RAPPORTI ISMAR (2010) **1**, 1–17

PROJECT BIGSETS: REPORT ON SEISMIC AND MAGNETIC INVESTIGATIONS DURING CRUISE BS98 WITH R/V *Urania*

N. Zitellini[1], E. Berton[1], G. Bortoluzzi[1], N. Calafato[1],
G. Centorami[1], F. Chierici[1], V. Landuzzi[1], M. Ligi[1],
D. Penitenti[1], E. Scipionii[1], M. Rovere[1],
L. Casoni[1], A. Correggiari[1], A. Magagnoli[1], G. Marozzi[1],
L. Vigliotti[1], P. Jornet[2], P. Rodriguez[2],
I. Thompson[2], A. Zahinos[2], R. Bartolome[3], E. Gracia[3],
P. Terrinha[4], A. Ribeiro[4]

[1] *CNR, Istituto di Scienze Marine, Italy*
[2] *UGBO, CSIC, Barcelona, Spain,*
[3] *IJA, CSIC, Barcelona, Spain*
[4] *UNILIS, Lisboa, Portugal*

Received: April 2010 / Accepted: April 2010 - PDF for print

SUMMARY

A summary of the ship-board activities of a Reflection Seismic, magnetics and coring survey on the offshore SW Portugal is presented. The survey used R/V *Urania* of CNR for 35 days, inclusive of transits from Livorno and to Napoli. Along with a description of technical details of the equipment employed, we discuss problems regarding data acquisition and quality, as well as presenting some initial results.

Key words: Reflection Seismic – Magnetometry – Bathymetry – Tectonics - – Tyrrhenian Sea

1 INTRODUCTION

Cruise BIGSETS 1998 was designed to accomplish two major tasks: (a) the geological and geophysical definition of the inferred seismogenetic area off C.S.Vicente (Sartori et al. 1994; Torelli et al. 1997), by mean of multichannel reflection survey, magnetics and SBP, and (2) the sampling of the seabed to constrain the age of deformation and detect fault displacements recorded in the sediment coverage, by means of gravity and piston corers.

After the approval of the Project by EC, the Italian Group made an application for ship's time to CNR, and a 40 days cruise with R/V Urania was scheduled for November 1998.

The cruise took place from 30-oct-1998 to 9-dec-1998, with two port calls to Cartagena for mobilization and demobilization of the Spanish equipment.

Hereafter, a description of the equipment and of their usage is given, along with details of the general setting and performances, as well as some preliminary results and concluding remarks.

1.1 State of the art

The Azores-Gibraltar Plate boundary (AGP) /Fig. 1 connects the Azores triple junction with the continental collision zone of the West-Mediterranean and separates the Eurasian Plate from the African plate. Along this line the relative motion is di-

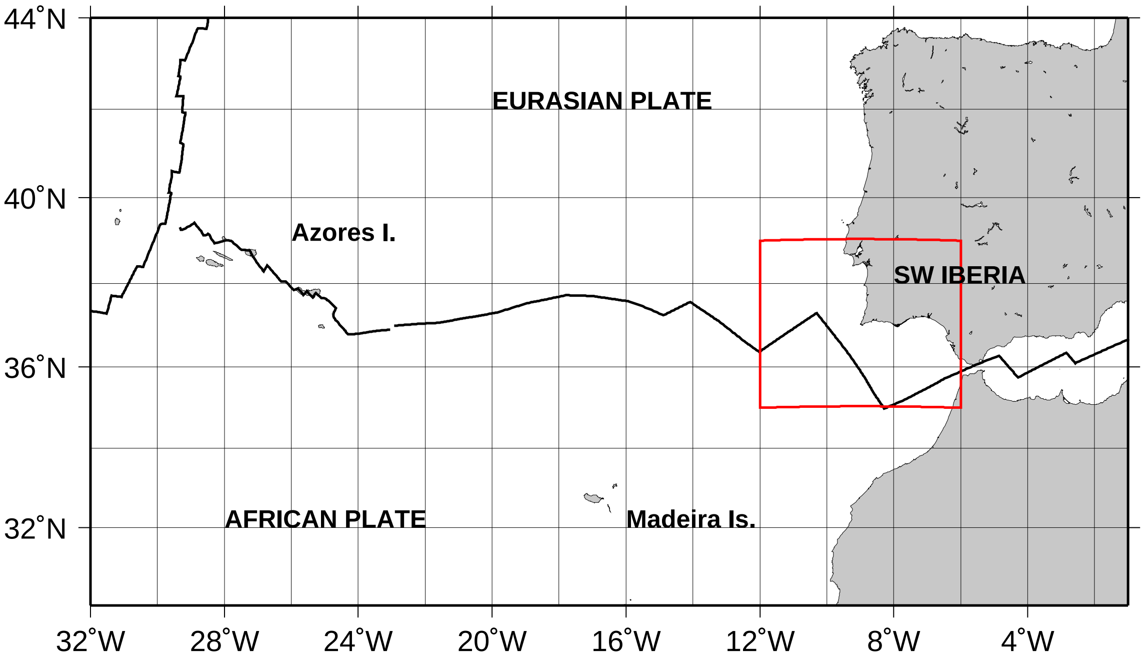

Figure 1. General setting and Study area (red box).

vergent West of the Azores, transcurrent in the middle part and convergent East of Tore Madeira ridge to the Gibraltar Strait. Here diffuse compressional deformation is present, as testified by scattered seismicity. Topography, geoid and gravity anomalies indicate significant deformation in a wide area, either in the oceanic or in the continental crust. Major seismic events, like 1755 Lisbon Earthquake (de Sousa 1919-1932) that may have reached extreme magnitude (M=8.5) require large rupture areas and perhaps large displacements. This suggests a transitional tectonic regime where new plate boundaries are being nucleated and significant deformation is occurring in a compressive setting (Ribeiro et al., 1996). Notwithstanding considerable efforts devoted during the last two decades in the understanding of the geodynamic regime at the continental margins of the Southwestem European block (Purdy 1975; Mauffret et al. 1989; Pinheiro et al. 1992; Whitmarsh 1993; Sartori et al. 1994; Banda et al. 1995; Gonzales et al. 1996) the deformational process present in the offshore of SW Portugal is practically still poorly understood.

PURPOSE OF THE SURVEY

The coasts of Portugal, Spain and Morocco are earthquake and tsunami prone area as testified by the historical occurrence of large events, among which the ”1755 Lisbon Earthquake” was one of largest episode ever occurred in this area. Part of the tectonic structure which probably cause this event has been recently identified offshore Cabo de Sao Vicente (Zitellini et al. 1999). This identification is also reinforced by a recent backward raytracing tsunami modeling (Baptista et al. 1998), showing that the preferred solution implies a double rupture, trending NNW-SSE to NW-SE, centered approximately at 100 km W of Cabo de Sao Vicente, within the area encompassed by the present survey. BIGSETS 98 cruise was planned in order to investigate the tectonic and sedimentary history of the sedimentary column, the deformation pattem of the area surrounding the structure and of the thrust itself A MCS survey together with a SBP survey and core sampling were performed. In particular the SBP survey was planned to locate the faults, previously imaged by MCS survey, cutting the sediments till the sea bottom. The target of sampling were the erosional areas wherein the eventually collected pre-compressional sediments would allow the estimate of the uplift rate over both recent and long time spans. Once the geometry and kinematics of a seismo-tsunamigenic structure is defined, it is possible to estimate the characteristic earthquake associated with the rupture in one or more of its segments; the knowledge of the geometry of the source area, the knowledge of its present day activity and of the slip rate of the active structure, that may be inferred from vertical separation and from the age of the displaced sediments, is part of the information required to work out this estimate. Moreover the detailed characterization of the seismo-tsunamigenic source allows a better risk assessment and the definition of specific tsunami warning criteria.

