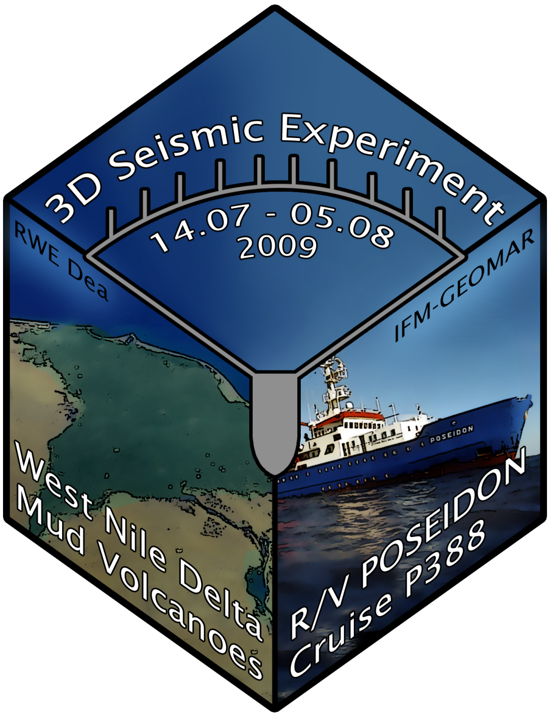
IFM-GEOMAR REPORT

IFM-GEOMAR
Leibniz-Institut für Meereswissenschaften
an der Universität Kiel

FS POSEIDON
Fahrtbericht / Cruise Report P388

West Nile Delta Project - WND-4

Valetta - Valetta
13.07. - 04.08.2009



Berichte aus dem Leibniz-Institut
für Meereswissenschaften an der
Christian-Albrechts-Universität zu Kiel

Nr. 31
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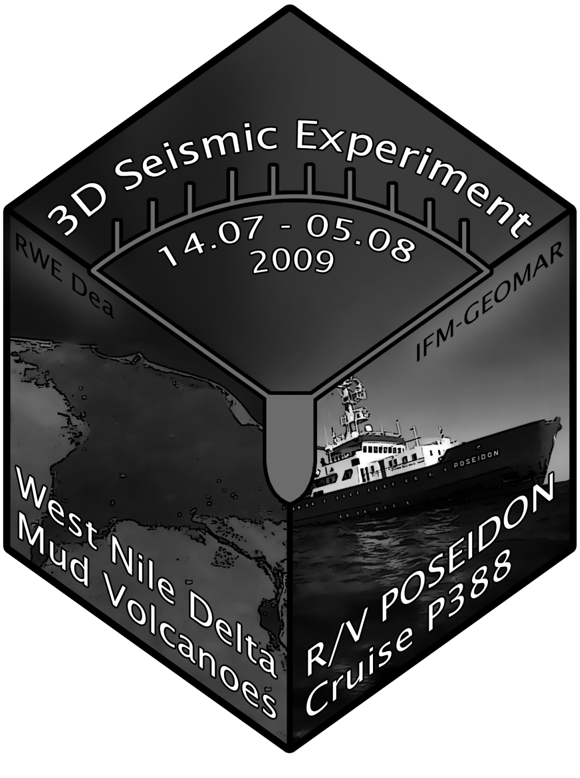

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Content

1. ABSTRACT

The major scope of the fourth cruise within the West Nile Delta Project (WND) was dedicated to the first deployment of the newly built 3-D seismic acquisition system. Following the design of the P-Cable system (VBPR, Norway) a modular streamer system was developed, which allowed to operate 11 parallel streamers behind the mid-size research vessel POSEIDON. The successful survey could be completed with a full 3-D seismic data cube of the North Alex mud volcano. Besides the streamer system 12 Ocean Bottom Seismometers (OBS) were used to record the airgun shots of the 3-D survey. The OBS were left behind after the cruise forming a seismological network for the upcoming months. Earthquake observations recorded since November 2008 provided a large number of large and small events. Frequency spectra revealed pronounced peaks at 6.5 Hz, 13 Hz indicating the observation of some resonance events. Long lasting tremors provide a second unexpected phenomenon in the OSB data, which were interpreted as an answer of the highly gas saturated top of the mud volcano to the trigger of seismological events. Tiltmeter observations indicate that these events appear in correlation with the tide signal. Geoacoustic observations were completed by the operation of a deep towed sidescan sonar. The back scatter data will be used for a detailed mapping of the ruptured central part of North Alex. As secondary information the location of some sparsely distributed active seeps were identified, while the mud volcano itself proved to discharge only minor amounts of gas. The deployment of four Piezometers proved that such instruments can be operated in a cost effective manner by multipurpose vessels. After recovery the records will provide the first data of the temporal variation of the pore pressure within the targeted depths. Recovery of two of a fleet of CAT meters will provide the first long-term observation of gas and fluid expulsion from the mud volcanoes.

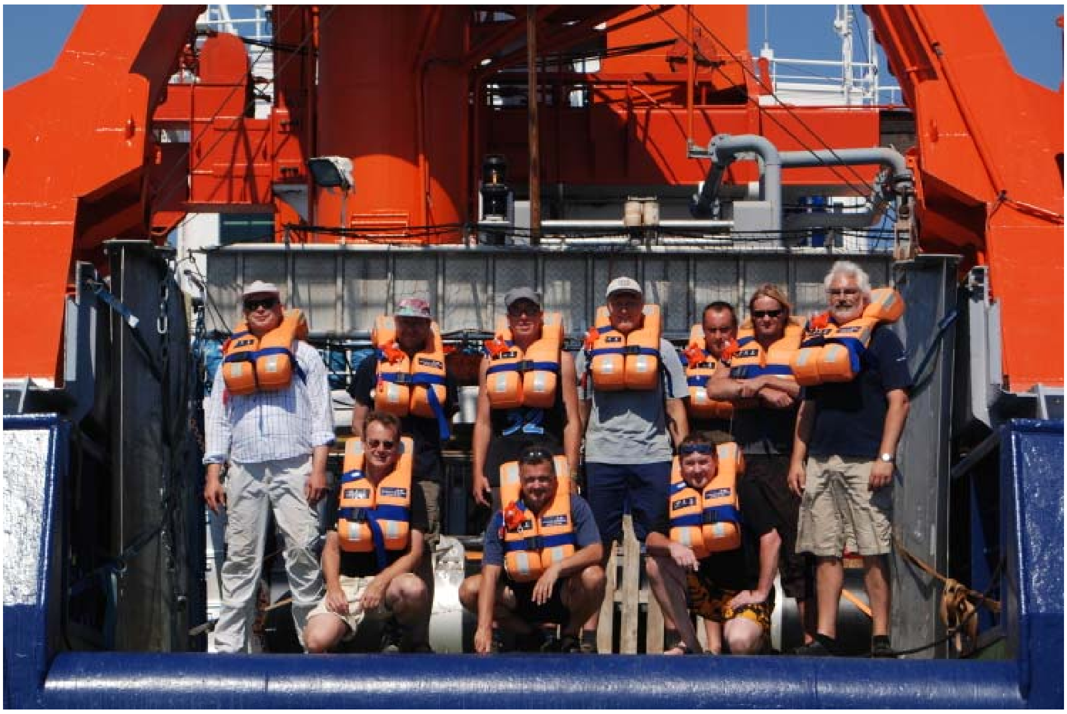


Figure 1.1: The P388 science crew. Above, from left to right: Bernd Hermann, Dirk Kläschen, Torge Matthiessen, Cord Papenberg, Klaus Cramer, Jörg Bialas. Below, from left to right: Warner Brückmann, Ingo Klaucke, Thomas Brandt.

2. INTRODUCTION

Work area of the West Nile Delta Project (WND) is the concession area operated by BP and RWE Dea offshore the Egyptian coast next to the city of Alexandria. Two prominent mud volcanoes, Giza and North Alex together with the deep cutting Rosetta Channel form the most prominent features within this part of the shelf. Promising gas reservoirs were located within the concession area next to the mud volcanoes. Therefore, the temporal development of the mud volcanoes as well as information about the slope stability of the shelf area are of major interest for the exploring companies. The WND Project sets out to investigate the mud volcanoes and provide further information to the understanding of the dynamics of such systems. Temperature and heat flow measurements showed that North Alex is the more active mud volcano, while Giza seems to be in a cooling phase. Therefore most investigation activities were concentrated on North Alex. The previous cruises to the West Nile Delta were mainly dedicated to geochemical, electromagnetic, 2-D seismic and video observations. The data sets showed that a very high gas saturation is to be expected right underneath the seafloor of North Alex mud volcano. Although only limited gas expulsion was observed along the video tracks observed by a ROV. Comparison with elder video observations from French observes confirmed that in recent times a significant tectonic event has lifted large size sediment blocks within the inner circle of the volcano centre. 2-D seismic data could be used to map large scale faults surrounding North Alex upslope, which seem to be still active in recent times. It is expected that gas and fluid migration within the mud volcano as well as the tectonic activity cause a significant amount of seismological events. Therefore a network of OBS was deployed for a time of 9 month to record possible events. The first data set should be recovered during the P388 cruise. If the records prove to be a successful tool for such observations the network should be enlarged and redeployed for another observation season.

A major goal of the seismic activities within the WND project was the development and production of a small-scaled seismic 3-D acquisition tool, that can be operated from mid-sized multipurpose vessels. Based on the P-Cable patent of VBPR, Norway, a new modular multichannel streamer system was designed. Two trawl doors are towed at the sea surface with an offset of 200 m or more. Between the trawl doors a data cable is towed perpendicular to the ships cruise. Several short streamer sections are attached to this strength member and towed parallel to each other in 15 m offset. A GI airgun will be used to serve as active seismic source while a dense network of profiles ensures the consistent coverage of the mud volcano.
Deep towed sidescan profiles will be achieved in order to achieve a high resolution map of the seafloor indicating the lateral extend of different lithology. Moreover will the sidescan allow to get an overview of active seeps sites that may be distributed over the mud volcano.
Slope stability is a topic less related to the mud volcano itself but of major interest for the surrounding slope. Up to now only dedicated ships with sophisticated deployment tools were able to install Piezometers in the seafloor, which allow to record the variability of the pore pressure at dedicated sediment depth as a proxy for the slope stability. During the cruise recently developed stinger systems will be tested as an easy deployment tool to be operated from mid-size multipurpose vessels.

3. GEOLOGICAL SETTING

The West Nile Delta forms part of the source of the large turbiditic Nile Deep Sea Fan. Crustal tectonics in the geodynamic framework around the Nile Fan are mainly influenced by the Suez-Rift area, the Arabian-African plate motion, and the subduction collision with the Anatolian Plate.. Since the late Miocene sediments have formed an up to 10-km-thick pile, which includes about 1 – 3 km of Messinian evaporates. The sediment load of the overburden implies strong overpressures and salt-related tectonic deformation. Both are favourable for fluid migration towards the seafloor channelled by the fractured margin. Deep-cutting channel systems like the Rosetta channel characterise the continental slope. Bathymetric expressions of slides and numerous mud volcanoes in the area are expressions of active processes, which contribute to the ongoing modification of the slope. The western deltaic system, Rosetta branch, has formed an 80-km-wide continental shelf. Here at 500 m and 700 m water depth the mud volcanoes Giza and North Alex developed two major bathymetric features, which proved to be active gas and mud-expelling structures.

4. CRUISE NARRATIVE

The fourth expedition of the West-Nile-Delta project (WND) was scheduled to take place on R/V POSEIDON from 13 July to 4 August 2009. R/V POSEIDON arrived at the port of La Valetta, Malta, in the morning of 12 July. The same day 5 scientists arrived on the island of Malta and boarded the vessel.

On 13 July the scientific equipment was delivered to the vessel. A compressor had been shipped by sea freight in due time. Due to delays in factory delivery, however, most of the equipment arrived from Germany by two trucks via the Genoa ferry connection. Some parts had been shipped via air freight from a previous cruise of R/V METEOR, which had terminated in the port of Montevideo, Uruguay. Other parts, again affected by delays in factory delivery, also arrived by air freight. The trawl doors of the 3-D seismic P-Cable system were immediately stored on board. After the floats had been mounted on the 2 m by 2 m - wide doors the skilled boatswain managed to fix them outboard for later operation at sea although only one winch per door was available. The 10” compressor container occupied almost all the space available on the aft deck, hence large spares like additional trawl doors and a spare compressor had to be left behind. In the late afternoon the remaining scientists arrived safely.

14 July was still available for installation of equipment in the port. During the day the last instruments were picked up from the quay side and the setup of the laboratories began. Dockings of the cruise liner “Norwegian Gem” and the four-mast bark “Sailing Clipper” were impressive eye catchers during the day. By the evening most of the laboratory equipment was set up and all parts were lashed, ready for departure.

On 15 July at 0700 POSEIDON left the port of La Valetta and set an easterly course to cross 810 nm of distance towards the research area. The scheduled four days of transit were used for final preparations and onboard tests of the equipment.

On 18 July at 21:00 POSEIDON reached its first station within the working area of the WND project. After completion of a CTD measurement and a depth test of the acoustic release systems the vessel moved on to the centre of Giza mud volcano. Temperature values of the last 9 months were downloaded from the long-term installation via acoustic modem. During the remaining night hours POSEIDON continued towards North Alex mud volcano along some profiles with multibeam bathymetry recording.

The daylight hours of 19 July were used for extensive testing concerning the operation of the trawl doors of the 3-D seismic system. In the evening hours the first two of six OBS, all of which had been deployed in November 2008, were recovered.

On 20 July at 03:00 in the morning R/V POSEIDON was approached by M/V NORMAND NEPTUN. The NEPTUN had recovered a drifting OBS about a month before and was now delivering the unit to POSEIDON. The remaining morning hours were used for additional bathymetry profiles. During the day the remaining 4 OBS were recovered. Deployment tests with a piezometer lance followed in the afternoon. After a quick service 5 OBS were redeployed for the upcoming active seismic experiment.

OBS deployment continued during the morning of 21 July. The active 3-D seismic system was deployed in the afternoon hours. After some repair work active seismic profiling could be started at 19:00. Seismic data acquisition along the 3-D network across North Alex mud volcano continued until 24 July, 10:30, when a broken towing rope of the data cable required service. Work continued by installation of a piezometer at location SET320. A release trial of CAT Meter #1 failed in the late afternoon. In the evening the acoustic modem was used again to reprogram the North Alex temperature sensor and to download the data once more. During the night we continued multibeam mapping.

During the morning hours of 25 July we successfully retrieved CAT Meter #3 and three OBT stations, one of them equipped with an additional CAT Meter (#7). As no more deck space was available, further instrument recovery was postponed and a deployment of 2 long-term OBS stations was completed during the afternoon. A deployment of the sidescan sonar failed after short time due to a short circuit in the electric connection between the ship cable and the umbilical. The night was again used for multibeam recording.

In the morning of 26 July, the second piezometer was deployed at location SET 320/2. Between 08:00 and 16:00, all remaining OBS could be recovered. Six of the instruments were redeployed at once after a short service. At 17:15 the sidescan sonar was deployed again and completed a survey until 08.00 on 27 July.

On 27 July at 08:00, piezometer number three was deployed at location SET 320/1. In the course of the day seven long-term OBS and two Tiltmeters were deployed, which lasted until 17:30. The night was used for bathymetry profiling.

The fourth piezometer was installed in the morning of 28 July from 08:00 to 10:00. From 10:00 on, a second sidescan survey followed with a set of profiles using the 410-kHz transducers. Wind speed and wave height increased during the afternoon but the instrument was recovered safely at 17:00 hrs.

Bathymetry recording was terminated on 29 July at 08:00, next to the temperature station at Giza mud volcano. Attempts to upload the data only succeeded in parts. The recovery of CATmeter #2 failed. After transit to North Alex it was decided that wave and wind conditions (> 2m swell, 9 ms) were not favourable for a deployment of any of the large instruments (3-D, Sidescan). Therefore the night was used to operate the GI airgun and three sections of a standard

2-D streamer only. Profiling was done in order to shoot crossing lines above each long-term OBS. The shots will be used to identify the orientation of the seismometers.

When airgun shooting was completed in the morning of 30 July at 08:00 the weather conditions had improved. After transit to Giza mud volcano the sidescan sonar was deployed again. The instrument failed immediately and needed to be recovered. It turned out that during the previous recovery the internal power cable had been squeezed during a contact between tow fish and vessel. The repair was estimated to last 3 – 4 hrs. Due to the dense time schedule of the vessel the departure from the working area needed to be scheduled about 12 hours earlier than planned. Therefore the remaining time window was too short to restart the sidescan survey. The evening hours were used to complete some bathymetry lines and give a second try to uploading the data from the Giza temperature sensor. During this procedure the topside acoustic modem failed after seawater had entered the enclosure.

All station work was finished on 30 July at 23:30, when POSEIDON set course to Malta. The cruise ended upon arrival at the port of La Valetta, Malta, on 4 August, 07:30.

5. CREW

Ship's crew

Name	Position
Michael Schneider	Captain
Bernhard Windscheid	Chief Officer
Cornelia Dahlke	2nd Officer
Hans-Otto Stange	Chief Engineer
Günther Hagedorn	2nd Engineer
Frank Schrage	Bootswain
Ronald Kuhn	Sailor ab
Bernd-Michael Haenel	Sailor ab
Ralf Peters	Sailor ab
Moritz Droege	Sailor ab
Bernd Rauh	Sailor ab
Benjamin Groenebaum	Motor Man
Ruediger Polter	Electrician
Johann Ennenga	Cook
Dieter Jordan	Steward

Science crew

Name	Institute	Function
Joerg Bialas	IFM-GEOMAR	Chief Scientist, Seismics
Warner Brueckmann	IFM-GEOMAR	Co-Chief Scientist, Piezometers
Klaus Cramer	E+JE	Compressor
Thomas Brandt	IFM-GEOMAR	Electrician
Bernd Hermann	IFM-GEOMAR	Electronic Engineer
Torge Matthiessen	KUM	Technician
Marten Lefeldt	IFM-GEOMAR	OBS
Dirk Klaeschen	IFM-GEOMAR	Seismics
Cord Papenberg	IFM-GEOMAR	Seismics
Ingo Klaucke	IFM-GEOMAR	Multibeam, Sidescan

6. INSTRUMENTATION

6.1 BATHYMETRY

Bathymetric data were collected using the portable ELAC Bottomchart Mk. II of IFM-GEOMAR. This system provides 126 beams at a full swath of 150 degrees and can be used with either 50-kHz or 180-kHz transducers. During cruise P388 the 50-kHz transducers were mounted in the moonpool (Fig. 6.1.1).

Figure 6.1.1: ELAC Bottomchart Mk. II 50-kHz transducers mounted in the moonpool of RV POSEIDON.

Attitude information was provided by a CodaOctopus motion sensor F180R whose gyro unit was mounted directly above the transducers. The F180R is supported by two GPS antennas that were mounted on the mast of RV POSEIDON so that they were two metres apart (Fig. 6.1.2). GPS information provided by this system was used for the multibeam system as well as for all other scientific systems running during the cruise. The swath width of the multibeam system was reduced to 100 degrees in order to increase the ping rate and consequently improve spatial resolution at surveying speeds of 4.5 knots. As a trade-off the system provides only 84 beams at these settings. Block depth was set manually to 50 metres in order to collect data from within the water column for the potential detection of gas bubbles. Corrections of the transducer alignment were not applied as shallow (< 100 metres water depth) and flat areas were not within the permitted working area. However, closely spaced survey lines with opposite directions recorded during the 3-D seismic survey will allow for proper roll correction during post-processing of the bathymetric data.

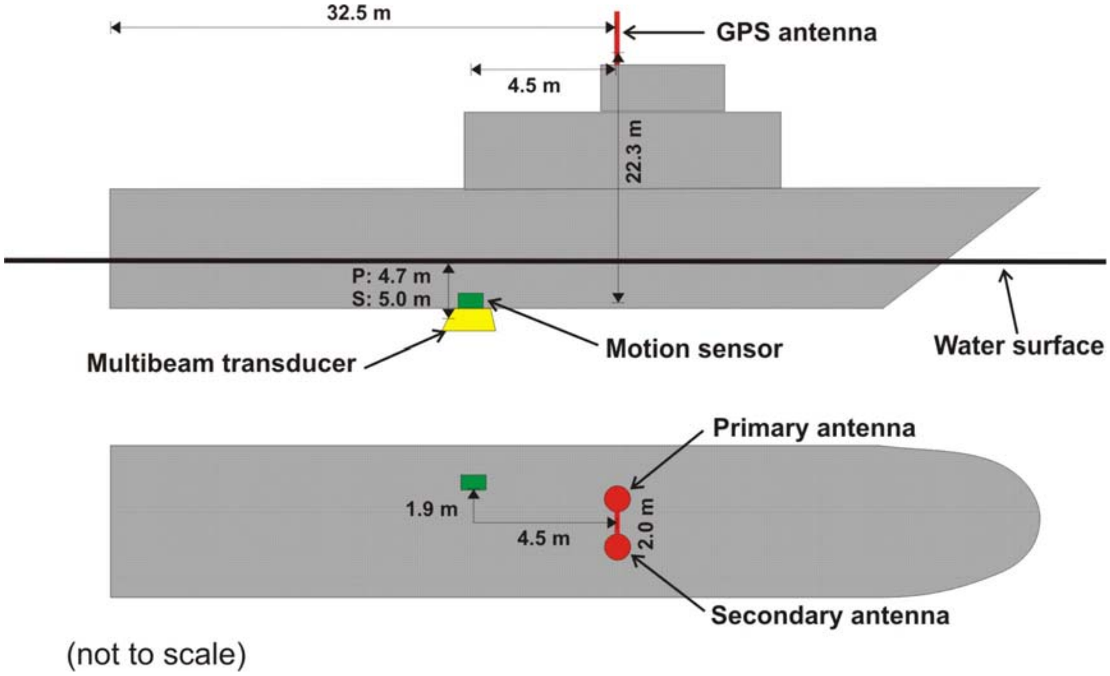


Figure 6.1.2: Schematic representation of the GPS configuration.

6.2 SEISMICS

During cruise R/V POSEIDON P388 the aft deck was mainly used for the installation of seismic equipment (Fig. 6.2.0.1).

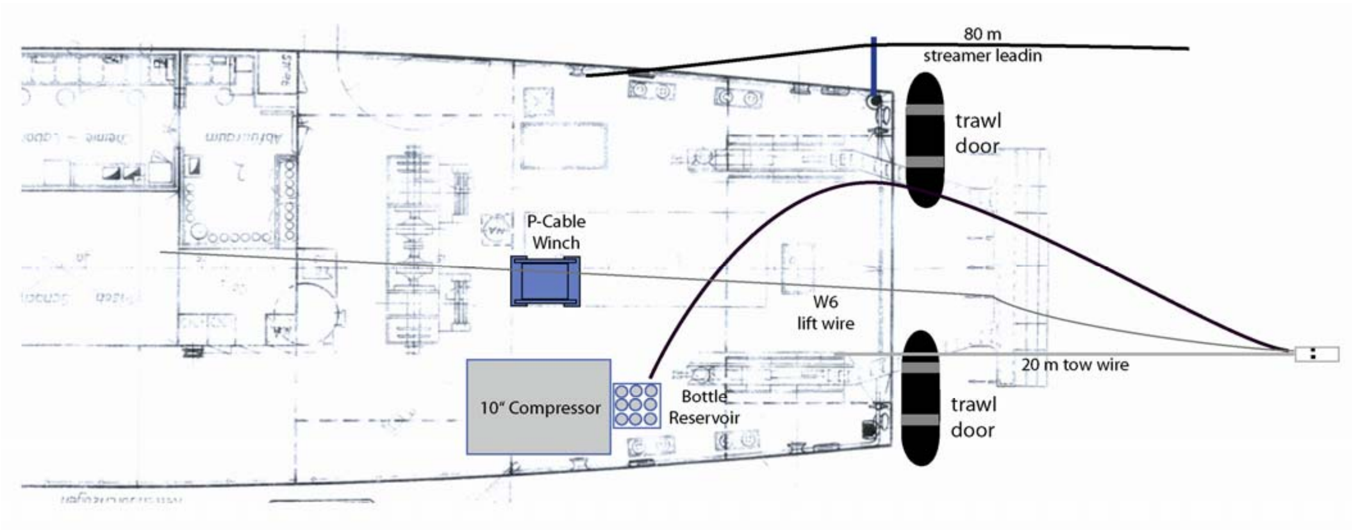


Figure 6.2.0.1: Configuration sketch of the aft deck of R/V POSEIDON during seismic operation on cruise P388

A 10” compressor container was located at the port side rail. A winch used for deploying the cross cable was located in the centre in front of the trawl winches. A 210 ccm GI gun was deployed and recovered using the W6 wire through the A-frame. The towing force went to a 20-m-long steel wire, which was attached at the inner port side of the A-frame. During 2-D operations of the streamer an 80-m-long lead-in cable was deployed over the starboard side rail. A 2-m-wide outrigger kept it clear from the starboard trawl door sitting in its rest position.

6.2.1 COMPRESSOR

For operation of the airgun, four Junkers compressors were provided in a 10“ container (Fig. 6.2.1.1) together with 800 l of storage volume. The compressors were capable of delivering 8 m^3 of compressed air per minute at a pressure of 200 bar. This amount was sufficient to operate the GI airgun (volume: 105/ 105 cu in) with a shot interval of 7 sec.

Fig. 6.2.1.1: Left: Junkers compressor container with Diesel tank
Right: view inside the compressor container showing two of the four Junkers compressors.

