Meteor Cruise M54/1

6.7. –11.7 / 14.7. – 10.8.

Short Cruise Report

The R/V Meteor Cruise M54/1 is the first in a row of 3 expeditions, which lead the vessel for the first time to the Pacific Ocean for research in the waters of Panama, Costa Rica and Nicaragua (Figure 1). The cruise began on July, 6th, with a transit from the final port of the M53 cruises in the Carribean, Pointe a Pitre in Guadeloupe (France). After 4 days of transit, combined with the setup of most of the seismic equipment on deck and in the labs to be used during the M54/1 Cruise, we reached the Panama Canal on July, 10th, for a spectacular passage at night, enlightened by frequent lightnings of a tropical thunderstorm, to reach Balboa (Panama) as the second port during the cruise in the early morning of July, 11th. Meteor reached Balboa a day earlier than originally planned which gave sufficient time for a major repair of the bow thruster system. Fortunately this repair was successfully finished with a operational test in the afternoon of July, 13th, as well as all loading of normal containers and the heavy compressor container could be performed. Ready to leave port, Meteor started the scientific part of the M54/1 Cruise on July, 14th, at 6 o'clock. The scientifc crew for cruise was now complete with 4 scientists from Geomar, Kiel, 1 scientist from the European Science Foundation, 3 scientists from Costa Rica, and a Nicaraguan observer, complementing the 12 scientists from the University of Bremen.

The subduction zone off Costa Rica is the subject of research of this cruise, mostly related to a major research project of the Kiel University and the Geomar Institute for Marine Research, the Special Research Project 574, which is funded by the German Science Foundation (DFG, Deutsche Forschungsgemeinschaft). In this area, the subduction process is characterized by a significant erosion of the upper plate through seamounts and plateaus on the oceanic plate, which leave visible traces and scars along the continental margin. The mass transport associated with this type of subduction differs significantly from accretionary margins, and major uplift and subsidence phases of several kilometers associated with frequent and massive slope failures result in irregular or chaotic depositional patterns.

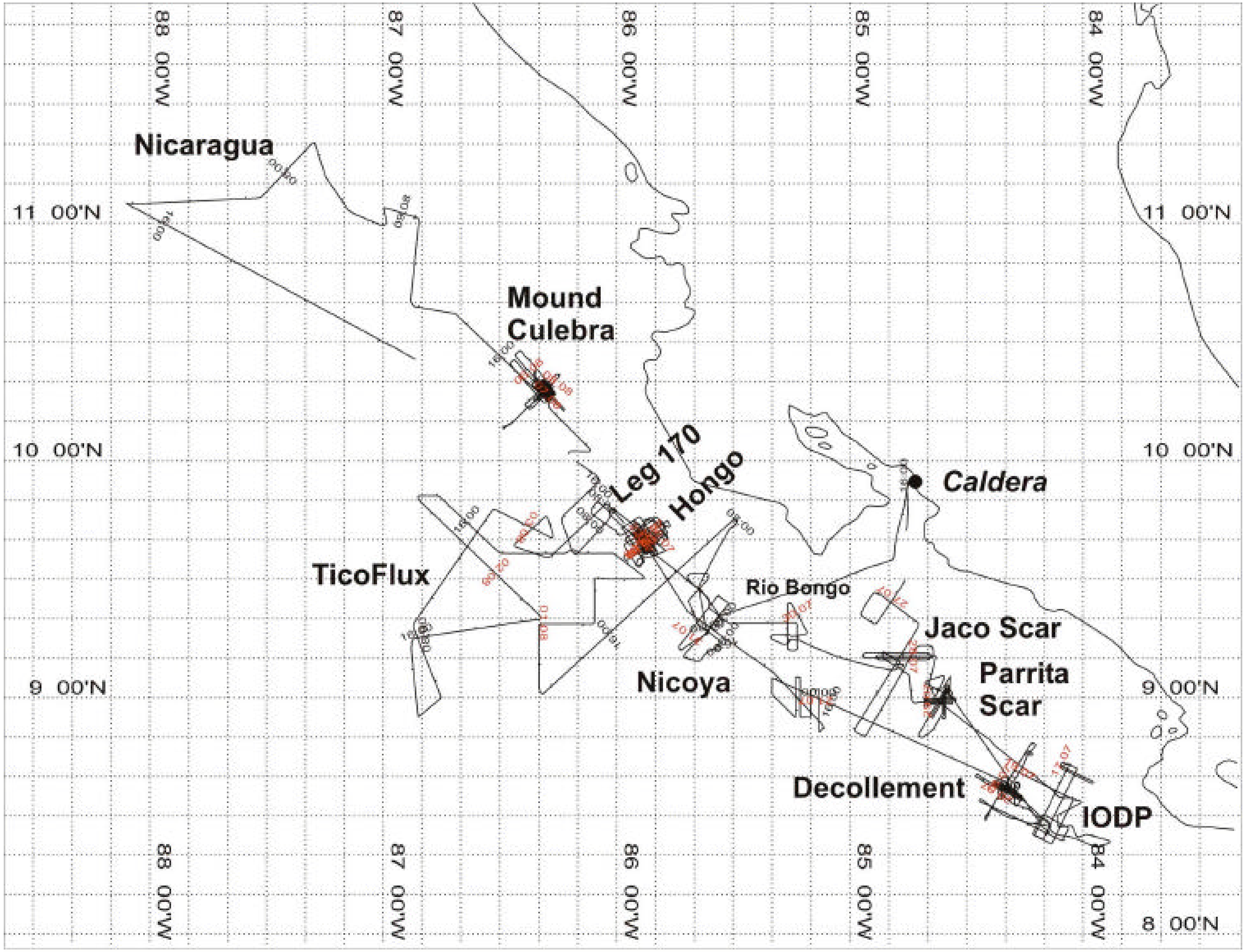

Figure 1: Track chart of R/V Meteor Cruise M54/1.