Generalities on tsunami forecast and modeling

Tsunami waves, like most waves, are characterized by three phases: generation, propagation and effects in the arrival area. A unified theory able to incorporate all these three phases to equivalent accuracy and under identical assumption would be highly desirable. Unfortunately this is not the current case: tsunami theories approximate or eliminate some aspects of the problem, hopefully unimportant, to reach some computable results. As a matter of fact during tsunami phenomena some previous unimportant quantities become important and vice-versa. Present day theories dictate separate formulation for tsunami generation, propagation and disposition. Many different approaches had been used to envisage this problem. Piston-like approach to the tsunami generation problem (based on Laplace equation; see for instance Honda & Nakamura (1951) and many others), though elucidating tsunami general properties, like dispersion and geometrical attenuation, could obtain virtually any tsunami motion by selecting initial water pile of suitable shape. This indetermination in the choice of water pile parameters is worsted by the still scarce knowledge of the earthquakes physical mechanisms; so tsunami theoretical work relies on 'ad-hoc' parametrization. From the '60, kinematics description of earthquakes had been used. The dislocation model and its extensions consider parameters like strike, dip, length and width of the fault plane, slip direction, rupture velocity etc. Faulting parameters are very difficult to be estimated within this description, as they do not depend linearly from the seismogram they generate. During the same period (Burridge & Knopoif 1964) developed a model based on an equivalent body force. In the equivalent force model, each multi-pole term of the force expansion depends linearly on the total seismic field, and hence on the tsunami field. Using a simple model, namely a point force derived from the divergence of a symmetric, second order moment tensor, only six parameters are needed to fit reasonably well the seismic radiation from earthquakes at regional far field distance (Ward 1980, 1981, 1982). In the local approach to tsunami wave modeling, an elastic half space overlaid by a water layer (Comer 1984) can also be used, without loss of generality instead of a spherical non-rotating Earth model (S. Ward, cit.). Elastic bulk parameters and local gravitational field must be supplied. Although real earthquakes have finite physical dimensions and at least a line source approach should be used, in first approximation a point source having same depth, moment and mechanism gives roughly the maximum amplitude expected to the one using a line source model. A peculiar feature in tsunami radiation patterns resulting from line source descriptions, which point source approximations are not able to recover, is beaming; the direction of which is mainly perpendicular to long and thin earthquake faults, regardless of the focal mechanism characteristics. In the tsunami generation problem the point source approach puts into light four different main features, depending on the excited wave periods. The values of the upper and lower limits of the period and the frequency range between two periods depend upon the earth model chosen:

A a long period region that deviates from $(gh)^{1/2}$ behavior, g being the gravity acceleration and h the water depth, where earth rotation and ellipticity become important, but where earthquakes are not very efficient in generating tsunami.

B a middle period region, where shallow water approximation can be applied and tsunamis are non dispersive and propagate at velocity near $(gh)^{1/2}$.

C a transition zone period, where tsunamis exhibit a combination of deep water and shallow water wave characteristics. This range of periods is strongly excited by submarine earthquakes.

D a short period region in which propagation is independent of water depth, but poorly excited by earthquakes.

The propagation characteristics of each normal mode are strongly dependent upon the media in the volume in which the energy is mostly concentrated, and for tsunamis this media is the ocean. The excitation characteristics of each mode are on the contrary determined by the amplitude of the eigenfunction in the source volume, which for tsunamis is the solid earth. In fact, sub-oceanic structures, while probably having little influence on tsunami propagation, could have great influence on tsunami generation. To give a rough idea, Ward (1980) suggests that “the variation in tsunami excitation, solely due to the Earth structure may be around 20% even in similar Earth models“.

1.2 Survey Planning

BIGSETS 1998 cruise was designed to accomplish two major tasks:

a the geological and geophysical definition of the seismogenic area offshore Cabo de Sao Vicente

b The acquisition and the evaluation of a geophysical data set that could allow the definition of geometrical constrains to be used in tsunami modeling. MCS survey, magnetics and Sea Bottom Profiler (SBP), and the sampling of the seabed, by means of gravity piston corers were planned to achieve this goal.

The Italian and Spanish partners agreed to merge their own geophysical equipment, with the aim of optimizing the results of the cruise. Specifically the Spanish Partner made available a 48 Channel streamer and a 5000 L/Min Compressor (Hamworthy), whereas the Italian Partner made available the Seismic Source (4 Sodera GI-GUN), the 48 Channel Seismograph (Geometrics Stratavisor), magnetometer (Gem) and a 2500 L/Min compressor (Bauer). All the instrmnents came with the ancillary control equipment and spares. In addition, ship's facilities for DGPS navigation and SBP were used. A visit of UGBO members on ship Urania (end of February 1998) confirmed the feasibility of the installation of the Spanish equipment onboard, and the process for this installation was started, in particular for the accommodation of the big winch and compressors on the deck. The cruise took place from 30-oct-1998 to 9-dec-1998, with two port calls in Cartagena for mobilization and demobilization of the Spanish equipment and one port call in Portimao for the turnover of scientific crew. Hereafter, a description of the equipment and of their usage is given, along with details of the general setting and performances.

1.3 Survey Description

This campaign was carried out on board of the Italian Oceanographic Vessel Urania which carried the instruments of the Italian and Spanish teams. R/V Urania departed from Livorno, Italy on 30th October and reached the harbor of Cartagena, Spain on 2nd November, where the Spanish equipment and crew was loaded. Departure from Cartagena towards study area offshore SW Portugal was on November 3rd. After crossing the Gibraltar Strait, on the 4th November, three days were spent on testing and calibrating of the streamer, the GI guns and the acquisition systems. Taking profit of the fact that the vessel had to cross an interesting area before reaching the study area offshore SW Portugal, we performed some test lines in the Gulf of Cadiz and South Portugal, from 7th to 10th November, for a total amount of 325 km of multichannel data profiles.

On the 10th November R/V Urania arrived in the study area and the acquisition of multi- channel seismic reflection profiles began as planned. Configuration parameters of seismic survey were changed (see Table **??** in the Appendix) during some segments of lines to allow the acquisition of refraction data on mobile stations located onshore. The acquisition was performed according to the scheme described in the following paragraphs. The first leg ended on Nov. 25 in Portimao (South Portugal). The second leg started on Nov. 26 and ended in Naples on Dec. 9, 1998. On Dec. 4, on the way back to Naples, the ship stopped in Cartagena to unload the Spanish equipment.

COORDINATES		
POINT	ALONG (Y)	ACROSS (X)
POS1	0.0	0.0
GYRO	-2.0	-2.0
DEPTH 1	1.5	-3.85
DEPTH 2	1.5	-0.15
CHIRP SBP	-11.0	-3.95
CORER	-18.5	5.0
STERN	-42.0	-2.0
MAG	-222.0	-10.0
GUN STBD	-52.0	2.5
ACTIVE STREAMER	-202.0	-2.0

Table 1. Offsets from primary navigation sensor (POS1). DEPTH1, DEPTH2 are Deso25 12/100 and 33/210 Khz.

2 MATERIALS AND METHODS

2.1 NAVIGATION

The ship's NAVPRO 5.4 Navigation Software by Communication Technology was used. The primary positioning sensor was the FUGRO DGPS Mod. 3000 SeaStar. The system was used for ship's guidance on the planned lines and targets, and for data logging of various sensors, among them gyrocompass, Atlas DESO 25 echo/sounder, meteo. In addition, it routed positioning data to the NAVMAP and SBP Computers. The system performed quite well. The availability of Differential GPS signals by the FUGRO 3000 receiver was good, thus allowing metric accuracy for most of the acquisition time.

The Navigation System had the following major settings: time zone GMT, Datum WGS84, Projection Direct Mercator on 37 N (for navigation), Output position POS1.

2.2 BATHYMETRY

Ship's ATLAS KRUPP DESO 25 was used. The speed of sound was set to 1500 m/s. Digitized data were recorded by NAVPRO, after correction for draught. Analog data were recorded at the range 0-5000.