Diesel fuel was provided from the ship’s bunker using a 200-l barrel, which was automatically refilled from the vessel’s tank by a pipe connection.

6.2.2 AIRGUN

For this survey, a GI airgun with a 105-cu in generator and a 105-cu in injector volume was provided (Fig. 6.2.2.1). During previous surveys it had turned out that a towing depth of 2 m provides a good compromise between signal strength and frequency content. The gun was towed 18 m behind the stern of R/V POSEIDON. For lifting purposes the gun carrier was connected to the W6 winch. In order to ensure a fixed towing offset a 20-m-long steel cable was attached at working deck level to the inner A-frame on the port side. The airgun shots were triggered by a LongShot gun controller, which was integrated into the seismic recording system described in paragraph 6.2.3.

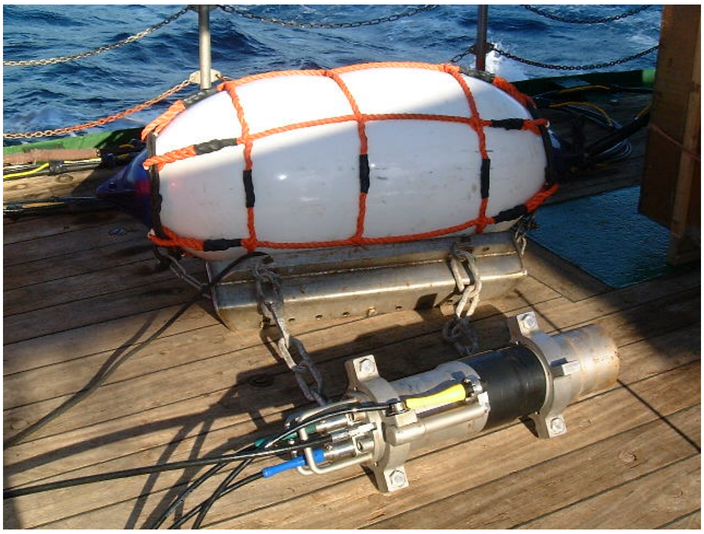


Figure 6.2.2.1: GI airgun with gun hanger and floatation.

6.2.3 STREAMER

6.2.3.1 P-CABLE

The P-cable (VBPR patent of 2003) system design is similar to the SwathSeis concept, which was investigated by IFM-GEOMAR in 2001/2002 by theoretical modelling funded through the DFG. The basic goal of both systems is three-dimensional seismic imaging of the oceanic crust. While SwathSeis is dedicated to basement mapping, the P-cable design aims at high-resolution imaging of shallow horizons. IFM-GEOMAR is holding an academic license for the P-Cable system, covering the development and application of such a system.

Compared to standard reflection seismic applications in 2-D and 3-D, the basic difference is that the P-cable has a cross cable that is towed perpendicular to the ship's heading (Fig. 6.2.3.1.1.a & b). Instead of a few single streamers, the P-cable uses a large number of short streamer sections towed in parallel from the cross cable. As a drawback, depth penetration is limited due to the short offsets, which do not allow for removal of the multiple energy. This is well compensated by the reduced costs of the system and the possibility to operate it from small multi-purpose vessels, the common platform for academic marine research.

Figure 6.2.3.1.1.a shows the basic principle of the P-Cable design. The advantages of the IFM-GEOMAR development are twofold. The cross cable is based on a strength member, a Dynema rope, which takes the stretching forces of the trawl doors (Fig. 6.2.3.1.c). The data cable with the streamer connections is attached to this rope(Fig. 6.2.3.1.2).

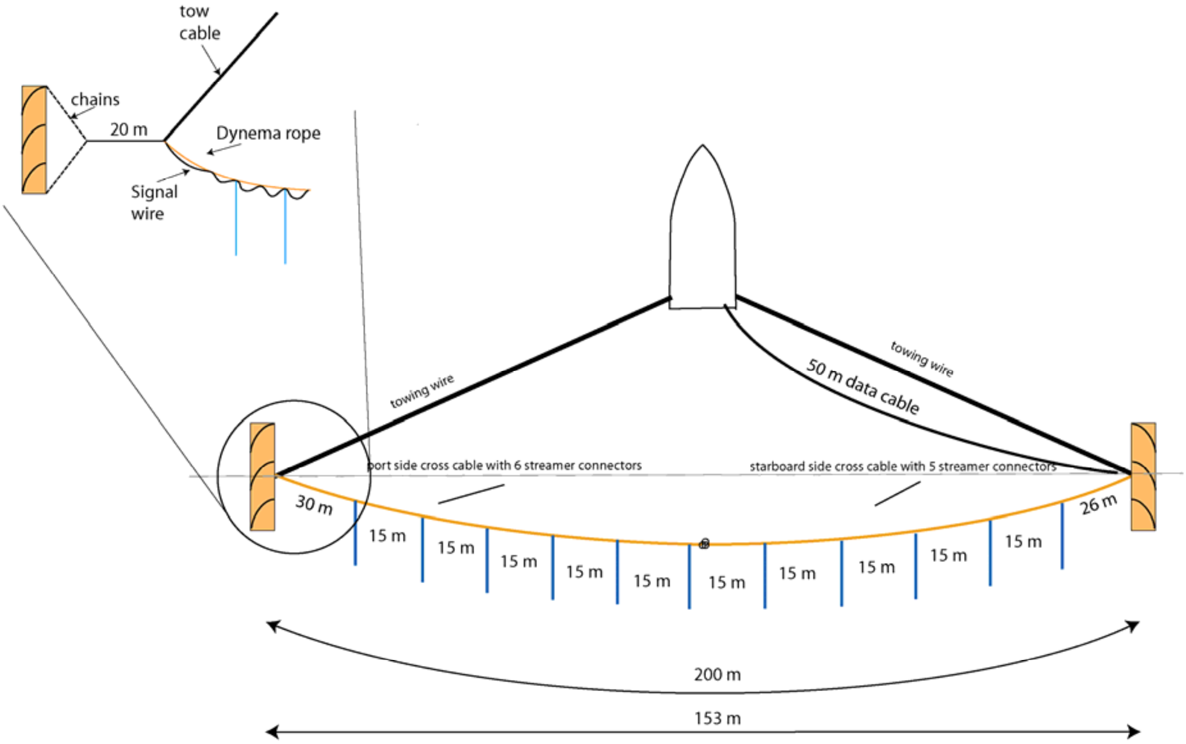


Figure 6.2.3.1.1.a: Sketch of the P-cable design applied during the P388 cruise

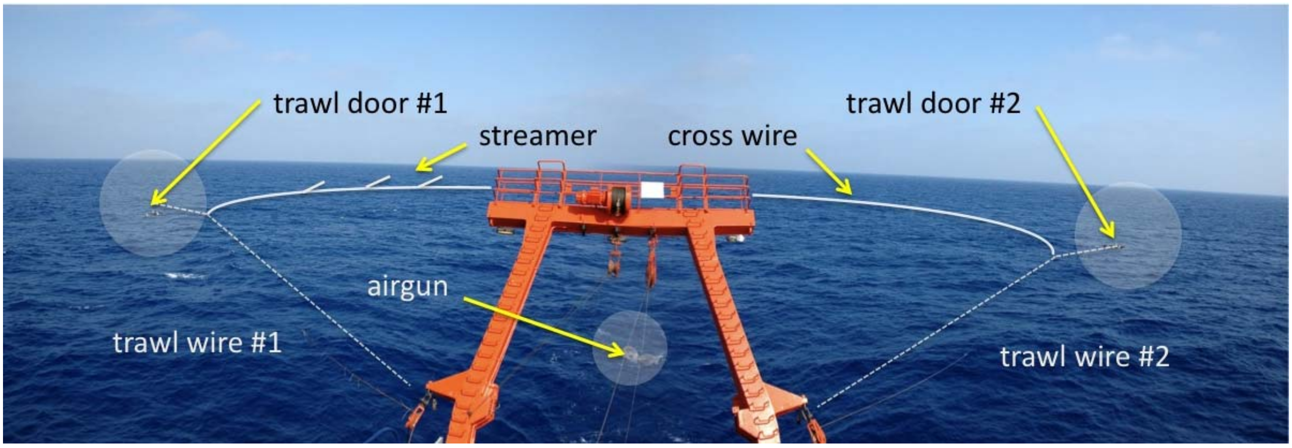


Figure 6.2.3.1.1.b: Photograph of the P-cable in operation from R/V POSEIDON. Floating devices like trawl doors and gun float are circled, submerged parts are indicated by line drawing (photo by Michael Schneider and montage).

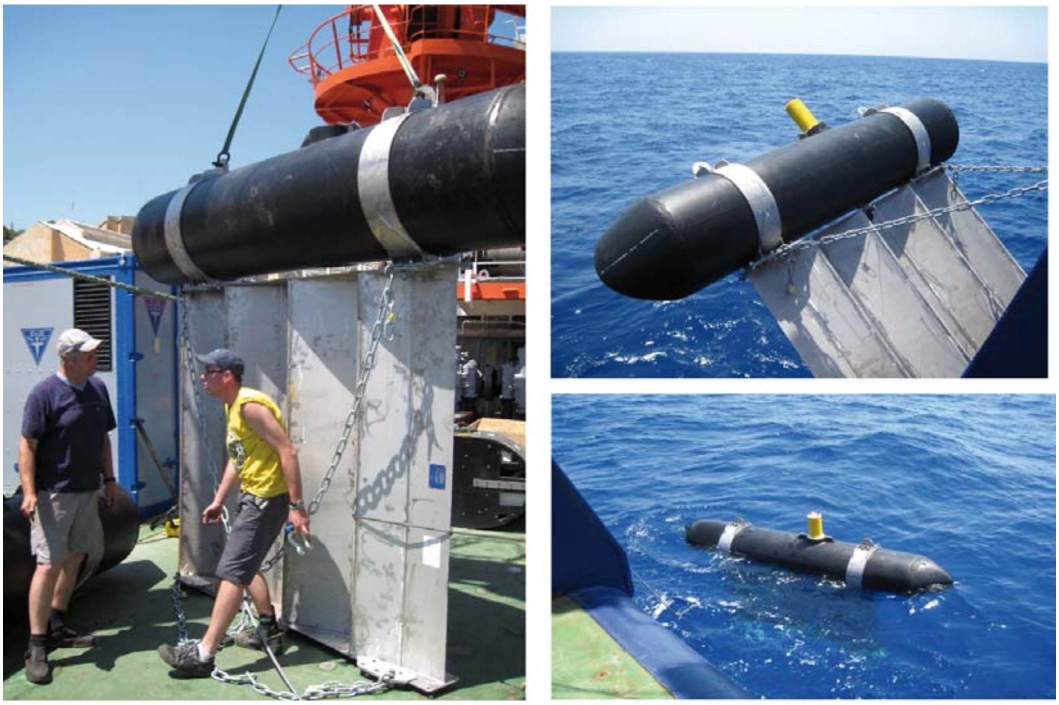


Figure 6.2.3.1.1.c: Photographs of the trawl doors.
Left: floats are mounted on the paravanes.
Top right: half-way lowered, ready for deployment. The yellow cylinder houses the GPS receiver and the radio modem.
Bottom right: floating away from the vessel

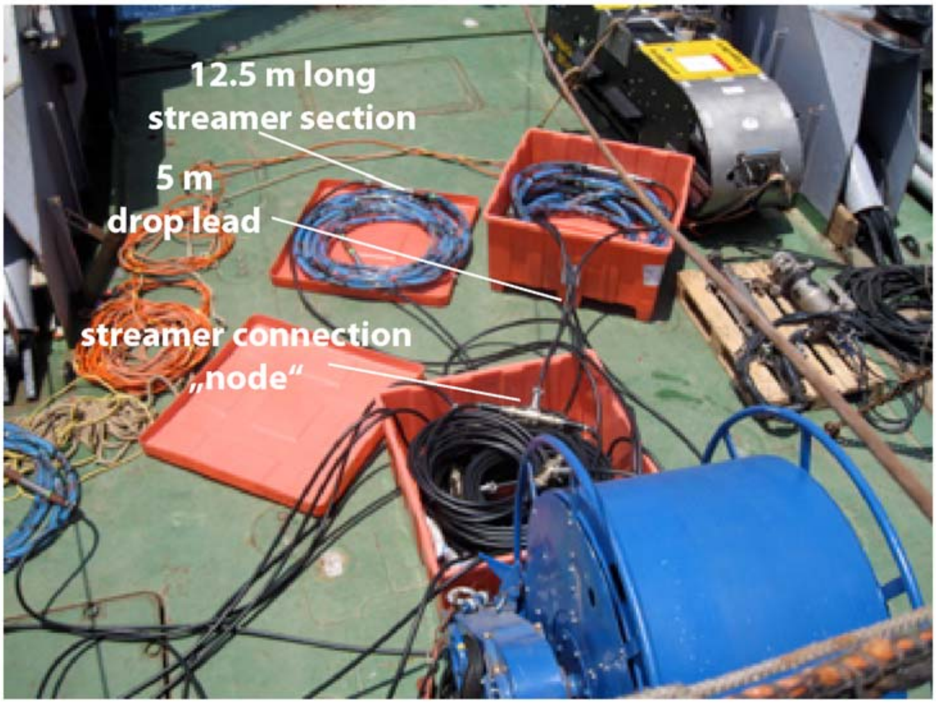


Figure 6.2.3.1.2: Photograph of cross cable, drop leads and streamer section during dry test on board.

IFM-GEOMAR has developed a modular cross cable, which allows exchanging each single streamer connector (node) in case of a malfunction. This means easy service and reduced service costs. Other systems consist of a data cable moulded in one piece, so that the whole set has to be replaced if one node fails. The modular design also allows for insertion of connecting cables of different lengths between the nodes. Hence an adaptation to different resolutions of P-cable and SwathSeis application is possible. The current grade of the system provides 11 active nodes connected by 15-m-long data cables. On port side the first node is located 30 m off the triple point, while the first node on the starboard side is 26 m off the triple point. The 200-m-long cross cable is stretched by two trawl doors, floating at the sea surface. Each of the trawl doors provides a lifting force of 2 tons. Although the doors are designed to provide maximum lift at 4 kn sailing speed the cross cable was stretched to 165 m width at 3 kn already.

Upon deployment both doors are released from their resting position (Fig. 6.3.2.1.2) while the ship sails against wind and waves at 0.5 kn through water. The starboard door is then first to be lowered into the water until a 20-m-long lead cable between the door and the connection point of cross cable and trawl wire (triple point) has reached the shift (Fig. 6.2.3.1.3.a). Subsequently, the data cable from the recording device to the door is connected to the triple point. The cross cable, previously stored on a supply winch, is connected to the triple point as well and the data connection is fixed. Now trawl wire, data cable and cross cable are payed out simultaneously (Fig. 6.2.3.1.3.b). At the same time streamer sections are connected to the nodes of the cross cable. Floatations are fixed to each node in order to keep the cross cable at even depth (Fig. 6.2.3.4). During the first deployment additional floats were inserted between each node. It turned out that at low speed the additional floats kept the cross cable at the surface and therefore we did without these floats for the remaining cross cable. When the entire cross cable is payed out, a 50-m support rope on the support winch is used to safely transfer the cross cable from the support winch to the port side triple point (Fig. 6.2.3.1.5.a). Now both trawl wires are run out to their final length when sufficient stretch of the trawl doors is reached (Fig. 6.2.3.1.5.b).

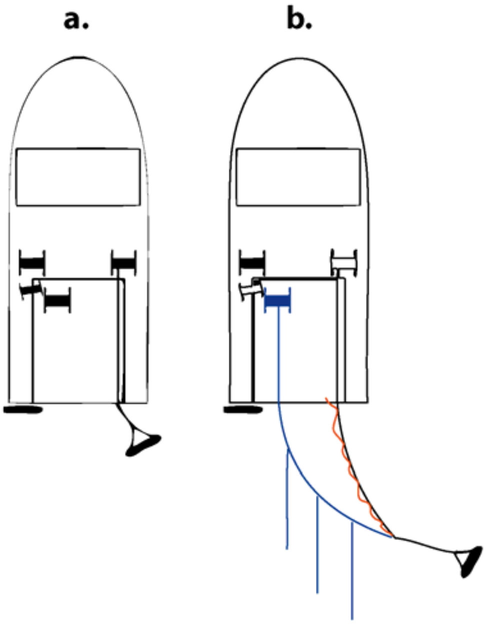


Figure 6.2.3.1.3: Sketch illustrating the first steps of the deployment. After the trawl door has been lowered, the cross cable is connected to the triple point on the trawl wire. While the cross cable is been paid out, the streamer segments are connected.

Figure 6.2.3.1.4: Floats are fixed on the cross cable in order to keep it at about 2 m depth during profiling

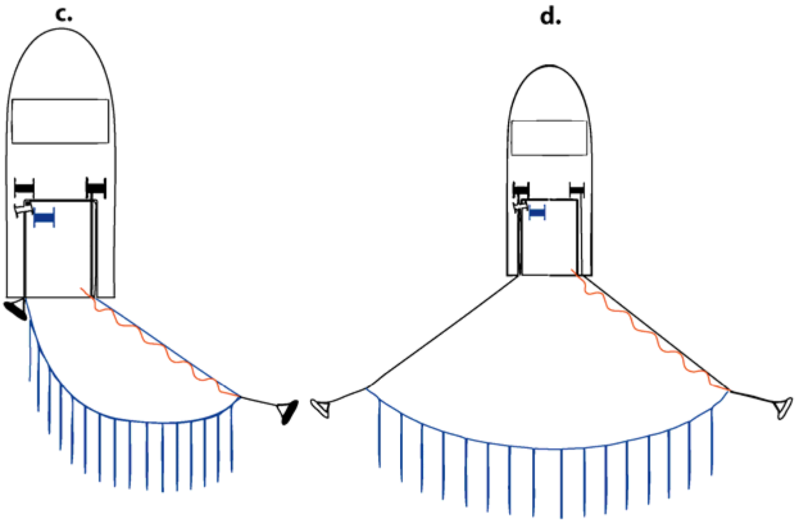


Figure 6.2.3.1.5: Sketch illustrating the final steps of the deployment. After the cross cable is payed out the port side trawl door is lowered and the cross cable is fixed.

The respective positions of the trawl doors with real coordinates and their relative distance to the vessel are provided by an online navigation package. Autonomous GPS receivers were mounted on each trawl door together with a serial radio link to the vessel (Fig. 6.2.3.1.6). Both radio links use the same frequency but transmit their signal with a short time delay of 80 ms. The GPS receivers are set to produce a POS NMEA string, which allows adding a code to identify the GPS receiver. The signal is fed into the EIVA NaviPac navigation software. Unfortunately NaviPac is not able to read the POS string. Therefore a self-coded routine "rs232-udp" takes up the NMEA strings from the serial interface and converts the POS strings into EIVA coded GGA strings. The GPS identifier is now encrypted in the GGA string ($xx,GGA,...). The strings are also separated according to the identifier and distributed to a selectable UDP port address. From here, the NaviPac software is now able to read the GPS positions of the trawl doors. Along the track a display line connects the moving points of the two GPS positions of the trawl doors and allows following the expected coverage of the 3-D seismic system (Fig. 6.2.3.1.6). During this cruise, the airgun shots were triggered by the NaviPac software in either time mode or distance mode. In both cases, offsets were observed between the true shot time and the time stamp written to the log file. Trigger signals were delivered to the Geometrics GeoEel Streamer control system and the LongShot gun controller. The air provided by the four Junkers compressors was sufficient to operate the 210-ccm GI gun at a 7-s shot interval with a nominal pressure of 200 bar.

An overview of the entire P-Cable control and processing system is shown in figure 6.2.3.1.7. Unfortunately, a 500-m umbilical with fibre-optic data transmission to be provided by Bennex, Norway, the use of which had been planned for this cruise, could not be delivered in time. Therefore, the standard streamer tow cable needed to be used as data connection between the vessel and the P-cable. As the tow cable is not designed to withstand the enlarged forces when towed rectangular to the ship's course, a Dynema rope was attached between the vessel the and trawl door to carry the cable.

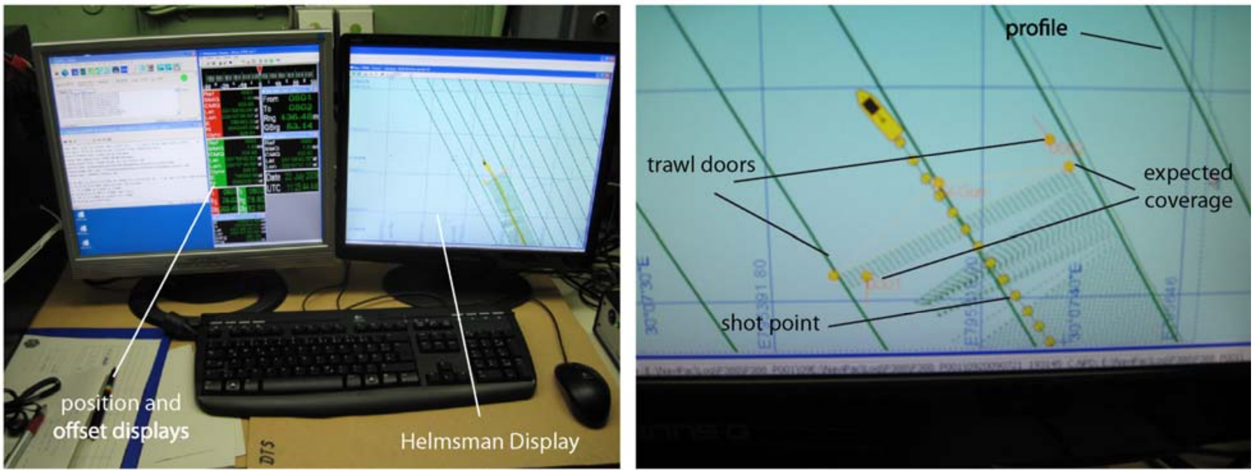


Figure 6.2.3.1.6: Photograph of the EIVA NaviPac control monitor.
Left: overview of control screens and Helmsman display.
Right: blow-up of the Helmsman display with details of towed equipment

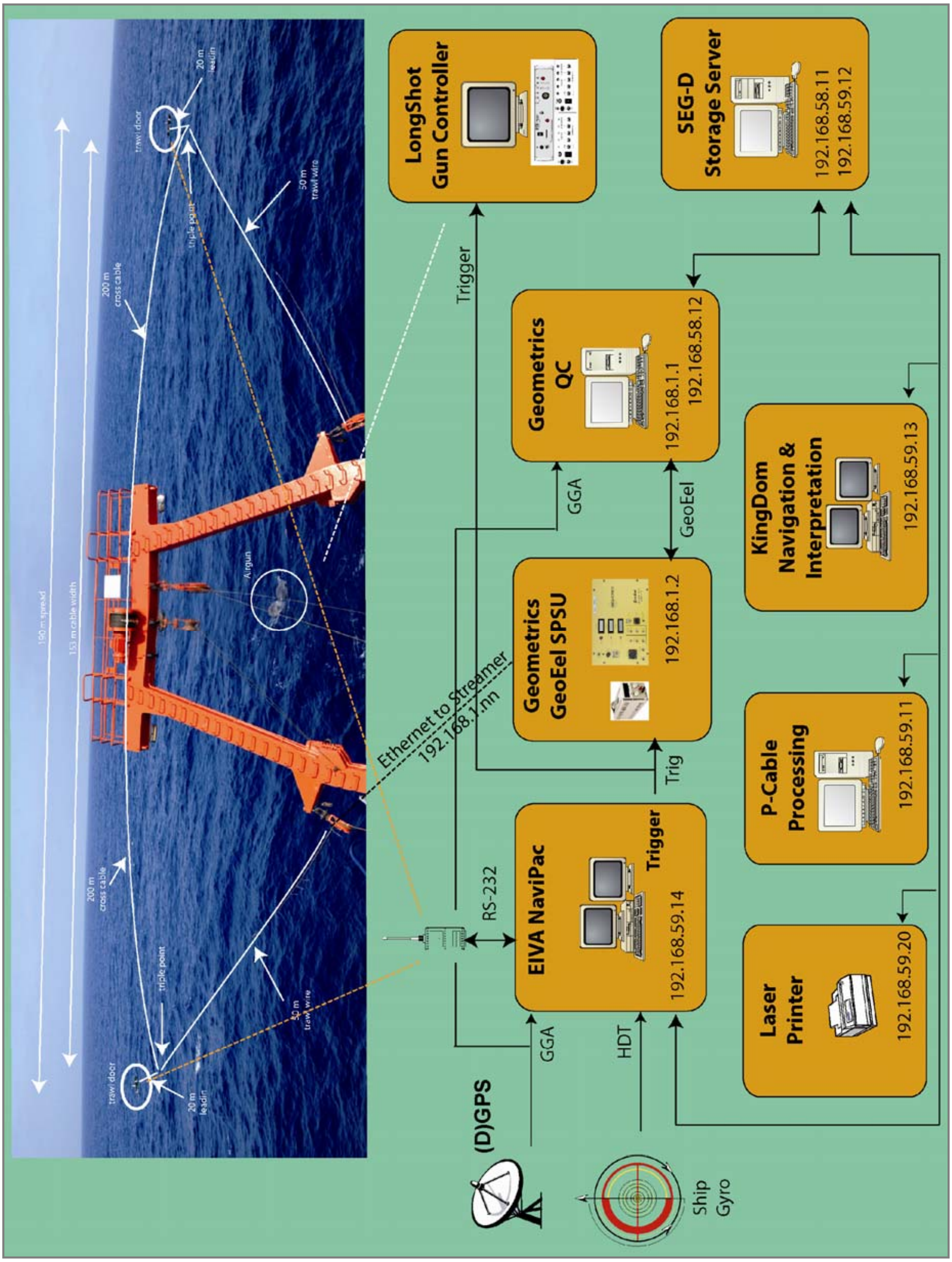


Figure 6.2.3.1.7: Layout of the entire configuration scheme.
Top: photograph of the towed equipment with indication of system parts
Bottom: schematic drawing of the control and processing PCs, radio, data and network connections are indicated

6.2.3.2 NAVIGATION

On board of R/V POSEIDON, the in-house DataVis system is used to collect all major research cruise information. All ship-related data (GPS, heading, course, speed) are stored in this database together with the depth values of the 12-kHz and 30-kHz sounders. Other information like winch operations is not included.

