R/V Meteor Cruise M56

Short Cruise Report,
Part A, 20.11. – 5.12.02
Douala - Libreville

For Meteor Cruise M56, marine geophysical, geological and geochemical investigations were planned at the Southwest African Continental Margin, starting from Abidjan (Ivory Coast) and finishing in Cape Town (South Africa). The cruise was split into two legs (A and B) with a port call in Libreville (Gabon). On short notice, the starting port of the cruise had to be moved to Douala (Cameroon) due to safety considerations. Although these changes were decided only weeks before the cruise, all containers and air freight reached its final destination in time and loading of equipment was finished before the planned departure. Altogether 17 scientists from the University of Bremen and the GEOMAR Research Center, Kiel, participated in the first part of the cruise, carrying out a geophysical program to survey the study area in sufficient detail to provide a basis for planning for subsequent sampling on the second part of the cruise.

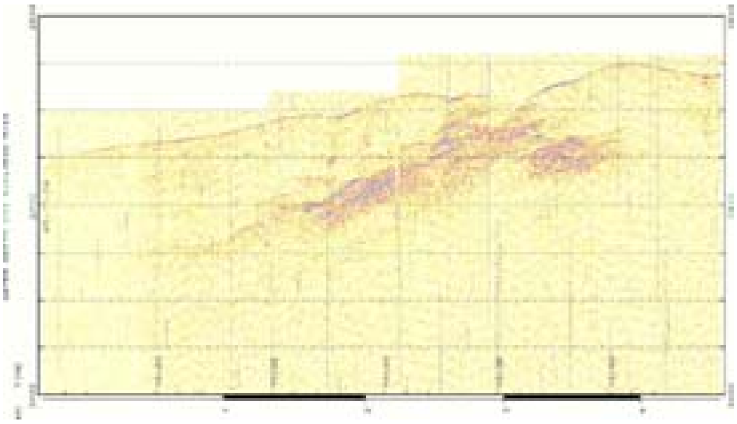
Meteor Cruise M56 is linked to the ***geotechnologien*** programme of the German minister of Education and Research (BMBF), financing the research project CONGO and other projects related to gas hydrates, as well as to the Deutsche Forschungsgemeinschaft (DFG), funding the Meteor research cruise.

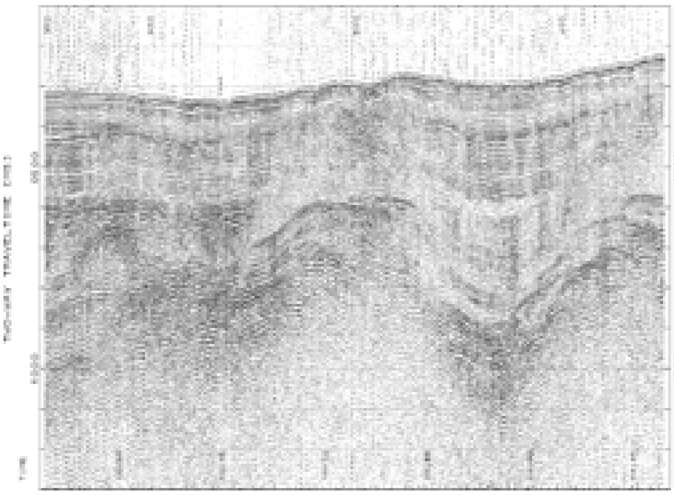
The cruise is focused on the identification and quantification of gas hydrates, which are related to intense upflow of fluids and methane and other gases, originating from organic rich near-surface sediments as well as hydrocarbon reservoirs from greater depth.

From Meteor Cruise M47/3 (June 2000) to the Congo margin we learned that numerous pockmarks exist on the sea floor, reaching several hundred meters diameters and some ten meters depth. Samples revealed evidence for recent fluid upflow through carbonates, methane anomalies, near-surface gas hydrates and different lifeforms related to active venting. The plan of R/V Meteor Cruise M56 is to survey during a first leg a small area and during the subsequent leg to investigate the sea floor with video sled, to take heat flow measurements and to collect water and sediment samples.

R/V Meteor left Douala in the afternoon of November, 20th, for a two-day transit into the working area, starting acquisition of sediment echosounder and swath sounder data during November, 21st. The time was just sufficient to set up the geophysical equipment, mainly multichannel seismics and the deep tow side scan sonar and seismic system. However, a technical problem with the streamer winch could not be solved despite strong support from the ship's machine shop, and we had to find a compromise of shortening the streamer to

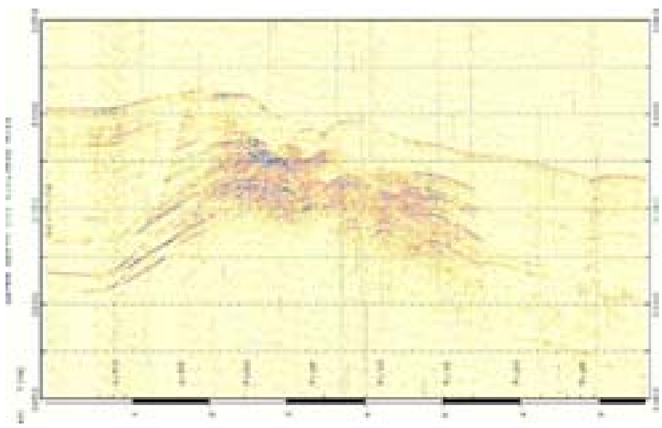
300 m, changing the configuration of seismic sources, and deploying the system manually, to be able to carry out multichannel seismics at all. An intermediate Parasound survey program across a number of bathymetric features, which mostly turned out to be pockmark type structures, allowed the necessary technical modifications on deck, and a day later than originally planned we could start the seismic surveying in the evening of November 23rd.





We started the seismic survey program at 1am on November 24th, around the Astrid Slump, which is related to a major diapir structure, previously investigated by IFREMER colleagues. This area is quite similar to the main working area around 'Hydrate Hole', and a large pockmark was surveyed in the vicinity, showing indication for active venting and near-surface gas hydrates or carbonates in echosounder data. Such data confirm that pockmarks and related features are typical for the area, more widespread than originally thought, and may provide thereby a significant contribution to degassing and exchange processes through the sediment-water interface.