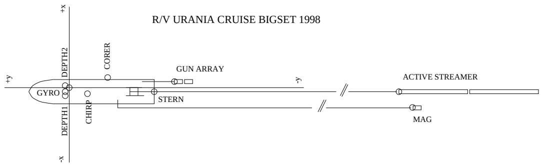

Figure 3. Offsets from primary navigation sensor (POS1)

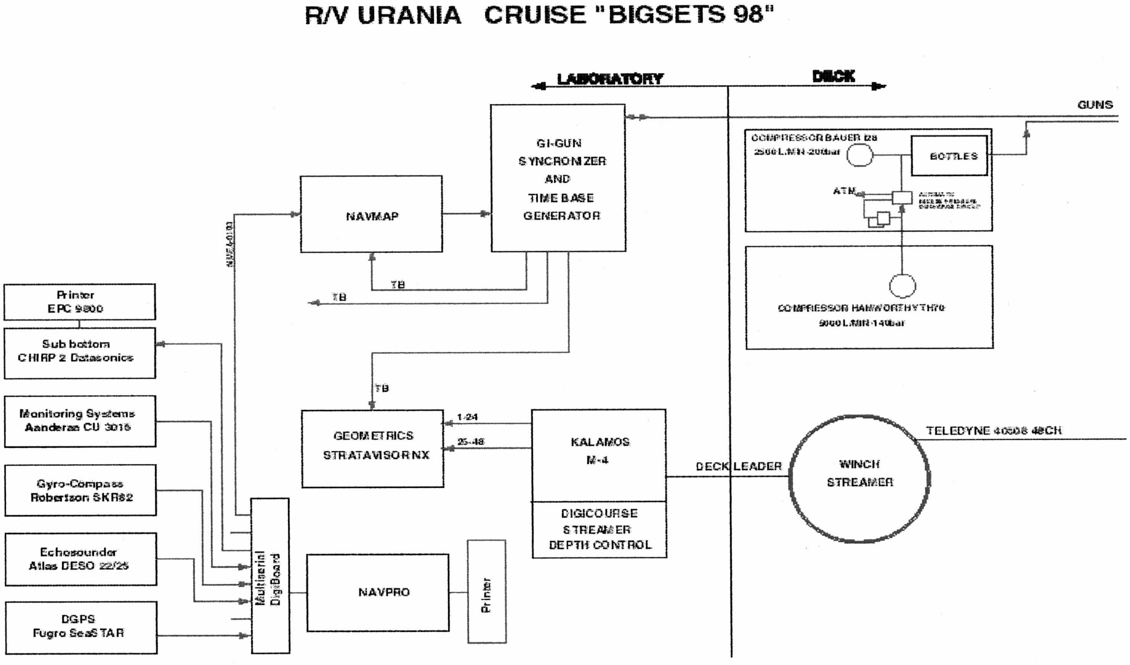

Fig.1 Schematic dataflow for MCS operations

Figure 2. MCS Data flow.

2.3 MULTICHANNEL

STREAMER

We used UGBO's Teledyne Mod. 40508 programmable array, with Group Interval set to 25 mt. Total number of active Channels was 48, plus stretch sections at the head and at the tail. The offset of the first active to source varied from 142 to 158 m. From the Sea-Mac Mod. 3530EHS-50 winch, seismic channels and control lines were run to a Kalamos Locate Type M-4 interface. The depth of the streamer ranged from 6 to 10 m, and was controlled by a group of 8 Digicourse Mod. 5010 Cable Levelers, three of which were equipped with pressure controlled safety buoys, controlled by an FSK modem using Digicourse Digiscan Software. From the M-4 ouput cable connector (configured for a DFSV) the 48 seismic channels were run to the seismograph by a jumper cable. In addition, we prepared another jumper which could connect the deck leaders directly to the seismograph.

Seismic Source

We used 4 SODERA-SSI GI-GUN with different volume chambers, ranging from 150 to 250 in^3 each. The deep penetration survey was accomplished with a synchronized array of two guns in Harmonic Mode Configuration 105+105 in^3 (6.9 L) and 150+105 in^3 (8.2 L), while the high resolution survey used a single gun in True GI configuration 45+105 in^3 (2.46 L). The guns were equipped with REF-TEK hydrophones and Accelerometers for the Time Break detection. The pressure was set to 138 bar for the deep penetration survey, whilst it ranged from 130 to 200 bars for the high resolution one. Some deep-penetration line was run with the two gun array powered at 200 bar, in synchronized Harmonic Mode, for onshore station recording. One of this lines, crossing C.S.Vicente, used 500 in^3 (8.2 L), while the other were set to 420 in^3. Shot distance ranged from 25, 37.5, 50 to 100 m, and was controlled by IGM's NAVMAP Navigation System and GI-GUN Synchronizer (Masini & Ligi 1995), with the former providing the shot timing information to the latter, which in turn provided time break and syncronization signals to the guns. In particular, the array synchronization was performed by measuring the response of any gun to Time Break after (a) cross-correlating the signals from gun hydrophones or (b) timing the Time Break Accelerometric Detector signals at the first zero-crossing, and displacing the appropriate delay or anticipation around a fixed delay of 10 msec at Time Break. The injection delay for each gun was set in order to have the best Peak to Bubble ratio, as shown on a monitor for each shot.

The source was powered alternatively by IGM's Bauer Mod. I28 (2500 L/min @ 250 Bar, regulated 0 to 210 Bar) and UGBO's Hamworthy Mod.TH-190-W70 (5000 L/min @ 140 Bar) through a 80 L bottle reservoir installed on IGM's Bauer I28. The Hamworthy was put into operation with an excess pressure discharge circuit, to avoid machine stops at maximum delivery.

Seismograph

We used a GEOMETRICS Mod. Stratavisor NX, 48 Channels seismograph, with embedded CNT-1 controller. The pre-amplifier gain was set to 36 db and the sampling rate was 1 msec, for record lengths ranging from 8 to 13.6 seconds. The data were recorded on 15GB DLT tape cassettes in the SEG-D 8058 Rev.1 and 8048 Rev.0 formats. DAT and 3480 tape drives available on line for emergency recording in case of faults of the DLT drive, but were never used. The automatic log files were recorded for every line shot, and supplemented the written operator's logs.

2.4 SUB BOTTOM PROFILING

We used ship's DATASONIC DSP-661 Chirp 2 Profiler. Trigger rates varied from 2 to 3 seconds, where chirp length was set to 120 ms. Data were displayed on an EPC 9600 and recorded on Magneto-optical disks in SEG-Y format, which were used off-line for post-processing.

2.5 MAGNETICS

We used IGM's GEM Mod. GSM-19MD Overhauser Effect Magnetometer. The sensor was towed at a constant offset of 220 m from ship's stern. Data were recorded at the rate of seismic shot acquisition by the NAVMAP computer.

The field data were reduced using the 1990 coefficients of IGRF. Some examples are shown in fig. 5.

2.6 DATA PROCESSING

We established a network of computers for seismic and general purpose data processing. Among them, several PC's running Windows and Linux OS, two SUN Sparc Station 20 and one SUN Sparc Station 5 running Solaris 2.5 OS, one VAX Station 3100 running VMS 8.0. One 24" OYO Mod. 624 Thermal plotter was connected to a Sparc Station 20 on a Versatec Interface.

Multichannel Seismic processing was performed by IGM's DISCO/FOCUS, and by CSIC's PROMAX packages on the two Sparc Station 20. Cartographic mapping and analysis was accomplished by the GMT (Wessel & Smith 1998) and PLOTMAP (Ligi & Bortoluzzi 1989) software.

2.7 SAMPLING

Sampling was performed after detailed SBP survey by gravity corers.

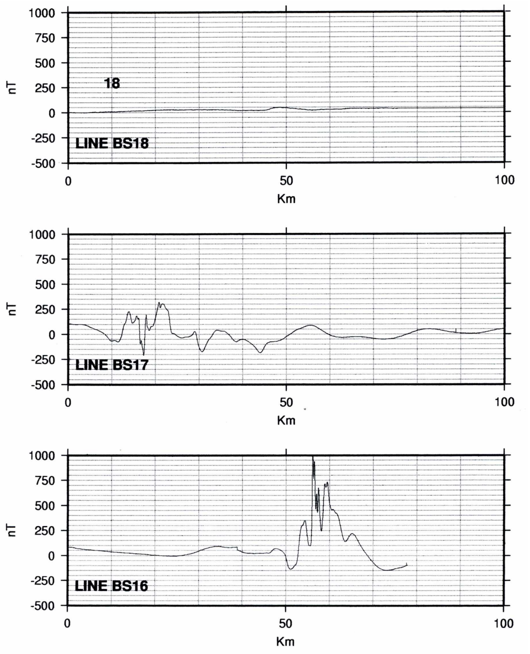

Figure 5. BS98. Examples of IGRF90 magnetic anomaly data along MCS lines.