During cruise P388 an Elac Nautic multibeam system was operated, equipped with a motion sensor and corresponding high-precision GPS receivers (see chapter 6.1). The GPS information of this system was distributed to the seismic navigation system as well as the GEOMETRICS QC. For track planning and online coverage control an EIVA NaviPac software package was set up. Within this system all crucial navigation data were merged and logged. Basic ship information was read from the multibeam GPS NMEA string, while heading values of the Gyro were provided through the ship's distribution panel.

During operation of the seismic 3-D P-cable system (see chapter 6.2.3.1) it is crucial for later navigation processing that the trawl doors which keep the cross cable stretched are tracked. For this purpose we developed a radio transmission for the autonomous GPS receivers mounted on the trawl doors (Fig. 6.2.3.1.1.c & 6.2.3.1.7). Within a water-tight housing a Thales AC12 GPS receiver is installed together with a SATELLINE-3ASd UHF radio modem. The GPS was set to produce the NMEA POS string which allows for inclusion of a system identifier together with all position and timing information. On board, a single SATELLINE-3ASd receiver modem was set up to receive the information sent from the two trawl doors. Radio transmission times for the first trawl door radio were set to send on the second, while the second transmission was delayed by 45 ms. Thus, the receiving radio modem could deliver the incoming NEMA strings well separated to the serial interface of the PC running the EIVA software. Unfortunately the NaviPac software is not able to handle the ID-coded POS string although it is a standard NMEA string. Therefore a small routine (rs232-UDP) had to be set up to read the POS strings from the serial interface and reconfigure the NMEA information into a GGA string. The GGA string used by EIVA was modified so that the two leading characters of the GGA string (Usually $GP,GGA,…) carried the ID code for the corresponding GPS receiver ($M1,GGA,…). Each of the new GGA strings was then distributed to a dedicated UDP port ID (4711, 4712). Within the EIVA software, dynamic objects were set up for each trawl door (Remote1 & Remote 2), which were told to receive the position information of the trawl door from one of the UDP ports. The offset between trawl doors and first hydrophone node (see chapter 6.2.3.1) was calculated by additional offset objects. During the survey a "range&bearing" information window was set up within the Helmsman display of NaviPac (Fig. 6.2.3.1.6). This range line was saved as a display line, to be reloaded after completion for a coverage display.

NaviPac software offers a choice between generating either time events or distance events. Such event signals can be sent out via one of the serial ports of the PC system. An EIVA Trigger-Box converts the serial output into TTL trigger pulses, which were distributed to the gun controller and the GEOMETRICS recording system (Fig. 6.2.3.1.7). Prior to the start of a survey, the file counters of the EIVA and GEOMETRICS systems respectively were set to the same starting values to allow for an easy correlation between log file information and shot file. For later synchronization of the autonomous ocean bottom seismometers (OBS), the event-time stamps need to be provided in an external shot table. It turned out that there were some time deviations between the release of the trigger and the time noted in the log file. Therefore, tests were made with an external data logger. The tests proved that there was a drift in the trigger times while the noted time stamps from the log file only reported drifts of more than 1s (Fig. 6.2.3.2.1). Such a quality of event information is dangerous when the affected information is used in high-resolution work where data are sampled at a 0.25-ms time interval. In a second trial the event trigger option was selected. The chosen offset of 10 m was generally kept within a few meters (Fig. 6.2.3.2.2). At a speed of 3 kn an offset of 10 m results in a time interval of approximately 5 s. During turns the distance calculation became unreliable. The shot time interval was calculated as short as 2 s. independent of the selected option "projection" or "cumulative". With recording time windows of 4 s. the GEOMETRICS system could not follow such short events and all file counting went off limits. Here a button for minimum time until next shot is urgently required.

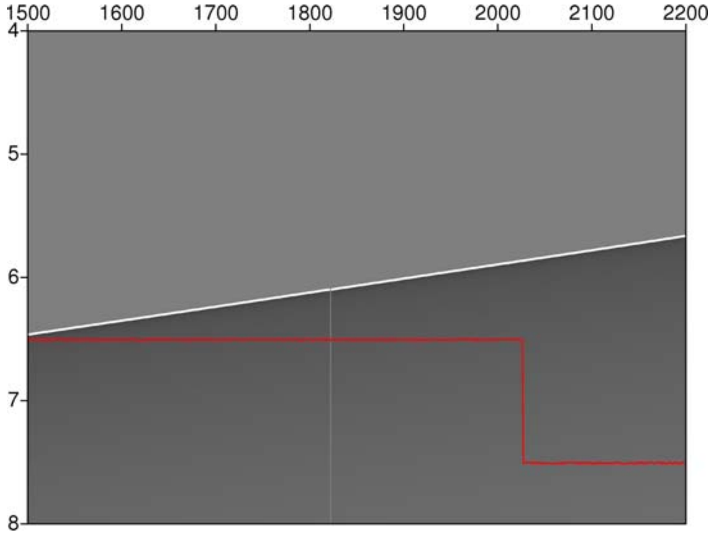


Figure 6.2.3.2.1: Graph display of external recorded trigger times (white) and trigger times read from the software log file (red)

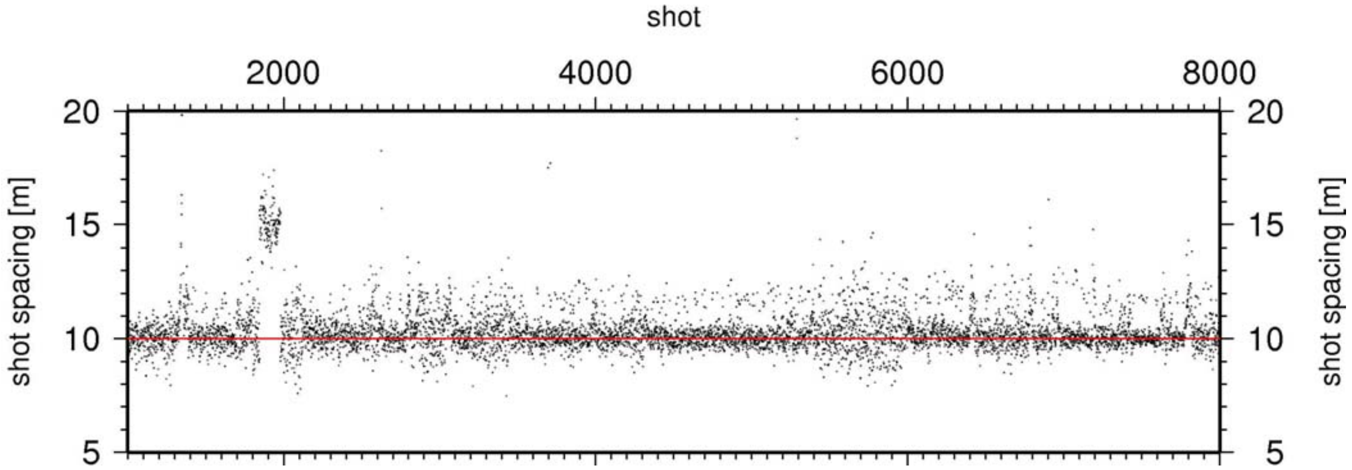


Figure 6.2.3.2.2: Graph of the true shot offsets achieved with the offset trigger option of the EIVA software package

6.2.3.3 PROCESSING

The main goal of the 3D-cube survey P338-01 navigation processing is to estimate a realistic source-receiver geometry which satisfies the known door positions, internal distances like cross cable length and lead-in lengths and the seismic travel time events of the direct water wave. At the end of the processing the locations of the sources and the 81 receiver channels of the 11 streamers for each source position must be known.

The existing information consists of a back-projected gun position from the ship's antenna and the two exact door positions. To set up a starting geometry for the individual streamer, a circular cross cable geometry was analytically calculated with a given cable length, lead-in length from the doors to the cross cable, streamer lead-in, and streamer distances along the cross cable of 15 m. In an ideal configuration this geometry is only based on the door-to-door distance. Alternatively a triangle cross cable geometry was calculated, but it seems that through the relation between the cross cable length and the door-to-door distance the circular geometry assumption was more realistic.

To verify or to improve this geometry setup the first arrival of the direct water wave was picked by an automatic event picker in a trace-by-trace procedure for each shot.

The direct water wave travel times of the first channels of the outmost streamers closest to the exact door positions were first used to relocate the source position. Geometrically this is the crossing point of two circles with the channel positions as the origin and the radius corresponding to the arrival times of the direct wave. In a second step the first channels of the individual streamers were relocated based on the picked arrival times and the relocated shot position. The moving direction for the repositioning is assumed to be orthogonal to the door-to-door azimuth. Geometrically this is an intersection of a circle and a straight line, where the shot location is the origin of the circle with a radius corresponding to the arrival travel time to the first channel of the streamer. The straight line crosses the channel position with an azimuth orthogonal to the door positions. All additional seven channels for each streamer were afterwards extrapolated backward from the first repositioned channel position with an azimuth orthogonal to the door-to-door azimuth. This travel time processing procedure, which is based on first arrival times and two exact door positions, is illustrated in Figure 6.2.3.3.1 for one shot gather. A comparison of a triangle and a circular geometry setup, a back-projected and relocated source position, and relocated receiver positions can be seen in Figure 6.2.3.3.2.

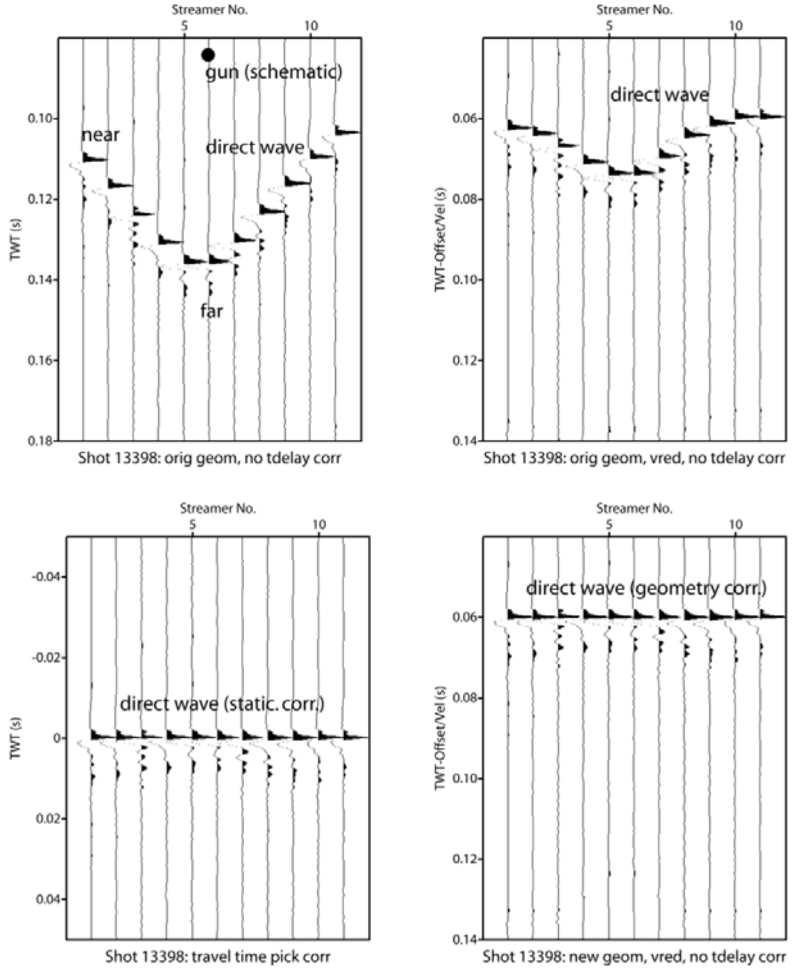


Figure 6.2.3.3.1: Relocation based on the travel time relocation of the direct wave of a shot gather. Gather with original geometry and no time delay correction (-60ms). Gather with original geometry and a water velocity reduction. The events should be aligned if the geometry is correct. Gather with travel time correction based on first arrival picking. Gather with new relocated geometry and a water velocity correction. All events are aligned and the new geometry fulfills the travel time information of the direct wave.

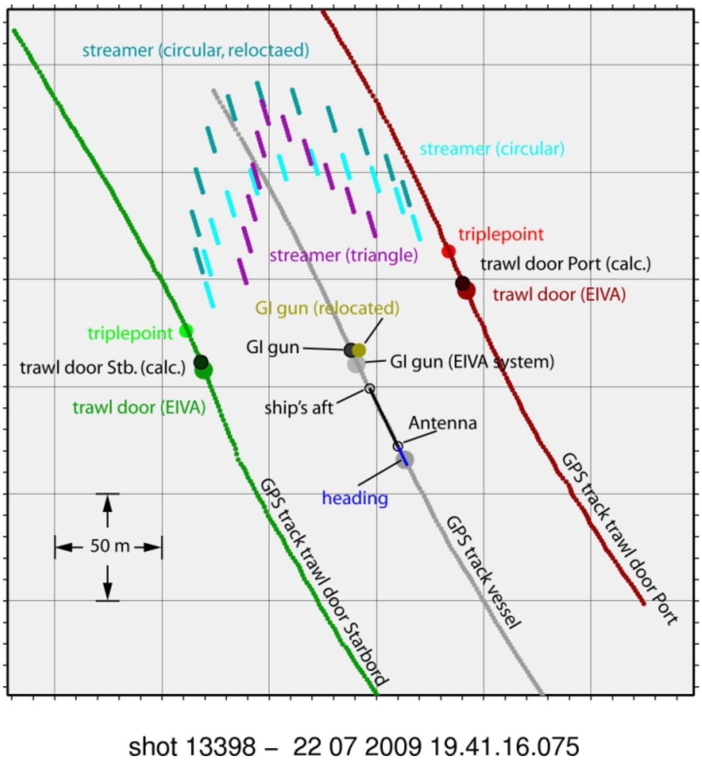


Figure 6.2.3.3.2: A comparison of a triangle and a circular geometry setup, a back-projected and relocated source position, and relocated receiver positions.

As soon as source and receiver positions were known a common midpoint coverage map was calculated. A squared bin size of 10m was defined on a rotated survey grid aligned with the main sail line direction. The bins were defined by rows and columns where the column numbering ran in the sail line direction and rows perpendicular to the sail line direction. The rotated coverage map is shown in Figure 6.2.3.3.3.

The 2-D survey P388-02 consists of only one streamer with 24 channels. Here, the source and receiver positions could not be relocated and an assumed geometry based on a back-projected gun position from the ship antenna and measured streamer lead-in was applied. A crooked line binning along the whole track with a bin size of 5m defined the common midpoint (CMP) for further processing (see 7.1.1.1).

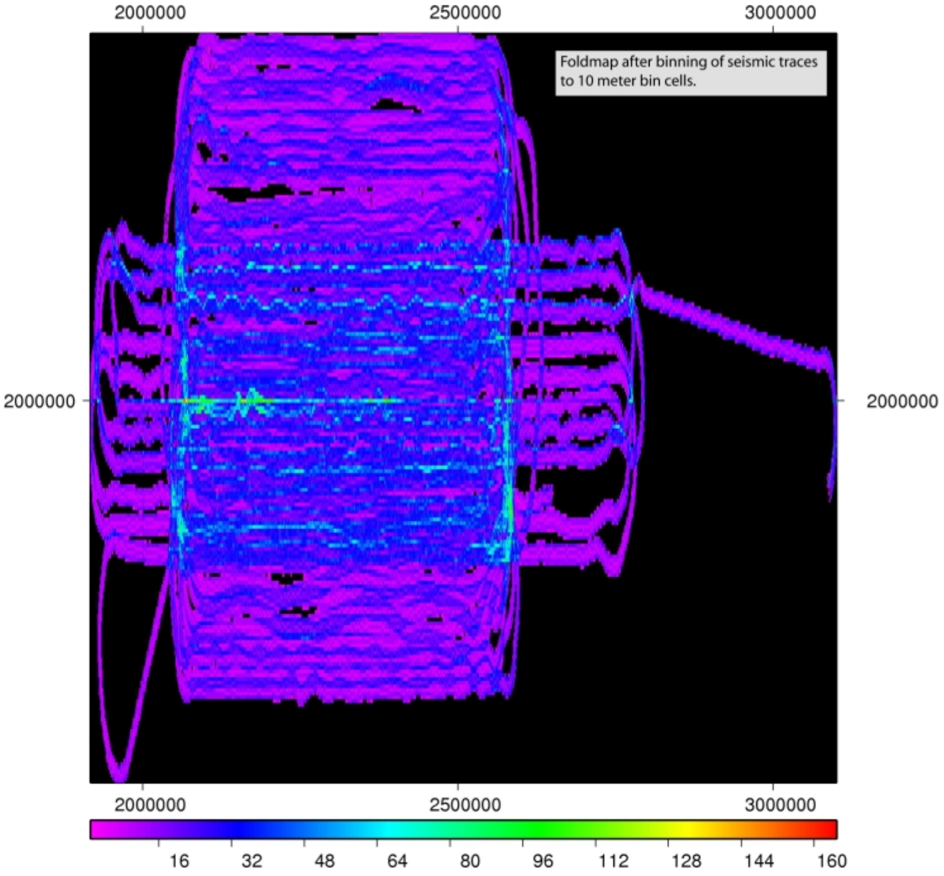


Figure 6.2.3.3.3: Coverage map of the rotated 3D-survey for a bin size of 10 m. Note: different scales on X and Y axis, laterally compressed by a factor of 1:5.

6.2.4 OCEAN BOTTOM SEISMOMETER - OBS

IFM-GEOMAR has been developing ocean bottom seismometers since 1991. The current “Lobster” design (Fig. 6.2.4.1) comprises four cylinders made from syntactic foam, which provide the buoyancy. They are mounted in a titanium frame to which pressure tubes with batteries and recording electronics are fixed. A 40-kg steel frame serves as anchor and is attached to the frame with an acoustic release system. A 4.5-Hz, three-component seismometer is included into the frame as well as a hydrophone. For seismological observations Guralp broadband sensors are available. A radio beacon, a flash light and a flag serve as recovery aids once the unit has been released and floats awaiting recovery.

Figure 6.2.4.1: Ocean Bottom Seismometer – OBS - during deployment.

In order to record active seismic signals, the system carries an MBS-type data logger. It is capable of recording events up to 1000-Hz sampling frequency. For long-term observation of passive seismic events, a low-power consumption data logger (MLS) is installed, which samples at 100 Hz.

6.2.5 TILTMETERS

On land, research and surveying in risk areas such as the vicinity of volcanoes and earthquake-prone areas has been supported by tiltmeters for years . Small-scale as well as integral, large-scale surveys are carried out - i.e., gauges with short (ca. 2 m) as well as long (several tens to hundreds of m) base lines are being used. Especially in areas affected by tunnels and mining, such systems have been used with success. Combinations of tiltmeter deployments and seismic surveys have yielded good results in the field of short-term forecasts of eruptions. In marine use, only recently tiltmeters have started to be used successfully. Many of the systems employed by now have been developed and constructed in academia. Short baseline systems constitute the majority among these. They are less expensive to develop, their deployment is less complicated and they can be mounted onto a variety of different platforms.

As the electronics of the referenced marine tiltmeters are all in-house developments that have not been designed to be used and operated by a wide community, the SFB574 decided in 2002 to complete a new easy-to-use instrument, making use of existing components as far as possible. Based on the experiences with marine long-baseline instruments published by , a short-baseline solution was favoured. For future operation this would mean that a larger number of instruments could be distributed over the area of investigation to allow minimization of station effects by an overall integration of the deployed systems. The restriction to short baseline allowed the use of the three-leg GEOMAR OBS design as a system carrier, thus further using the available periphery of support (e.g. release system, relocation tools, etc.; Fig. 6.2.5.1).

As sensors the type 501 and 900-45 tiltmeters from Applied Geomechanics were chosen (Fig. 6.2.5.2). In general, tilt values can be expected to be in the range of a few 2.5 urad to 200 urad, which can be easily resolved by the type 510 (+/- 1400 µrad, < 10 nrad resolution). The basic type 510 tiltmeter was developed for drill hole deployments, therefore it could only compensate for a small amout of tilt. To adapt it to sea floor applications and to larger angles of tilt as might be caused by the slope of the sea floor, in the IFM-GEOMAR sensor the levelling system was extended to +/- 30 degrees. The type 900-45 clinometer can be operated over a range of +/- 50 degrees with a resolution of 0.02 degrees. It is used to give an overall impression of large-scale tilt variations throughout the deployment. As the complete system is designed to reach the seafloor in free-fall mode, a C-100 compass from KVH Industries is implemented in the tiltmeter housing to allow for later orientation of the tilt axis (Fig. 6.2.5.2). It is well known from earlier studies that such high-precision instruments are sensitive against temperature changes so that this value requires continuous recording. For data recording the easiest solution was to modify two of the long-time MLS-type seismic data loggers from SEND. The X-axis and the Y-axis of the 510 tiltmeter as well as temperature are permanently recorded at 1-s sample intervals while the 900-45 and the magnetic compass are read after each levelling operation.

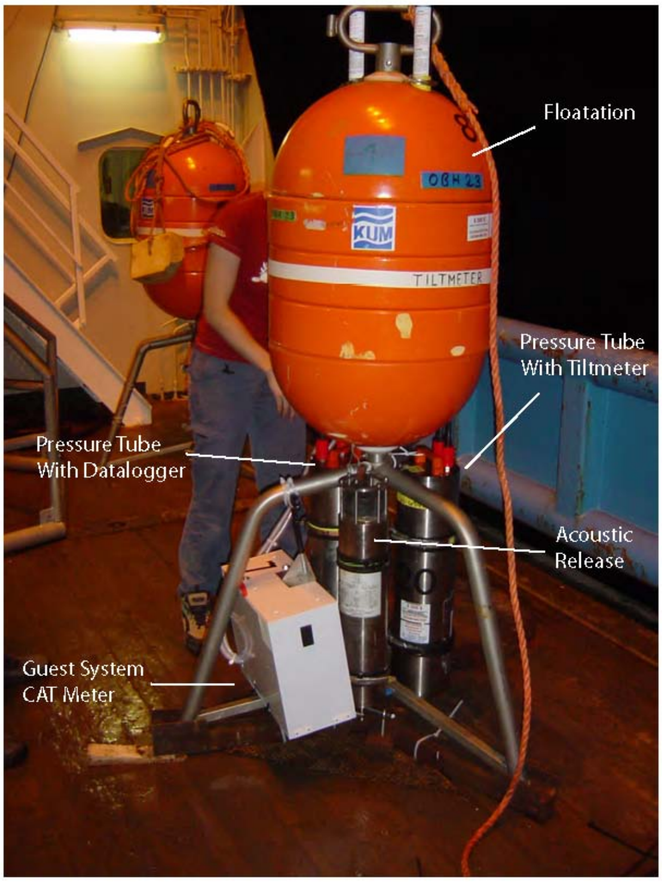
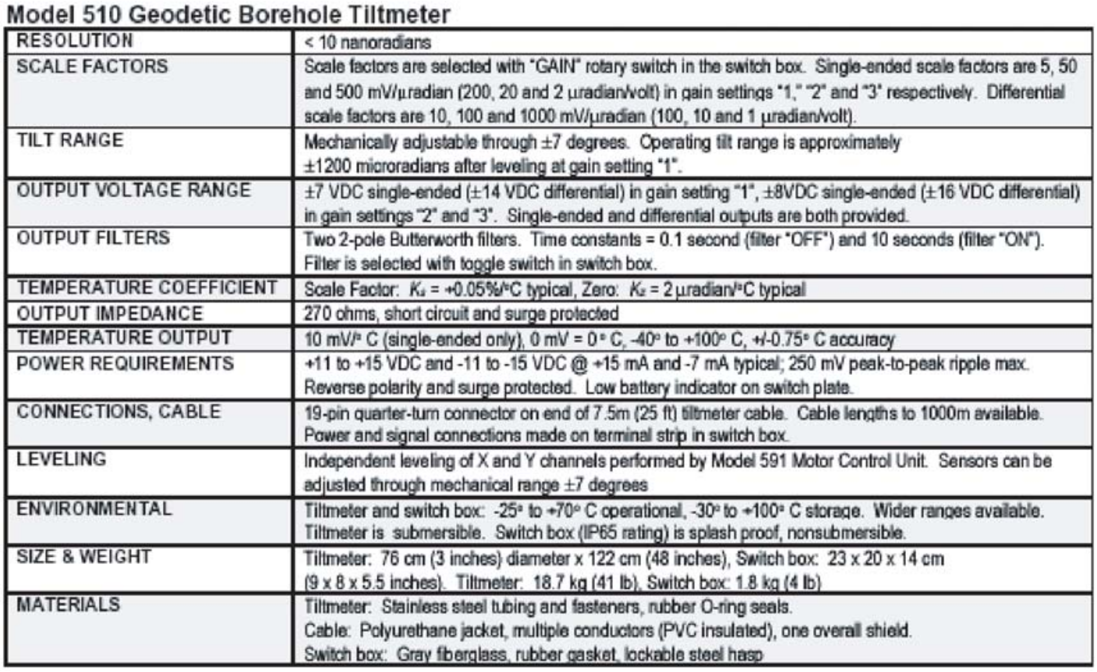


Figure 6.2.5.1: Photograph of the tiltmeter system carrier ready for deployment in November 2008 from R/V PELAGIA.