In this context, processes of fluid flow and mass budgets of subduction and volcanism are the main themes of the Meteor M54 cruises. During the first leg, near surface investigations are carried out using high resolution seismics of the University of Bremen combined with ocean bottom intstrumentation of the SFB 574 to achieve a detailed seismic imaging of the sea floor on vertical scales of several meters and horizontal scales of a few tens of meters.

Before deployment of the seismic gear only little time was available for setting up the compressor, ocean bottom instruments and streamer parts, since steaming through Panamese waters to the first working area took hardly a full day.

In addition, during this leg we had planned to use for the first time shear boards, known from fisheries and commercial seismics, to separate two seismic sources by as much as 40 meters from each other. This allows to collect simulataneously two parallel seismic lines of 20 meters lateral distance.

The overall plan of the cruise included surveying in several different areas, which had been selected from numerous previous cruises with R/V Sonne of Geomar and of the Bundesanstalt für Geowissenschaften, to combine the results with deep seismic data on the one side and surface sampling and deep tow measurements on the other side.

The continuous data acquisition, which also included a preliminary data processing and interpretation, started in the afternoon of July, 16th, with a survey program around an area, where a German drilling proposal for the Integration Ocean Drilling Program IODP had been submitted to drill deep into the crust and to penetrate the seismogenic zone. Crossing lines to an existing grid of data were requested as well as high resolution information in the vicinity of proposed drill sites to image sedimentary structures in greater detail. Local fishing activities made it dfficult to perform our program, and survey plans had to be modified frequently to avoid collisions of the 750 m long seismic streamer with several kilometer long fishing lines.

For the IODP area most of the planned lines could be measured. To start the work with ocean bottom instruments, OBS/OBH systems had to be recovered from a microseismic network on July, 17th. They were deployed on July, 18th in a nearby study area, where the reflection of the decollement, the gliding plane and boundary between the two plates, shall be studied in greater detail. Subsequently, the missing survey lines were shot across the IODP transect as well as some lines in the vicinity of the deformation front. Seismic measurements were continued in the decollement area, and seismic gear as well as the 7 ocean bottom systems were retrieved on July, 20th (Figure 2).

In the second week of the M54/1 Cruise seismic survey work was continued, while we used a transit of several hours to maintain the reflection seismic equipment and to carry out a sediment echosounder survey in the vicinity of normal faults of >50 m vertical offset within the oceanic plate. In the morning of July, 21st, we continued our survey activities with a long line, connecting the oceanic realm through the large Nicoya slide with one of the main working areas, where carbonate mounds were found and mud volcanism was assumed.

