The experimental-methodical geophysical studies in the RV POSEIDON cruise 405

© J. Bialas[1], S. Mykhaylyuk[2], A. Vasiliev[3], I. Klaucke[1], C. Papenberg[1], K. Schwalenberg[4], 2011

[1]Leibniz Institute for Marine Sciences, IFM-GEOMAR, Kiel, Germany

[2]Institute of Geophysics National Academy of Sciences of Ukraine, Kiev, Ukraine

[3]Institute of Oceanology Bulgarian Academy of Sciences, Varna, Bulgaria

[4]Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, Germany

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Наведено основні результати експериментально-методичних геофізичних досліджень у 405-му рейсі НДС "Посейдон" з 8 по 22 грудня 2010 р. у північно-західній частині Чорного моря. Мета круїзу POS-405 — дослідження нового геофізичного обладнання, розробленного в межах цільового проекту "SUGAR". Нову систему багатопроменевого ехолоту SBE 3050 Multibeam компанії ELAC Nautik було встановлено на НДС "Посейдон" під час останньої стоянки корабля в сухому доці. Ехолот здатний записувати водну товщу та відображувати газові бульбашки на екрані дисплея за допомогою переглядача зображень (WCI). У ході зіставлення з батиметричною картою каньйону Дунаю тестування дало позитивний результат. Вперше було розгорнуто новий глибинний буксируваний багатоканальний стример. За допомогою глибоководної лебідки були завершені і записані перші сейсмічні сигнали. Після заміни членів наукового екіпажу було випробувано нову електромагнітну систему з контрольованим джерелом (CSEM). Вперше буксировано приймач завдовжки 1000 м. У зв'язку з погодними умовами (вітер силою понад 25 м/с) НДС "Посейдон" 3,5 дні з 15 робочих перебував у штормовому положенні. Ці обмеження не дали змоги провести інтенсивні випробування буксированих приладів. За домовленістю з Інститутом геофізики НАН України протягом 15 днів було проведено електромагнітні дослідження за інноваційним методом аналізу спонтанного електромагнітного випромінювання (АСЕМВ).

Представлены основные результаты экспериментально-методических геофизических исследований в 405-м рейсе НИС "Посейдон" с 8 по 22 декабря 2010 г. в северо-западной части Черного моря. Цель круиза POS-405 — испытание новой геофизической аппаратуры, разработанной в рамках целевого проекта "SUGAR". Новая система многолучевого эхолота SBE 3050 Multibeam компании ELAC Nautik была установлена на НИС "Посейдон" во время последней стоянки корабля в сухом доке. Эхолот способен записывать водную толщу и отображать газовые пузырьки на экране дисплея с помощью программы просмотра изображений (WCI). В ходе сопоставления с батиметрической картой каньона Дуная тестирование дало положительный результат. Впервые был развернут новый глубинный буксированный многоканальный стример. С помощью глубоководной лебедки были завершены и записаны первые сейсмические сигналы. После замены членов научного экипажа была испытана новая электромагнитная система с контролируемым источником (CSEM). Впервые буксировался приемник длиной 1000 м. В связи с погодными условиями (ветер силой свыше 25 м/с) НДС "Посейдон" 3,5 дня из 15 рабочих находился в штормовом положении. Эти ограничения не дали возможности провести интенсивные испытания буксированных приборов. По договоренности с Институтом геофизики НАН Украины на протяжении 15 дней проводились электромагнитные исследования с помощью инновационного метода анализа спонтанного электромагнитного излучения (АСЭМИ).

Introduction. In summer 2008, the SUGAR project (Submarine Gas Hydrate Reservoirs) was launched in Germany. The project aims to produce natural gas from marine methane hydrates and to extract carbon dioxide (CO_2) from power plants and other industrial sources as CO_2 hydrate in marine sediments. This large-scale national project is funded by two federal ministries and German industries. The total funding is • 13 billion for an initial funding period of three years. The project involves 30 institutional partners from academic and industry organizations and is coordinated by the Kiel-based Leibniz Institute for Marine Sciences (IFM-GEOMAR). Project partners are the scientific institutes: IFM-GEOMAR, Kiel (coordinator); BGR Hanover, FH Kiel; Fraunhofer Institute for environmental, safety and energy techniques UMSICHT; GFZ Potsdam; Integrated Exploration Systems, Aachen; IOW Warnemunde; ITE / TU Clausthal; University of Bremen (MARUM); as well as the commercial enterprises: 24sieben Stadtwerke Kiel AG; Aker Yards; BASF AG; CONTROS GmbH; E.ON Ruhr gas AG; R&D Center FH Kiel, Germanischer Lloyd, K.U.M. Umwelt- und Meerestechnik GmbH, L-3 Communications ELAC Nautik GmbH; PRAKLA Bohrtechnik GmbH; RWE-DEA AG; SEND Offshore GmbH; Trans Electronic Equipment Consult GmbH; Wintershall AG and Wirth GmbH.