Model 510 Geodetic Borehole Tiltmeter

RESOLUTION	< 10 nanoradians
SCALE FACTORS	Scale factors are selected with "GAIN" rotary switch in the switch box. Single-ended scale factors are 5, 50 and 500 mV/μradian (200, 20 and 2 μradian/volt) in gain settings "1," "2" and "3" respectively. Differential scale factors are 10, 100 and 1000 mV/μradian (100, 10 and 1 μradian/volt).
TILT RANGE	Mechanically adjustable through ±7 degrees. Operating tilt range is approximately ±1200 microradians after leveling at gain setting "1".
OUTPUT VOLTAGE RANGE	±7 VDC single-ended (±14 VDC differential) in gain setting "1", ±8VDC single-ended (±16 VDC differential) in gain settings "2" and "3". Single-ended and differential outputs are both provided.
OUTPUT FILTERS	Two 2-pole Butterworth filters. Time constants = 0.1 second (filter "OFF") and 10 seconds (filter "ON"). Filter is selected with toggle switch in switch box.
TEMPERATURE COEFFICIENT	Scale Factor: K_s = +0.05%/°C typical, Zero: K_z = 2 μradian/°C typical
OUTPUT IMPEDANCE	270 ohms, short circuit and surge protected
TEMPERATURE OUTPUT	10 mV/° C (single-ended only), 0 mV = 0 ° C, -40° to +100° C, +/-0.75° C accuracy
POWER REQUIREMENTS	+11 to +15 VDC and -11 to -15 VDC @ +15 mA and -7 mA typical; 250 mV peak-to-peak ripple max. Reverse polarity and surge protected. Low battery indicator on switch plate.
CONNECTIONS, CABLE	19-pin quarter-turn connector on end of 7.5m (25 ft) tiltmeter cable. Cable lengths to 1000m available. Power and signal connections made on terminal strip in switch box.
LEVELING	Independent leveling of X and Y channels performed by Model 591 Motor Control Unit. Sensors can be adjusted through mechanical range ±7 degrees
ENVIRONMENTAL	Tiltmeter and switch box: -25° to +70° C operational, -30° to +100° C storage. Wider ranges available. Tiltmeter is submersible. Switch box (IP65 rating) is splash proof, nonsubmersible.
SIZE & WEIGHT	Tiltmeter: 76 cm (3 inches) diameter x 122 cm (48 inches), Switch box: 23 x 20 x 14 cm (9 x 8 x 5.5 inches). Tiltmeter: 18.7 kg (41 lb), Switch box: 1.8 kg (4 lb)
MATERIALS	Tiltmeter: Stainless steel tubing and fasteners, rubber O-ring seals. Cable: Polyurethane jacket, multiple conductors (PVC insulated), one overall shield. Switch box: Gray fiberglass, rubber gasket, lockable steel hasp

Figure 6.2.5.2: Photograph of the tiltmeter with the control electronics on top. Positions of the 900-45 clinometer and the compass are indicated.

6.3 SIDESCAN

The mud volcanoes were mapped with the DTS-1 sidescan sonar system (Fig. 6.3.1) owned and operated by IFM-GEOMAR, Kiel. The DTS-1 sidescan sonar is a dual-frequency, Chirp sidescan sonar (EDGETECH Full-Spectrum) working with 75-kHz and 410-kHz centre frequencies. The 410-kHz sidescan sonar emits a pulse that has a bandwidth of 40 kHz and a duration of 2.4 ms (which results in a range resolution of 1.8 cm), and the 75-kHz sidescan sonar offers a choice between two pulses of bandwidths of either 7.5 and 2 kHz and pulse lengths of 14 and 50 ms, respectively. They provide a minimum across-track resolution of 5.6 cm. With typical towing speeds of 2.5 to 3.0 kn and a range of 750 m for the 75-kHz sidescan sonar, minimum along-track resolution is on the order of 1.25 metres, while the 410-kHz sensor has a resolution of 0.25 metres and a range of 150 metres. In addition to the sidescan sonar sensors, the DTS-1 carries a 2-10-kHz, 20-ms pulse length Chirp subbottom profiler yielding a nominal vertical resolution between 6 and 10 cm. The sonar electronics provide four serial ports (RS232) to attach up to four additional sensors. One of these ports is used for a Honeywell attitude sensor providing information on heading, roll and pitch and a second port is used for a pressure sensor. Finally, there is the option of recording data directly in the underwater unit through hard disk with a total storage capacity of 30 GByte (plus 30 Gbyte emergency backup).

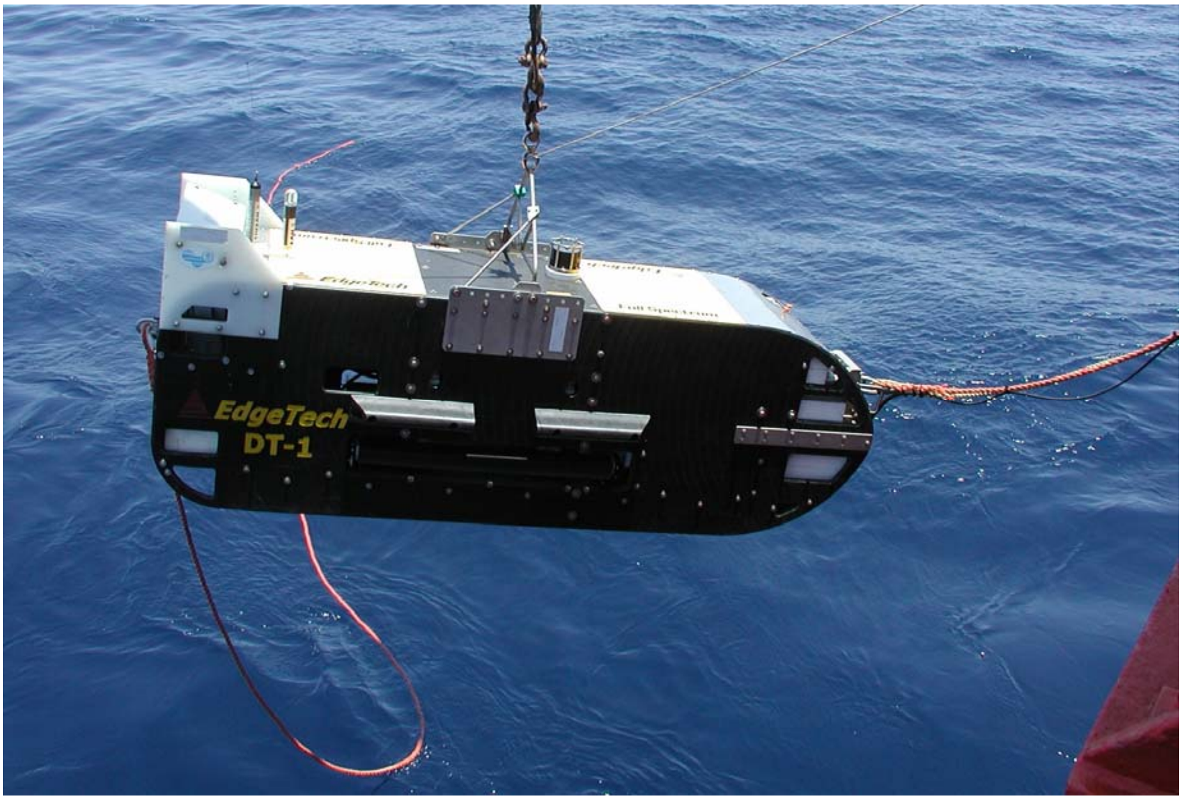


Figure 6.3.1: The DTS-1 sidescan sonar towfish during deployment.

The sonar electronics are housed in a titanium pressure vessel mounted on a towfish of 2.8 m x 0.8 m x 0.9 m in dimension (Fig. 6.3.1). The towfish houses a second titanium pressure vessel which contains the underwater part of the telemetry system (SEND DSC-Link). In addition, a releaser capable of working with the POSIDONIA USBL positioning system (IXSEA-OCEANO) with a separate receiver head, an emergency flash and radio beacon (NOVATECH) are included in the towfish. The towfish is also equipped with a deflector at the rear in order to reduce negative pitch of the towfish due to the weight of the depressor and buoyancy of the towfish. The positive buoyancy of the towfish is on the order of 25 kg.

The towfish is connected to the sea cable via the depressor through a 45-m-long umbilical cable (Fig. 6.3.2). The depressor serves for pulling the towfish to depth while the umbilical disconnects the towfish from movements of the ship. The umbilical cable is tied to a buoyant rope that takes up the actual towing forces. An additional rope has been taped to the buoyant rope and serves for retrieving the instrument during recovery.

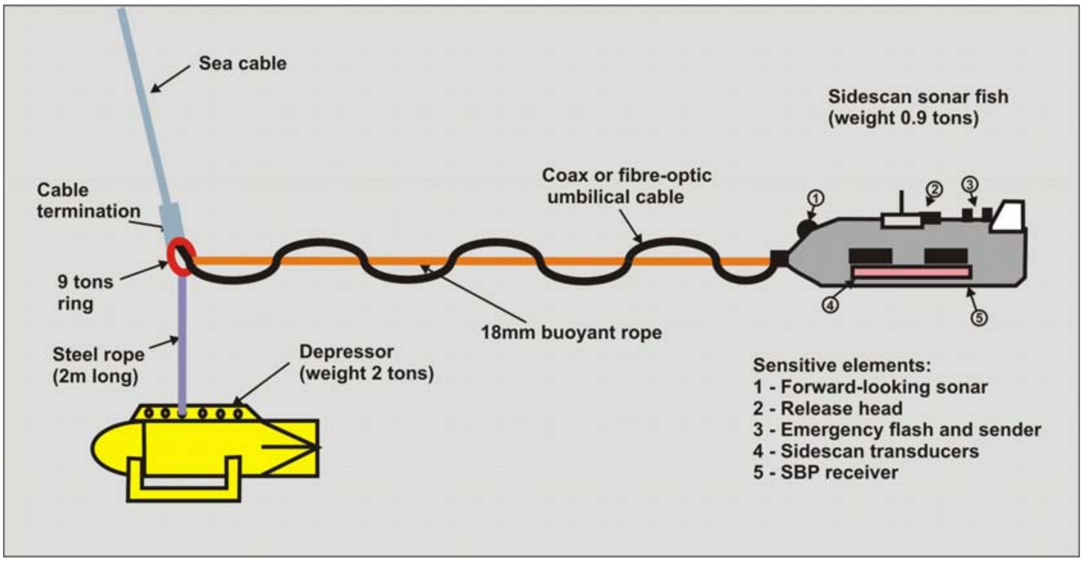


Figure 6.3.2: The DTS-1 towing configuration. During cruise P388 a lighter depressor (650 kg) was used.

The main operations of the DTS-1 sidescan sonar are run using HYDROSTAR ONLINE, the multibeam bathymetry software developed by L3 COMMUNICATIONS ELAC NAUTIK and adapted to the acquisition of EDGETECH sidescan sonar data. This software package allows for onscreen presentation of the data, of the tow fish's attitude, and of the tow fish's navigation. USBL navigation was not available onboard RV POSEIDON as the moonpool was occupied by the multibeam system. A layout method based on cable length and towing speed was therefore used for towfish navigation. Unfortunately, the cable length of the W6 winch was not available digitally and had to be logged manually.

6.4 CAT METERS

During cruise 64PE298 of R/V PELAGIA in November 2008, a total of 7 CAT meters were installed on North Alex mud volcano (6) and Giza mud volcano (1) to determine fluid flow rates at specific locations, for example in bacterial mats. Two types of CAT meters were installed, only distinguished by the mode of their recovery: three instruments were deployed without a release system, three with an integrated release system, and one was attached to a releasable tiltmeter

OBMT. The three releaser system CAT meters and the one attached to the OBMT were scheduled for recovery during cruise P388.

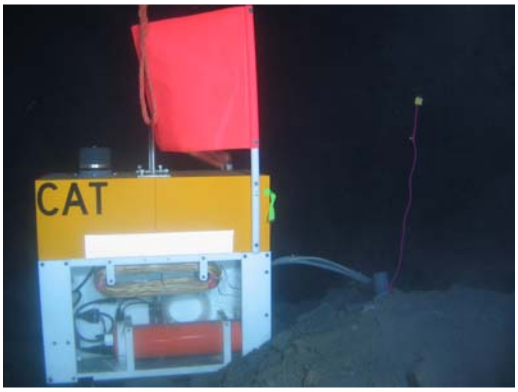


Figure 6.4.0.1: CAT meter with acoustic release system.

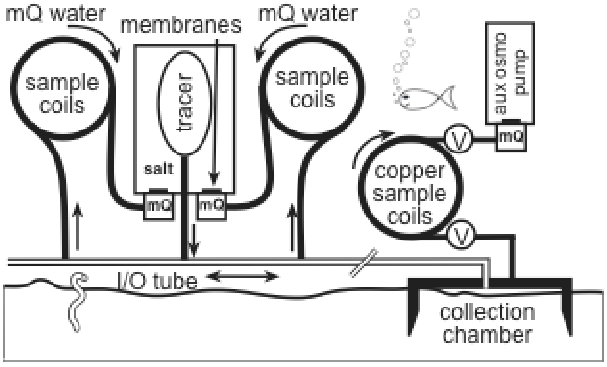


Figure 6.4.0.2: CAT meter schematics.

The Chemical and Aqueous Transport (CAT) meter (Fig. 6.4.0.1) (Tryon et al., 2001*) is designed to quantify both inflow and outflow rates on the order of 0.01 cm/yr to 100 m/yr. At high outflow rates, a time series record of the outflow fluid chemistry may also be obtained. These instruments have been in use since 1998 and have been very successful in monitoring long-term fluid flow in both seep and non-seep environments. The CAT meter uses the dilution of a chemical tracer to measure flow through the outlet tubing exiting the top of a collection chamber (Fig. 6.4.0.2). The pump contains two osmotic membranes that separate the chambers containing pure water from the saline side that is held at saturation levels by an excess of NaCl. Due to the constant gradient, distilled water is drawn from the fresh water chamber through the osmotic membrane into the saline chamber at a rate that is constant for a given temperature. The saline output side of the pump system is rigged to inject the tracer while the distilled input side of the two pumps is connected to separate sample coils into which fluid is drawn from either side of the tracer injection point (Fig. 6.4.0.2). Each sample coil is initially filled with deionized water. With two sample coils, both inflow and outflow can be measured. A unique pattern of chemical tracer distribution is recorded in the sample coils, allowing for determination of a serial record of the flow rates. Upon recovery of the instruments the sample coils are subsampled at appropriate intervals and analysed using a Perkin-Elmer Optima 3000XL ICP-OES. Both tracer concentration and major ion concentration (Na, Ca, Mg, S, K, Sr, B, Li) are determined simultaneously. A subset of these instruments are equipped with an auxiliary osmotic pump connected to copper coils and high pressure valves so that they can be returned to the surface at ambient pressure, maintaining the gas composition of the fluids for analysis.

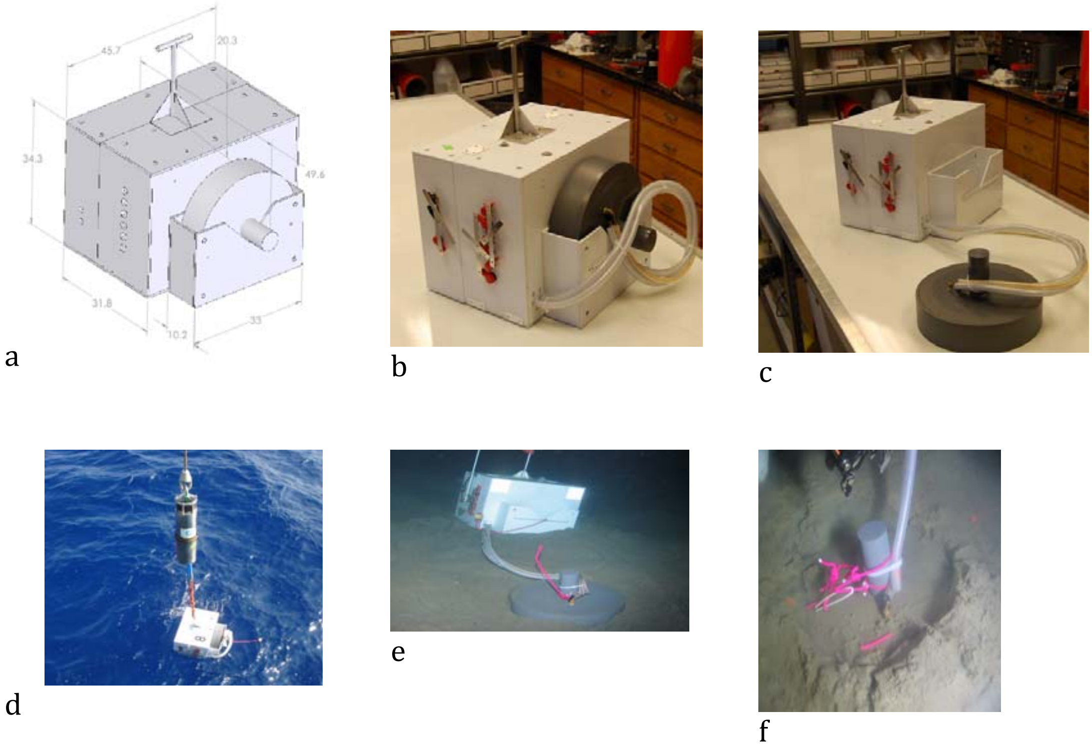
As explained in Tryon et al., 2001*), diffusion in the sample coils is negligible. Typical sample sizes are 25-75 cm of tubing, many times the characteristic diffusion length for typical seawater ions at ocean bottom temperatures. Previous data have shown that typical resolutions are ~0.5% of the deployment time in the latest portions of the record and ~2% in the oldest portion for deployments of a year. At this time, there are no quantitative data with regards to long-term He diffusion in the copper coils, however, since the diffusion coefficient (D) of He is ~7x10-5, and that of typical seawater ions is ~1-3x10-5. The characteristic diffusion length (∝D1/2) for He should only be about twice that of the other species we analyse for (45 cm for a year at 25°C and much less at ocean bottom temperatures). The copper coils used here are a smaller diameter than the plastic coils and thus our samples are typically twice the length, offsetting any difference in diffusion length.

*)Tryon, M., K. Brown, L.R. Dorman, and A. Sauter, (2001), A new benthic aqueous flux meter for very low to moderate discharge rates, *Deep-Sea Research Part I-Oceanographic Research Papers*, *48*, 2121-2146.

6.4.1 Basic Hand-Held CAT

Dimensions: 50 x 46 x 55 cm (base x base x height)
Weight in air: 36 kg
Weight in water: 15 kg

The instrument housings and structures are PVC, the switching valves are made of PVC, while all other hardware is 316 stainless steel: the top handle is a 316 stainless steel - standard Alvin T-handle. The dissolved gas system is made of copper refrigeration tubing with brass couplers and valves.



a b c

d e f

Figure 6.4.1.1 a-f: Standard CAT meter design, deployment and installation on the seafloor.

6.4.2 Acoustically Releaseable CAT

Dimensions: 80 x 38 x 91 cm (base x base x height)
Weight in air w/ ballast: 138 kg
Weight in air w/o ballast: 110 kg
Weight in water w/ ballast: 12 kg
Weight in water w/o ballast: -15 kg

The instrument consists of the basic CAT as described previously and the frame, releaser and floatation. The frame is made of high-density polyethylene, the hardware is 316 stainless steel. The top handle is a 316 stainless steel hoop. The floatation is syntactic foam rated at 50 MPa (Syntech AM-37). The acoustic release electronics are in a 7075 Aluminum housing rated at 50 MPa and certified to 4500 meters for use with manned submersibles (safety factor of 1.5). All other components are solid, oil- or water-filled: There are no other implodable volumes.

a b c

Fig. 6.4.2.1 a-c: Releaser-equipped CAT meter, deployment (a) and installation (b) on the seafloor, standard CAT meter attached to OBT-1 (c).

6.5 PIEZOMETERS

As part of a cooperation with the BP West Nile Delta Geohazards Assessment Team (WND-GAT), a total of 4 piezometers were deployed during POSEIDON cruise P388. These instruments are designed to measure the variability of differential pore pressure at a specific sediment depth. This is accomplished by penetrating the seafloor with a “stinger” assembled from several standard 1-m CPT stands with a special filter tip. From the filter tip a pressure-tight teflon tubing runs to the top-end of the “stinger” which terminates in a hydraulic stab above the seafloor. The hydraulic stab itself is connected to the data acqusition box by a pressure-tight coupling system . The data acquisition box houses two differential pressure sensors and loggers. These sensors compare pressure at the seafloor to the pressure at the filter tip. To measure verticality of penetration an independent tiltmeter is included in the acquisition box.

The piezometer consists of a small number of components enclosed in a block of POM plastics. The center of the block has an opening through which the hydraulic stab is protruding. The tip of the hydraulic stab mates with a pressure coupling that connects to two Keller DCX-22PDH pressure sensors (0-1bar, 0-2bar) with attached data loggers. The second sensor is an NGI-supplied tiltmeter in a bottle. The instrument design and parts are shown in Figs. 6.5.0.1, 6.5.0.2 and 6.5.0.3.

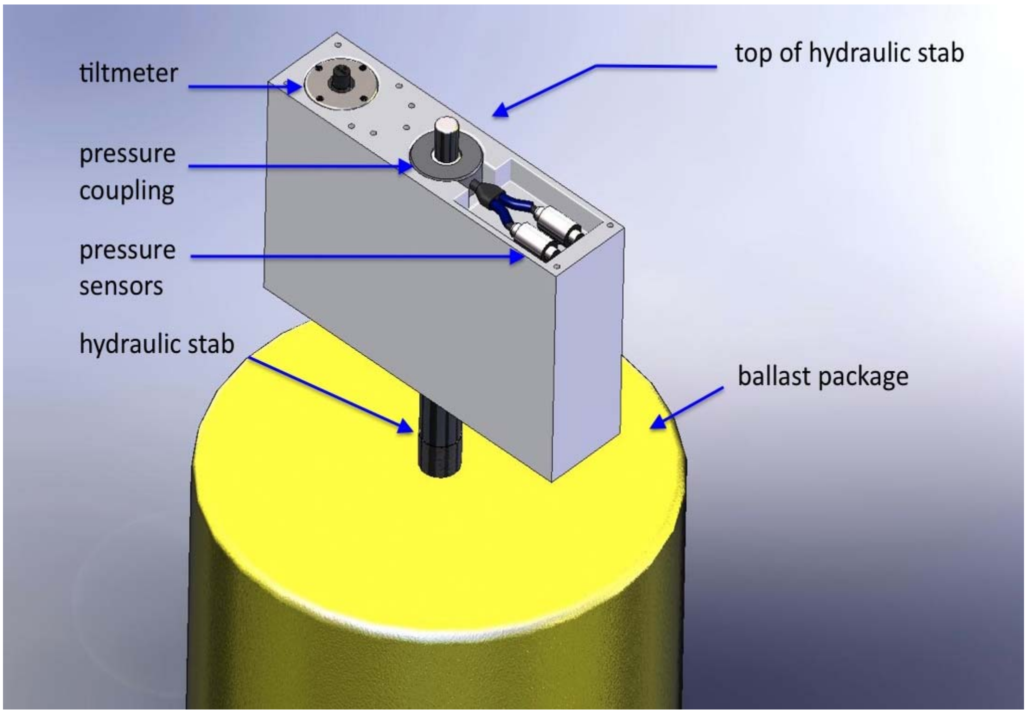


Fig. 6.5.0.1. Piezometer components positioned on top of the ballast package.

Fig. 6.5.0.2. a-f: Data acquisition box (a), with top cover opened (b), Keller differential pressure sensors and data loggers – pressure coupling – tiltmeter removed (c), sensors and data logger – pressure coupling (d, e), hydraulic stab and filter tip (f). Note that the handle for ROV operations is not shown here.

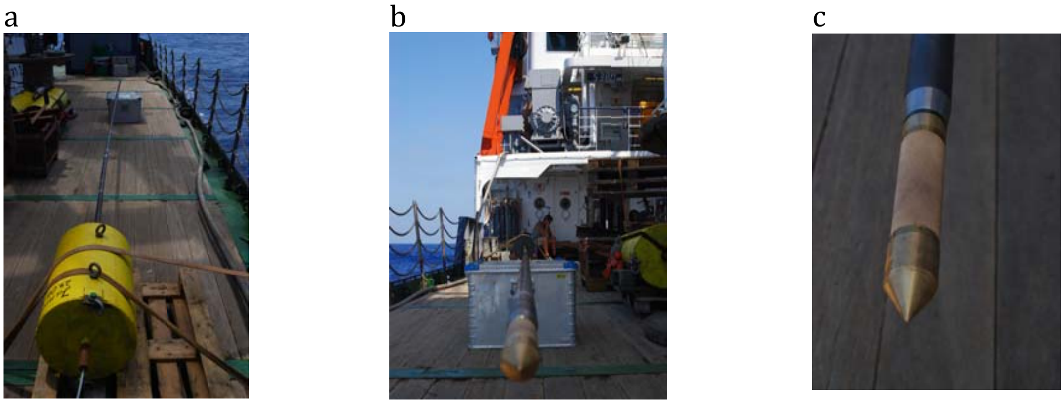


Fig. 6.5.0.3. a-c: Ballast package (a), assembled stinger with filter tip (b), filter tip detail (c).

