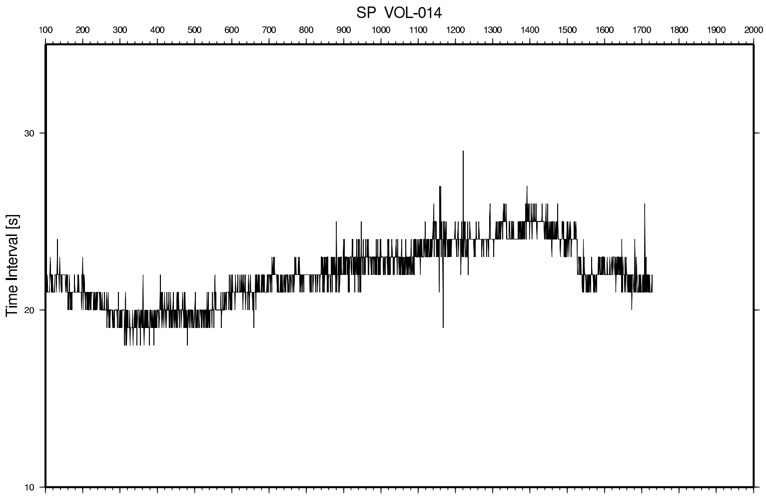

Figure 26: quality control on MCS shooting acquisition, based on time interval.

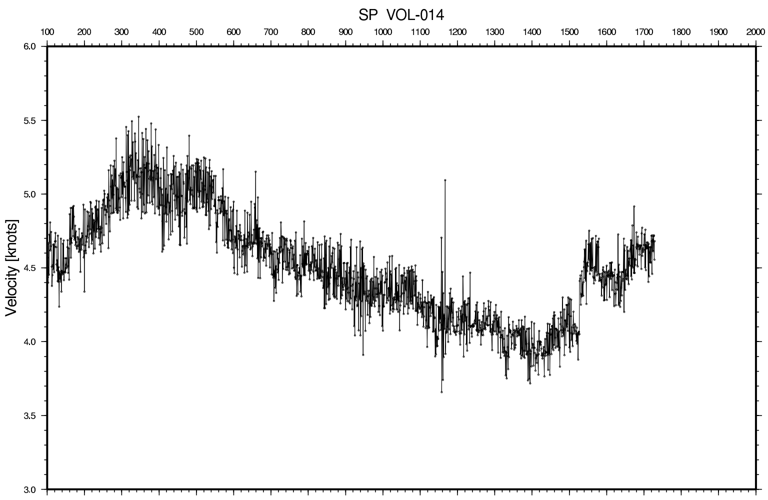

Figure 27: quality control on MCS shooting acquisition, based on velocity measurements.

6.4 Quality control on bathymetry

The bathymetric data are extracted from the navigation files by the nav03-b.f program to obtain bathymetric profiles suitable for plotting. These profiles were then compared to the known bathymetry of the area by extracting profile data from the Smith & Sandwell (1997) predicted bathymetry or from Gebco97 Digital Atlas data. The script plota-brut.csh performs the track extraction and plotting. An example is shown in Fig. 28. We have observed that some areas are well represented by the available data while others are still poorly known. As a rule, in the abyssal plain the observed topography is flatter than any available compilation would predict. In the Gulf of Cadiz where many topographic features in the sea-bottom have a clear recent tectonic origin, we observe differences between the surveyed and predicted profiles greater than 200 m. In the example shown (Fig. 28), which is located offshore the Algarve margin, the difference is greater than 500 m in the central part of the profile. This shows how important it is for the near future to complete the available dataset of Multibeam coverage.

Using the synthesis files for mcs (all-mcs.txt), magnetics (all-mag.txt) and chirp (chirp.txt), the programs ocupa.f, ocupa-m.f and ocupa-c.f provide the basic statistics on geophysical data acquisition: length, time and totals and output gmt files that are plotted by the plota-brut.csh script. See the result in Fig. 7.