The SUGAR project aims to develop technology and to obtain knowledge in the field of methane production from gas hydrates in a combination with CO_2 storage. For this purpose the whole sequence of prospecting, explorating, quantificating, and transporting is studied in different subprojects. Although gas hydrates are well known on almost every continental margin, not all findings are commercial accumulations of hydrocarbons. For such occurrences a gas hydrate zone is required with a thickness of at least several meters and a sufficient top sealing layer. From synthetic modeling it is known that thick hydrate layers typically occur within a high permeable sediment matrix with sufficient gas production.

To address increased requirements in prospecting and exploring technology new or improved geophysical equipment was developed. Among them are new instruments: multibeam echosounder, deep towed multichannel streamer and bottom trawled electromagnetic system. All three systems should be first tested during this cruise. The best calibration of this equipment can be done when a good knowledge of the region is available. Therefore a suitable location is needed to be found, which could be reached within the overall travel schedule of the expedition. From this point of view in the Black Sea the Danube delta was one of the possible target areas (Fig. 1). Gas flares were mapped on the shelf brake off the Bulgarian and Romanian coasts [Poort et al., 2005; Vasilev, Dimitrov, 2002; Vasilev, 2006; 2010]. Most of them are located shallower than 700 m water depth, which is the upper limit of the gas hydrate stability zone [Bohrmann, Schenk, 2002; Lericolais, 2002; Lüdmann et al., 2004; Zillmer et al., 2005]. Next to the Danube canyon off the Constanta port two areas with BSR features were already known from the literature [Popescu et al., 2006; 2007]. Seismic images identified even multiple BSR events in the centre of this region. Therefore all features, which are to be targets of investigation for the three systems, were available in the close neighbor port.

Due to the amount of deck space required for the equipment and the available berth places aboard the POSEIDON the trackcruise was divided into two cruise-legs. The first leg started on December 7 with installation of the seismic equipment in the port of Constanta. A change of equipment and crew members took place on December 15 again in Constanta, where the electromagnetic equipment was set up. Finally the cruise terminated on December 22 in Constanta, when all equipment of the electromagnetic group was shipped home. The Multibeam measurements were used during the entire cruise, as the system has recently been permanently installed on the POSEIDON.

1. EQUIPMENT

1. 1. ELAC Nautik SBE 3050 Multibeam. In the frame of the SUGAR project a new multibeam sonar system was developed. Experiments were performed to test its capability to record and visualize full water column data (WCI-data) to detect and map gas flares rising from the seafloor into the water. The ELAC Nautik SBE 3050 multibeam was recently installed on the RV POSEIDON. For this purpose a gondola was fixed underneath the hull of the POSEIDON that provides space for the transducers and provides the best protection against bubble disturbances. Due to the size limitations the transducer arrays were chosen in a dimension of 1,5 by 2°. The SeaBeam 3050 is the latest generation of middle and shallow water multibeam bathymetric sonar systems from L-3 Communications ELAC Nautik GmbH. The

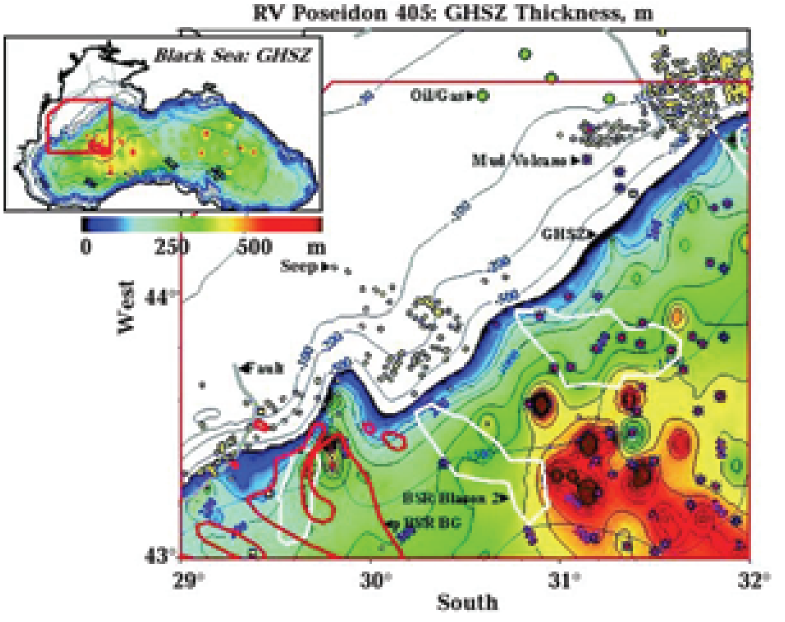

Fig. 1. Study area of the Poseidon cruise 405 1 — Bathymetry; faults, oil and gas fields, seeps, potential BSRs and mud volcanoes, model of GHSZ [Vasilev, 2010].