6.5.1. DEPLOYMENT SEQUENCE

As the piezometers available had originally been designed for positioning of the stinger with a wheel-drive system, followed by ROV-assisted installation of the acquisiton box, the installation procedure had to be significantly modified for gravity deployment. First of all, the full assembly consisting of stinger, filter tip, teflon tubing, hydraulic stab, data acquisition box, and ballast package had to be completed on deck before deployment. During the course of the cruise we developed a simple yet efficient way to ensure a successful installation.

The following series of steps proved to be most efficient:

1 – Penetration test

Prior to installation of the tiltmeter the appropriate ballast package was outfitted with a stinger of the intended total length and lowered to the seafloor. Several trial penetrations were conducted as close as possible to the installation site with different winch speeds until we were convinced that full penetration was achieved.

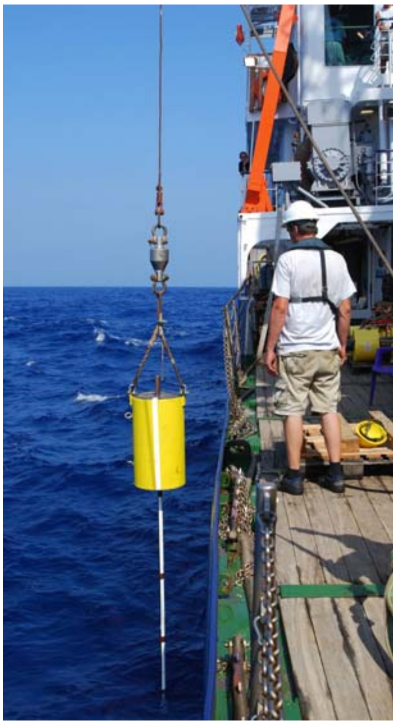
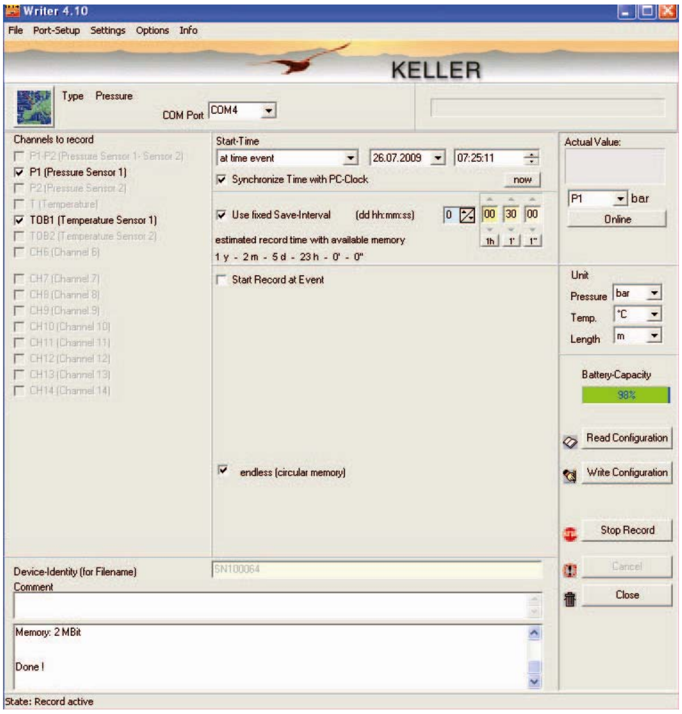


Fig. 6.5.1.1 Ballast package and stinger assembled for penetration testing prior to actual installation.

2 – Sensor preparation

In advance of the deployment the energy supply of all sensors (pressure, tilt) was renewed. The sensors were reset and initialized via serial port (by proprietary “Keller Reader” and “Keller Writer”9. For pressure and temperature, measurement intervals of 2 per hour were chosen. This ensures a lifetime of about 14 months with a battery capacity of 99%. The tiltmeter was connected via a terminal programme and its memory was reset to ensure enough memory for at least one year of measurements. The frequency is fixed at 1 per hour and cannot be adjusted. Finally the top cover was closed and the ROV handle attached.



Type Pressure

COM Port COM4

Channels to record

☐ P1-P2 (Pressure Sensor 1- Sensor 2)
☑ P1 (Pressure Sensor 1)
☐ P2 (Pressure Sensor 2)
☐ T (Temperature)
☑ TOB1 (Temperature Sensor 1)
☐ TOB2 (Temperature Sensor 2)
☐ CH6 (Channel 6)
☐ CH7 (Channel 7)
☐ CH8 (Channel 8)
☐ CH9 (Channel 9)
☐ CH10 (Channel 10)
☐ CH11 (Channel 11)
☐ CH12 (Channel 12)
☐ CH13 (Channel 13)
☐ CH14 (Channel 14)

Start-Time: at time event 26.07.2009 07:25:11

☑ Synchronize Time with PC-Clock

☑ Use fixed Save-Interval (dd hh:mm:ss) 0 00 30 00

estimated record time with available memory
1 y - 2 m - 5 d - 23 h - 0' - 0"

☐ Start Record at Event

☑ endless (circular memory)

Actual Value: P1 bar

Unit
Pressure bar
Temp. °C
Length m

Battery-Capacity 98%

Device-Identity (for Filename) SN100064

Comment

Memory: 2 MBit

Done !

State: Record active

Fig. 6.5.1.2 Screenshot of Keller Writer software to adjust pressure sensor settings.

3 - Assembly of piezometer

CPT rods, ballast package, filter tip, and teflon tubing were assembled and tightly screwed together on deck. An acoustic releaser system was then fitted to the top wire. The upper end of the teflon tubing was left unattached. This assembly was then lowered into the water and left submerged for 15 minutes until the stinger had completely filled with seawater.

Fig. 6.5.1.3: After completion of assembly, the data acquisition box/ unit was attached to the hydraulic stab

4 – Completion of the system

The system was then hoisted back up on the side of the vessel and the teflon tubing extending from the stinger above the ballast package connected to the hydraulic stab via a Legris coupling. Then the hydraulic stab was carefully screwed into the upper end of the stinger.

The data acquisition box was positioned on top of the hydraulic stab to slide over it until the indicator knob was just visible in the centre. Special care was taken, however, that the box did not slide completely over the top of the hydraulic stab. A rope was then attached to the ROV handle and the complete system was put into the water again for another 30 minutes until it had completely de-aired. By pulling the rope the box could be easily rotated until it fully slid into its arrested position.

5 – Final installation

The piezometer assembly was then lowered to about 50 metres above seafloor with a winch speed of 0.8 m/sec. From there the whole piezometer gravity system was lowered at the appropriate speed determined from the penetration test (step 1) until the winch load indicated that penetration was complete. Immediately after that, the acoustic release was activated and the wire pulled back on deck.

The complete sequence of installation took between 2 and 4 hours in total.

6.6 TEMPERATURE MONITORING

To investigate the temporal variability of mud volcano activity, both North Alex mud volcano and Giza mud volcano were fitted with a temperature observatory during the November 2008 R/V PELAGIA cruise 64PE298. As illustrated in Fig. 6.6.1, each observatory consists of a 6-m-long solid steel lance with a concrete weight at the top, which is connected to a buoy. A thermistor chain with 7 temperature sensors is attached to the lance so that it enters the sediment when the lance penetrates the seafloor and records changes in the vertical sediment temperature profile. Bottom water temperature and the pressure at the position of the observatory are recorded by additional sensors mounted between the concrete weight and the buoy. Additionally, there is a second thermistor chain consisting of 24 temperature sensors, evenly distributed over an active length of 92 m. Following the winch-controlled deployment of the observatory, this thermistor chain is laid out on the seafloor away from the lance to provide information about the spatial extent of seepage events.

The main components of the observatory are integrated into the buoy. Each thermistor chain is connected to a separate data logger which controls the measurements and stores the readings. The data loggers were synchronized and programmed to a sampling rate of 30 minutes. Each data logger mirrors the recorded data to an underwater serial port connected to an acoustic modem, which stores a copy and transmits the data to a surface vessel on demand.

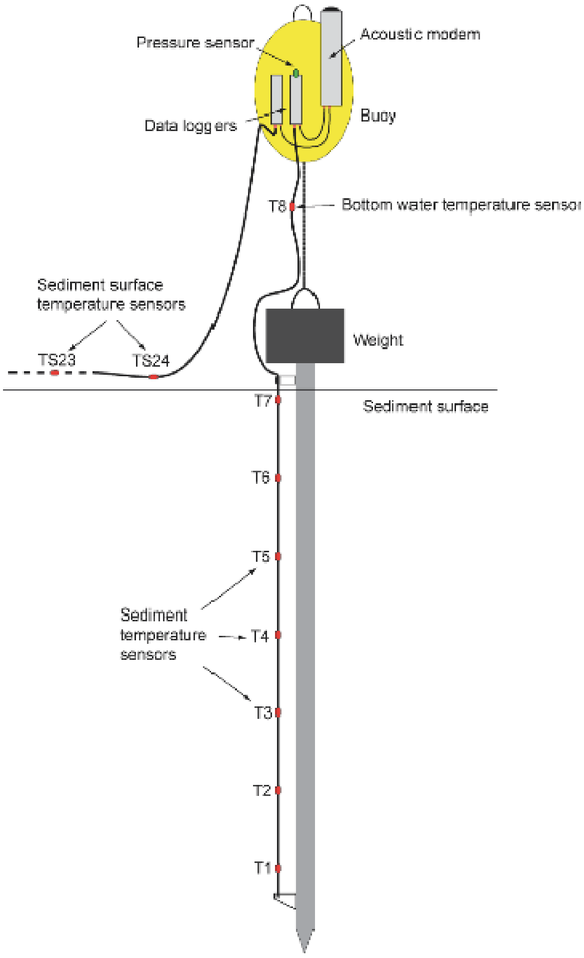


Figure 6.6.1: Design of the long-term temperature observatory.

7. Work Performed

7.1. Seismics

7.1.1. MCS Seismics

The 3D-survey partly covered the mound structure. A location map with the sailing lines and the short-term ocean bottom station locations is shown in Figure 7.1.1.1.

The processing of the multichannel reflection streamer (MCS) seismics mainly included a band pass filter (20/50 – 350/450Hz), especially to reduce the low-frequency noise on the near traces of each streamer, and a trace normalization followed by spherical gain correction. Based on a CTD measurement a stacking velocity was calculated and applied by a normal move out correction to each trace. Additional stacking based on the row and column definitions (see 6.2.3.3) resulted in a stacked cube with a bin size of 10 m.

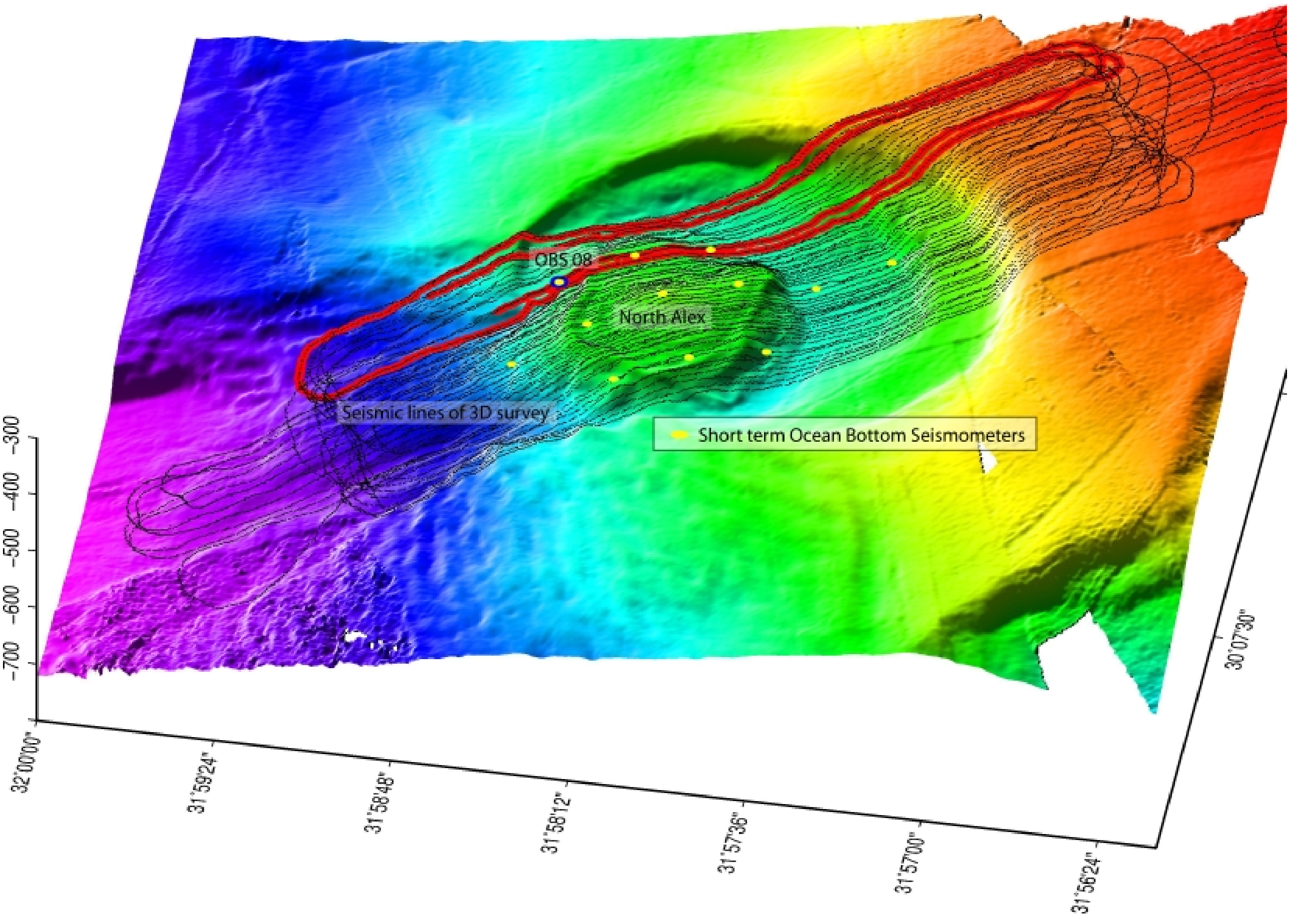


Figure 7.1.1.1: Location map of the 3D-survey with sailing lines and locations of the short term ocean bottom seismometers.

Due to the gaps in the coverage map and strong diffraction tails, approaches to a meaningful geology by visualization and interpretation were suboptimal. To increase the signal-to-noise ratio and to fill in the gaps of coverage in the cube a post-stack 3-D time migration was applied. Two examples of perspective views of the migrated 3-D cube are shown in Figure 7.1.1.2. Further examples of one inline section and one time slice are displayed in Figure 7.1.1.3.

The 2D-survey (Fig. 7.1.1.4) crossed the mound structure and especially the long-term ocean bottom station for later relocation and orientation of the 3-component seismometers. The post-stack time-migrated stacked section marked in the location map is displayed in Figure 7.1.1.5.

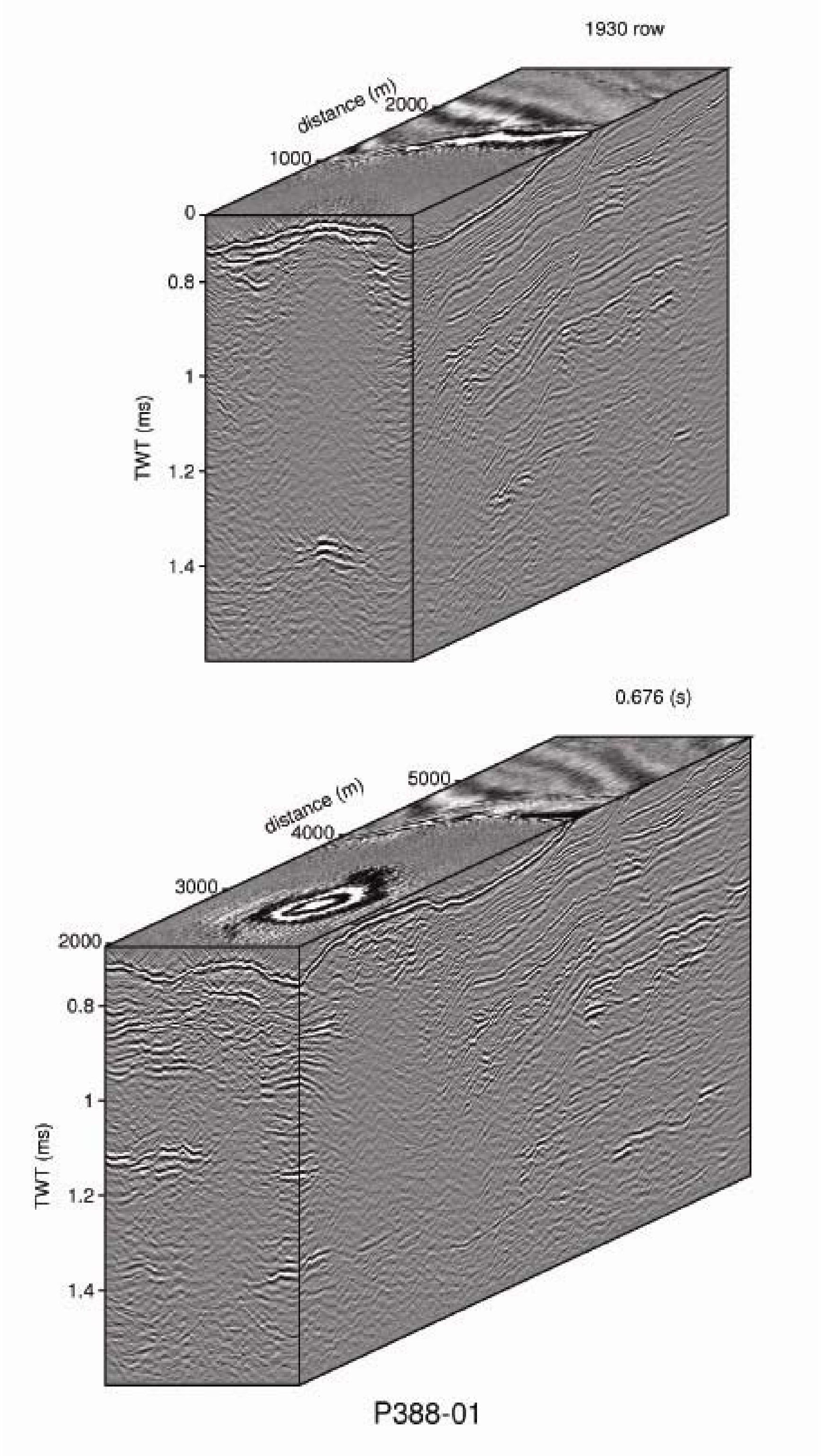
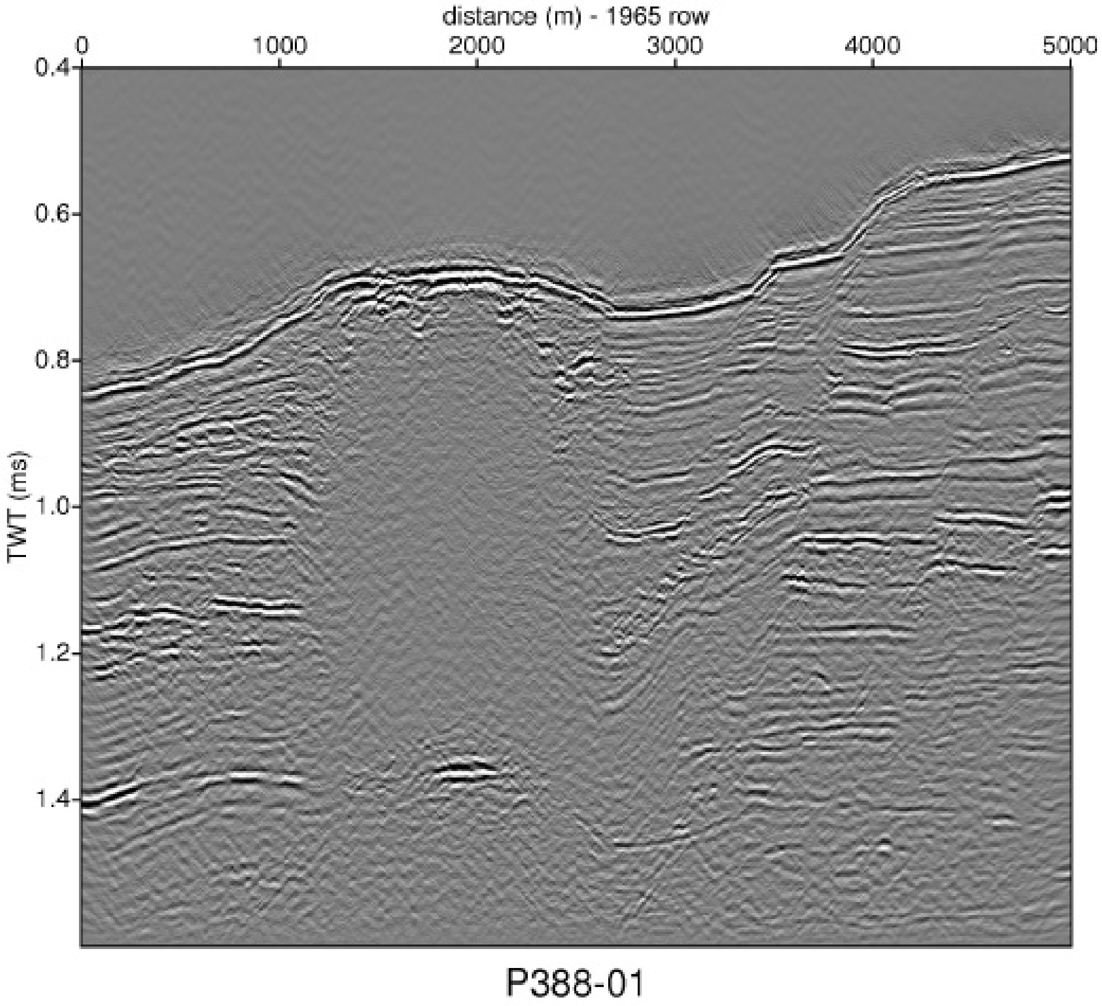


Figure 7.1.1.2: 3-D perspective views of the time-migrated volume.



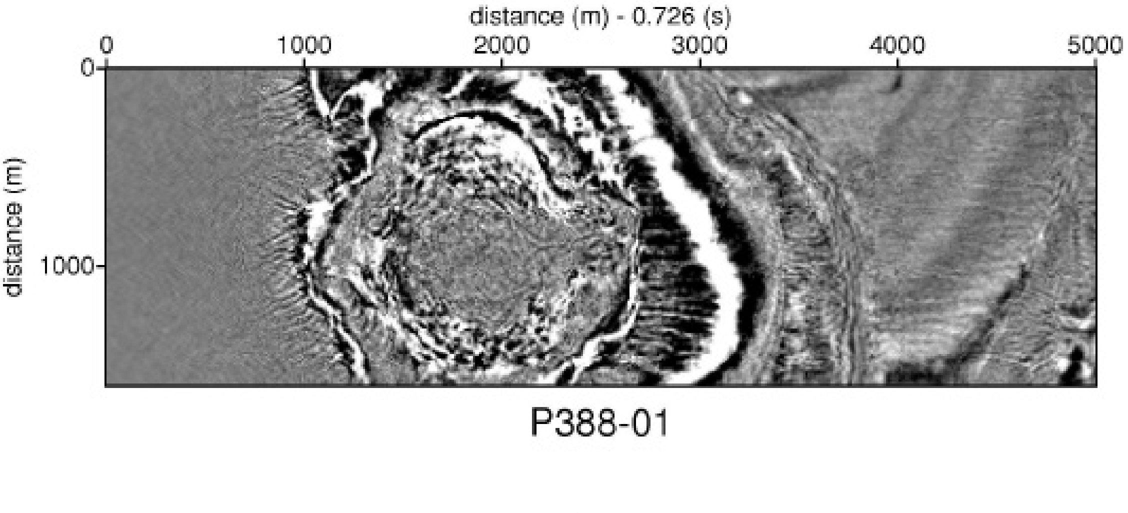


Figure 7.1.1.3: An inline section and a time slice of the migrated volume.