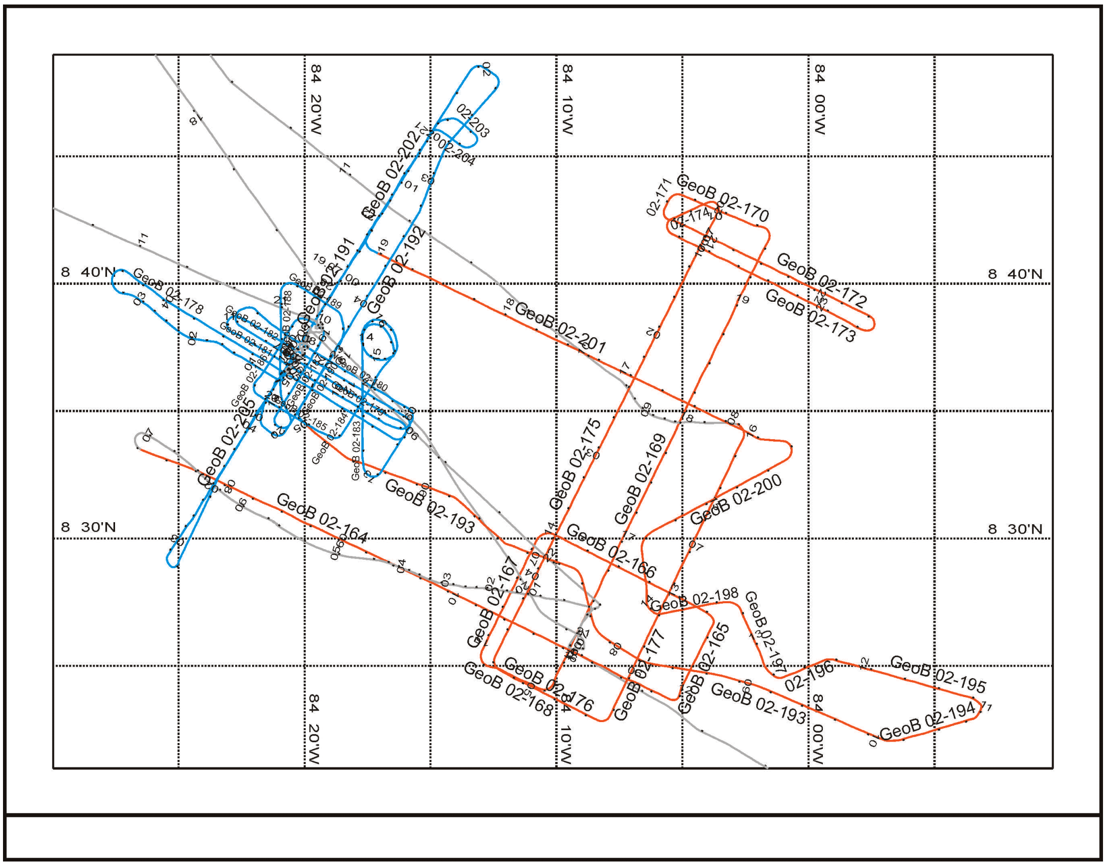

Figure 2: Track chart of M54/1 Cruise in the IODP and decollement area

The main objectives of the cruise were focused on the seismic imaging of areas, where vertical fluid flow occurs, which may be caused by mud vulcanism, active faulting or slope failure. All these processes leave identifiable traces on the sea floor and within the sediment column, which are to be investigated. Many of these features are furthermore related to the subduction of seamounts and oceanic ridges or plateaus. To identify such structures, to determine possible sampling locations for the following cruises and to reconstruct deformation processes in space and time, combined reflection seismic and ocean bottom seismic surveys were designed in several specific areas.

The Hongo Area (Figure 3) is located in the direction of the triple junction trace, which at the same time is a thermal and structural boundary on the oceanic plate. Here we carried out the only 3D-seismic survey of the cruise, since during previous cruises distinct surface indications were found for fluid venting. On the approach to the area, several single lines were shot to determine a structural overview, which the lead to the decision to carry out a 3D survey, since interesting structures and amplitude anomalies were identified down to 1 second two-way traveltime.

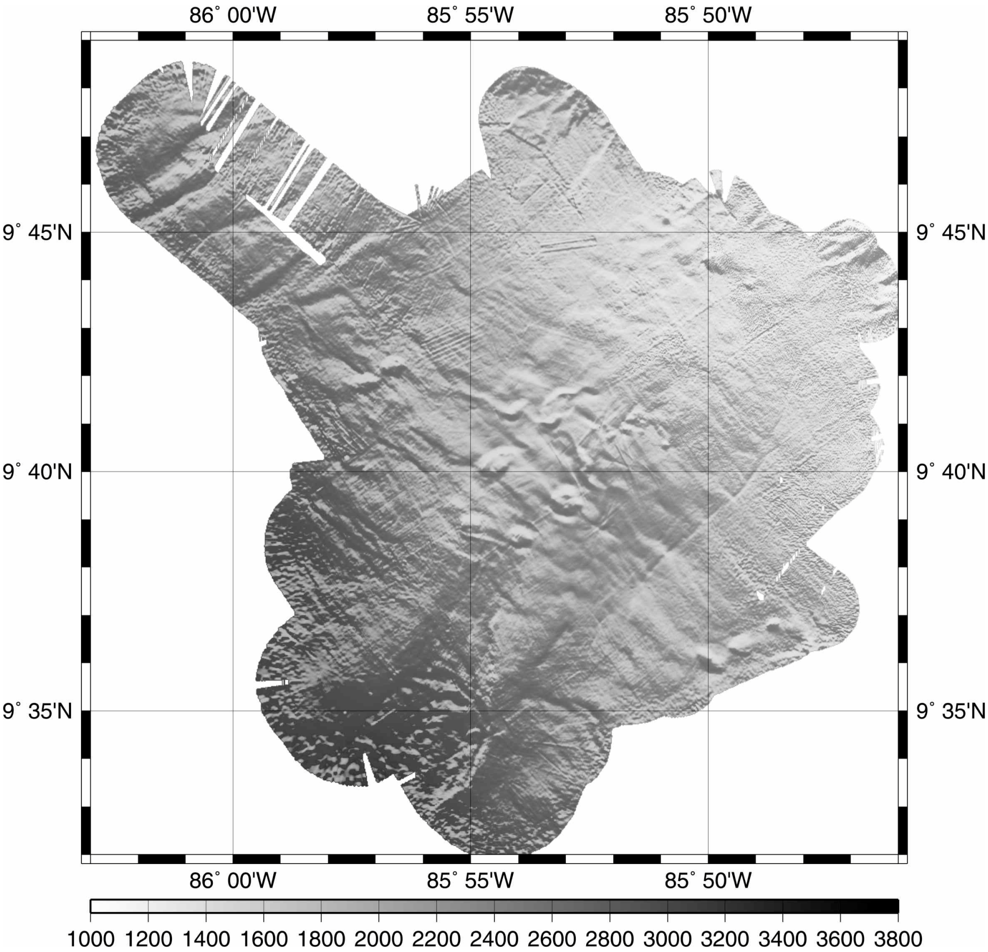

Figure 3: Bathymetry of the Hongo Area. The 3D survey area is located in the center.