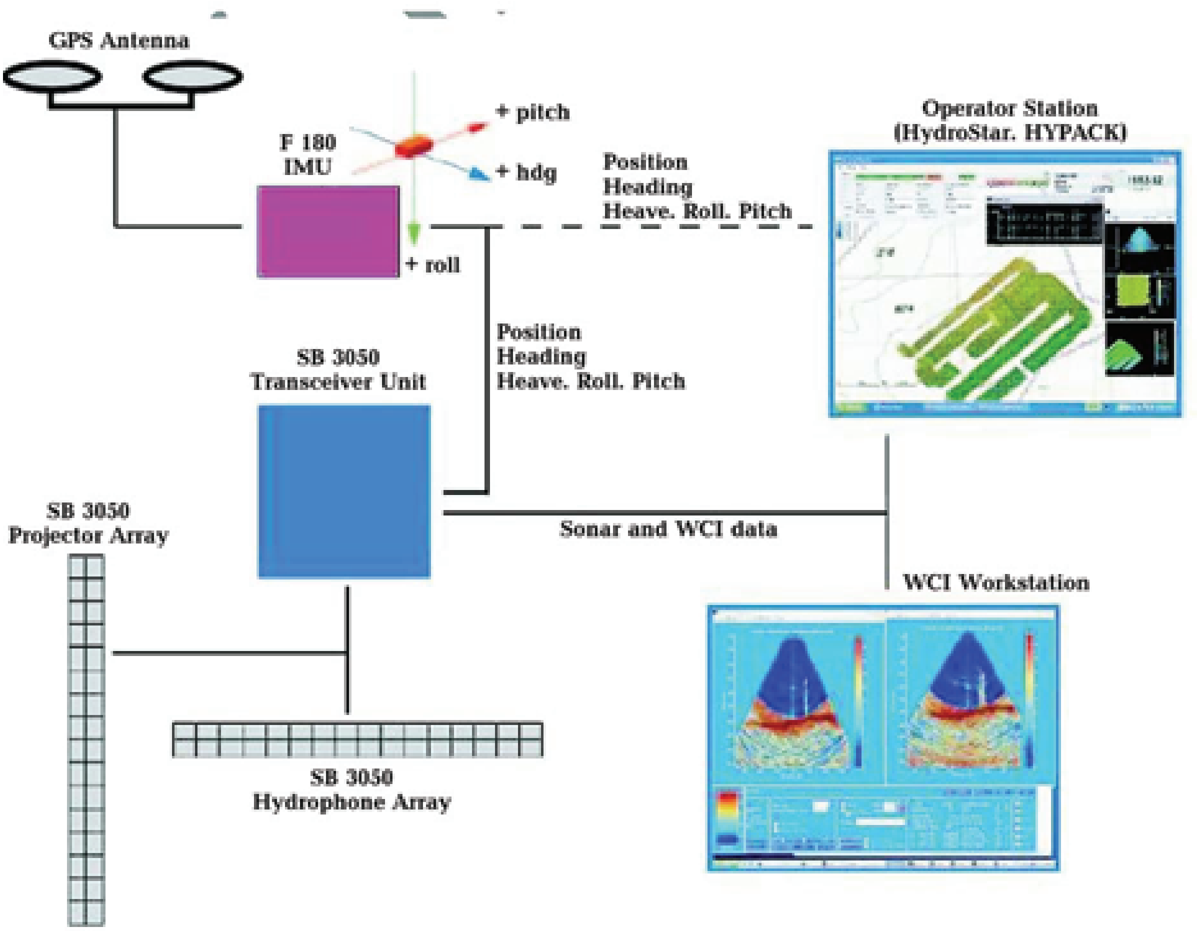

Fig. 2. The data flow of the Sonar system, motion sensor and operating PC.

new multi-ping technology of the SeaBeam 3050 allows a higher maximum survey speed without losing 100 % bottom coverage by creating two swaths per ping cycle. The system operates in the 50 kHz frequency band on water depths ranging from 3 m to approximately 3,000 m. The system can be utilized at a survey speed of up to 14 knots. It has an across-ship swath wide of up to 140 degrees. A maximum of 386 reception beams is provided for each multi-ping. The SeaBeam 3050 uses a transmit technique, which compensates fully vessel pitch and yaw motions, recorded by the Coda Octopus motion sensor F180 (see below) and which is integrated into the system's network. The compensation is achieved by splitting the transmit fan in several sectors which can be individually steered. This technique achieves full motion compensation and guarantees stable straight profile coverage. The SeaBeam 3050 generates sonar data of wide-swath contour charts, backscatter data of seabed sediment classification, raw data of water column imaging (WCI) and sidescan data of side-scan images (Fig. 2).

The F180 Inertial Attitude and Positioning System from Coda Octopus is integrated into the sonar system network, making precision measurements of vessel attitude (including heading), dynamics and geographical position for use in compensating the vessel motion during hydrographic surveying. The system is a multi-sensor system consisting of an inertial measurement unit (IMU), built up of three solid-state gyros and three inertial grade accelerometers, and two survey grade GPS receivers.

1. 2. Deep Tow Multichannel Streamer. With standard surface streamers the lateral resolution is reduced with increasing a water depth. Instead a deep towed streamer could provide a constant improved resolution as the receiver array is towed about 100 meters above the seafloor (Fig. 3).