3 FIRST LEG - MCS SURVEY

The seismic survey performed during this campaign is shown in fig. 4. Orientation of the lines was chosen in order to satisfy firstly, parallelism with respect to present day compressive field in this region, secondly, perpendicularity with respect to the orientation of the major deformation structures located in the area. Some lines were extended outside the target area to achieve a more general picture of the regional deformation pattem. Lines BS07 - BS16 are approximately parallel to the trajectories of the compressive stress in this area. Line BS17 is a strike line across the Gorringe Bank; it was shot in order to achieve a better understanding of the three-dimensional structure of this outcrop of mantle and eventually to reveal part of its rift stage history. Lines BS18 and BS19 were shot approximately perpendicularly to the eastern boundary of the Tagus Abyssal Plain and to an important geo-morphological scarp of the continental margin. This scarp might be a sort of northward continuation of the active thrust structure located west of Cabo de Sao Vicente, possibly the source structure of the lst November 1755 Lisbon earthquake. Lines BS20 - BS24 were shot in order to study in detail the orientation, geometry and kinematics of the above mentioned active thrust. Line BS25 were shot parallel to the axis of the thrust structure, to image the lateral variability of the faults. Line BS26 was designed for land recording of the refracted waves only, with shooting interval of 150 meter. The linees started 50 miles offshore Cabo S.Vicente with direction N50E. Be-

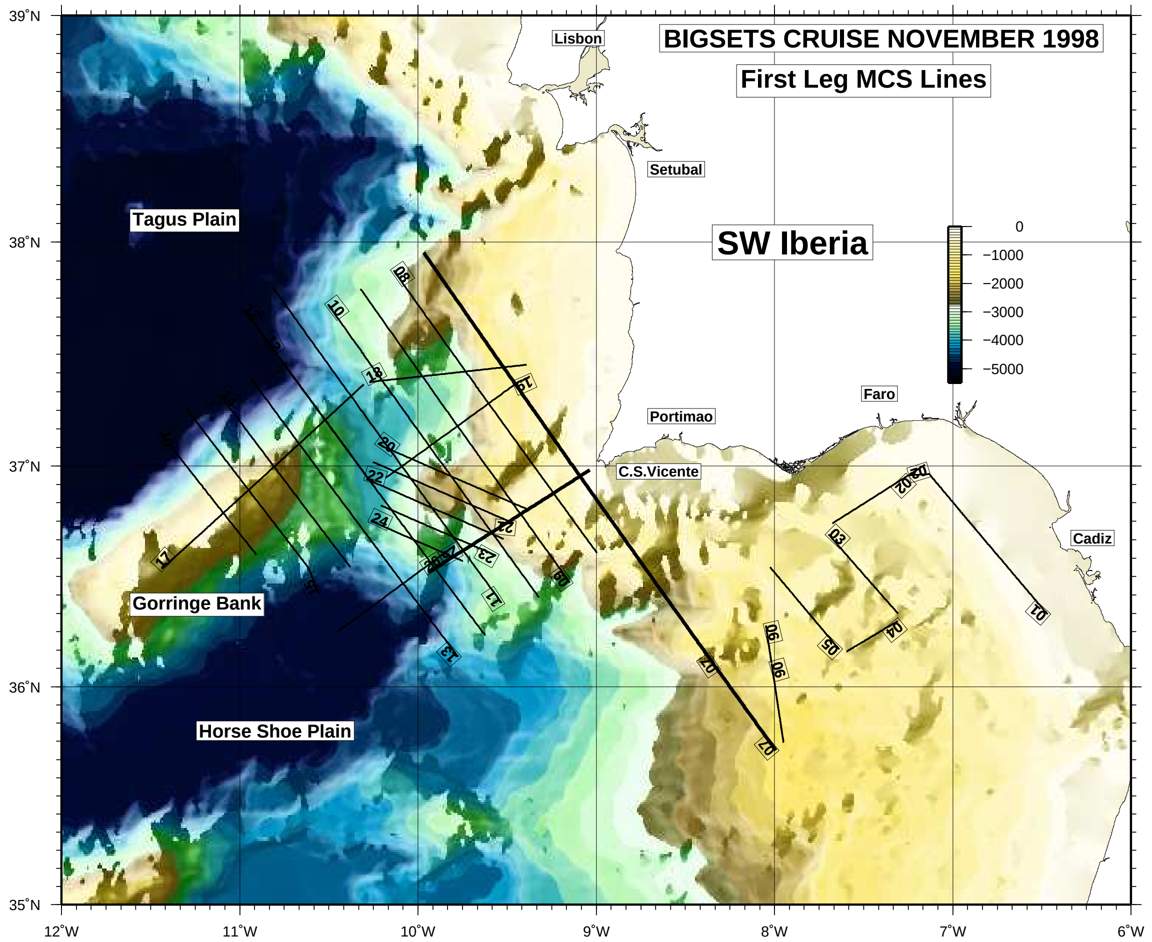

Figure 4. BS98. LEG1. Navigation MCS.

cause of the intense ship traffic around Cabo san Vicente the line was performed without the multichannel streamer towed to allow to shoot very close to Cabo S.Vicente itself

During the survey some lines were shot to collect both reflection data and refraction data (lines BS06 and BS07A and line BS26 for refraction data only). In order to obtain good results for the acquisition of refraction data, these lines were shot with a shot interval of 100m, and using a GI Gun extra chambers 150 in^3 with 200 bar working pressure. The refraction signals were recorded by five mobile stations located onshore in the following sites:

1 37 10’ 07”N, 8 51’ 52.9”W (two stations) I
2 37 13’ 52.6”N, 8 48’ 28.7”W (three stations).

Each station was equipped with a seismograph and a DGPS both for positioning and reference clock. These data will be used to make a velocity model for the upper crust in this region, using backward ray-tracing technique with the purpose of constraining the geometrical and structural interpretation of the seismic reflection profiles. The results of this study will be used, at a later stage, to reprocess the reflection profiles and to refine structural models for the crust in this region. Refraction data acquired during the survey will be processed by Spanish team.

3.1 Standard procedures for the processing of multichannel seismic data

PROMAX

1 SEG-D input (two format codes had been used: 8048,8058)
2 Re-sampling data at 4 ms
3 Band-pass filter: 6-9-58-62.5 Hz
4 Edit traces
5 Hand Statics: -20 ms
6 Load Geometry and CMP sorting fold: 6 or 16 or 24 (100m,37.5m,25m distance between shots)
7 Interactive Velocity Analysis
8 NMO Correction and Stack
9 Top mute
10 Minimum phase predictive deconvolution: decon operator length: 300 ms; prediction distance: 20 ms
11 Band pass filter: time and space-variant Ormsby band-pass filter

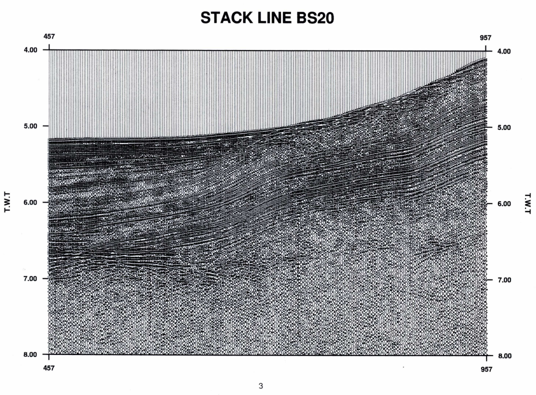

Figure 6. BS98. MCS line BS20, stack.

12 True Amplitude Recovery: basis for spherical spreading (1/dist)
13 Trace Mixing: trace mixing algorithm: weighted mix. 5 traces to mix over with trace weights 1,3,7,3,1
14 Time Scaling: Automatic Gain Control type of AGC scalar: normally 2000ms but sometimes 6000ms
15 Trace plotting in a Oyo Geospace plotter: plotter device 24 inch, bytes per scan 1184

DISCO-FOCUS

1 SEG-D input (two format codes had been used: 8048,8058)
2 Load Geometry: fold, 6 or 16 or 24 (100m, 37.5m, 25m distance between shots)
3 Re-sampling data at 4 ms
4 Band-pass filter: 6-9-58-62.5 Hz
5 Edit traces
6 Hand Statics: -20 ms
7 True Amplitude Recovery: basis for spherical spreading (1/dist)
8 Gapped deconvolution op. Length:400ms; prediction leg: 24ms; time variant trace equalization
9 CMP sorting
10 Interactive Velocity Analysis
11 NMO Correction and Stack
12 Top mute
13 Finite difference time migration
14 Band pass filter: time and space-variant Ormsby band-pass filter
15 Time Scaling: Automatic Gain Control type of AGC scalar: normally 2000ms but sometimes 6000ms
16 Trace plotting in a Oyo Geospace plotter: plotter device 24 inch, bytes per scan 1184

Figures 6, 7 and 8 show examples of segments of seismic profiles obtained during this campaign.