The bathymetry of the region shows a rigdge-type structure with two sedimentary basins on both flanks. The rough topography in the center is characterized by significant disturbances of sedimentary structures, different strike directions of surface expressions and near-surface anomalies in reflection amplitudes in sediment echosounder and multichannel seismic data. The seismic line in figure 4, oriented in NE-SW direction, reveals a bottom-simulating reflector (BSR), which clearly indicated trapped gas beneath massive gas hydrate occurrences at depth. In the center of the profile and at other locations, high reflection amplitudes at shallower depth as well as the absence of the BSR in some parts, may be indicative of gas traps and fluid flow, which may lead to possible vent locations at the sea floor.

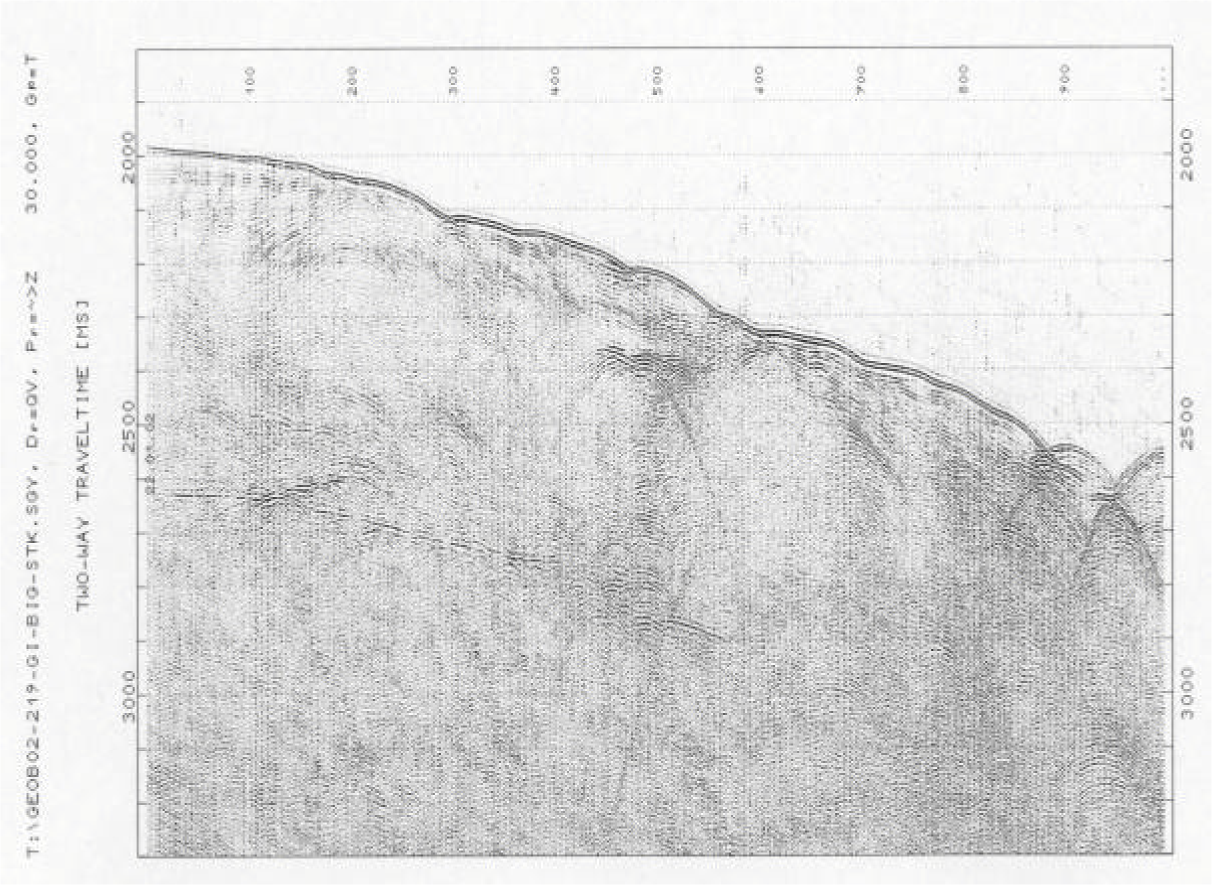

Figure 4: Multichannel seismic line GeoB 02-219 from the Hongo Area.

To optimize the available ship time, we used for the first time in the Hongo area shear boards to separate the seismic sources by 40 meters, which allows to increase line spacing in 3D grids from 25 m to 40 meters. Two parallel lines are measured at 20 m lateral distance through this method, and survey areas could be increased by 60%. The first use turned out to be very successful, although sometimes sensitive to heavier weather conditions. The geometry was very stable, however, and also during turns the handling appears simpler than without shear boards.

Figure 5:
Towing of shear boards for seismic sources.

Until July, 24th, the overview survey was continued. Subsequently, the survey was interrupted, a 3D box was selected as well as locations for 7 ocean bottom instruments to be deployed for a tomographic experiment with pathwys across assumed fluid upflow zones and the gas hydrate stability field. Furthermore, we expect to derive a much more precise sound velocity field than would be possible with reflection seismic data alone, to improve processing as well as to quantify properties of the sediment column. The survey was continued until July 25th, with more 40 seismic lines, which were to be complemented in a second phase in the following week. The ocean bottom systems were retrieved, and a few hours later again deployed in the Nicoya slide area. Before the seismic studies were continued, we steamed to Caldera for an intermediate port call to pick up freight on July, 26th as well as to carry out intense maintenance work on the seismic equipment.