Due to the drag of the deep sea cable in the water the tow fish is expected to be 2 to 2,5 times less than a water depth behind the vessel A standard GI airgun as sound source allows undershooting of high reflective seafloor elements (e. g. carbonate crusts). Therefore the Deep Tow provides the opportunity to resolve reflection interfaces in regions where standard surface streamers can image only blanking areas. With the source still at the sea surface and the receiver deployed at depth

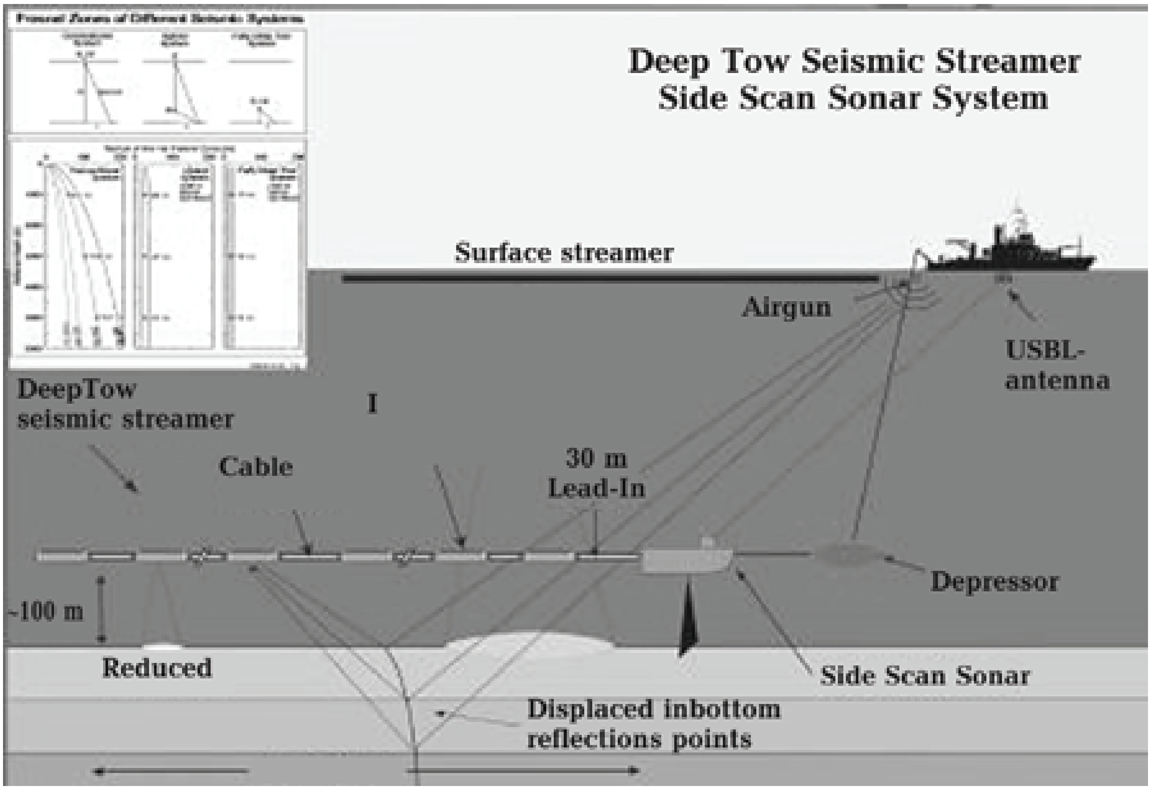

Fig. 3. The DeepTow system with multichannel streamer and Sidescan.

the ray path for the sound emission is no longer symmetric and hence the concept of CTD stacking does not hold any more. Therefore full waveform migrations are needed to be applied to integrate all streamer channels into one seismic section.

The deep towed multichannel streamer is a new device designed by companies SEND Off-shore, Hamburg, and KUM, Kiel (Fig. 4). It consists of single hydrophone modules and modular cable connections. The Bottom-PC (BPC) in the tow fish and the GeoEel seismic QC recording system from Geometrics are connected. The sidescan sonar PCs in the tow fish and on board the vessel is connected via the TPC, BPC and the connected modems (Fig. 4). The TPC runs a control program for the deep towed streamer.

1. 3. Bottom towed Controlled Source Electromagnetic System. Marine electromagnetic methods are used to derive bulk resistivity of the sub-seafloor sediment sections, which can be helpful for evaluating the nature of the pore fluid. Natural hydrocarbons like oil, gas and gas hydrate are electrically resistive in contrast to the conductive seawater filling pore space under normal conditions. Active or controlled source electromagnetic methods (CSEM) are used when the seafloor depth is several hundred meters to be investigated. Together with seismic profiling CSEM is the only remote method covering the entire gas hydrate stability zone. The two methods provide complementary information: the CSEM structure from seismic data, bulk properties from CSEM data. Together with seismic profiling is the only remote marine controlled source electromagnetic method to derive electrical properties of the seafloor to a depth of 1—2 km (Fig. 5). In recent years, marine CSEM became increasingly attractive to the offshore hydrocarbon industry because of its potential capability to image the presence of natural hydrocarbons such as oil, gas, and gas hydrates. A unique bottom-towed electric dipole-dipole system [Edwards, 1997; Schwalenberg et al., 2005] was used to explore the upper seafloor to a depth of several hundreds of meters. Near the seafloor, the system consists of a transmitting dipole (Tx, 124 m long) and two 15 m long receiving dipoles (Rx1 and Rx2). The receivers were towed in in-line configuration behind the Tx. A heavy weight (a pig) is attached to the front of the system to keep it in a contact