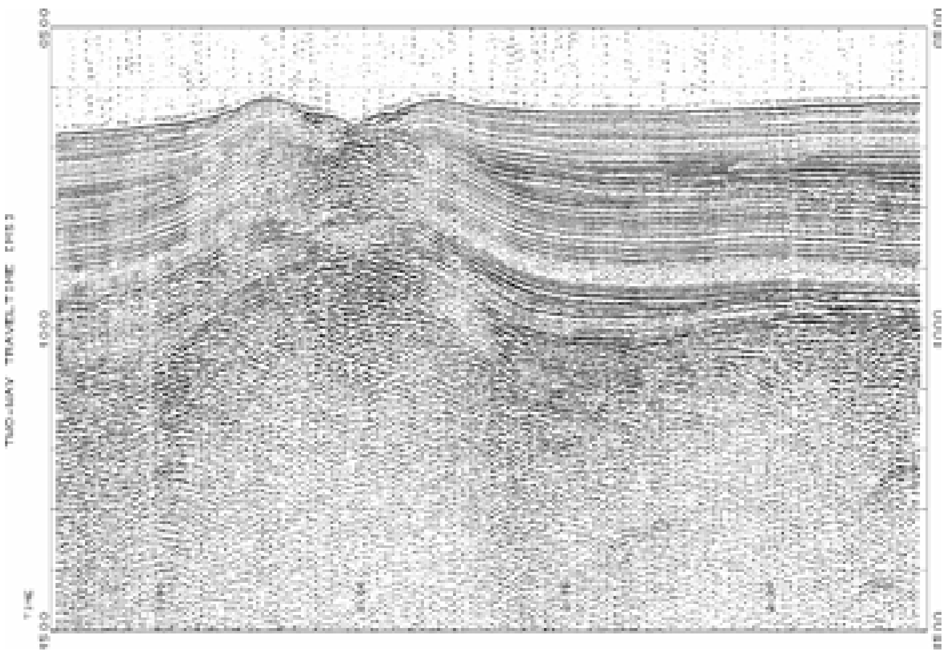
This first survey was also used to optimize the airgun towing construction and the use of shearboards, which turned out to be difficult at some higher sea state and surface currents though.



When we left the Astrid area in the evening of November, 24th, we decided to run the 3D seismic survey in the main working area (of 8 km x 9 km size) with a single GI Gun and a single watergun.

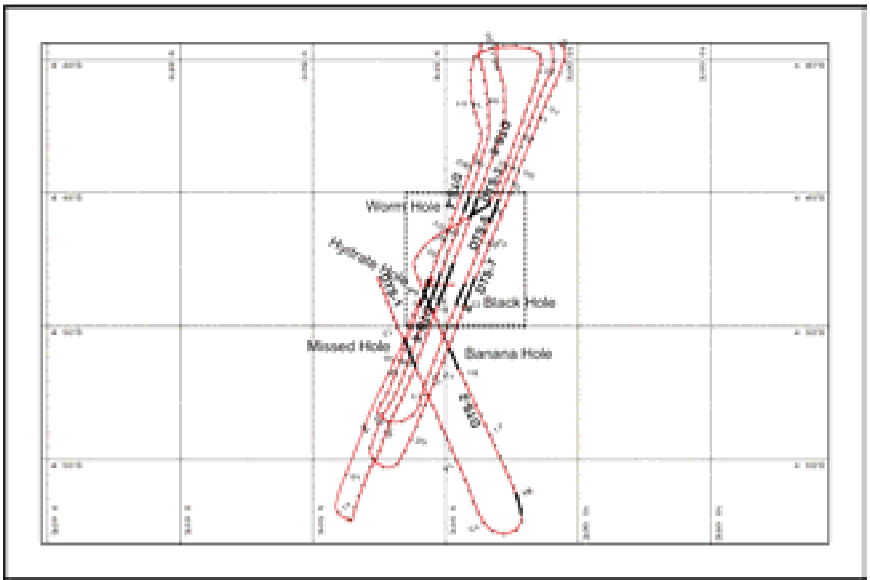
In the first working week from November 25th to December, 1st, the ship time was spent on geophysical surveying, before we had to leave around December, 3rd, for the port call in Libreville (Gabon). Until the morning of November, 26th, we collected overview profiles of sufficient quality within the 3D box across the most important and largest pockmarks: Hydrate Hole, Black Hole and Worm Hole. The digital Parasound line shows the significant size of 'Worm Hole' of nearly 2 km diameter and up to 50 meters depth below the flank height. Deformed sediments and high reflection amplitudes indicate local movements/tectonics and modifications of the physical properties since the time of deposition. They could be explained by the presence of carbonates or gas hydrates which might be a result of processes driven by uprising fluids and gases.

The seismic data from 'Worm Hole' confirm that the origin of the upflow zones is located at some hundred meters depth below the sea floor, where a local elevation of sedimentary layers is observed. Near salt diapirs, fracturing of sediments may have created increased permeability, resulting in focusing of flow and enhanced fluid and gas supply to the vent sites. The higher reflection amplitudes at greater depth can be typically attributed to the occurrence of free gas, as they can be typically expected in active hydrocarbon regions. The brute stacks show already a variety of features, promising interesting structural information and the reconstruction of fluid pathways and free gas and gas hydrate occurrences from the shorebased final processing of the 3D seismic data set.