After a short transit during noon time, we continued surveying in the afternoon of July, 26th, from the shelf edge into the deep sea to study major slump and scar areas. In particular, we focused on Jaco Scar and Parrita Scar, where a great interest of the SFB research exists to understand deformation processes and tectonic structures initiated by seamount subduction and associated uplift and subsidence. This region is characterized by more than 1000 m high scars, pronounced surface deformation patterns, large areas of carbonate crusts and active venting. Echosounder and seismic data were collected to image subsurface structures (Figure 6) which may indicate position and depth of deep and potentially active fault zones, many of which were clearly found in TOBI and deep tow side scan sonar data. The survey revealed a pronounced complexity of normal faults, radial fault patterns, slide masses or carbonate crusts, which could only be investigated by a larger number of profiles in different directions perpendicular to structural trends.

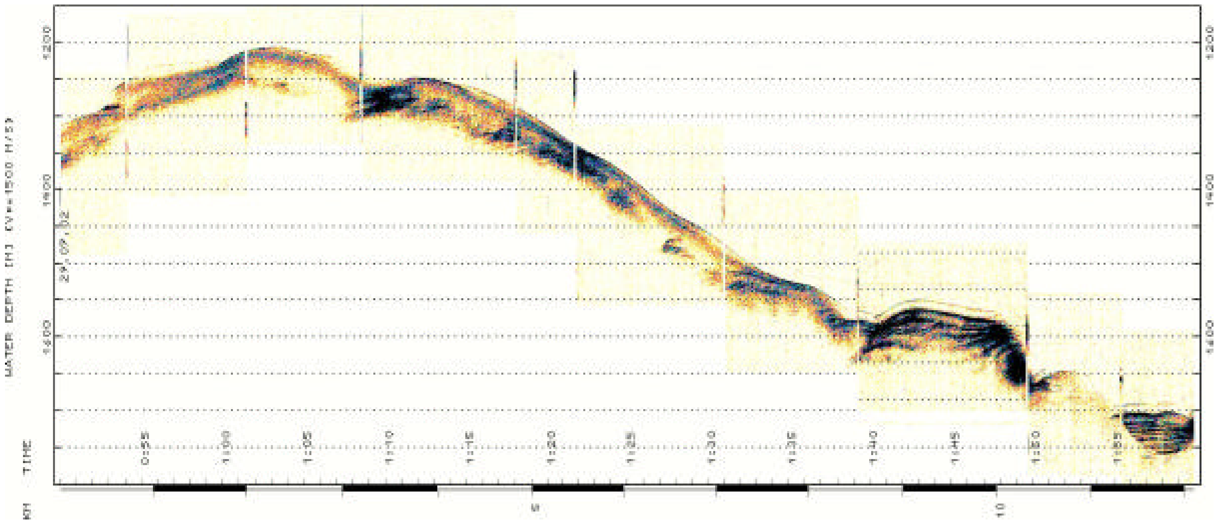

Figure 6: Digital Parasound profile across Jaco Scar with pronounced amplitude anomalies indicating the assumed presence carbonate crusts and vent sites.

The seismic grid shown in Figure 7 was designed to cover different questions beyond local tectonic deformation, as for example a comparison of low and high frequency seismic data, the mapping of a bottom simulating reflector and the internal structure of slump masses as well as hemipelagic deposits.

Near Parrita Scar we could carry out a complete survey of 30 hours, including crossing lines across Quepos mound, located north of Parrita Scar. An ambitious plan to survey Jaco Scar in the same level of detail failed due to the presence of numerous fishing boats with km long lines, which left us with an unsatisfactory short 24 hour survey grid. In particular, Parasound lines showed interesting surface features, which we hope to see calibrated by a subsequent sea floor survey with video systems and sampling.