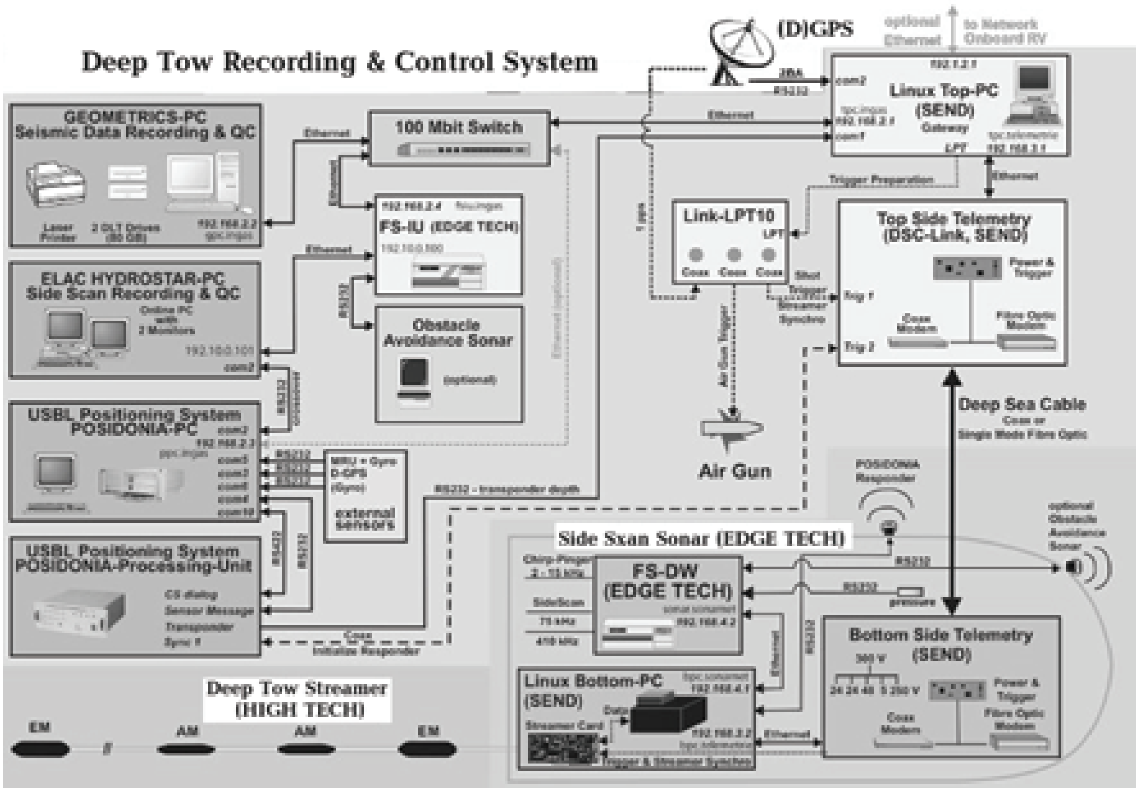

Fig. 4. The data connections within the DeepTow control system.

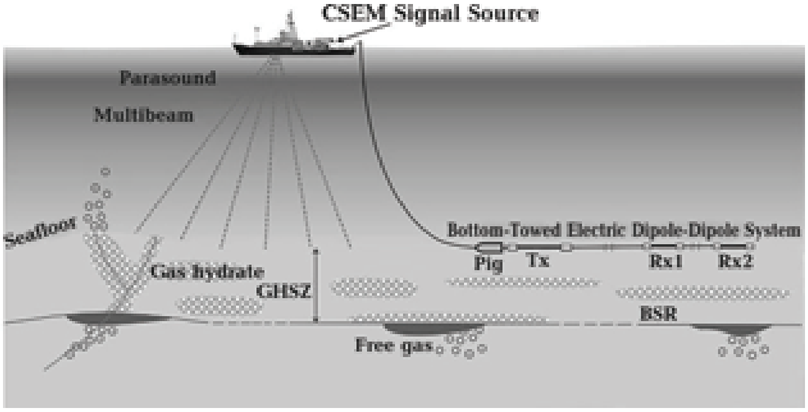

Fig. 5. The towed BGR marine CSEM System, it is also shown IFM-GeoMar ocean bottom EM receivers.

with the seafloor. An acoustic device is used for instrument relocation.

The design is based on a previous system from the Toronto University, Canada. It is a modular system that consists of an up to 1000 m long data cable that links a 100 m long transmitting dipole and four modular electrical receiving dipoles at increasing offsets. The source signal is generated by a current transmitter onboard the vessel and is sent down to the transmitting dipole on the seafloor via the coaxial deep-tow cable. The pig contains the control unit which sends a timing pulse along the data cable to synchronize the receiving units and records the current signal. It is also hosted an acoustic transponder to locate the seafloor position of the system and a CTD sensor to measure seawater conductivity and velocity.