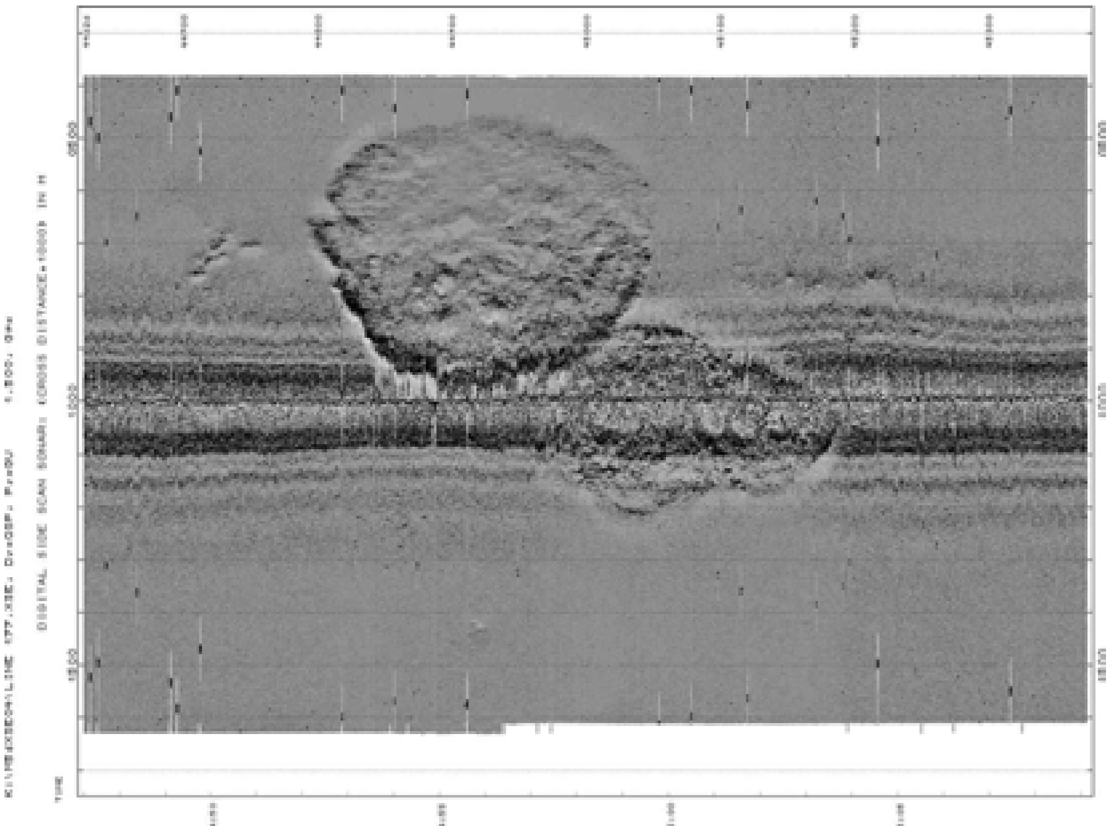
In addition to multichannel seismics, a deep tow fish is available for the cruise, which can host both a high resolution side scan sonar instrument and a multichannel marine streamer system. After finishing the first half of seismic surveying on November, 26th, we deployed the deep tow system to collect deep tow data in the vicinity of the major pockmarks as shown in the track chart. The collected data from seismics, sediment echosounder and bathymetric surveying were sufficient to plan both side scan sonar and deep tow seismic profiles and the deployments of ocean bottom seismometers and hydrophones.

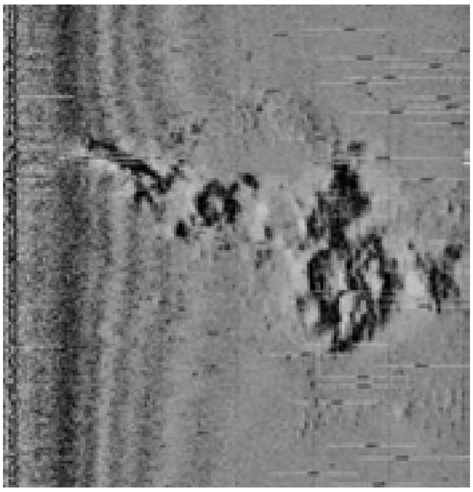
The side scan sonar data were most important to compare with bathymetry and to find out, which parts of the pockmarks reveal some surface acoustic anomalies related to active venting. Small scale variability of such systems is difficult to image from 3000 m distance, and several parallel, overlapping side scan sonar tracks should provide a meter resolution of surface structures, which could be targets for subsequent sampling with TV grab, multicorer or gravity corer.