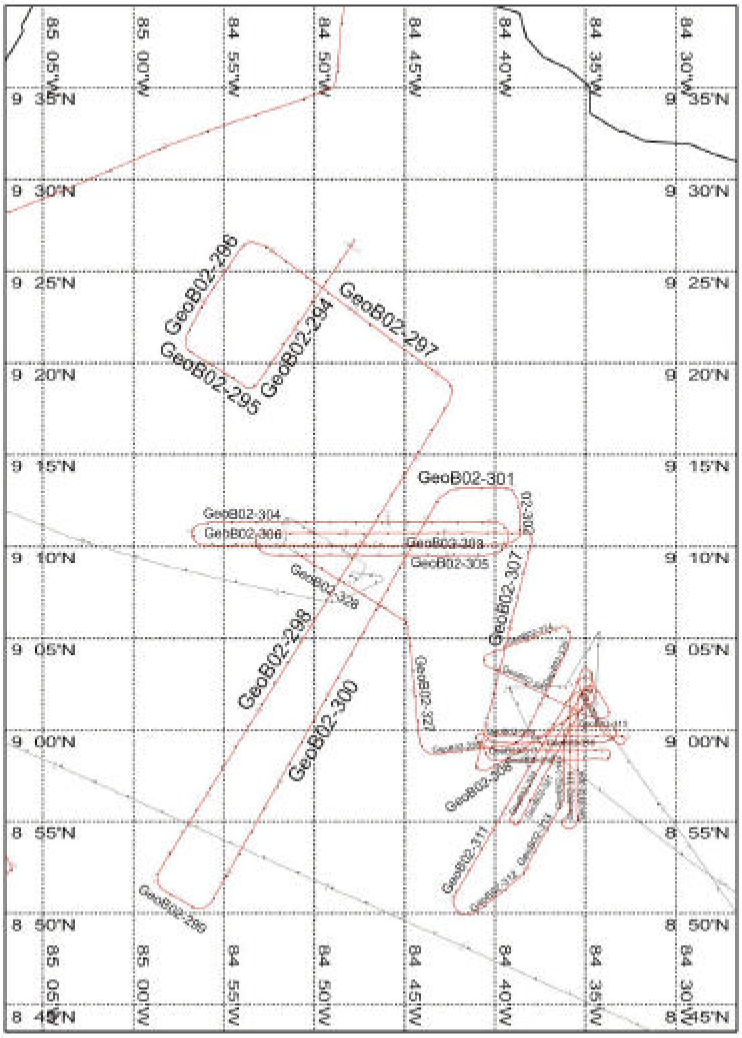

Figure 7: Track chart of multichannel seismic survey in the Jaco Scar and Parrita Scar area.

On July, 30th, we abandoned operation due to intense fishing activities, and moved to Rio Bongo area, where we started a few crossing lines on our way to Nicoya slide. There, we shot specific lines over selected ocean bottom seismometer locations to analyze the nature of the gas hydrate zone, of the bottom simulating reflector and in particular the generation of shear waves. Furthermore, we intended to reconstruct the temporal evolution of Nicoya slide, which may have developed over several phases of slope failure. In early morning of July, 31st, we recovered all 4 ocean bottom instruments, just in time after more than 4 days of operation, and steamed towards the Hongo area again.

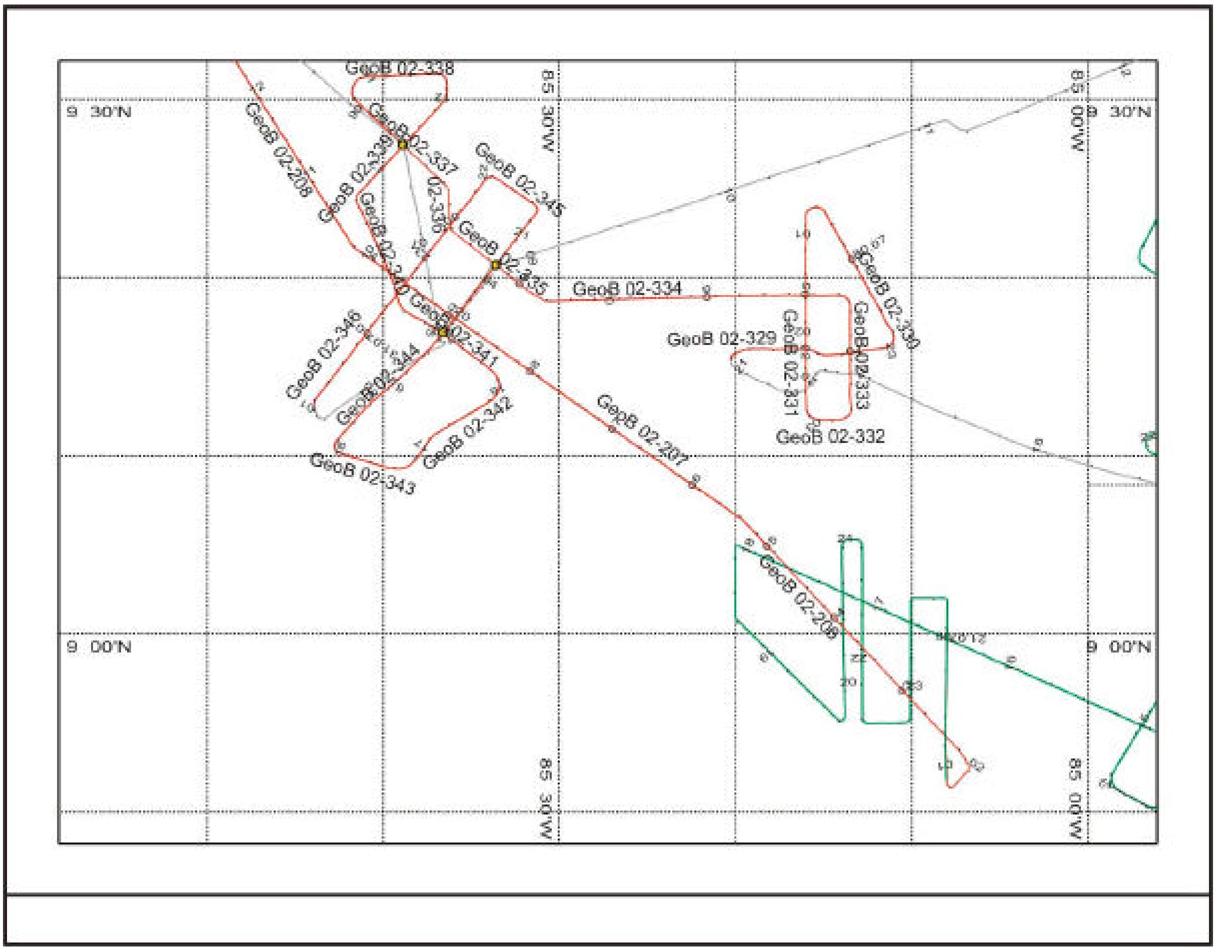

Figure 8: Track chart of multichannel seismics in Rio Bongo and Nicoya slide areas.