The current transmitter has two output ranges for shallow (40 A, 200 V) and deep water applications (15 A, 1000 V). The signal form is typically a square wave with a period between 1 and 4 s, but any signal i. e. sine, ramp can be applied. Each receiver records the transient decay of the transmitted signal through the ambient seafloor and seawater. Amplitude and signal form depend on the seafloor resistivity and can be analyzed to determine sediment properties such as gas hydrate or fluid content.

Another set-up to collect CSEM data is the several free fall EM receivers in conjunction with a deep- or bottom-towed source dipole [Schwalenberg et al., 2010]. An Ag / AgCl electrode is mounted at either end of the 15 m long receiving dipoles. Each receiving dipole is equipped with a self-contained, battery powered electronic unit which digitizes and records the voltage between the electrodes on a sampling rate of close to 1 ms. The electronic parts and battery packs are inside a pressure cylinder attached to the front end of the Rx.

A third identical electronic unit stays onboard during the experiment and records the transmitted signal during the deployment in synchronization with the two seafloor receiver units. For instrument positioning an acoustic transponder was attached to the pig. The array is towed on the seafloor along profiles. However, to get clean data it is necessary to stop the array on a series of sites. Data recorded during transits between the sites are chaotic and cannot be used for the analysis.

2. Operations and results

2. 1. SBE3050 Multibeam. One prerequisite of multibeam surveys is the exact knowledge of the water sound velocity. Therefore we deployed a CTD (conductivity, temperature, and depth) at 31 : 17 E and 43 : 42 N in a water depth of 1600 m (Fig. 6), which would well cover a foreseen survey depth. The table was extended to 2,000 m depth with an interpolated value of 1505 m/s measurements reached 1,600 m water depth.

The graph was extended to a 2,000 m water depth by interpolating values. During a first calibration run it was observed that the multibeam data were displayed in the HydroSweep software package with an offset of about 180 m, corresponding to a time delay of 72 s. Due to this delay no proper calibration could be calculated. Despite intensive inspection of all system no reason could be found for this error. As HydroSweep allows full recalibration in post processing, it was decided to continue

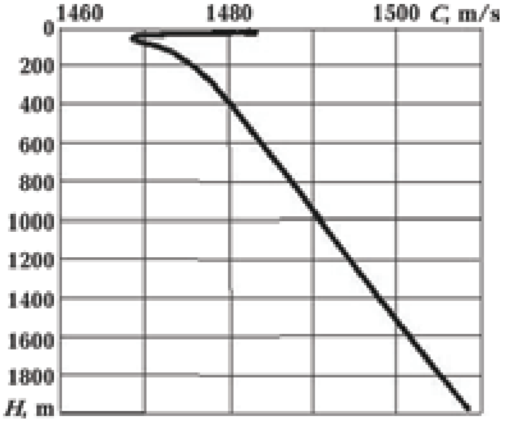

Fig. 6. Sound vs. velocity profile calculated from CTD cast.

a first survey near the shelf break where gas bubble expulsion was reported (Fig. 7).

Unfortunately no bubble echoes were detected in the water column images of the multibeam system, since the water-column viewer (WCI-Viewer) worked only sporadically in online-mode, due to the heavy data load. Meanwhile software and data treating routines and networked between the various PC systems were further improved. In preparation for a deployment of the deep towed streamer a second area was mapped with the multibeam system. From this area (BSR North) a wide distribution of a BSR reflection has been reported in different publications.

Shortly after mapping, the survey was interrupted due to strong northerly winds, which forced the vessel to veer off for a northerly course for one day. The bathymetric work continued after the weather calmed down and the target area could be successfully mapped (Fig. 8).

A second survey, dedicated to image and map gas flares, was conducted at the shelf break. Now, the survey area was targeted at the flanks of the Danube Canyon (Fig. 9), approximately 5 km west of the first survey area. An additional calibration was first applied to correct possible inaccurate roll, pitch and yaw angles. Unfortunately, mapping the Danube Canyon was interrupted again due to bad weather, but could be successfully continued 12 hours later. On a track across the canyon numerous gas flares of different shapes were visible on the online WCI-Viewer (Fig. 10).

This example shows the great advantage of multibeam techniques in flare imaging, because swath systems are able to detect flares offline to the center beam. A single-beam system would have missed the flare, shown in Fig. 10. A newly developed post-processing sequence of a wider range of WCI-data was earlier tested. This known specific area was shown to be promising for possible flare bursts.

The area of intensive bubble expulsions was revisited for a detailed study. Four radial track lines were performed in an area of numerous seeps to ensonify the water column at different azimuths. Later, this data were improved with the post-processing algorithm to detect flare motion. While mapping the Danube Canyon, the online water column monitor showed almost no flare activity on the eastern flank. It seems that the most active seeps are limited to the western part of the canyon. But a lot of data could not be monitored online. Gas flares, other than at the positions marked in Fig. 10 (A), are most likely to be detected during the post-processing of the whole data set.