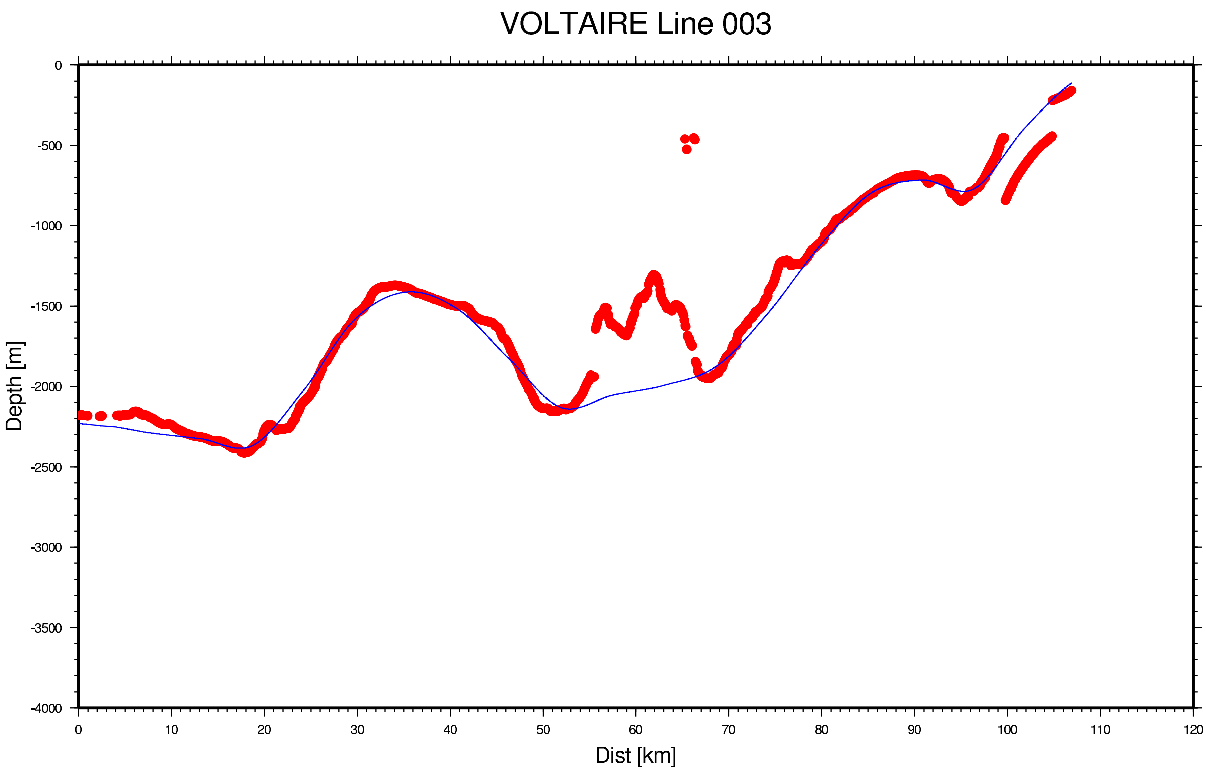

Figure 28: example of accuracy of the acquired bathymetry along MCS profile VOL03.

7 CONTACTS

7.1 Crew

NAME	POSITION
Vincenzo Lubrano	Master
Ernesto Violetta	Chief Mate
Massimo Colorito	Second Mate
Pietro Ciano	Chief Engineer
Giosuè Aorta	First Engineer
Carmine Scotto di Covella	Mach.
Luigi Mastronardi	Bosun
Nicola Vasto	Sailor
Salvatore Remiggi	Sailor
Michele Valente	Deck Boy
Ettore Guida	Deck Boy
Pietro Di Cristo	Chief Cook
Mauro Domenico Povia	Messman

Table 2: crew aboard the R/V Urania during the VOLTAIRE 2002 campaign.

7.2 Products & Manufactures

ACRONYM	DESCRIPTION	URL-email
CNR	Consiglio Nazionale Delle Ricerche	www.cnr.it
IGM	Istituto per la Geologia Marina CNR	www.igm.bo.cnr.it
MCS	Multichannel seismic	
SBP	Subbottom profiler	
SEG	Society of Exploration Geophysicists	www.seg.org
GPS-DGPS	Global Positioning System	samadhi.jpl.nasa.gov
GMT	Generic Mapping Tool	gmt.soest.hawaii.edu/gmt
DISCO	Digicon Seismic Computer (Paradigm)	www.digicon.org
FOCUS	Digicon Seismic Computer (Paradigm)	www.digicon.org
GEOMETRICS	Stratavisor	www.geometrics.com
FUGRO	FugroOceansismica Teledyne	www.fugro.com
GEI	Global Electric Italiana	info@geitaliana.com
DIVESTCO	Kernel Technologies	www.kerneltech.com
SMT	Seismic Micro-Technology	www.seismimicro.com

Table 3: acronyms of Organizations, Manufacturers, Products.