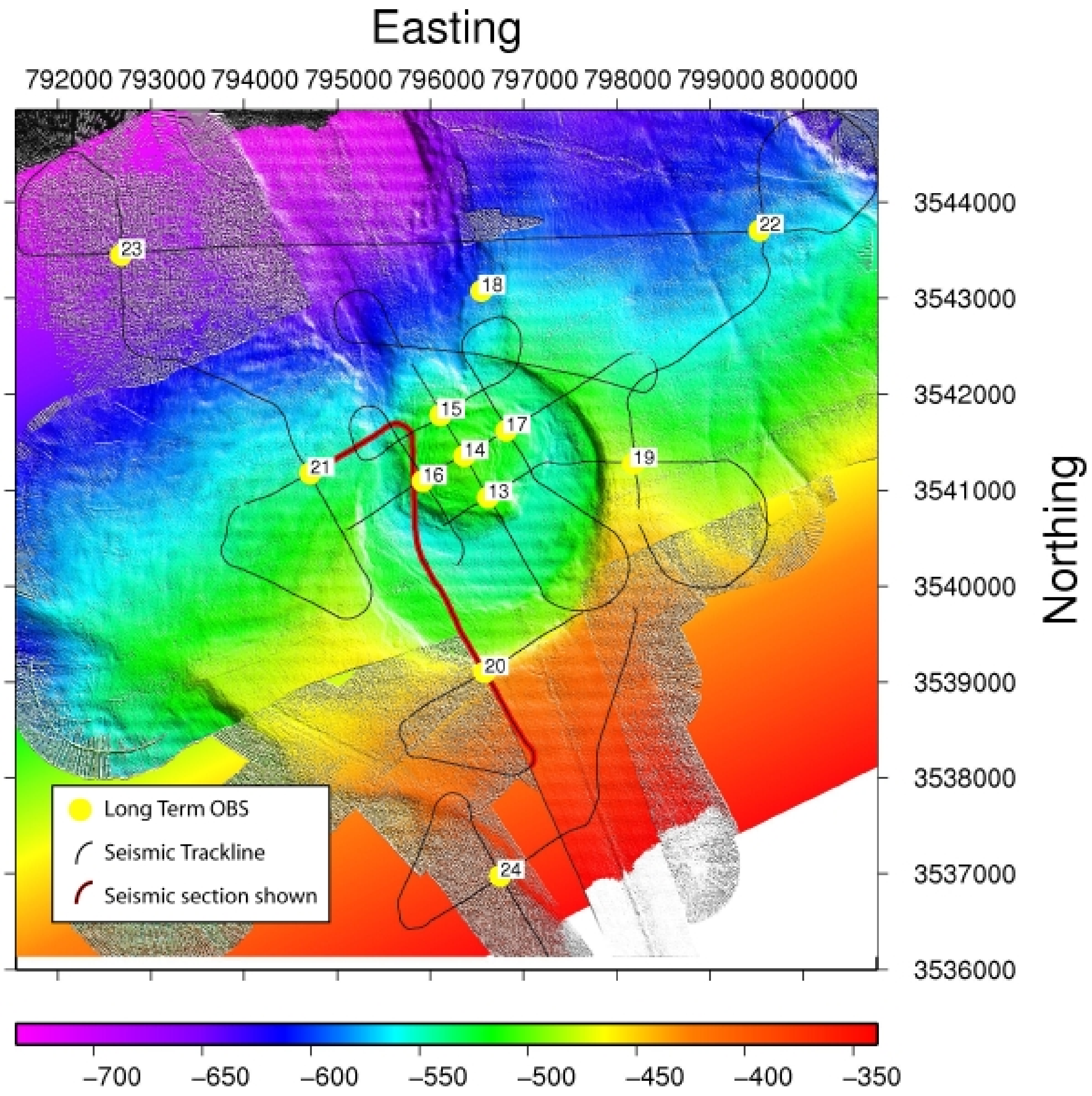


Figure 7.1.1.4: Location map of the 2-D survey with the long-term ocean bottom seismometers.

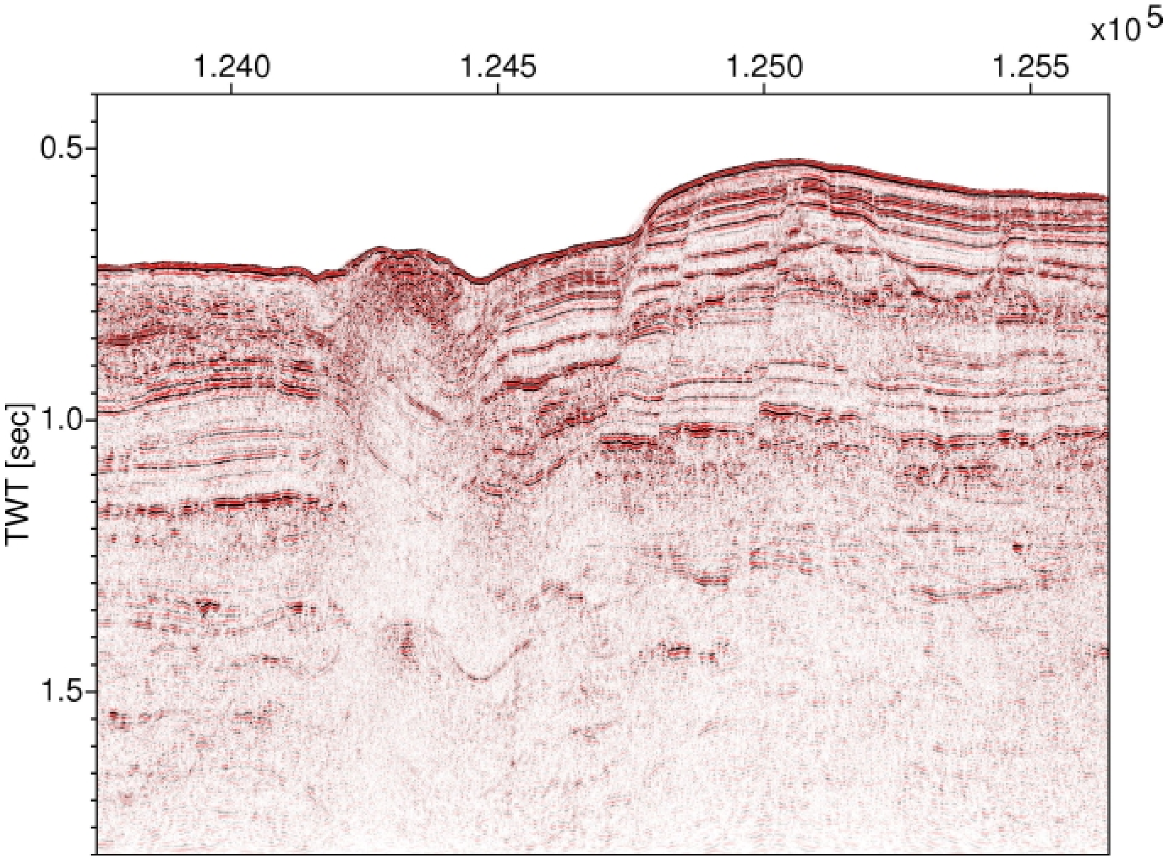


Figure 7.1.1.5: Time migrated seismic section of the 2D-survey. Location marked on Fig. 7.1.1.1.4.

7.1.2 OBS DEPLOYMENTS

7.1.2.1 SHORT-TERM

During the 3-D survey, 12 ocean bottom hydrophones and -seismometers were deployed to simultaneously record wide-angle reflections additional to the 3-D streamer data.

The OBH/S were deployed in close vicinity to North Alex mud volcano (Figure 7.1.1.1). Further OBH/S data analysis will provide seismic velocities of the subsurface, especially in the region directly beneath the mud volcano, where the penetration of near-vertical incidence streamer data is very poor ('undershooting'). A first impression of data quality and signal penetration is displayed in figures 7.1.2.1 and 7.1.2.2. The section shown here is marked as a red track line in the overview figure 7.1.1.1.

The onboard processing of short-term OBH/S data was restricted to quality control and geometry setting using the master navigation file (see 6.2.3.2).

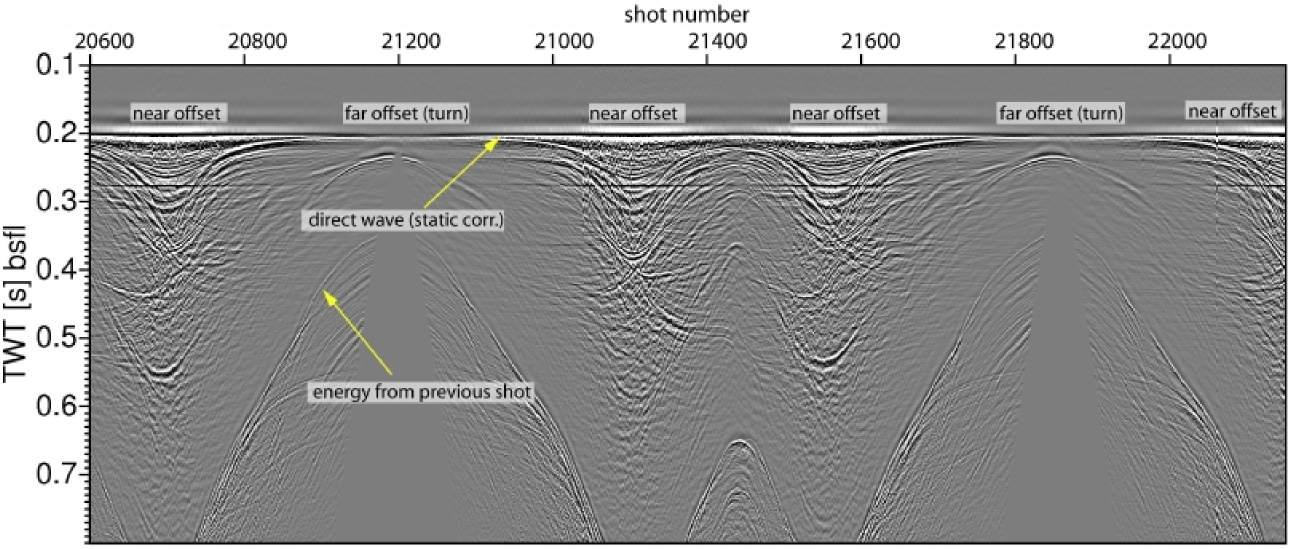


Figure 7.1.2.1: Seismic section displaying continuous records of four hours of airgun shots recorded by one OBS;
Seismic events are corrected for waterdepth, hence the water wave is stretched horizontal
near offset instrument passage and far offset turns at change of profiles are indicated

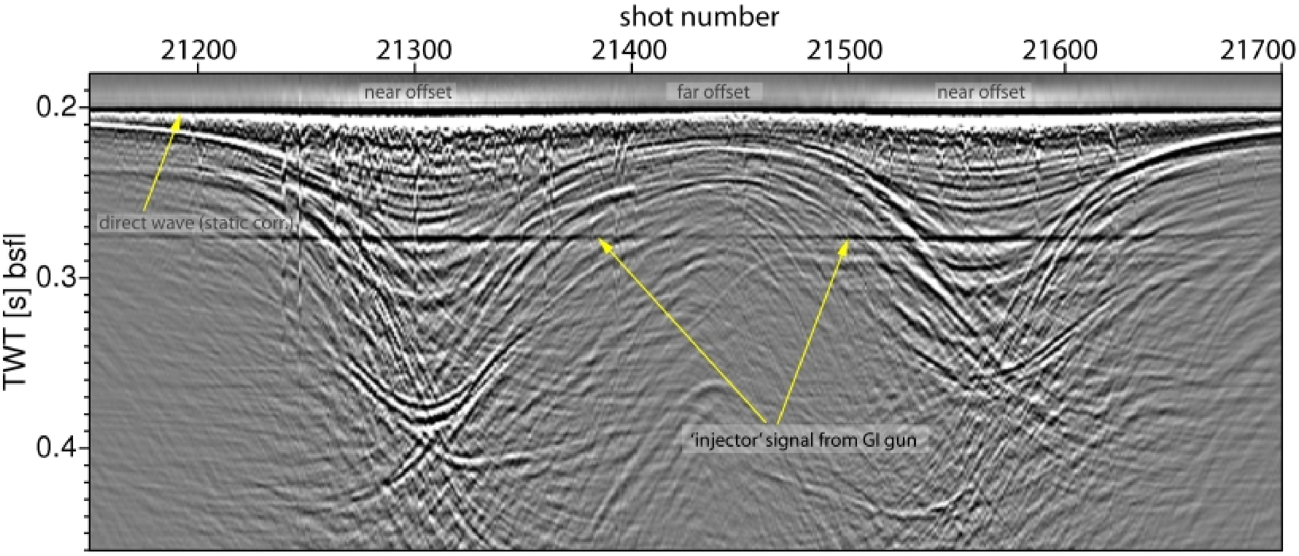


Figure 7.1.2.2: Blow up covering two adjacent profiles indicates the high resolution of the wide angle observations

7.1.2.1 LONG-TERM

During cruise 64PE298 six seismometers were deployed in November 2008 (Fig. 7.1.2.3). All instruments were safely recovered during cruise P388. First data analysis confirmed a successful seismological experiment. A large number of far and near offset events were recorded during the entire period of observation (Fig. 7.1.2.4). Regular seismic amplitudes from far offset exploration surveys can easily be distinguished from natural events. Amplitudes and arrival times indicate seismicity caused by tele-seismic sources had been recorded as well as micro seismicity generated within the mud volcano. Frequency analysis revealed distinct frequency peaks at 6.5 Hz, 13 Hz and higher modes. Several minutes lasting tremors were observed as well. Tiltmeter records compared with the onset of the tremors showed their correlation with tidal signals. Further analysis is required to deduce the source of these local events.

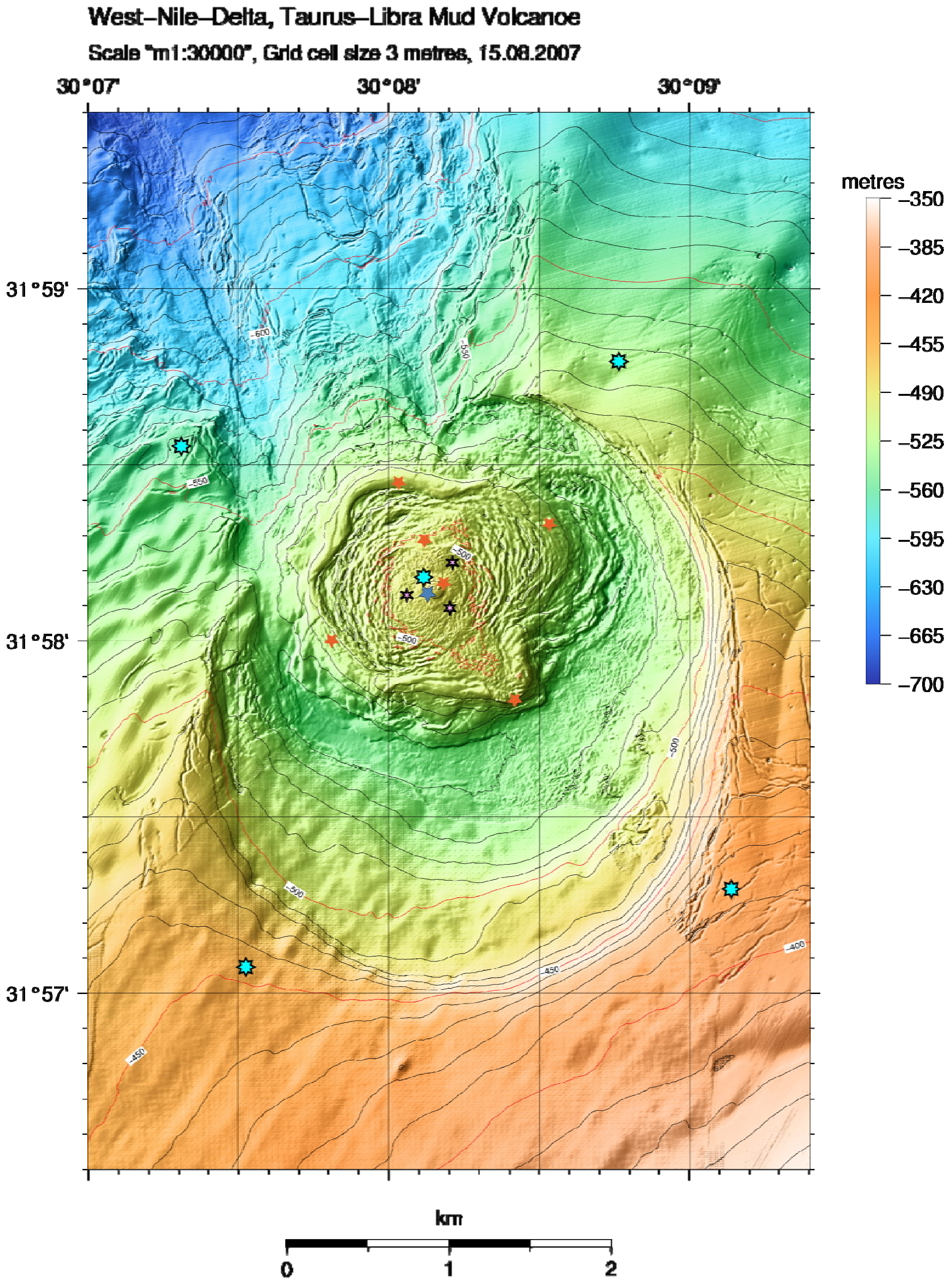


Figure 7.1.2.3: Deployment positions of six long-term OBS

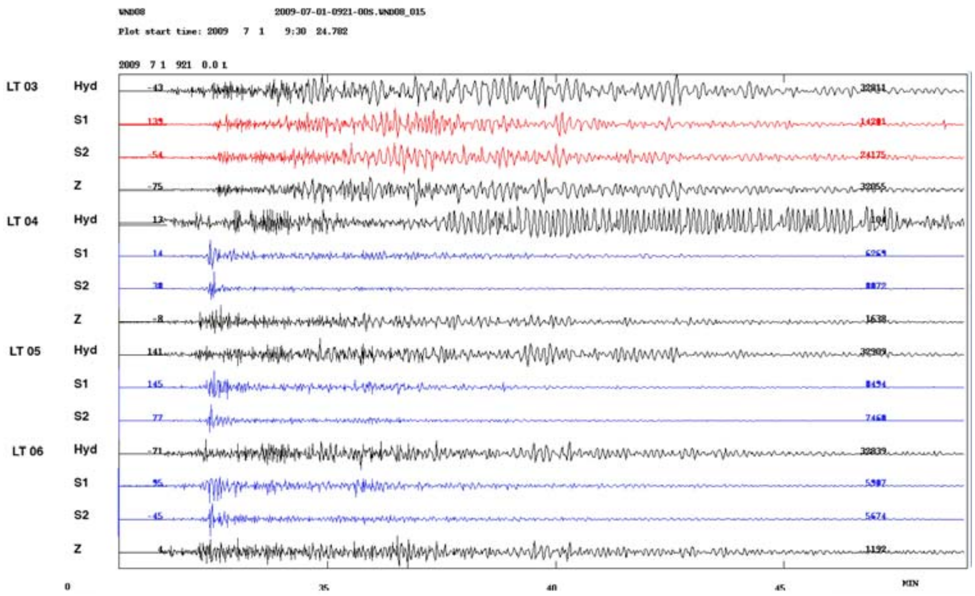


Figure 7.1.2.4: Data example from 4 OBS demonstrating the good data quality and the lateral variation of the frequency content observed within the data sets

7.2 SIDESCAN SONAR

Three deployments of the DTS-1 sidescan sonar were carried out in the area of North Alex mud volcano. The first survey aimed at mapping the mud volcano and its vicinity with the 75-kHz signal. The deployment started on 25 July at 16:20 UTC and had to be stopped at 16:55 UTC because of a short circuit in the power supply of the towfish. After repairs of the power cable the DTS-1 was redeployed on 26 July at 15:08 UTC for five parallel SW-NE trending profiles across North Alex mud volcano and one E-W profile right across the centre of the structure (Fig. 7.2.1). The unprocessed sidescan sonar data showed the presence of gas bubbles (so-called flares) in the water column right at the centre of the mud volcano and much weaker flares at several locations on the rim of the structure (Fig. 7.2.2). Large gas emissions are also visible at pockmarks outside the structure (Fig. 7.2.3). Geo-referenced sidescan sonar images show a high backscatter intensity at the centre of the mud volcano, where gas flares are visible (Fig. 7.2.4). This central area of roughly 200 metres in diameter shows some relief as indicated by small shadows and is surrounded by a 200-m-wide rim of similar relief but much lower backscatter intensity. Finally, another zone of some 200 metres in diameter surrounds this second area and has more relief and much wider structures culminating at the south-western rim of the mud volcano.

The objective of a third deployment of the DTS-1 on July 28 at 07:40 UTC was to obtain high-resolution (410-kHz) images of the central, active area of North Alex mud volcano and one of the large gas flares outside of the structure (Fig. 7.2.1). Three profiles crossing the mud volcano provided detailed views of gas flares in the water column (Fig. 7.2.2) and confirmed the maximum extension of the active area in a north-south direction. A first analysis of the high-resolution sidescan sonar images indicates a clear separation between the central dome of the mud volcano with a small-scale (few metres across) blocky structure and the surrounding area that contains much larger blocky elements (Fig. 7.2.5).

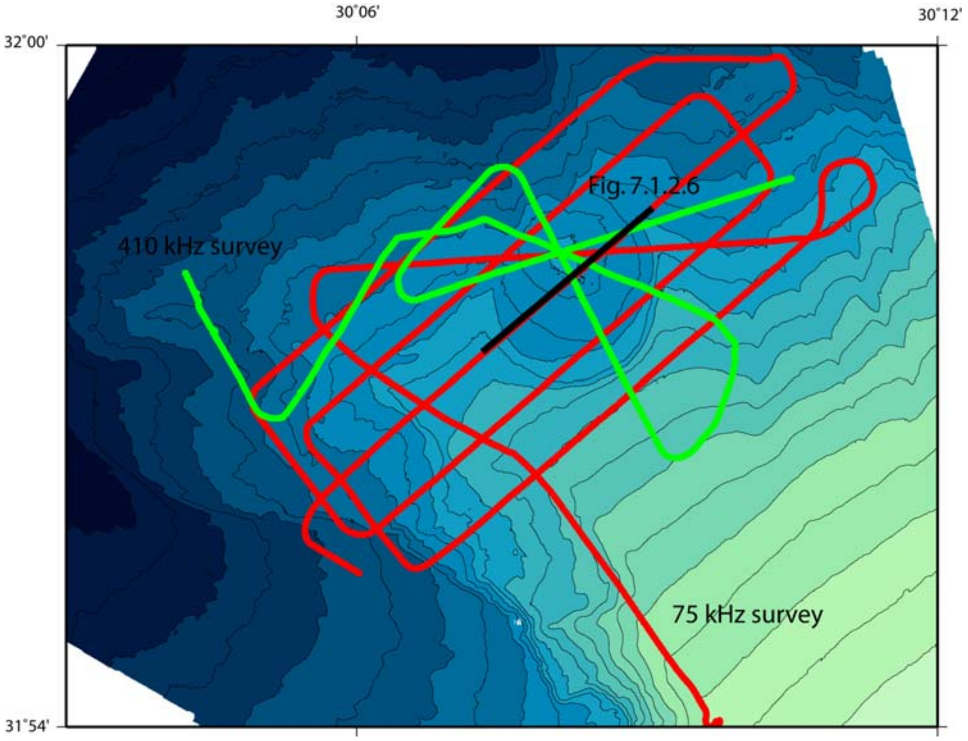


Figure 7.2.1: Tracklines of 75-kHz (red) and 410-kHz (green) DTS-1 sidescan sonar survey over North Alex mud volcano.

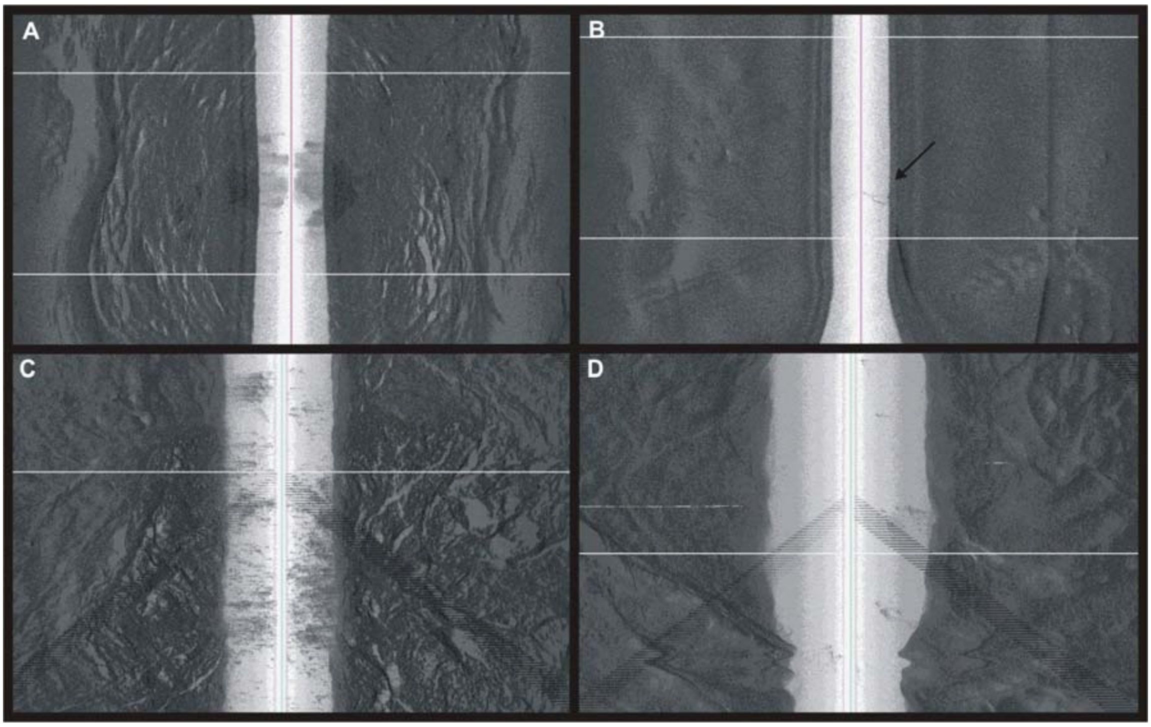


Figure 7.2.2: Unprocessed 75-kHz sidescan sonar records showing anomalies within the water column. The anomalies are most likely to be caused by gas bubbles and are concentrated at the centre (A and C) or the rim (B and D) of North Alex mud volcano. High backscatter is dark.