M56 CONGO - DTS Tracks

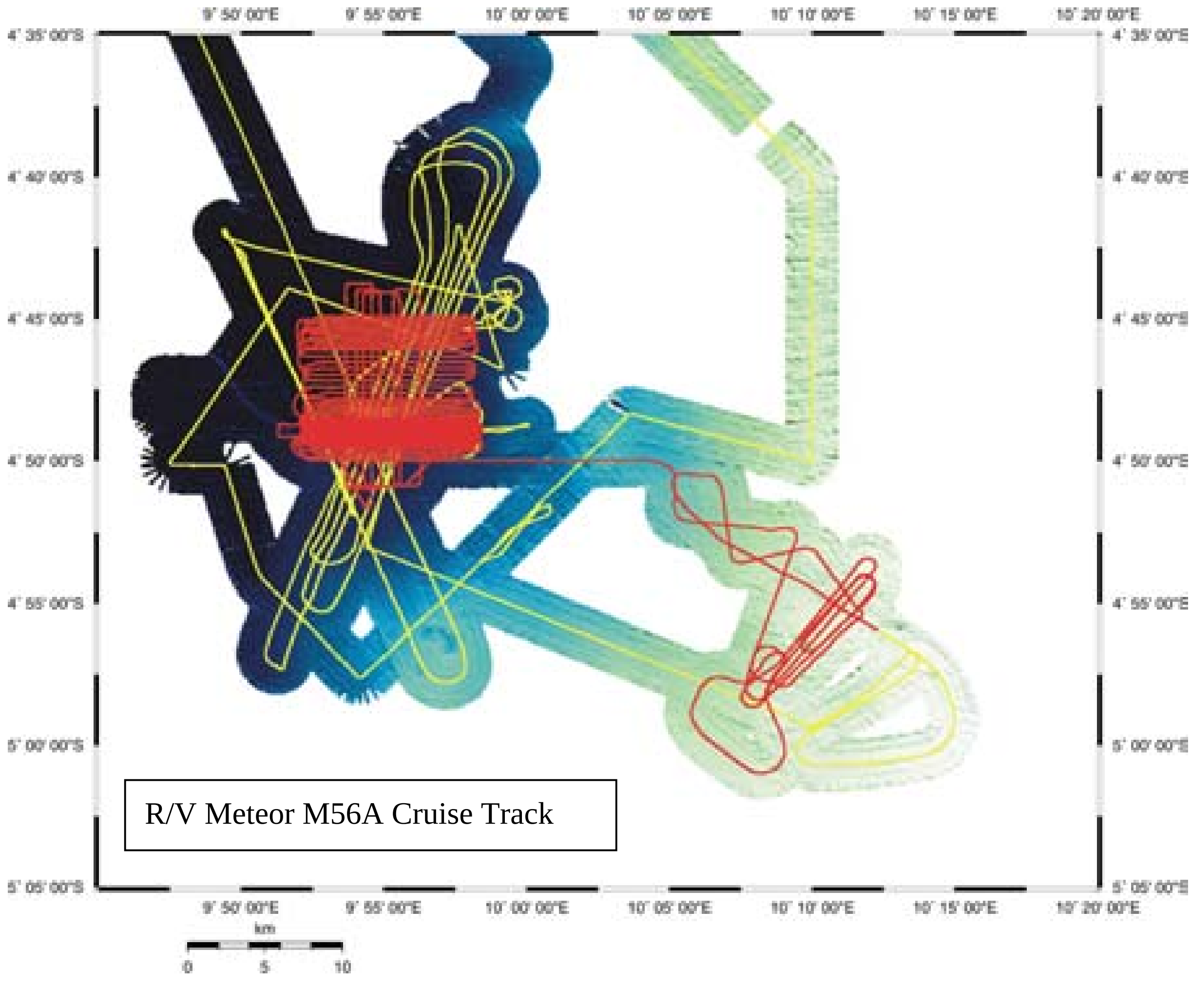
Besides the large scale features, numerous small surface anomalies, most of them depressions, were found and could be related to amplitude and structural anomalies within the sediment column. They are also potential vent locations, which were selected as targets for sampling and heat flow measurements.





In the vicinity of Hydrate Hole we found two pockmark structures of equal size, but significantly different depth, as well as many smaller features in distances up to one kilometer. The shallower large pockmark was the location, where gas hydrates were found during the M47/3 Cruise. Five larger pockmarks, which had been sampled during Meteor Cruise M47/3 - Hydrate Hole, Worm Hole, Black Hole (Figure), Banana Hole und Missed Hole – were covered, revealing a pronounced structural complexity. Since the 'blind' sampling two years ago was quite successful, we were quite optimistic to carry out a much more specific sampling program with the new database. In addition, both sediment echounder data from the fish and deep tow seismics provided useful high resolution information for site selection. All data confirm a widespread vent activity, and video surveying during the second part of the cruise is targeted to provide more detailed information from the vicinity of these locations.

Unfortunately the *Posidonia* positioning system for the deep tow fish did not work properly, and georeferencing of the measurements was not possible



onboard. However, a careful analysis of ship's track, fish behaviour and cable length as well as the overlap of side scan sonar swaths allowed to estimate the fish position with sufficient accuracy to generate a preliminary mosaic in the vicinity of the pockmarks. This extensive work was carried out from the end of the DTS survey on November, 29th, until the beginning of the sampling work on the second part of the cruise.
During November, 29th, ocean bottom instruments were deployed in the vicinity of Hydrate Hole, to carry out a tomographic experiment in conjunction with the second part of multichannel seismic surveying. The 3D seismic grid was located around Hydrate Hole and Black Hole at a line spacing of 25 meters, and the 3.6 day survey was designed to fill most of the gaps between the overview lines. It turned out that the area affected by fluid upflow is probably much larger than originally assumed and the survey grid was extended to the north and the south. On December, 3rd, the second survey campaign was finished and the multichannel seismic equipment was retrieved, and subsequently all ocean bottom systems after 3.6 days of continuous recording. In the afternoon, we left the working area for a 1.5 day transit to the North, heading for Libreville in Gabon for a short, intermediate port call on December, 5th, to exchange the scientific crew and equipment. Part A of R/V Meteor Cruise M56 provided through the combination of different geophysical data types, frequencies, recording locations, resolution and depth penetration an excellent data base for the subsequent work, both on the following leg and for the structural analysis and quantification of gas hydrate occurrence based on shorebased data analysis and interpretation.

Part B, 6.12. – 29.12.02
Libreville - Capetown

The port call in Libreville was only planned for 1.5 days and we were quite pleased that all the packing, container handling and exchange of the scientific crew could be finished before the scheduled departure, although the ship could only dock in the afternoon of December, 5th. The 20 new scientists had arrived on the 5th, and were ready to set up the labs and equipment for the second part when boarding the ship in the morning of December, 6th. Six scientists continued the journey, complementing the team from the University of Bremen – Geophysicists, Geologists, Geochemists -, Microbiologists from the Max Planck Institute for Marine Microbiology, and earth scientists from GEOMAR, Kiel, the University of Oldenburg and the Moscow State University.
After departure in the afternoon of December, 6th, and after bunkering in Port Gentil during the next morning, there was little time of one and a half days to return to the working area. However, most labs, the video guided systems and the seismic streamer winch could be set up and repaired in time for the morning of December, 9th, when working started again. In the night before, a first video