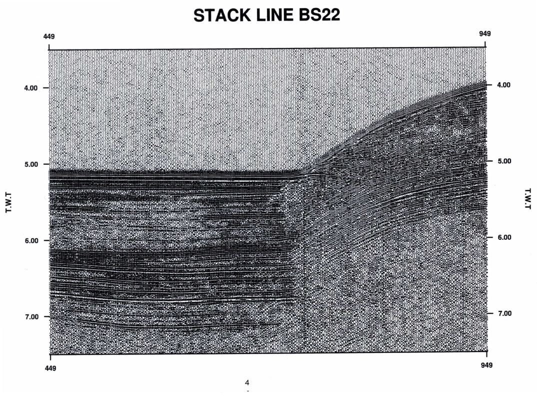

Figure 7. BS98. MCS line BS22, stack.

4 2ND LEG - CHIRP AND SAMPLING SURVEY

The second leg was devoted to the high resolution SBP (CHIRP) investigation of the thrust fault described by (Zitellini et al. 1999). Only after the detailed survey of this structure the sampling stations were chosen. A total of 6 cores were recovered (table 2), 4 in front of the thrust with the purpose of possibly dating, the most recent tectonic activity; 2 on the hanging wall of the structure, to date the first stages of the tectonic deformation.

4.1 CHIRP sub-bottom survey and coring METHODS

A sequence of 13 parallel lines trending E-W, named BS27 to BS39 from, have been recorded with the SBP along the area, between 10:15W, 37N and 10W, 36:40N (Fig. 9). Where the active deformation was detected, coring stations were performed (Fig. 10). The CHIRP profiles, ranging from 5 to 7.5 miles length, were firstly spaced every 2 miles, and from 36:48N, they were spaced every 1 mile and systematically shifted 1 mile towards the east in order to follow the structural trend. A longitudinal line trending NNE-SSW and 17 miles

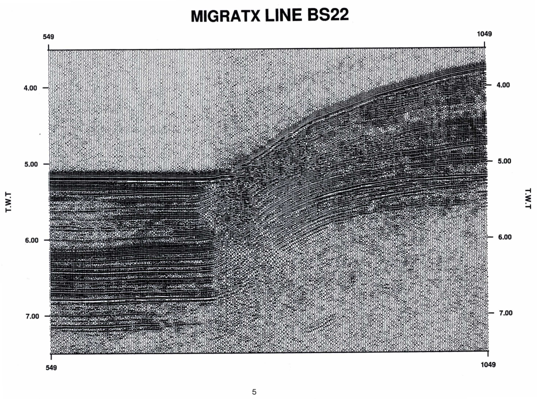

Figure 8. BS98. MCS line BS22, migrated.

CORE	DATE	LAT	LON	DEPTH
BS01	281198	36:52.993	-10:05.522	-1.00
BS02	281198	36:52.991	-10:06.700	2588
BS03	301198	36:47.001	-8:36.998	781
BS04	301198	36:46.968	-8:37.032	480
B005	301198	36:46.714	-8:37.394	512
BS06	011298	36:51.000	-10:08.623	721
BS07	011298	36:39.922	-9:46.465	54
BS08	011298	36:40.109	-9:46.311	891

Table 2. Core Locations.

long (named BS42) was acquired in order to correlate all the transverse lines. A parallel longitudinal line (BS41) unfortunately had to be stopped just at its beginning because the weather conditions become too rough for good acquisition. To maximize the resolution of the SBP data, all these lines were run at an average speed of 2.5-3 knots, using a trig rate of 2 sec. The maximun penetration achieved was around 60 m (depth calculations have been made assuming a sound speed of 1500 m/s), while the average penetration was around 35 m.

MAIN RESULTS

To characterize the recent tectono-sedimentary history of the contractional feature named “Marques de Pombal“ Thrust, we have distinguished two main physiographic provinces: (a) the basin floor and (b) the fault scarpment and slope.

The Infante D. Henrique Basin

This basin, here named ”Infante D. Henrique Basin“, corresponds to a topographic threshold between the structural highs of Gorringe Bank and Marques de Pombal Thrust, west and east respectively, and raising more than 1000 m from the floor of the Tagus and Horseshoe abyssal plains.

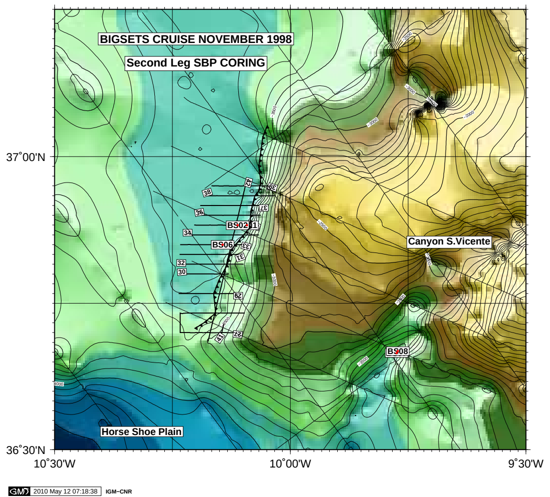

Figure 9. BS98. LEG2. Chirp lines.

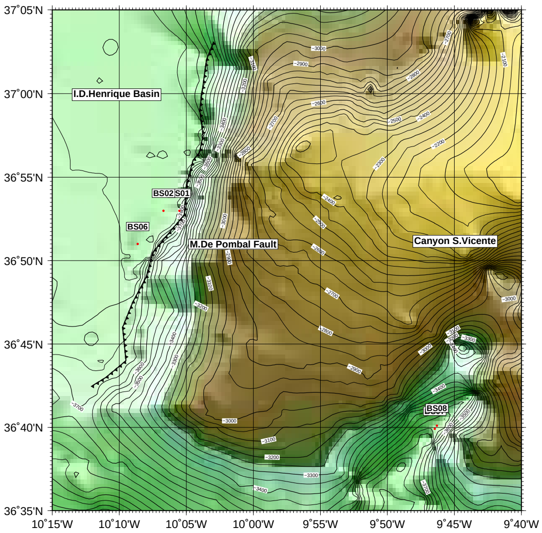

Figure 10. BS98. Cores locations.

The Inf‘ante Don Henrique Basin has triangular shape, widening (from 2.3 to more than 18.1 km) and deepening (from 3725 m to more than 3900 m) northward. The CHIRP data cover just half of the basin, from the center to its eastern edge. In cross section, this basin has a asymmetrical shape: the basin axis (present-day depocenter) is located at the foot of the eastern wall, whereas the topography towards the western limit is dominated by a gentle (5°) and smooth slope. At least four main units (referred to as A to D, from top to bottom) have been identified from the CHIRP profiles (Fig. 11):

- Unit A: this unit is about 4.5 m thick and is characterized by a transparent to semi-transparent acoustic facies. Sometime a discontinuous reflector can be identified within this unit.
- Unit B: this unit is about 10.5 m thick. It is characterized by continuous, high amplitude and well stratified reflectors. They are most probably related to turbiditic sedimentation.
- Unit C: this unit is about 7 m thick and shows characteristics similar to Unit A.
- Unit D: this unit is at least 8.3 m thick (its lowermost limit is not always well determined) and has similar characteristics to Unit B.

All the sedimentary units show a relatively high degree of deformation. They are folded forming antiforms and sometimes they are affected by reverse faults, resulting from the compressional tectonic activity. The upper units tend to thin as they approach the edge of the basin.

The fault escarpment

The eastern limit of the Infante D.Henrigue Basin is a steep, locally up to 65°, slope corresponding to the front of the ”Marques de Pombal” Thrust.