7.3 Scientific & Technical Parties

Figure 29: people on board the R/V Urania, during VOLTAIRE cruise 2002. Refer to Tab. 4 for contacts.

NAME	INSTITUTE	POSITION	tel & email & www
Nevio Zitellini	IGM-CNR	Chief-Scientist	nevio.zitellini @igm.bo.cnr.it
Luis Matias	CGUL	Co-Chief	lmatias@fc.ul.pt
Marco Ligi	IGM-CNR	Geophysicist	marco.ligi @igm.bo.cnr.it
Marzia Rovere	IGM-CNR	Geologist	marzia.rovere @igm.bo.cnr.it
Stefano Carluccio	IGM-CNR	System Administrator	stefano.carluccio @igm.bo.cnr.it
Giovanni Bortoluzzi	IGM-CNR	Chief-Technician	gb @igm.bo.cnr.it
Karol Bonati	DSTGA-UNIBO	Student	kcbonati@tin.it
Paola Mussoni	DSTGA-UNIBO	PhD student	paolamuss@libero.it
Francesca Camurri	DST-UNIPR	PhD student	camurri @nemo.cce.unipr.it
Francesco Borraccini	UNIURB	PhD student	borraccini@uniurb.it
Luis Somoza	IGME	Geologist	l.somoza@igme.es
Emmanuelle Thiebot	UNIBREST	PhD student	ethiebot @sdt.univ-brest.fr
Vojko Daneu	CIMA-Ualg	Geophysicist	daneu@oninet.pt
Cristina Roque	IGM-Lisboa	PhD student	croque@igm.pt
Fernando Teixeira	CGUL	Geophysicist	fabteixeira@fc.ul.pt
Leire Iribarren Gonzales	IJA-CSIC	PhD student	iribarren @ija.csic.es
Jose Vicente	IGM-Lisboa	Geologist	zepvicente @hotmail.com
Mario Raspagliosi	SO.PRO.MAR	Technician	m.raspagliosi @katamail.com
Marco Lagalante	GEI	Technician	marcantonio.lagalante @geitaliana.com
Daniele Gitto	GEI	Technician	dgitto@tiscalinet.it
IGM	Istituto di Geologia Marina		www.igm.bo.cnr.it
CNR	Consiglio Nazionale delle Ricerche		www.cnr.it
DSTGA-UNIBO	Dipartimento di Scienze della Terra e Geologico-Ambientali		www.geomin.unibo.it
DST-UNIPR	Dipartimento di Scienze della Terra		www.dst.unipr.it
UNIURB	Università di Urbino		www.uniurb.it
IGME	Instituto Geologico y Mineiro de España		www.igme.es
UNIBREST	Université de Brest		www.univ-brest.fr
IGM-Lisboa	Instituto Geològico e Mineiro de Lisboa		www.igm.pt
IJA-CSIC	Institut de Ciències de la Terra Jaume Almera		www.ija.csic.es
CSIC	Consejo Superior de Investigaciones Cientificas		www.csic.es
CIMA-Ualg	Centro de Investigação Marinha e Ambiental		www.ualg.pt/cima
CGUL	Centro de Geofíca da Universidade de Lisboa		www.cgul.ul.pt
SO.PRO.MAR	Società Prospezioni Marine S.p.A.		

Table 4: scientific and technical parties for cruise VOLTAIRE 2002.