A few hours later, we continued the 3D seismic survey in the Hongo area and planned to add another 80 seismic lines. During this survey we experienced for the first time some stronger winds, which lead us to leave to area close to the coast for a survey on the oceanic plate, until weather conditions improve again to achieve the high positioning accuracy required for the 3D survey.

A long profile from the shelf across the slope with pronounced normal faulting and bright spots lead us to the subduction zone and the oceanic plate, where TicoFlux expeditions of U.S. American colleagues found interesting anomalies in heat flow and thermal cooling of the plate. The results were attributed to a significant cooling caused by lateral flow within the plate, but inflow and outflow zones for the large amounts of seawater required are yet unknown. In this respect, the nature and morphology of the ocean crust near the sharp transitions in heat budget may be important factors, which we investigated during a 2.5 day reflection seismic survey program (Figure 9) by imaging the pelagic sediment cover, deformation patterns within sediments and crust, variability of the sediment-crust interface and sea floor morhology. We found clear rough-smooth transitions of the crust near thermal boundaries, but spatial patterns have yet to be determined (Figure 10).

Figure 9: Track chart of reflection seismic lines in the Hongo, TicoFlux and ODP Leg 170 working areas.

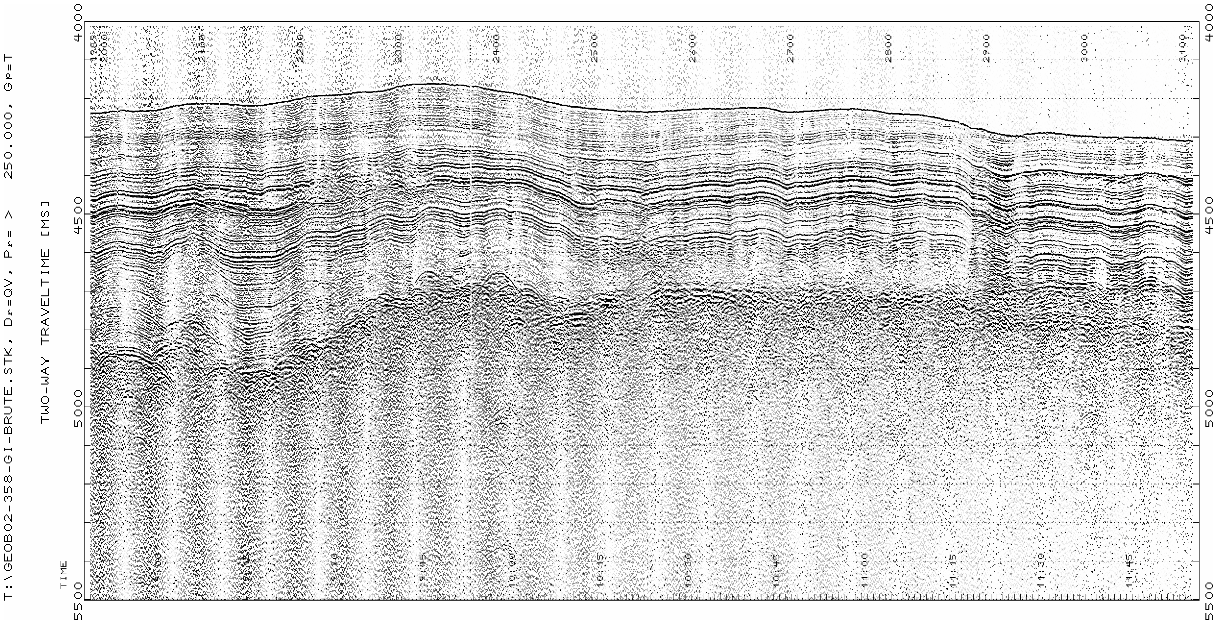

Figure 10: Multichannel reflection seismic line from the ocean plate.

We left the oceanic plate across the drilling transect of ODP Leg 170 towards the Hongo area, where we finished between August, 3rd, and August, 5th, the 3D survey at much better weather conditions. On the leave, we crossed again the ODP Leg 170 working area, where in many places, diffuse bands of higher reflection energy were observed, which might well be associated with gas or gas hydrate accumulations. Also, a transition between BSR occurrence and areas of BSR absence was surveyed several times. Further north, on the way to the Mound Culebra area, clear BSR reflections were observed again, but the variability appears more complex than is so far known from the few available seismic data sets from the region.