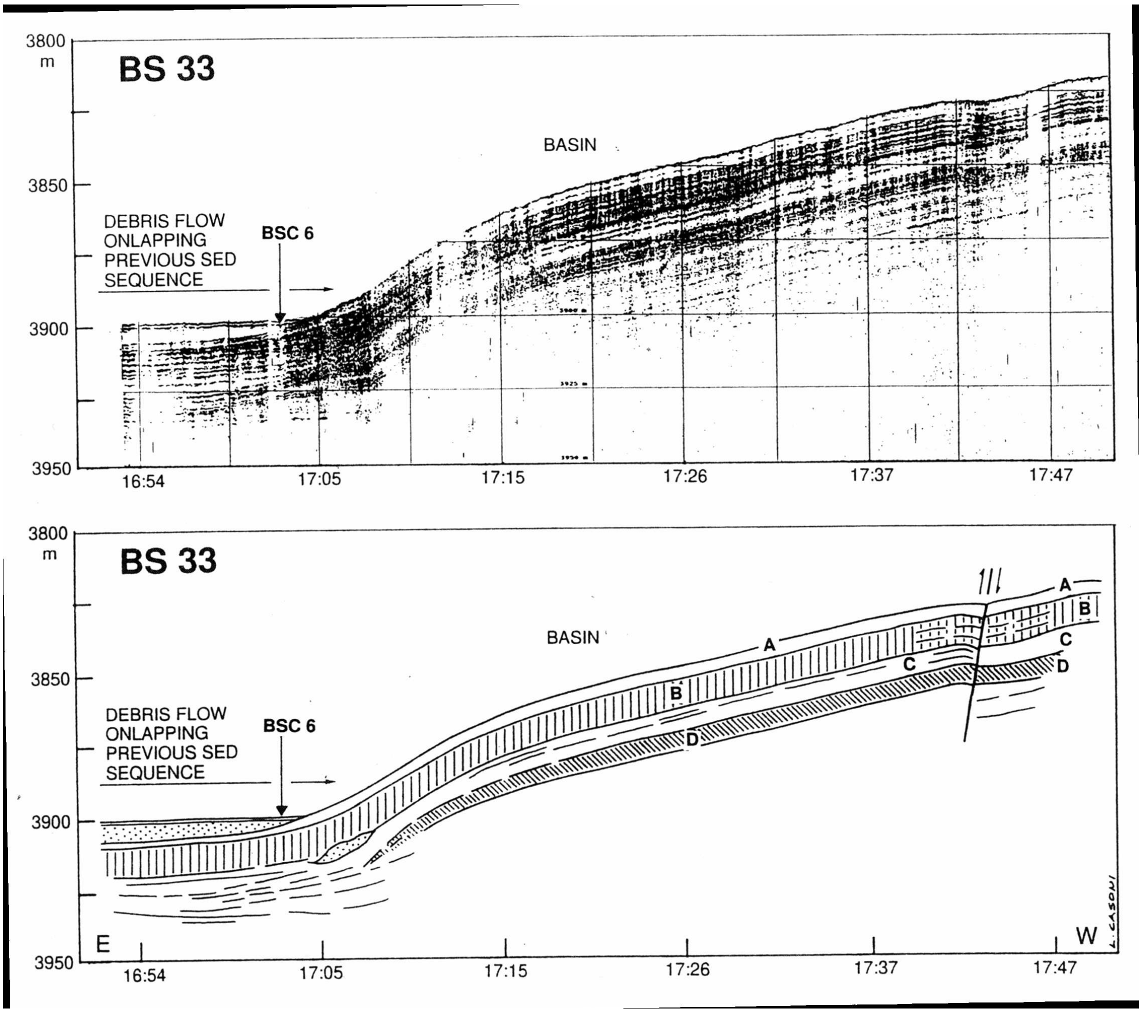

Figure 11. BS98. CHIRP LINE BS33, with interpretation.

The fault scarp, trending N15E, has been mapped from the Chirp-sonar profiles. (Fig. 12). The lower part of the escarpment corresponds to the free face, characterized by the outcropping of the hanging block material. The slope sometime shows a step-like topography, with narrow terraces covered by a thin (less than lm) pelagic drape. The base of the scarp (slope break) is covered by a debris talus fan, filling and/or onlapping the lowest part of the basin (Fig. 13). Diffraction hyperbolae from the foot of the scarp make difficult to well constrain the limits of this talus. The debris talus is characterized by a rough ondulated topography, transparent acoustic facies, and a lenticular-wedge shape. Its thickness varies from 5 m up to 12 m. It has a good lateral continuity and extends up to 4 km away from the fault scarp. Chirp-sonar profiles show similar transparent lenticular bodies interstratified within the turbiditic sedimentary sequences. In this area three gravity cores have been acquired (BSC1, 2 and 6) to study this unit in order to have an age constrain for the deposition of most superficial debris deposit.

4.2 Magnetic Susceptibility Measurements

Magnetic Susceptibility (MS) is a simple and rapid tool for reconstructing the paleo-enviromnental records of deep sea sediments (e.g. Robinson 1982; Bloemendal 1983; Oldfield and Robinson 1985). Variations in whole-core volume MS are controlled by the concentration, mineralogy and grain size (domain configuration) of magnetic minerals in the sediment (usually present only in trace quantities in most pelagic sediments, i.e. <1 x 10^{-7}); by the concentration and type of pararnagnetic (Fe^{2+}, Fe^{3+}, and Mn^{2+} bearing) clay, or labile minerals in the sediment when magnetic mineral concentration is very low. The potential stratigraphic value of logging MS variations in deep-sea cores has already been noted in quite old studies, e.g. Radhakrislmamurty et al. (1968) and Amin et al. (1972), and in recent years it has become clear that lithologically-modulated variations in the amount of magnetic material in deep-sea sediments, are often associated with changes in the source of

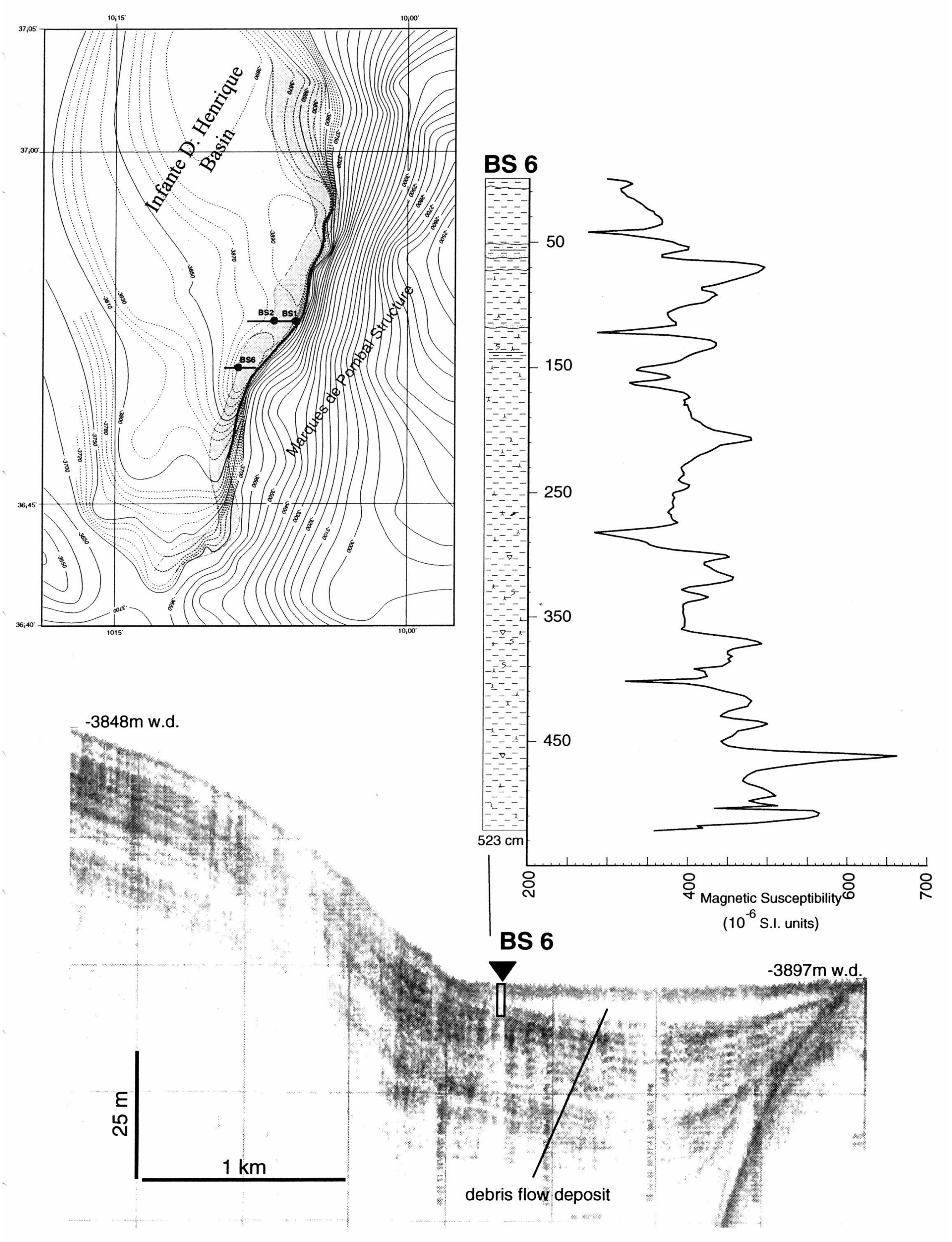

Figure 12. BS98. Core BSC6 and chirp data interpretation.