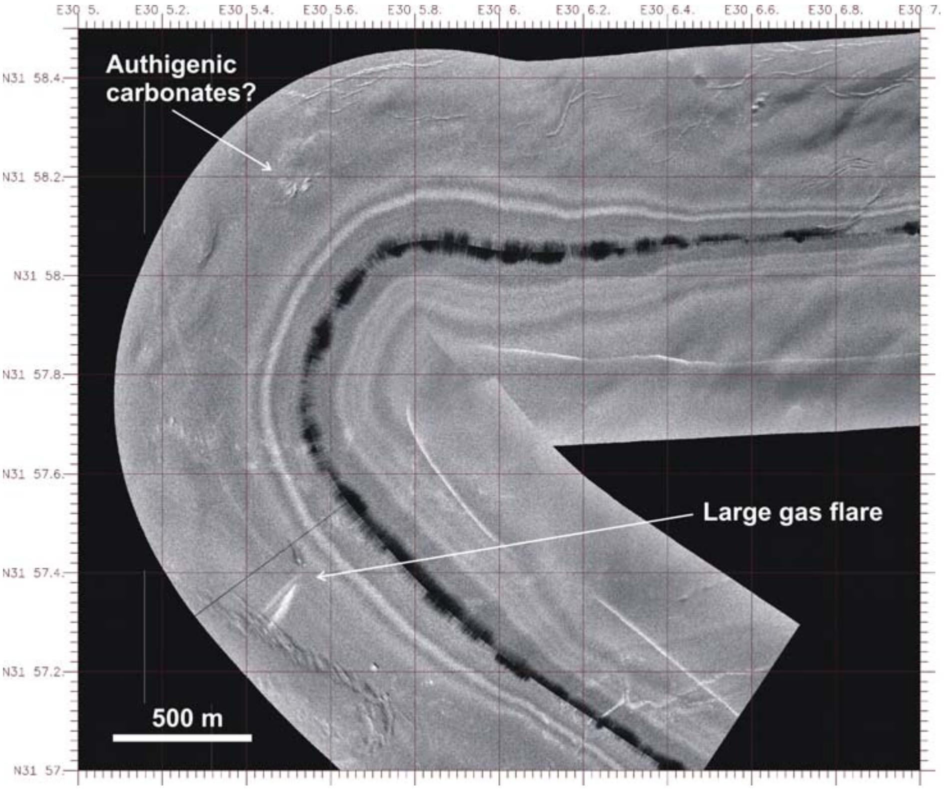


Figure 7.2.3: 75-kHz sidescan sonar image of possible authigenic carbonate pavements and large gas flare on the continental slope off North Alex mud volcano. High backscatter is light.

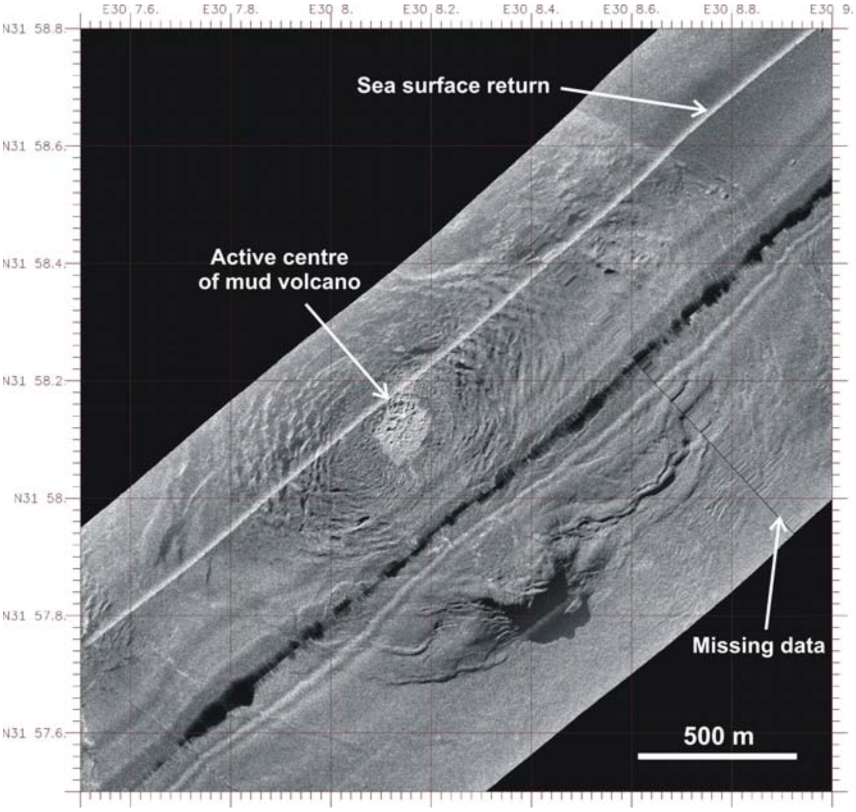


Fig. 7.2.4: 75-kHz sidescan sonar image of North Alex mud volcano. The centre of the mud volcano is particularly active as evidenced by very high backscatter intensity (light tones).

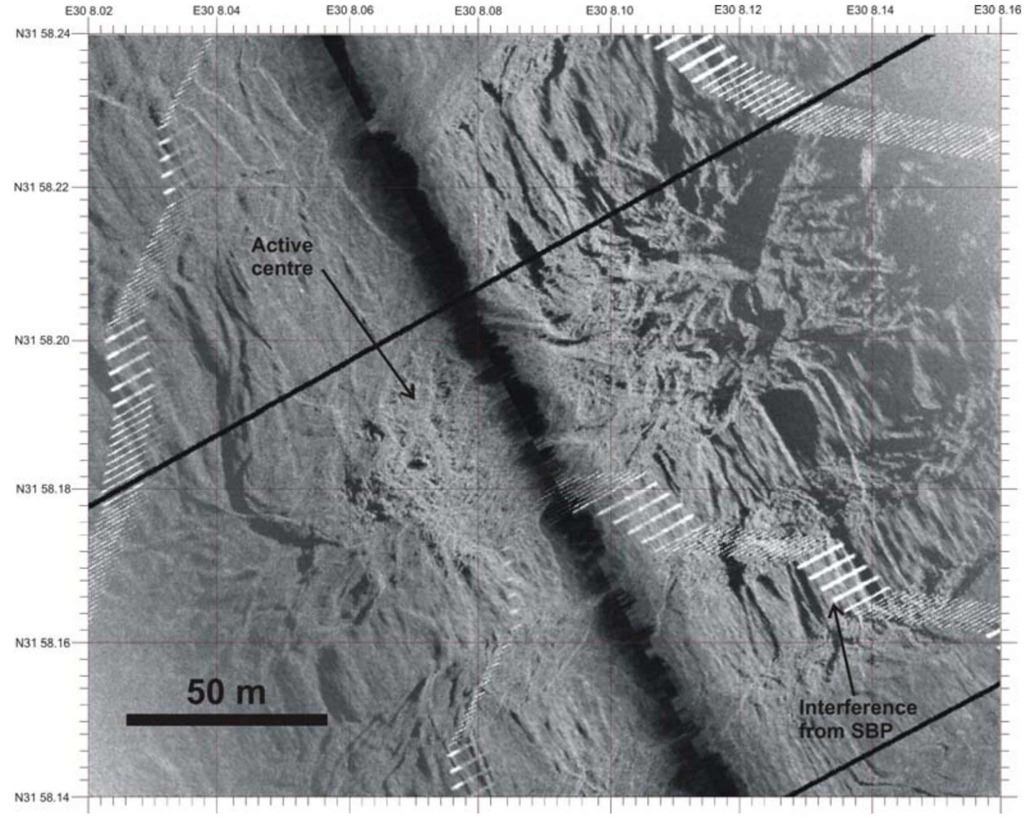


Fig. 7.2.5: Very high-resolution (410 kHz) sidescan sonar image of the active centre of North Alex mud volcano. High backscatter is light.

Such a differentiation of North Alex mud volcano also becomes clear on 2-8 kHz Chirp subbottom profiles (Fig. 7.2.6), where sediments outside the collapse structure are well stratified and continue significantly towards the mud volcano on the south-western flank. Most of the mud volcano between shots 4800 and 5800 shows a blocky surface with little signal penetration, while the centre of the mud volcano between shots 5000 and 5300 is situated some 5-10 metres higher and indicated much higher amplitudes that might reflect the presence of gas in the sediments.

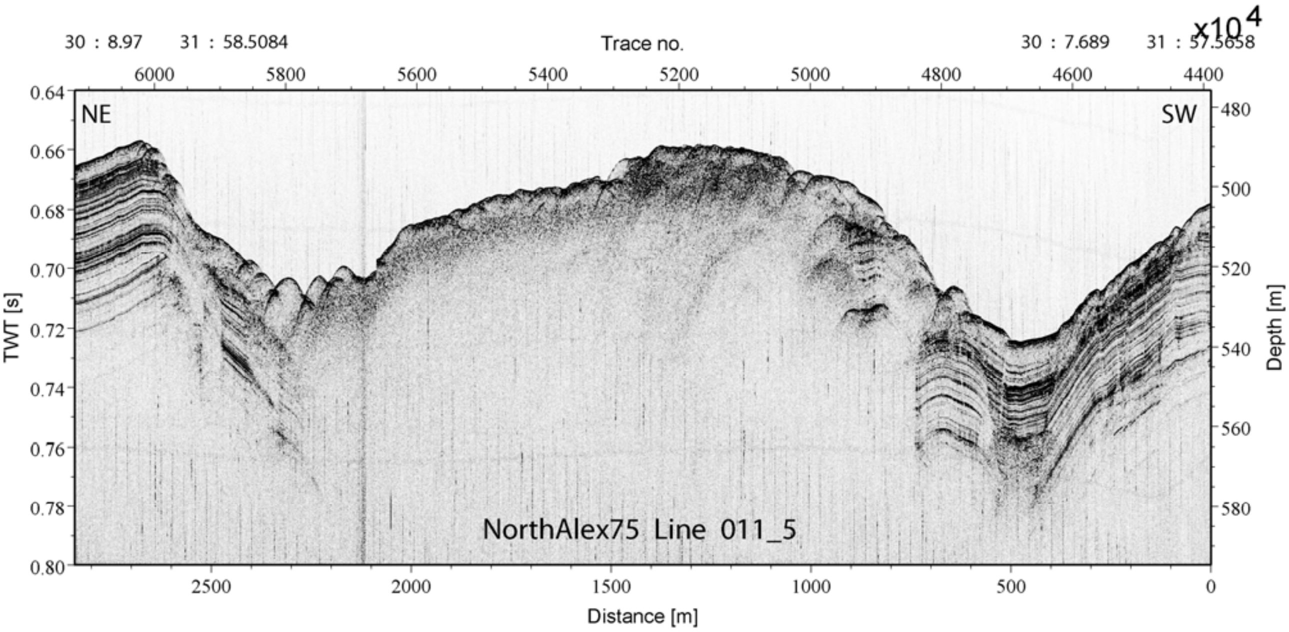


Fig. 7.2.6: 2-8-kHz subbottom profiler record crossing North Alex mud volcano showing strong, diffusive reflections at the mud volcano and well-stratified reflections at the surrounding seafloor that extend into the collapse structure. For profile location see figure 7.2.1.

7.3 CAT METERS

The P388 cruise plan included the recovery of CATmeters #1 and #3, which were equipped with a releaser system and CATmeter #7, which was attached to OBMT#2. The recovery operations were only partially successful.

CATmeters #3 and #7 (Fig 7.3.1) were recovered without problems, both instruments were released and taken on board without any trouble. The fluid and gas sampling units were in good working condition although both frames showed signs of intense corrosion and biofouling. All metal surfaces were encrusted with carbonate.

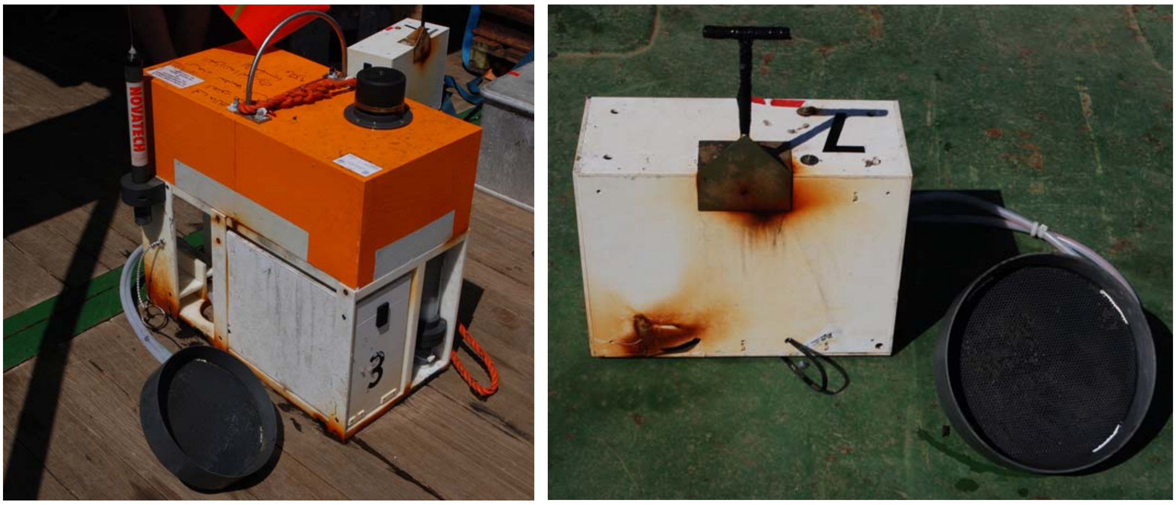


Figure 7.3.1: Photographs of CATmeters #3 and #7 recovered after 9 month of operation

CATmeter #1, which had been positioned off-centre at North Alex, could not be recovered. Although the release code was sent and acknowledged several times by the instrument at depth, it did not rise from the seafloor. We returned to the site twice and could still locate and range the instrument at the same position.

Presumably, the failure is caused by a strong carbonate encrustation which affected the burn-wire system.

7.4 TEMPERATURE MONITORING

During the previous cruise to the working area on R/V PELAGIA, permanent temperature observatories had been installed both on North Alex MV and Giza MV. They have been monitoring the temperature development along a 6-m depth profile and along a surface cable that extends for about 92 metres across the centres of the respective mud volcanoes.

We approached the position of the Giza MV temperature observatory on 19 July and contacted the seafloor modem. We were able to download a total of 211 files of temperature data covering the time period from late November 2008 to July 2009. Upon closer inspection we discovered the same error as observed at the North Alex MV seafloor modem (see 7.1.4). Several months worth of data were missing due to the fact that files had been overwritten multiple times with identical file names. On a second visit on 29 July, the programming error within the data logger which was responsible for this error was corrected by re-setting the record ID to a higher number to prevent overwriting of files in the future.

We approached the position of the North Alex MV temperature observatory on 24 July and made contact with the seafloor modem. We were able to download a total of 168 files of temperature data covering the time period from November 2008 to July 2009. Upon closer inspection we discovered that several months worth of data were missing due to the fact that files had been overwritten multiple times with identical file names. This was caused by a programming error within the data logger which was corrected by reassigning a higher file-ID range.

7.5 TILTMETER DEPLOYMENTS

Three tiltmeter systems had been deployed during R/V PELAGIA cruise 64PE298 in November 2008 (Fig. 7.5.1). All three instruments were successfully recovered during R/V POSEIDON cruise P388. Unfortunately one unit turned out to have been affected by failure of the battery pack, so that no data could be retrieved from that one. One of the remaining units had already failed in May 2009, but the third unit had recorded until June 2009.

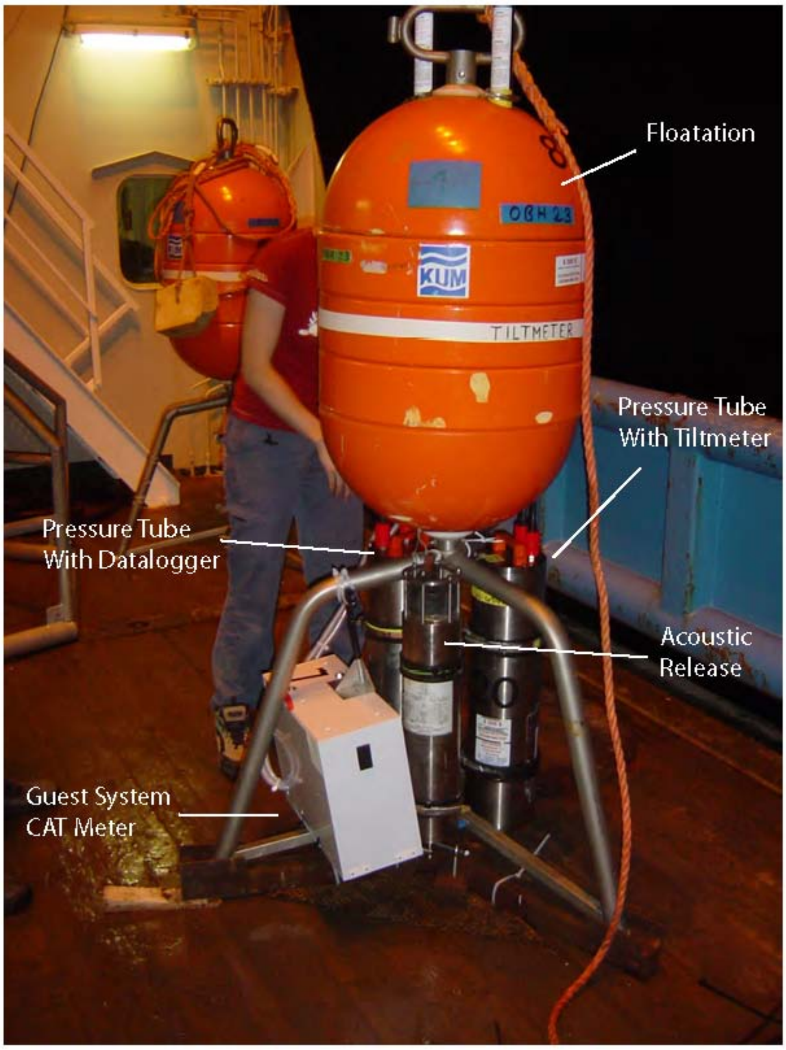
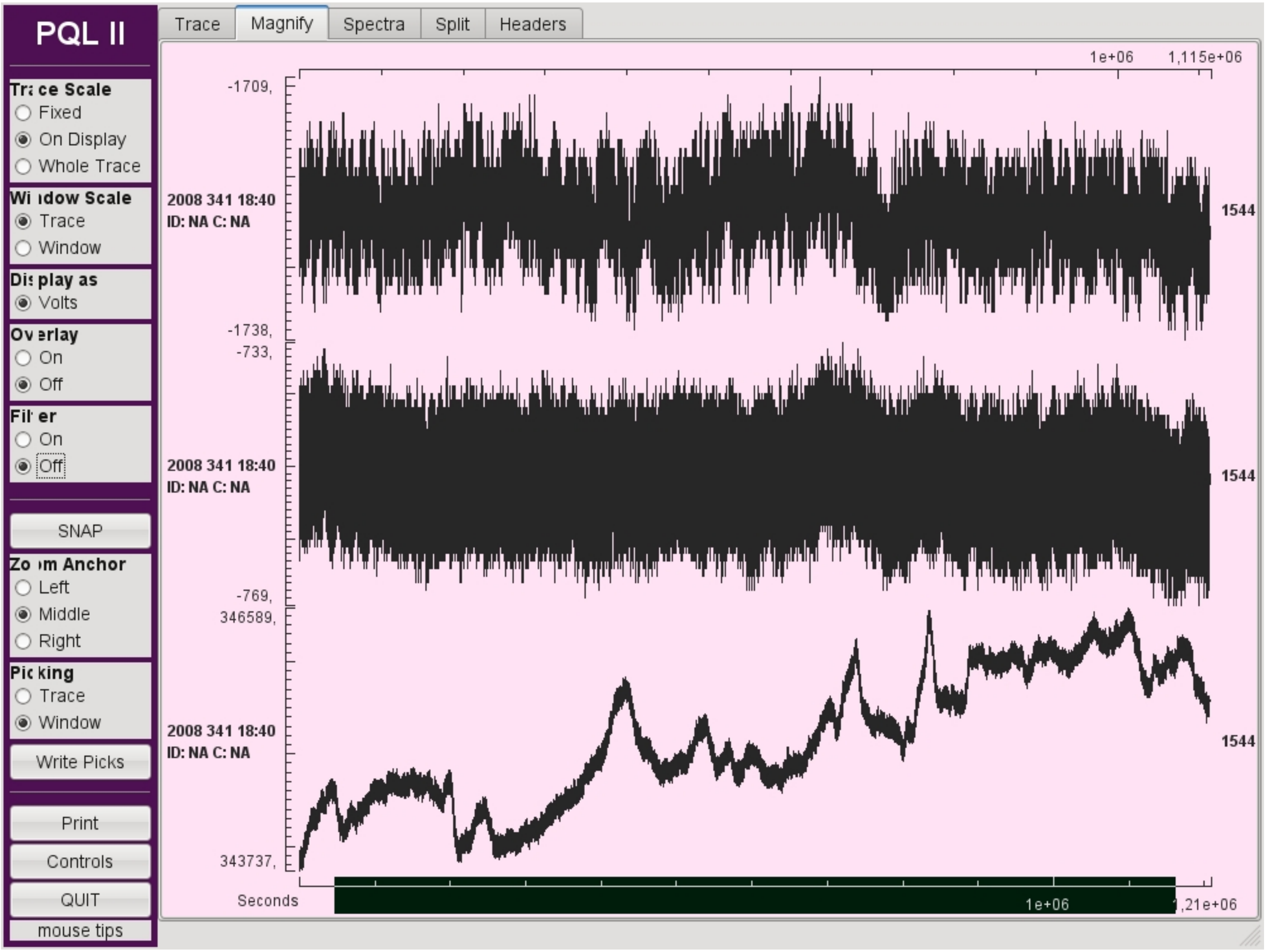


Figure 7.5.1: A tiltmeter frame ready for deployment. Pressure tubes with sensor, data logger and acoustic release are indicated. This time CAT Meter was installed as a guest system.

First investigations of the data show a high-frequency noise level on all three permanently recorded data channels (Fig. 7.5.2). Channels one and two are the tilt values measured perpendicular to each other while channel three is the temperature value. Amplitudes from the records cannot be converted to absolute temperature or tilt but need to be converted by a specific calibration formula first. In order to compensate for possible tilt events and to keep the sensors within their measuring window, a levelling sequence was activated every two weeks. The entire data set is therefore split into 14-day records which need to be adjusted and connected to allow for investigation of possible long –term tilt events. In addition, the records of both stations have to be correlated in order to distinguish between self-settling and real signals. Nevertheless after application of a low pass filter it becomes evident that the unit worked and events can be retrieved from the records (Fig. 7.5.3).