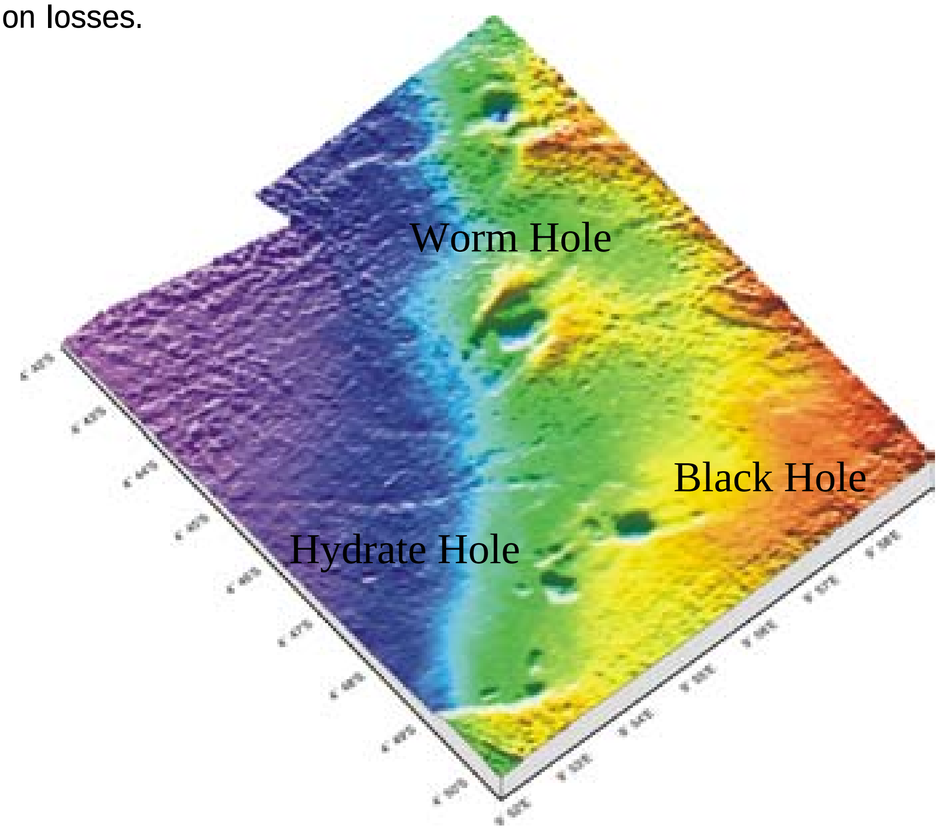
survey of the sea floor in the vicinity of Hydrate Hole with the OFOS (ocean floor observation system) system has provided overwhelming evidence for active venting, confirming the preliminary results of the M47/3 Cruise: carbonate precipitates spread over large areas and extended (living and dead) clam fields and pogonophora 'forests'. Whether bacterial mats and gas hydrate are present, could not be confirmed, though, due to the limited quality of the video information.
The sampling started on December, 9th, with the video-guided multicorer near living clam fields. However, three attempts missed by only a few meters, showing the general difficulty of sampling in a highly complex environment.
Another video survey in the following night was carried out to extend the spatial information about the three structural units near Hydrate Hole, to search for surficial gas hydrate occurrences and to map out live forms and carbonates. The observations confirmed the complexity of the side scan sonar images and variability. Several phases of pockmark development may be present within the three structural elements of Hydrate Hole: 1) miniature pockmarks without topography, 2) rough sea floor patches of several hundred meters diameters and few meters topography, and 3) a cone shaped depression of several 10 meters depth.

The second area of Hydrate Hole is characterized by high reflection amplitudes in the Parasound data, which we referred to occurrences of either carbonates or gas hydrates. In turn, we concentrated our sampling work in this area, starting with a TV grab. The first attempt provided large volumes of pogonophora, carbonates and traces of disseminated gas hydrate or bubbling gases.
Subsequently, we decided to use the gravity corer for the first time, the most important sampling device for the project due to our interest in the upper 5 to 15 meters of the sediment column. Samples should provide information about fluid flow, the distribution of methane gases, associated processes of gas hydrate growth and decomposition, chemical boundaries and their relationship to physical property anomalies imaged in sediment echosounder data in the vicinity of the vent fields.

The first two cores on Site GeoB 8203, which was identical to a station of the M47/3 Cruise, had been successful in the sense that massive gas hydrates could be recovered, indicated by strong

H_2S smell and a water fountain pushed upwards out of the corer. This time we were prepared to store the hydrates in liquid nitrogen for further shorebased analyses, to speed up the procedure of core treatment on deck, in the lab, in the H_2S container and to improve documentation of the sampling procedures.

An interesting observation was related to the varying orientation of hydrate layers within the sediment, which show a large variability. Not only horizontal, but also numerous near-vertical layers and tubes were found to be fully or partially hydrate-filled, which seem to image pathways of fluid and gas transport on cm-scales. The second core was used for dense geochemical sampling to analyze methane occurrence, hydrate distribution, sulfate reduction and diffusion losses.



In the evening of December, 10th, in-situ measurements of the sea floor temperature and temperature gradient were started. Heat flux is a major factor to control the distribution of gas hydrates at depth and near the sea floor in the vicinity of vent locations, and several transects across pockmarks had been planned to understand the long term history of venting. A 6 m long rod was equipped with several autonomous temperature loggers deployed at station spacings from 500 m to 50 m which was adapted to the spatial scales of venting within the pockmarks. A clear increase of heat flux, but also local minima, were observed within the pockmarks, and a smooth decrease outside, which both confirm a massive heat transfer through the pockmark chimneys.

With another gravity core from Site GeoB 8204 from the southern Hydrate Hole and the continuation of the 3D multichannel seismic survey we completed the working program of December, 11th. The next day we interrupted the seismic survey for two gravity cores from Site GeoB 8205, which were taken from Black Hole. The first core recovered normal sediments, but in the second core massive gas hydrates were found at the shallowest depth of all cores of the M56 Cruise, roughly a meter sub-bottom depth. In contrast, at Hydrate Hole hydrate depths were several meters below the sea floor. While the seismic survey was continued at night, we switched to the coaxial wire to be able to use video systems again on December, 12th.