magnetic material input linked to changes in the provenance and/or delivery mechanism of terrigenous detritus. Thus, MS measurements are considered as effective tool for monitoring variations in the supply of terrigenous sediment to the oceans. Whole-core measurements of volume magnetic susceptibility (K), of the cores retrieved during the BIGSETS 98 Cruise, were made at two centimeters intervals by using a Bartington MS2 meter connected to a pass through loop-type sensor of 100 mm diameter. The noise of this sensor is approximately 1x10^{-6} dimensionless S.I. units.

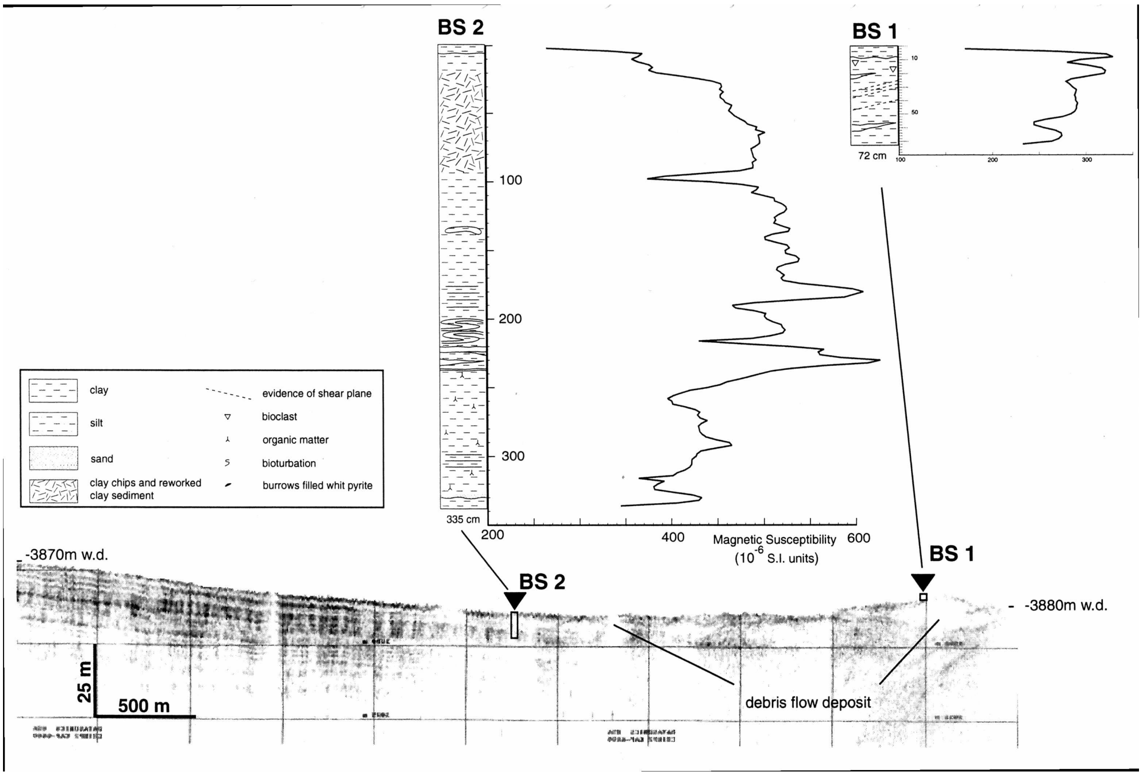

Figure 13. BS98. Cores BSC 2 and 1, with Chirp data.

Magnetic Susceptibility Results

As described in the coring paragraph, five cores have been collected during the cruise. Three gravity cores (BS98-1, BS98-2 and BS98-6) were recovered from the basin adjacent to Marques de Pombal thrust with the target of investigating the depositional history and emplacement timing of a recent depositional body, identified on the CHIRP profiles and possibly related to the 1755 seismic event (see chapter 4.1). Two piston cores (BS98-7 and BS98-8) were retrieved from the inner wall of the Cabo de Sao Vicente Canyon with the aim of constraining the age of the uplift (deformation) of the tectonic structure. The magnetic susceptibility plot of the cores is shown in figure 14. The MS values from the cores recovered in the basin, range from about 300x10^{-6} S.I. units in Core BS98-1, which was collected very close to the fault escarpment, to 350 and 600x10^{-6} S.l. units for Cores BS98-2 and BS98-6. Several peaks and troughs observed in the MS curves of the latter two cores (Fig. 14) suggest a complicated depositional history for the basin, at least in recent times. A correlation between the two cores is not straightforward, but some features can be recognized in both the plots suggesting that the same processes are responsible of the sedimentation within the basin. The two cores recovered from the Capo Sao Vicente Canyon (BS98-7 and BS98-8) show quite low and constant susceptibility values exceeding 150x0^{-6} S.I. units only at the top and near the bottom (Fig. 14). MS profiles appear quite similar suggesting that probably the same stratigraphic interval was sampled, in spite of a different position of the two cores. Peak values observed near the top of the cores can be related to the deposition of recent material probably covering pelagic sediments, which might be mostly supplied by biogenic productivity.

5 CONCLUSIONS

We acquired a total of ∼ 2715 Km of 48 Multichannel Seismic Data (fig. 4), with CDP coverage ranging from 2400 to 1200%, along with bathymetry, SBP and magnetics. Two lines were shot with a coverage 600% every 100 m for reflection and refraction purposes. After an aproximate 2 days initial phase for balancing the streamer and resolving installation problems with the streamer and gun array, the geophysical data acquisition was performed smoothly and continuously during the entire first leg. Some leakage and noise problems on some traces persisted up to the end. The GI-GUN lived up to its name for repeatability and performed reliably, except for very short periods, owing to some overcharging of the 2500 L compressor at abnormally high vessel speed.

The Multichannel data processed on board revealed reflectors down to the acoustic basament, even with one single gun, with resolution from ac-