2. 2. DeepTow system with multichannel streamer and Sidescan. After intensive laboratory tests of the electronic the DeepTow streamer was first completely mounted on board the RV POSEIDON. After set up of a local network with control PCs, data storage and QC computers dry tests of the entire system were undertaken. It was the first time that all electronics could be tested with a 4 km long deep sea cable included in the transmission route. After adjustment of several threshold values in the data transmission modems and power supply the first deployment was done right from the aft deck. Amplitude adjustments and tests were performed during this first deployment. After a time gap due to difficult weather conditions a full deployment was performed next day. The streamer was lowered to about a 200 m water depth and a small GI airgun was used to provide seismic signals every 7 s. Further adjustments were undertaken and system control parameter was tested. Unfortunately it turned out that one of the hydrophone nodes seemed to become uptight. Although the streamer did continue to work the power drain increased from 0,5 A to about 1. As a result the power supply in the streamer chain was reduced to limited value and some of the nodes started to behave unstably. Flow control and data transmission by the DSL modems were also deteriorated. Still resets of the system enabled to continue with tests and adjustment of the system and network parameters. A continuous operation could not be performed as required for a scientific profiling without physically exchanging the damaged node. Therefore the system was recovered after complit-

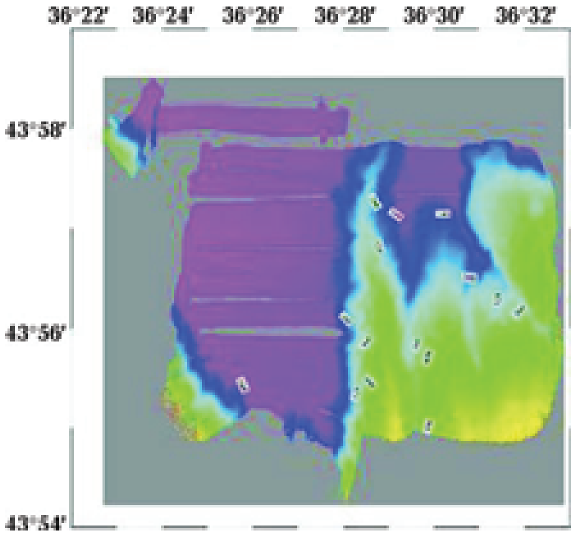

Fig. 7. Shelf area, east of the Danube canyon.

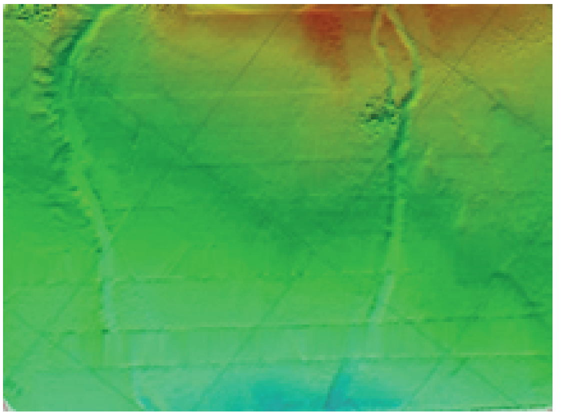

Fig. 8. Screenshot of raw bathymetry data showing the area of the deep tow deployment planned (BSR North).

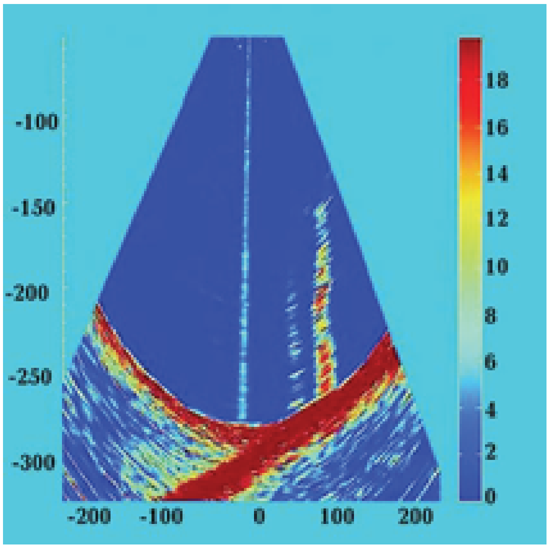

Fig. 9. Gas flares rising from the seafloor, imaged online by the WCI-viewer.