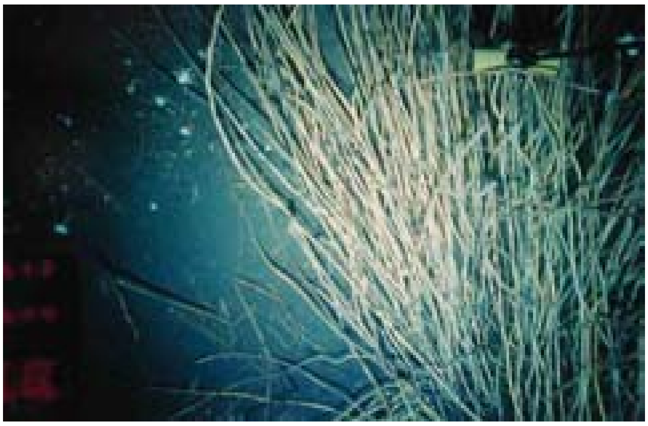
Subsequently, video multicorer and TV grab were used to sample Black Hole and Hydrate Hole. Again, no near-surface gas hydrates were recovered, but increasing amounts of carbonate precipitates with a large variety of shapes. From the different shapes, a close relationship to the life forms at the vent sites, in particular worm tubes, can be derived. They seem to serve as small scale pathways for fluid and gas transport, for hydrate growth and carbonate precipitation.

In the following night to December, 14th, the 4th deployment of the OFOS system was used to investigate Worm Hole, where we found the most pronounced indications for venting of all three pockmarks. Again, the subsequent TV grab provided carbonates, and two gravity cores at Site GeoB 8208 recovered gas hydrates in some meters sub-bottom depth. We could thereby confirm that all three pockmarks were hosting gas hydrates as a result of 'recent' venting, an important result of this cruise.

Another heat flow program was carried out in the night to December, 15th, to complete the data grid across Hydrate Hole and Black Hole, providing a long, connecting upslope profile of 5 km length with 39 stations. On Black Hole, the highest temperatures so far had been measured, 30% higher than at Hydrate Hole.

Based on the evidence collected during the first working week of leg B, we gained a good overview, and a more focused, small scale sampling program was developed for the second week. To handle a larger number of cores, core liners were replaced by bags to speed up the procedure of laying out the sediment on deck for photographing and sampling and to deploy the gravity corer more than once in a row. Sites were chosen at only 50 m spacing to learn more about the small scale variability of gas hydrate and carbonate occurrences. Although difficult even at moderate to good weather conditions, the quality of the positioning at sites was sufficiently good to collect samples, which provide consistent results on lateral scales of less than hundred meters, as we could find out from three gravity cores at Site GeoB 8209. Complimentary near-sea floor horizontal transects

with a water sampler at Hydrate Hole and at Black Hole did not provide evidence of very strong methane expulsion into the water column, as they are known from some active continental margins. Gravity coring on December, 16th, at Site 8211 provided another three cores with gas hydrates, adding to a total number of 8 gravity cores with massive gas hydrates, six at Hydrate Hole, one at Black Hole and one at Worm Hole. Although gas hydrates were not collected with TV grab or multicorer, all deployments had provided vent indicators as methane traces in sediment, carbonates, living or dead remains of clams or pogonophora.

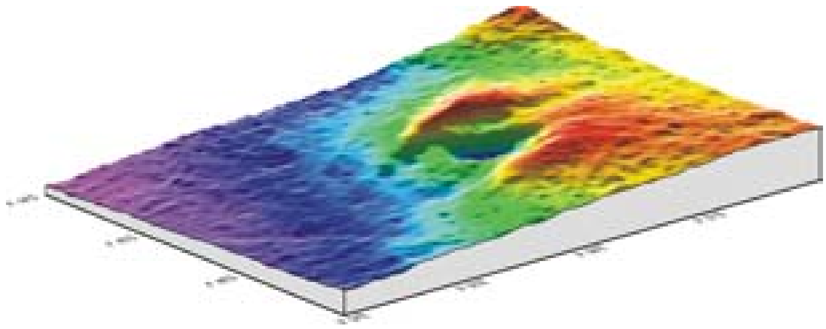


The heat flow program in the night to December, 17th, completed the Hydrate Hole survey with a North-South transect, confirming the high variability as well as the local heat flow high around the center of Hydrate Hole.

During the second week of work of leg B, the program, a mixing of multichannel seismics, heat flow measurements and sampling of sediments and water column, was continued. A surprise were the results of TV grab deployments at Site GeoB 8212, where we recovered enormous amounts of carbonate precipitates, individual pieces showing a range of sizes up to 20 cm diameter. The

material of 3 runs covered all space in the geoloab, documenting different phases of precipitate growth and their intimate relation to worm tubes.

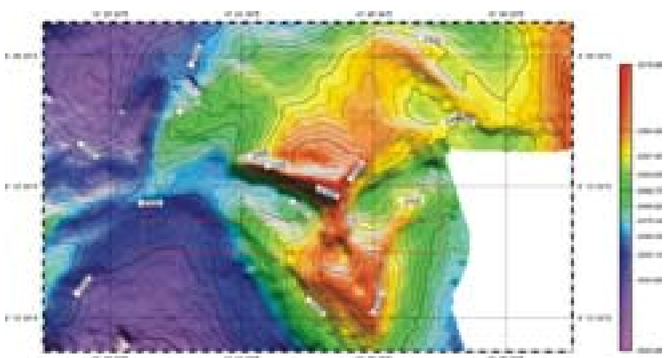
In the night to December, 18th, the last temperature measurements were carried out across Worm Hole. Within the central depression we measured the highest values, twice as high as at Hydrate Hole and 2.5 times the values in the wider vicinity. This confirm the video observations, that Worm Hole is among the most active systems in the working area. Also, the pronounced morphology north and south of the depression reveals a very active process responsible for the pockmark generation.



The following day, another three gravity cores were taken, one for geochemical analyses from Hydrate Hole and two at a reference site in sufficient distance from any pockmark.

In the evening and during December, 19th, the seismic and sediment echosounder survey program was finished with a grid of lines of 100 m and 200 m spacing across Worm Hole. On departure, we collected data across a newly found pockmark north of Worm Hole and in the Astrid Slump area, to complement the regional seismic coverage across fluid escape structures. In the early morning of December, 20th, we reached on our way south ODP Site 1077, which had been drilled during Leg 175 of the Ocean Drilling Program, to take a core for biomarker investigations on fresh material.