8 CONCLUSIONS

During the VOLTAIRE 2002 cruise, despite technical failures and bad weather, capable to invalidate our results, we have acquired a network of MCS lines, that will contribute in better defining the shallow structure and neotectonics of this area located off the SW corner of the Iberian Peninsula. We have focused the investigation upon three main topics:

1. the Guadalquivir Bank: lines VOL01, VOL02, VOL03, VOL04, VOL05;

2. the active faults located in the Horseshoe Abyssal Plain, the Horseshoe fault after Zitellini et al. (2001) and an eastern thrust that seems to follow the contour of the SW Iberia continental margin: lines VOL13, VOL15, VOL14, VOL16;

3. the southeastern tectonic termination of the Marquês de Pombal structure: lines VOL17, VOL18, VOL19, VOL20.

These MCS profiles will integrate the preexisting data set and will allow us to study the geometry of the faults related to the above mentioned regional tectonic structures. The accurate knowledge of the geology of these structures, coupled with a constant monitoring of the regional seismicity, will contribute in assessing their potenzial hazard on the coasts of SW Portugal and NW Morocco.

9 APPENDIX: SOFTWARE SCRIPTS AND PROGRAMS

All the scripts (except geonew.c) written by Luis Matias. The scripts can be downloaded hereafter. Feel free to use them, please remember to aknowledge the VOLTAIRE 2002 cruise report, IGM-CNR Technical Report N. 79., at http://doc.igm.bo.cnr.it.

mag01.f
mag02.f
roa01.f
roa02.f
ocupa.f
ocupa-c.f
ocupa-m.f
plota-brut.csh
nav03m.f
geonew.c

Bibliography

[1] Borges, J.F., Fitas, A.J.S., Bezzeghoud, M. & Teves Costa, P. (2001). Seismotectonics of Portugal and its adjacent Atlantic area. Tectonophysics, 337, 373-387.

[2] Mauffret, A., Mougenot, D., Miles, P.R. & Malod, J.A. (1989). Cenozoic deformation and Mesozoic abandoned spreading centre in the Tagus Abyssal Plain(west of Portugal): results of a multichannel seismic survey. Canadian Journal of Earth Sciences, 26, 1101-1123.

[3] Ribeiro, A., Cabral, J. Baptista, R. & Matias, L. (1996). Tectonic stress pattern in Portugal mainland and the adjacent Atlantic region (West Iberia), Tectonics, 15, 641-659, 1996.

[4] Sartori, R., Torelli, L., Zitellini, N., Peis, D. & Lodolo, E. (1994). Eastern segment of the Azores-Gibraltar line (central-eastern Atlantic) : An oceanic plate boundary with diffuse compressional deformation. Geology, 22, 555-558.

[5] Smith, W.H.F. & Sandwell, D.T. (1997). Global seafloor topography from satellite altimetry and ship depth soundings. Science, 277, 1957-1962.

[6] Torelli, L., Sartori, R. & Zitellini, N. (1997). The giant chaotic body in the Atlantic Ocean off Gibraltar: new results from a deep seismic reflection survey. Marine and Petroleum Geology, 14, 5 p.I, 125-138.

[7] Verhoef, J., Roest, W.R., Macnab, R., Arkani-Hamed, J. & Members of the project team (1996). Magnetic anomalies of the Artic and North Atlantic oceans and adjacent land areas. Parts a and b (CD-ROM and project report). Geological Survey of Canada, Darthmouth NS, Open file 3125a.

[8] Wessel P. & Smith W.H.F., New version of the Generic Mapping Tool released, EOS Trans. AGU, p.329, 1995.

[9] Zitellini, N., Chierici, F., Sartori, R. & Torelli, L. (1999). The tectonic source of the 1755 Lisbon earthquake and tsunami. Annali di Geofisica, 42, 1, 49-55.

[10] Zitellini, N., Mendes, L.A., Cordoba, D., Danobeitia, J., Nicolich, R., Pellis, G., Ribeiro, A., Sartori, R., Torelli, L., Bartolome, R., Bortoluzzi, G., Calafato, A., Carrilho, F., Casoni, L., Chierici, F., Corela, C., Correggiari, A. Della Vedova, B., Gracia, E., Jornet, P., Landuzzi, M., Ligi, M., Magagnoli, A., Marozzi, G., Matias, L., Penitenti, D., Rodriguez, P., Rovere, M., Terrinha, P., Vigliotti L. & Zahinos Ruiz A. (2001). The 1755 Lisbon earthquake and Tsunami: localization and investigation of the possible tectonic source. EOS Transactions, 82, 26, 285-291.