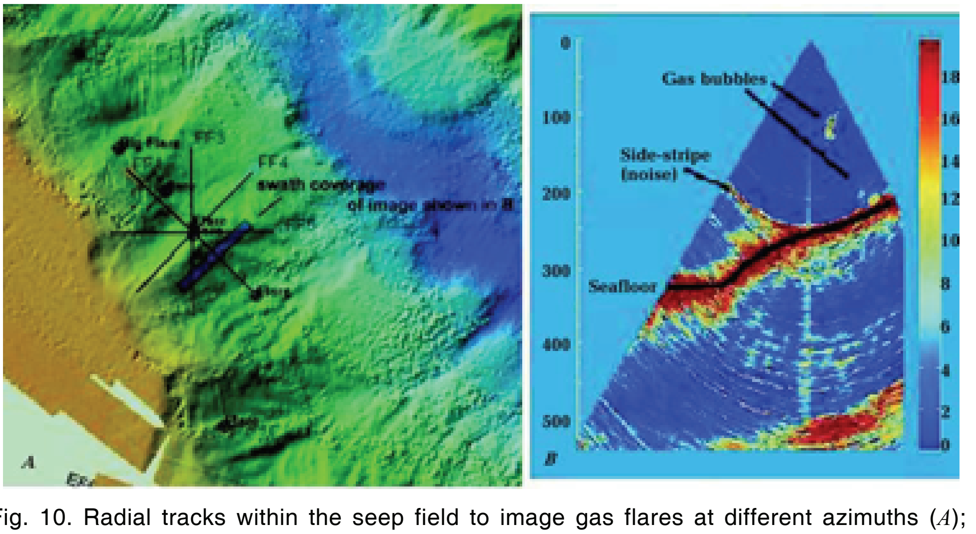

Fig. 10. Radial tracks within the seep field to image gas flares at different azimuths (*A*); the acoustic image of rising gas bubbles in the water column (*B*).

ing main tests. Due to worsening weather conditions a re-deployment was not possible. Nevertheless replacement of the broken node on the deck enabled a continuous noise record of the system during the night. Inspection of the broken node showed that one of the connector bulkheads was not properly mounted and caused flooding of the pressure tube. A second hydrophone node showed water penetration through the depth transducer sealing. Fortunately only limited amount of water entered the cylinder and the main electronic board was still operating keeping the entire chain alive.

2. 3. Bottom towed Controlled Source Electromagnetic System. The CSEM system was used three times during the second cruise-leg. A bad weather period during the first half of the week was used to carry out final assemblies and run final tests in the laboratory.

All three deployments have been successfully performed. All equipment was safely sinked and recovered. Data were collected with all recording devices. The handling of the equipment on board was safe and satisfactory. Prior to the CSEM experiments the profile conditions were monitored with the Multibeam system to make sure the CSEM system can be safely deployed. A new spooling device was used to unreel and coil the 100 to 340 m long cable segment. However, the spooling device did not have enough power to haul the complete array from the water. A capstan was used to sink and recover the cable segments and the spooling device was only used for coiling.

2. 4. Geophysical survey with analysis of spontaneous electromagnetic radiation (ASEMR method). It is based on a notion that dynamic processes in the Earth and sources for hydrocarbon generation produce signals of wide range frequencies. To register them an "ASTROGON-M" [Пат. ..., 2004] device was especially designed. It is a 12-channel recorder of magnetic components which measures signals with amplitude of above 5 μV along three orthogonal coordinate axes. Electromagnetic pulses are received by block antennas, amplified and processed by a microprocessor (Fig. 11). The result is displayed on a computer monitor. Sophisticated software (wavelet transformation or wavelet image of an electromagnetic signal, singular spectral analysis) is used to process the data. This makes it possible to increase the reliability of geological interpretation.

Conclusions

1. During the 405-th cruise on the RV POSEIDON a modern multibeam sonar system SeaBeam 3050 of ELAC Nautik Company was installed and tested to study the geological structure of the seafloor and to search for gas flares in water areas.

2. Methodical approaches are developed and tested to use a new digital seismic telemetry system "Deep Tow system with multichannel streamer and Side scan sonar system" of the Companies SEND Off-shore, Hamburg, and KUM, Kiel, which provides different parameters of excitation and registration of seismic reflection waves.

3. It was installed and tested a new CSEM system with a long electromagnetic transmitting dipole and reception dipole.

4. For the first time extensive, multi-day measurements with the "ASTROGON-M" device were conducted abord the RV POSEIDON in the NW Black Sea.

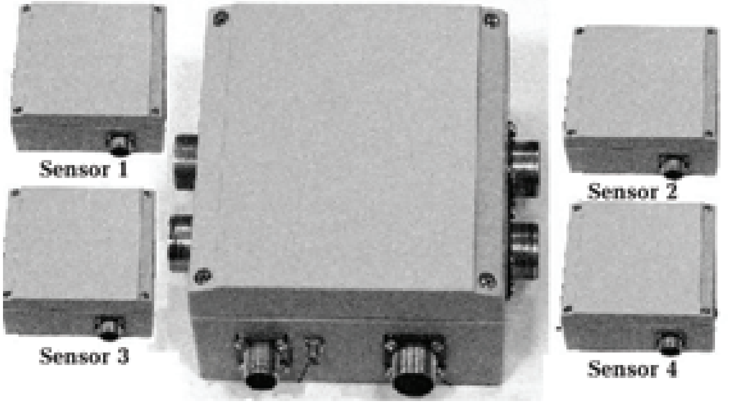

Fig. 11. The "ASTROGON-M" device.

Acknowledgements

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