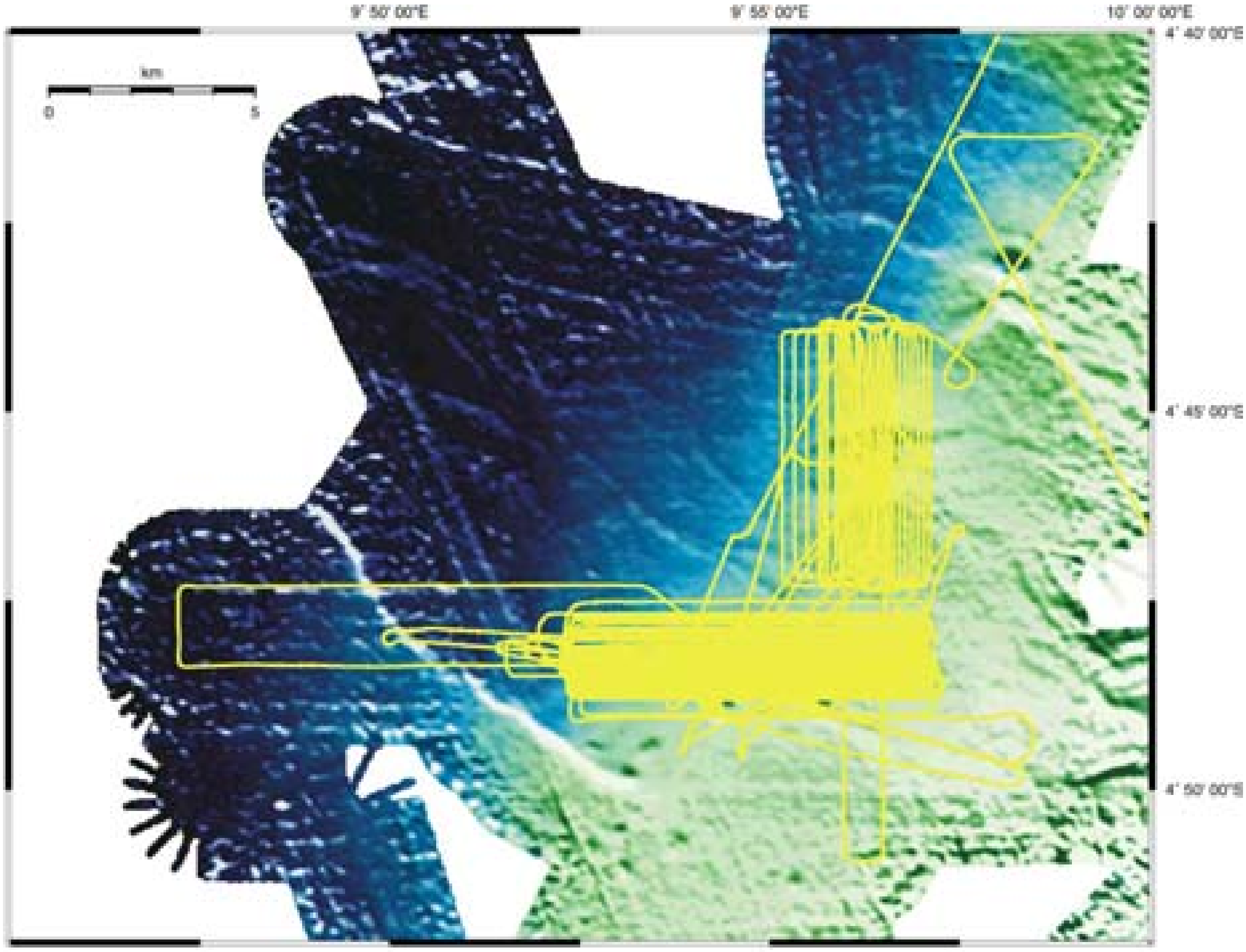
The remaining working time of the cruise was used to collect a few more seismic and sediment echosounder lines during December, 20th, across other pockmark structures near the Congo canyon for a comparative study. On the way south, we had also chosen a target for a final study, which is different from the previous survey – a pronounced ridge structure above a salt diapir. Here, the driving forces, tectonics, and geometry of potential fluid pathways are very different from the pockmark area, but typical shallow gas accumulations are found in the vicinity of the ridge structure. Based on the complex bathymetric chart derived from a few hours of seismic surveying. In the morning of December, 21st, a video survey was started to search for vent indications near the top part of

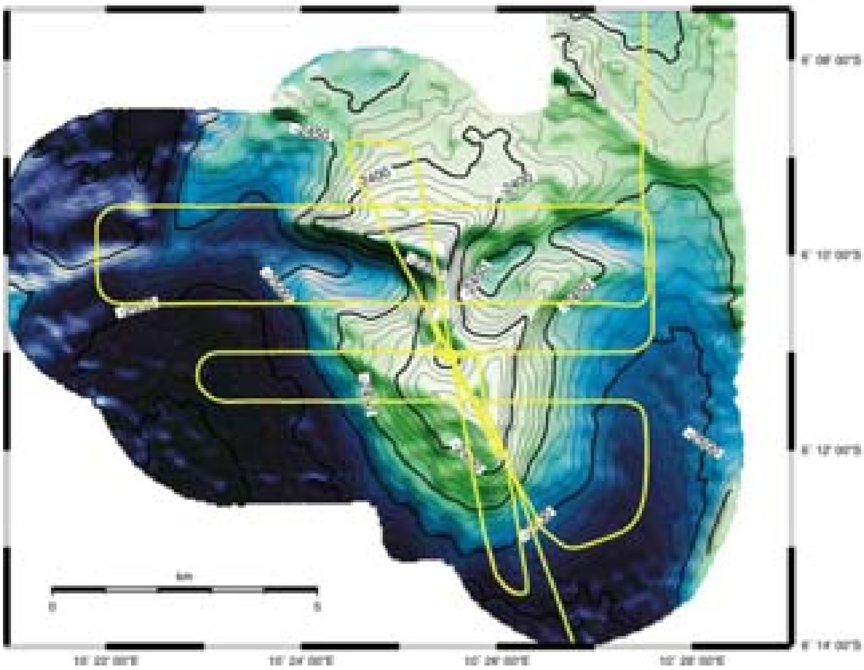


the structure. After a few hours, we found typical features, very similar to the observations in the pockmark area: clam fields, carbonates, pogonophora. During the definitely last TV grab run – a shovel broke - we collected the largest proportion of carbonates from all deployments of the cruise, the largest carbonate samples and the highest variety of clams, a surprising result. These samples confirmed a very active vent system, which would certainly be an interesting target for future investigations, although the subsequent gravity cores, applied in a very patchy environment, did not provide any additional information or gas hydrates, but at least general indications for venting in all cores. In the night to December 22nd, we left the working area of Dark Hole, and took a last sediment core on the way south for biomarker studies from a location, which is not affected by input from the Congo river. We finished the sampling program of the M56 Cruise in the morning of December, 22nd, to head for Capetown during a 1727 nm long transit for a scheduled arrival on December, 29th.