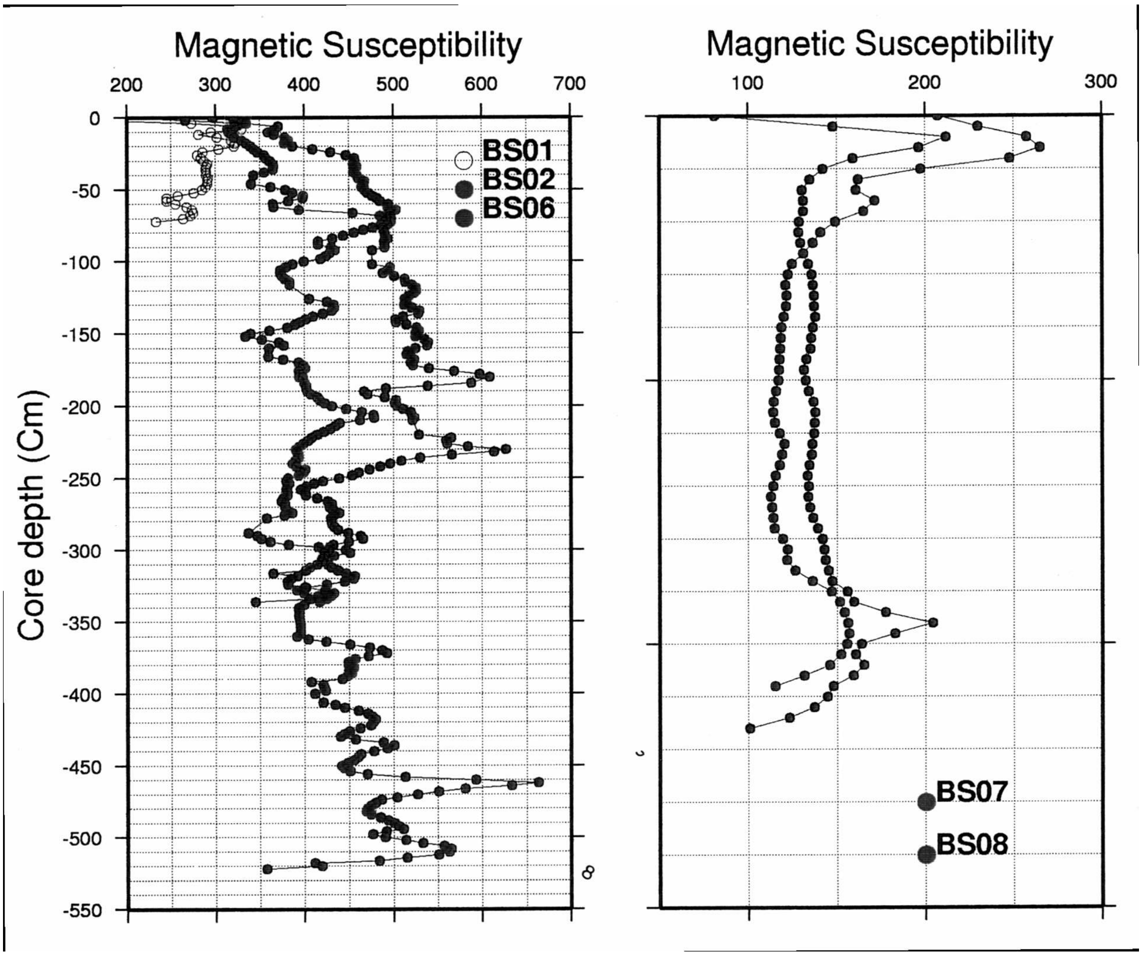

Figure 14. Magnetic susceptibility data.

ceptable to very good, thus confirming the capabilities of well tuned, very small GI-GUN arrays.

The digitized bathymetric data was acceptable for more than 85 % of the acquisitions, and will need some postprocessing for cleanups.

Magnetic recordings showed an oustanding continuity of data and lack of spikes, requiring just a minimal pass for filtering. One line shows some features that, while awaiting land based observatory data, can be probably related to a storm. Once the observatory data is available, the data will be cleaned for diurnal variations and IGRF corrections will be applied. An example of the acquired magnetic data data is presented on Fig. 5.

The elastic bulk parameters of the studied area will be hopefully estimated from the refraction data acquired (lines BSO6, BS07A, BS26) and from the foreseen Ocean bottom Seismograph (OBS) and deep penetrating surveys, (the OBS survey would furnish also natural seismic activity, source depth and the eventual motion of the sea bottom during earthquake). The local gravitational field can be obtained from available satellite data (Sandwell et al.,1996)

The data collected during the MCS and SBP surveys would allow the evaluation and the test of both body force approach and linear approach for the above mentioned reasons.

The MCS survey imaged well enough the structural features, like length of a portion of rupture, fault dip, length, rupture direction etc. of the explored area and the SBP survey were able to detect the fault and the free face fault displacement. The long pattern fault detected during this survey, together with the foreseen high resolution bathymetric survey and the OBS survey may furnish the major elements to an accurate tsunami modeling, regarding both generation and arrival zones, and hopefully early warning.

We collected a very interesting and complete geophysical and geological data set.

Ship Urania performed well and all the heavy geophysical equipment were quit easily allocated and operated on the deck, thus demonstrating the feasability of sharing equipment and personnel for heavy seismic cruises.

The Italian, Spanish and Portugese teams worked together in good harmony, and, finally, the work onboard was performed smoothly without significant equipment problems, with no personnel or environmental problems, and in perfect agreement with the ship's officers and crew.

ACKNOWLEDGMENTS

We wish to thank the Captain V. Lubrano Lavadera, officers and crew of R/V Urania for the efforts and professionalism during the cruise.

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APPENDIX A: SCIENTIFIC CREW AND INSTITUTIONS

APPENDIX B: CRUISE SUMMARY

NAME	INSTITUTE	TITLE	CONTACT
Nevio Zitellini	IGM-CNR	Chief Expedition	+39-0516398889 nevio.zitellini@ismar.cnr.it
Elisabetta Berton	IGM-CNR		
Giovanni Bortoluzzi	IGM-CNR		g.bortoluzzi@ismarcnr.it
Nino Calafato	IGM-CNR		
Gabriella Centorami	IGM-CNR		
Francesco Chierici	IGM-CNR		F.Chierici@bo.ismar.cnr.it
Marco Ligi	IGM-CNR		M.Ligi@ismar.cnr.it
Daniela Penitenti	IGM-CNR		
Elena Scipioni	IGM-CNR		
Marzia Rovere	IGM-CNR		m.rovere@ismar.cnr.it
Pedro Jornet	UGBO		
Pablo Rodriguez	UGBO		
Ian Thompson	UGBO		
Abel Zahinos	UGBO		
Rafael Bartolome	IJA		
Pedro Terrinha	UNILIS		
Ist.Geologia Marina CNR	IGM-CNR	Via Gobetti 101	Bologna Italy
Un.Gest.Buque Ocean.	CSIC		Barcelona Spain
Ist."Jaime Almera"	CSIC		Barcelona Spain
Univ.Lisboa	UNILIS		Lisboa Portugal

Table A1. Scientific Crew

SHIP	R/V *Urania*
START	1998-10-30 PORT: Livorno
END	1998-12-09 PORT: Napoli
SEA/OCEAN	Atlantic Ocean, SW Portugal
LIMITS	NORTH: 38 SOUTH: 35.5 WEST: -12 EAST: -6
OBJECTIVE	STRUCTURAL GEOLOGY
COORDINATING BODIES	ISMAR-CNR
CHIEF OF EXPEDITION	Dr. Nevio Zitellini
CONTACT	N. Zitellini at ismar.cnr.it
DISCIPLINES	GEOPHYSICS BOTTOM SAMPLING
WORK DONE	2715 KM MCS, ~ 2700 KM MAGNETOMETRY, ~2900 KM SBP, 6 GRAVITY CORES

Table A2. Cruise Summary.

APPENDIX C: PROBLEMS AND RECOMMENDATIONS

The success of the cruise points to the possibility of future sharing and integration of geophysical equipment and personnel between CNR and CSIC. Hereafter, a brief discussion on some problems and recommendations for any future joint cruise on R/V Urania.

DECK OPERATIONS

Due to the large volume and quantity of materials to be operated on the deck, including the seismic array, the streamer's winch, and the spare sections for the streamer, we would recommend that the ship had some more space available. This in the case of operations with longer streamers, e.g. 96 channels, 2400 m, and to make available the deployment of another string of 2 guns. IGM should provide a different way of deploying and recovering the seismic array, to make it more reliable and secure during poor weather conditions. A more specific document with some suggestions will follow. It was demonstrated, however, that the ship is capable to make heavy seismic cruises.

COMPRESSORS

The two compressors were accomodated on the deck without particular problems, by using the 20' platform built for the TOBI winch (UGBO 10' containerized Hamworthy 4TH), and two beams screwed to ship's deck (IGM's BAUER I28). The Hamworthy was put in operation smoothly, by using ship's services for electrical power and salt water and fresh water delivery for refrigeration. A reduction from UNI45 to 2 1/2 " was required for the salt water delivery. The power electrical cable for R/V Esperides was bypassed by new cables to ship's 270 KW generator. For any other possible stand-alone operation, we would recommend that the compressor had some bottles and excess pressure discharge safety valves. This could also be accomplished by installing on the ship a bottle reservoir and valves for the delivery of compressed air to guns. Yet, another document with more detailed suggestions will follow.