Trace Scale
○ Fixed
● On Display
○ Whole Trace

Window Scale
● Trace
○ Window

Display as
● Volts

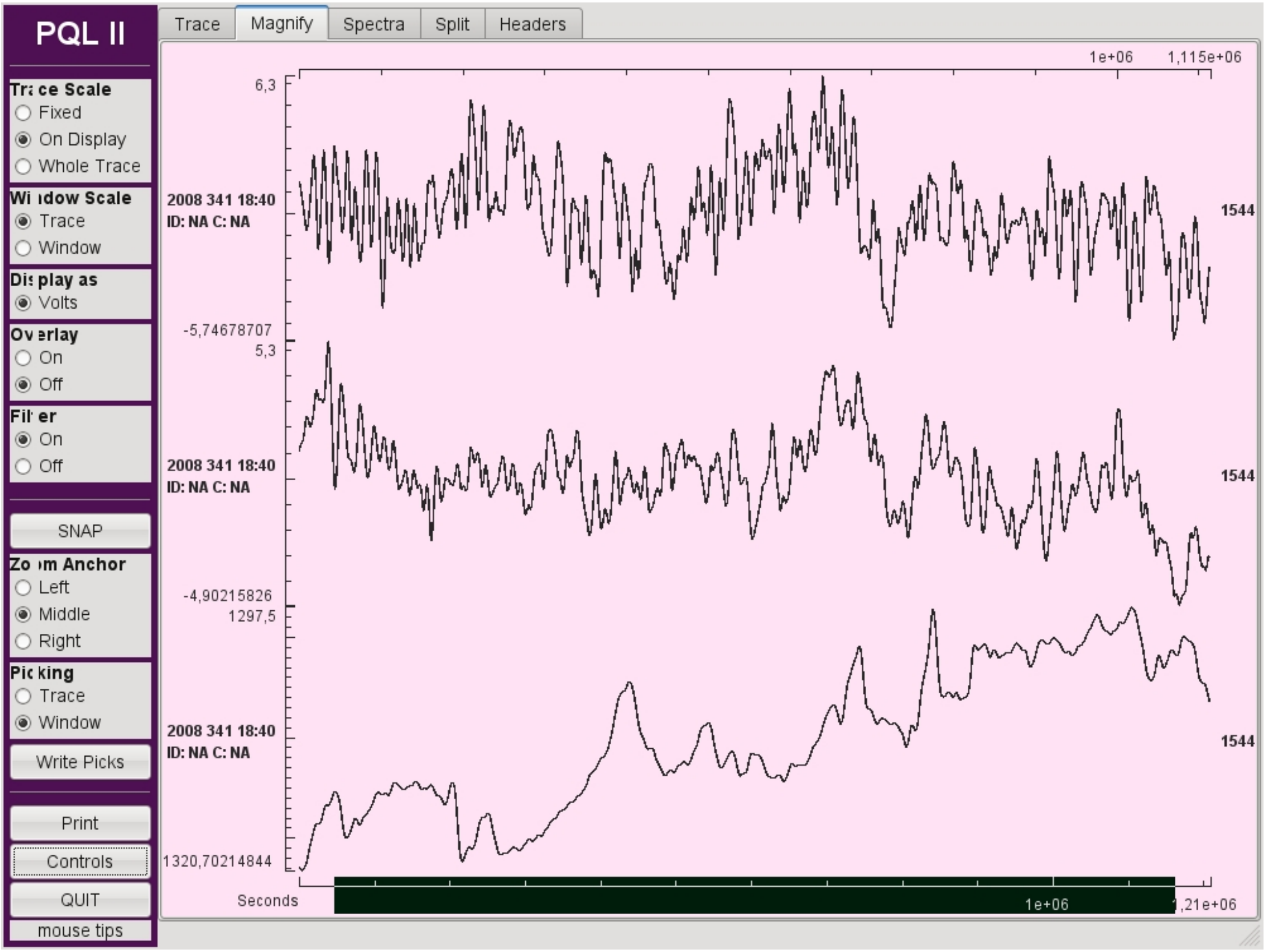
Overlay
○ On
● Off

Filter
○ On
● Off

Zoom Anchor
○ Left
● Middle
○ Right

Picking
○ Trace
● Window

Figure 7.5.2: A 14-day record sequence in raw data display. The high-frequency noise level is visible on all three channels.



Trace Scale
○ Fixed
● On Display
○ Whole Trace

Window Scale
● Trace
○ Window

Display as
● Volts

Overlay
○ On
● Off

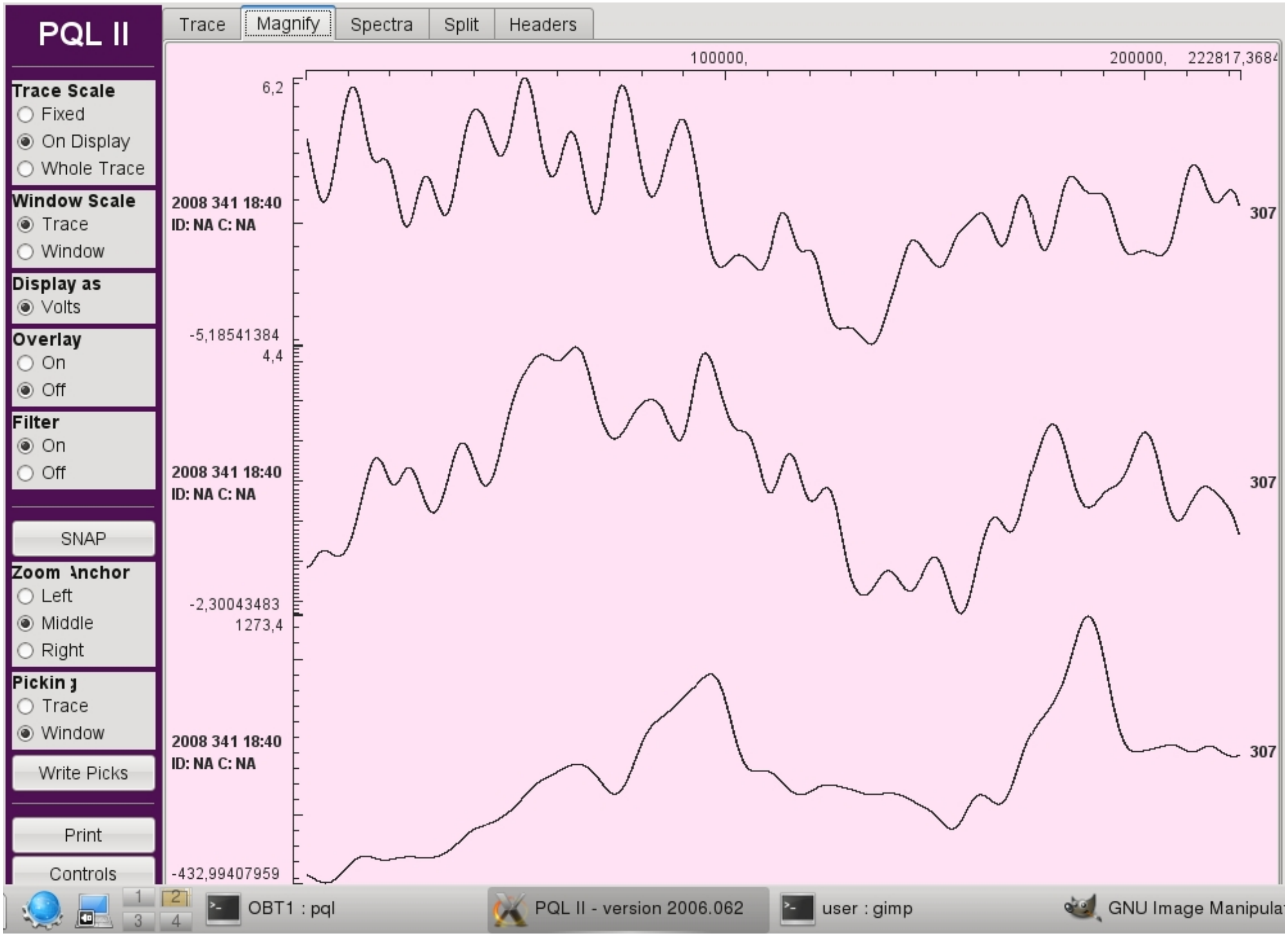
Filter
● On
○ Off

Zoom Anchor
○ Left
● Middle
○ Right

Picking
○ Trace
● Window

Figure 7.5.3: The same data segment as in Fig. 7.5.2 after application of a 0.0001-Hz low pass filter.

A blow-up of an approximately 7-hour-long part of the data shows that after low pass filtering a long-wave tidal signal is visible as expected. Short-term events have been recorded intermediately (Fig. 7.5.4). It can be speculated that movements of the buoyant recovery rope attached to the instrument carrier in the water column have caused the high-frequency noise level on the instruments. This would be a drawback of the chosen type of self-lowering and self-ascending instrument carrier which is well compensated by the cleanness of the data after filtering and the fact that no ROV is required for deployment and recovery.



Trace Scale
○ Fixed
● On Display
○ Whole Trace

Window Scale
● Trace
○ Window

Display as
● Volts

Overlay
○ On
● Off

Filter
● On
○ Off

Zoom Anchor
○ Left
● Middle
○ Right

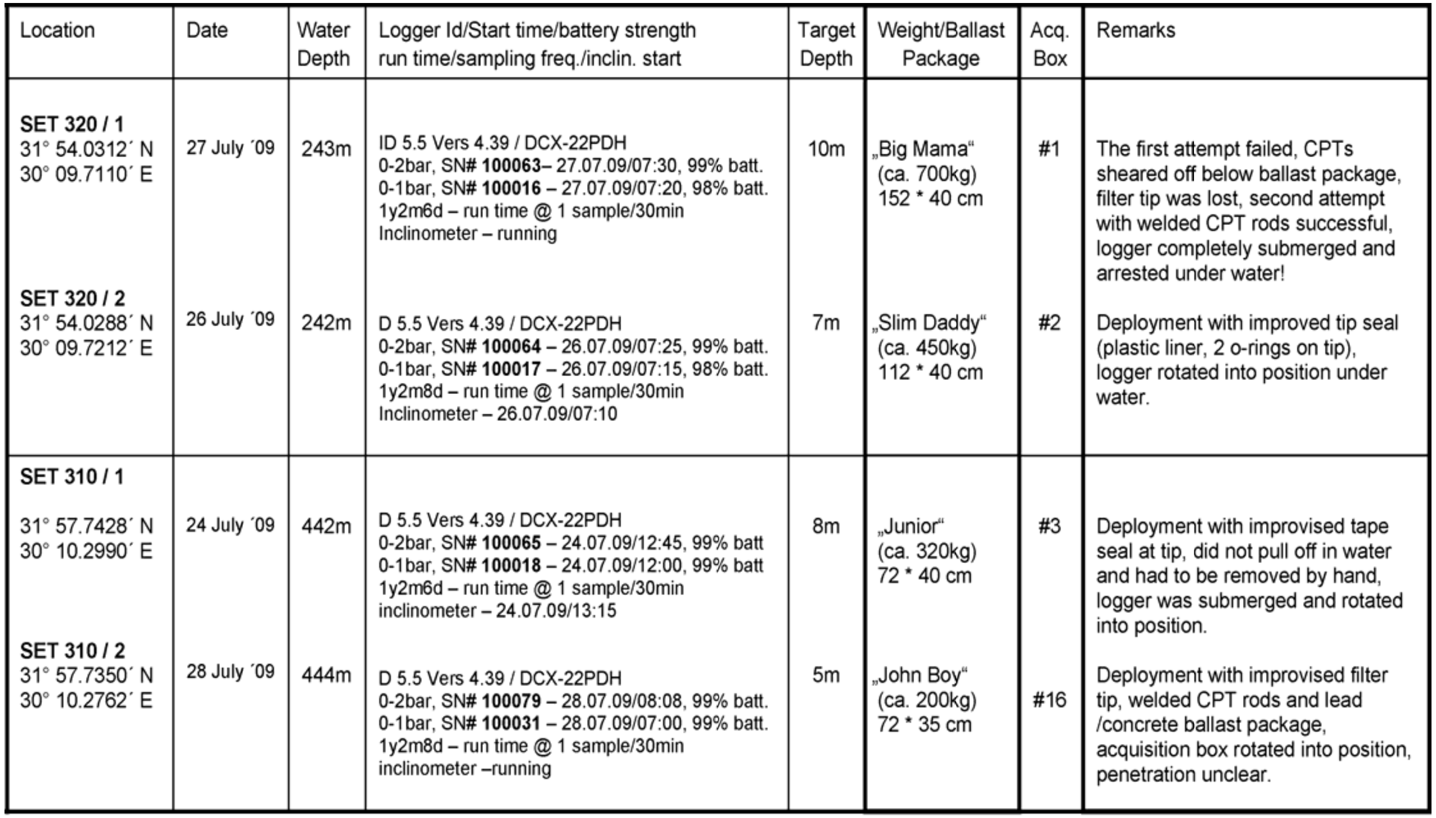
Picking
○ Trace
● Window

Figure 7.5.4: A blow-up of about 7 hours of recording time. After application of a 0.0001-Hz low pass filter, long-term tidal events become visible as well as intermediate short term signals.

7.6 PIEZOMETERS

One of the priority goals of the cruise was the installation of 4 piezometers at two sites on the slope of the West Nile Delta fan. This was accomplished as planned in all cases. The specifics of each deployment are listed in table Tab. 7.6.1 , a detailled station/activity list is given in table 7.6.2.

Table 7.6.1: Piezometer deployments during P388.



Location	Date	Water Depth	Logger Id/Start time/battery strength run time/sampling freq./inclin. start	Target Depth	Weight/Ballast Package	Acq. Box	Remarks
SET 320 / 1 31° 54.0312´ N 30° 09.7110´ E	27 July ´09	243m	ID 5.5 Vers 4.39 / DCX-22PDH 0-2bar, SN# **100063**– 27.07.09/07:30, 99% batt. 0-1bar, SN# **100016** – 27.07.09/07:20, 98% batt. 1y2m6d – run time @ 1 sample/30min Inclinometer – running	10m	„Big Mama“ (ca. 700kg) 152 * 40 cm	#1	The first attempt failed, CPTs sheared off below ballast package, filter tip was lost, second attempt with welded CPT rods successful, logger completely submerged and arrested under water!
SET 320 / 2 31° 54.0288´ N 30° 09.7212´ E	26 July ´09	242m	D 5.5 Vers 4.39 / DCX-22PDH 0-2bar, SN# **100064** – 26.07.09/07:25, 99% batt. 0-1bar, SN# **100017** – 26.07.09/07:15, 98% batt. 1y2m8d – run time @ 1 sample/30min Inclinometer – 26.07.09/07:10	7m	„Slim Daddy“ (ca. 450kg) 112 * 40 cm	#2	Deployment with improved tip seal (plastic liner, 2 o-rings on tip), logger rotated into position under water.
SET 310 / 1 31° 57.7428´ N 30° 10.2990´ E	24 July ´09	442m	D 5.5 Vers 4.39 / DCX-22PDH 0-2bar, SN# **100065** – 24.07.09/12:45, 99% batt 0-1bar, SN# **100018** – 24.07.09/12:00, 99% batt 1y2m6d – run time @ 1 sample/30min inclinometer – 24.07.09/13:15	8m	„Junior“ (ca. 320kg) 72 * 40 cm	#3	Deployment with improvised tape seal at tip, did not pull off in water and had to be removed by hand, logger was submerged and rotated into position.
SET 310 / 2 31° 57.7350´ N 30° 10.2762´ E	28 July ´09	444m	D 5.5 Vers 4.39 / DCX-22PDH 0-2bar, SN# **100079** – 28.07.09/08:08, 99% batt. 0-1bar, SN# **100031** – 28.07.09/07:00, 99% batt. 1y2m8d – run time @ 1 sample/30min inclinometer –running	5m	„John Boy“ (ca. 200kg) 72 * 35 cm	#16	Deployment with improvised filter tip, welded CPT rods and lead /concrete ballast package, acquisition box rotated into position, penetration unclear.

Table 7.6.2: Piezometer deployments: details.

cruise	station	year	month	day	hour	min.	device / position / priority	activity	latitude	longitude	depth
POS-388	445-1	2009	07	24	13	35	Piezometer SET 310 / 1	arrived on station	31.96220	30.17212	443.0
POS-388	445-1	2009	07	24	14	10	Piezometer SET 310 / 1	to water	31.96250	30.17142	442.0
POS-388	445-1	2009	07	24	14	25	Piezometer SET 310 / 1	at bottom/released	31.96238	30.17165	442.0
POS-388	445-1	2009	07	24	14	25	Piezometer SET 310 / 1	heave started	31.96238	30.17165	442.0
POS-388	445-1	2009	07	24	14	34	Piezometer SET 310 / 1	releaser on deck	31.96257	30.17212	442.0
POS-388	445-1	2009	07	24	14	35	Piezometer SET 310 / 1	station completed	31.96245	30.17243	442.0
POS-388	464-1	2009	07	26	07	03	Piezometer SET 320 / 2	arrived on station	31.90115	30.16287	238.0
POS-388	464-1	2009	07	26	07	05	Piezometer SET 320 / 2	to water	31.90108	30.16287	238.0
POS-388	464-1	2009	07	26	07	48	Piezometer SET 320 / 2	40m over bottom	31.90048	30.16193	242.0
POS-388	464-1	2009	07	26	08	00	Piezometer SET 320 / 2	released	31.90048	30.16202	242.0
POS-388	464-1	2009	07	26	08	07	Piezometer SET 320 / 2	station completed	31.90145	30.16183	242.0
POS-388	473-1	2009	07	27	07	11	Piezometer SET 320 / 1	arrived on station	31.90090	30.16232	240.0
POS-388	473-1	2009	07	27	08	57	Piezometer SET 320 / 1	to water	31.90053	30.16183	243.0
POS-388	473-1	2009	07	27	09	23	Piezometer SET 320 / 1	at bottom	31.90045	30.16183	243.0
POS-388	473-1	2009	07	27	09	31	Piezometer SET 320 / 1	released	31.90052	30.16185	243.0
POS-388	473-1	2009	07	27	09	37	Piezometer SET 320 / 1	releaser on deck	31.90158	30.16198	242.0
POS-388	473-1	2009	07	27	09	38	Piezometer SET 320 / 1	station completed	31.90180	30.16217	240.0
POS-388	483-1	2009	07	28	06	10	Piezometer SET 310 / 2	arrived on station	31.96338	30.17210	448.0
POS-388	483-1	2009	07	28	06	16	Piezometer SET 310 / 2	to water	31.96265	30.17172	445.0
POS-388	483-1	2009	07	28	06	47	Piezometer SET 310 / 2	at bottom	31.96227	30.17123	445.0
POS-388	483-1	2009	07	28	06	57	Piezometer SET 310 / 2	released	31.96225	30.17127	444.0
POS-388	483-1	2009	07	28	07	07	Piezometer SET 310 / 2	releaser on deck	31.96252	30.17157	445.0
POS-388	483-1	2009	07	28	07	07	Piezometer SET 310 / 2	station completed	31.96255	30.17158	445.0

7.7 BATHYMETRY

The bathymetric work performed during P388 can be divided into three parts: a survey of the upper continental slope between North Alex mud volcano and Giza mud volcano, bathymetric mapping parallel to 3-D seismic data acquisition on North Alex mud volcano and bathymetric mapping during sidescan sonar deployments.

The survey lines along the continental slope between the two mud volcanoes complemented the bathymetric data collected on the R/V Pelagia cruise both upslope and downslope (Fig. 7.7.1), with particular attention to the upper reaches of Rosetta canyon. Major portions of the upper continental slope at water depths between 250 and 1200 metres have now been mapped, although the transition from the shelf to the uppermost slope has only been covered at distinct locations, most notably around North Alex mud volcano. A first 100-metre-grid of unedited and uncorrected but filtered bathymetric soundings shows several remarkable features (Fig. 7.7.1).

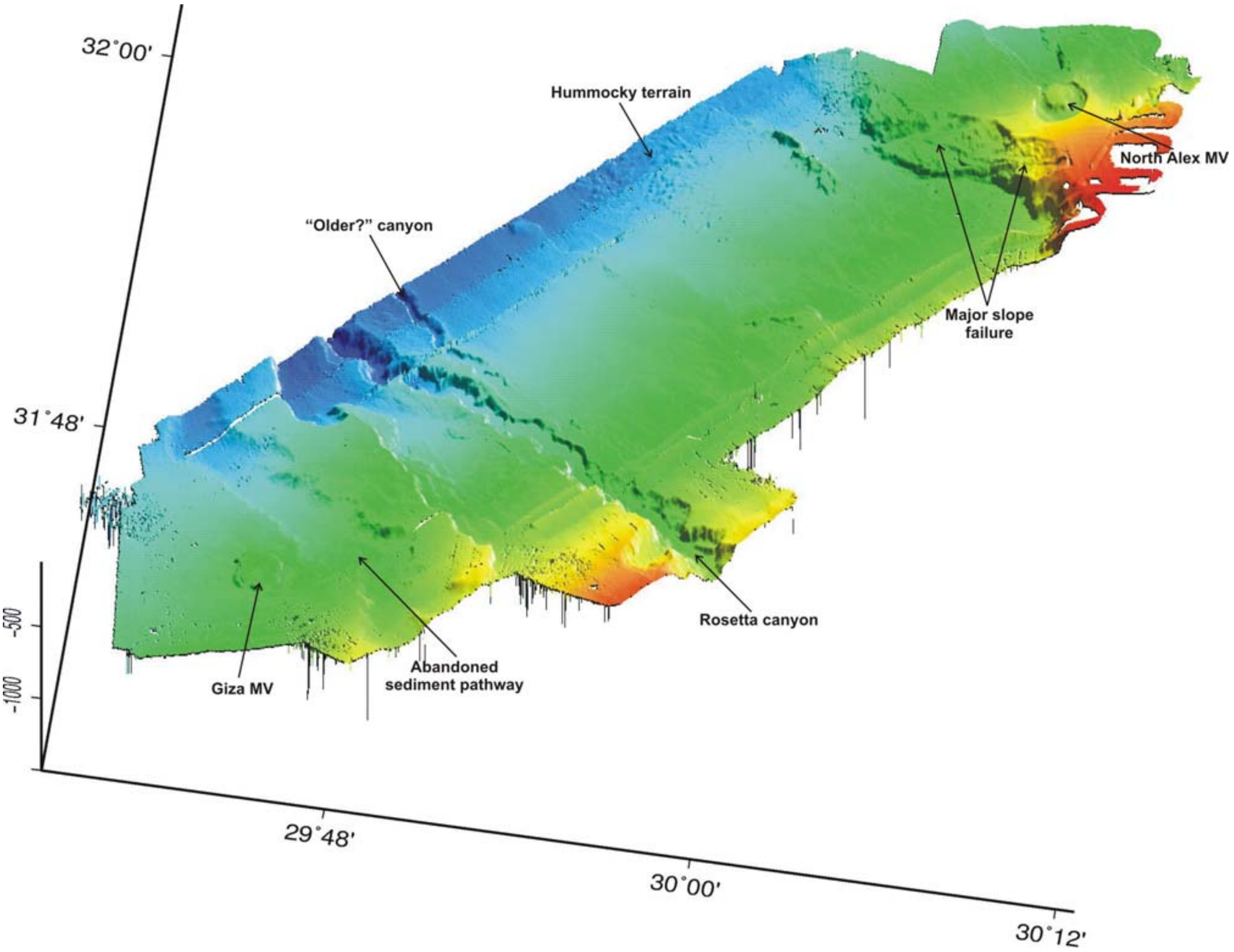


Fig. 7.4.1: Bathymetric map compiled with raw data recorded during cruises with RV PELAGIA and RV POSEIDON

A roughly 50-km-wide stretch of the continental slope corresponding to the actual Rosetta canyon shows a retreat of the shelf break that is unfortunately not imaged. Apart from the Rosetta canyon several other canyons or wide sediment pathways are imaged and most likely represent former positions of the Rosetta canyon. The Rosetta canyon itself is almost straight but cut up to more than 100 metres below the surrounding seafloor. The thalweg of the canyon is not well imaged but slightly sinuous and the canyon walls show multiple indications for sediment failures. Large-scale sediment failure is also shown at the southwestern flanks of the promontory that contains North Alex mud volcano. Here, wide areas of the upper continental slope failed. Whether hummocky structures on the middle continental slope of this area represent deposits from mass failures or whether they are the result of salt or mud tectonics cannot be distinguished from these data. Finally, both Giza and North Alex are well imaged. Their structure is quite different with Giza mud volcano being a flat “mud pie” type of structure while North Alex mud volcano is surrounded by a wide terraced moat and also shows the presence of an outflow or dejection cone towards the northwest. Careful editing of the data and proper roll correction will ultimately allow gridding these data at a 50-metre grid spacing, which will greatly improve the spatial resolution and geomorphologic interpretation.

The bathymetric data taken concurrently during 3-D seismic and sidescan sonar surveys will ultimately lead to a well improved bathymetric database of North Alex mud volcano. During the 3-D seismic survey, line spacing was as short as 25 metres (Fig. 7.1.1.1) and survey speeds as low as 2.5 knots, which results in multiple oversampling of the bathymetric soundings. This type of data may allow gridding the data at a 25-metre grid spacing or less, providing a much sharper image of the mud volcano, its central active cone, the surrounding terraced moat and the side-walls of the moat. These data may show small differences in the morphology of the mud volcano and improve other high-resolution images of the mud volcano such as sidescan sonar data (see chapter 7.2).

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9. APPENDIX

CTD location

CTD-2009	29:38.589 E	31:43.329 N

Long-term deployment of Methane sensors

OBMets-1	31:58.133 N	30:08.151 E
OBMets-2	31:58.141 N	30:08.160 E

Deployment positions of short term OBS

	Lat	Long
OBS_13	31:57.9350	30:8.3040
OBS_14	31:58.1720	30:8.1510
OBS_15	31:58.4070	30:7.9980
OBS_16	31:58.6380	30:7.8460
OBS_17	31:58.2730	30:7.7130
OBS_18	31:58.0390	30:7.8650
OBS_19	31:57.7990	30:8.0180
OBS_20	31:58.5430	30:8.2850
OBS_21	31:58.3080	30:8.4410
OBS_22	31:58.0740	30:8.5910
OBS_23	31:57.6980	30:8.4570
OBS_24	31:57.4590	30:8.6130

Deployment position of Tiltmeters

OBT_4	31:57.993	30:8.413
OBT_6	31:57.955	30:8.279

Deployment positions of long-term OBS

Name	Latitude N-S	Longitude E-W
SP_25	31:57.9350	30:8.3040
BB_26	31:58.1720	30:8.1510
SP_27	31:58.4070	30:7.9980
SP_28	31:58.0390	30:7.8650
SP_29	31:58.3080	30:8.4410
SP_30	31:59.1000	30:8.3000
SP_31	31:58.1000	30:9.3000
SP_32	31:56.9500	30:8.2500
BB_33	31:58.1000	30:7.1000
SP_34	31:59.3940	30:10.2070
SP_35	31:59.3630	30:5.8540
SP_36	31:55.7990	30:8.3150

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