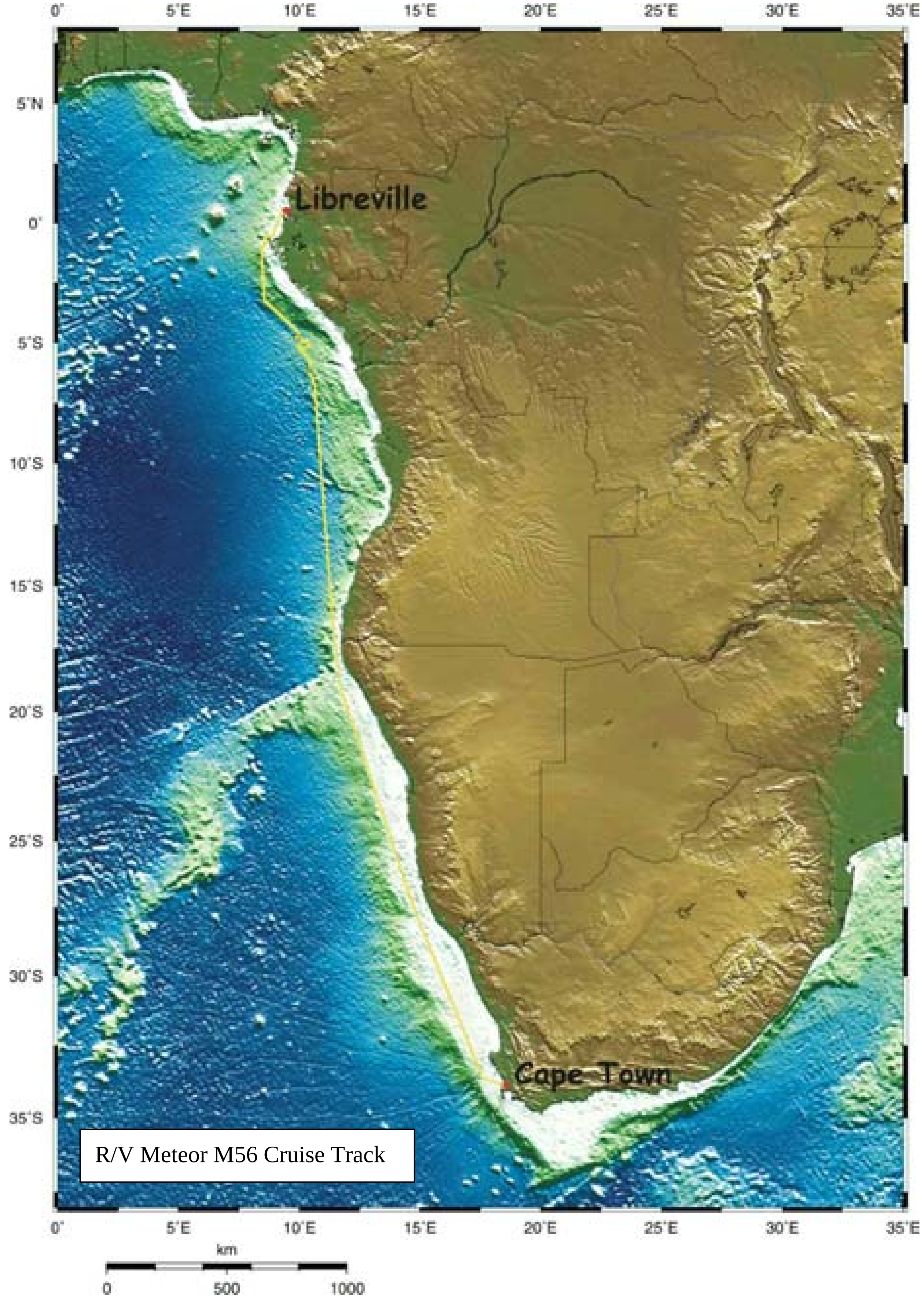
Scientific work continued, however, with watchkeeping for the recording of sediment echosounder and swath sounder data, which was important for subsequent Meteor cruises to the area, in particular the M57 cruises to take place in the beginning of next year. The remaining time had to be used to work up the cores in the geo lab, to finish geochemical sampling and analyses, and to work on the geophysical data collected. Good weather conditions on the transit finally allowed us to enter the port of Capetown half a day early in the evening of December, 28th, although the work could only be finished with container packing on December, 29th and 30th in the port.
Scientists departed just in time to arrive at home before New Year's Eve, looking back on a particularly successful cruise with respect to the main objectve, the research on gas hydrates. During 24 working days we collected 22 gravity cores, 8 TV grabs, 4 multicorer, 5 OFOS dives, more than 70 heat flow measurements, appx. 280 km of deep tow side scan and seismics, 3.5 days of OBS and OBH recordings, 1760 km of multichannel seismics and 4730 nm of sediment echosounder and swath sounder data. We collected one of the most diverse data and sample sets around a gas hydrate site, and we look forward to interesting results from the integration of these data and the shoredbased analyses and interpretation, to image fluid pathways, to reconstruct the presence of gas hydrates, to understand the carbonate system in association with chemical and biological boundary conditions, to investigate the growth and

decomposition processes of near-surface gas hydrates, to understand the temporal succession of fluid flow events and pockmark generation.





R/V Meteor M56B Cruise Track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