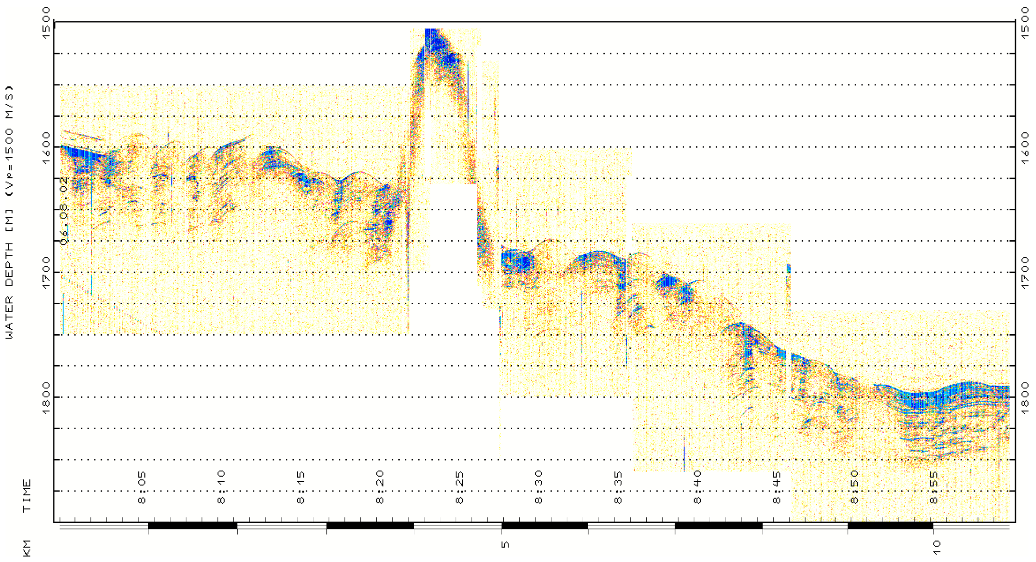

Figure 11: Digital Parasound line across Mound Culebra.

The Mound Culebra region is characterized by more pronounced layering of sediments despite distinct indications from bathymetry for slumping and erosion (Fig.s 11, 12). The internal signature of Mound Culebra appeared somewhat similar to mud volcanoes which we recently surveyed in the Black Sea, which were lacking internal structures just underneath the mound. Whether the mound surface, which has a different morphology than typical mud volcanoes and may be covered by carbonate crusts, is masking seismic energy or whether the columnar transparent zone is caused by fluid flow or increased gas content, is yet unclear. The bottom simulating reflector is clearly interrupted and sightly bent upwards, which may hint to a distortion of local isotherms and recent activity.

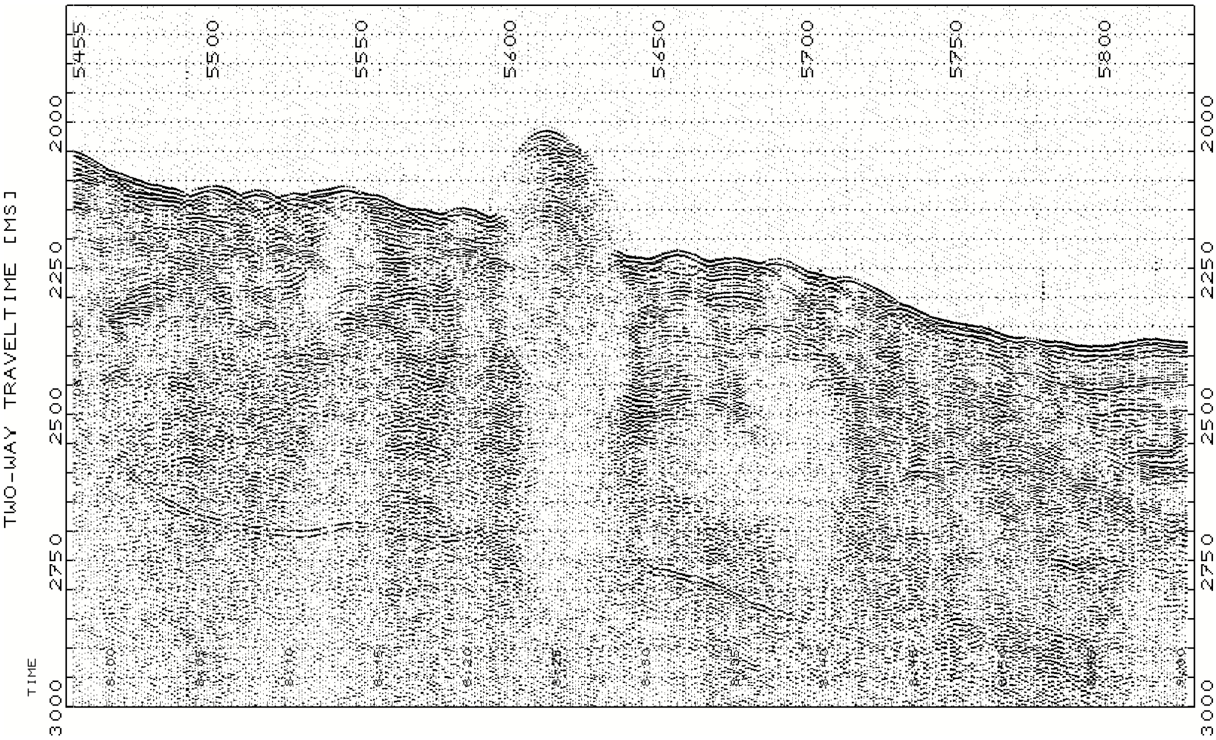

Figure 12: Multichannel seismic line across Mound Culebra.

For the last time during the cruise, we deployed 7 ocean bottom instruments in the vicinity of Mound Culebra before starting a detailed survey of 100 to 150 m line spacing at August, 6th (Fig. 13). A tomographic imaging of the central feeder channel is intended, using raypaths reflected from the BSR through the central part, as well as a regional mapping of BSR properties, in conjunction with high resolution seismics, to unterstand the complex nature of such structures typical for wide areas of the Costa Rican continental margin.

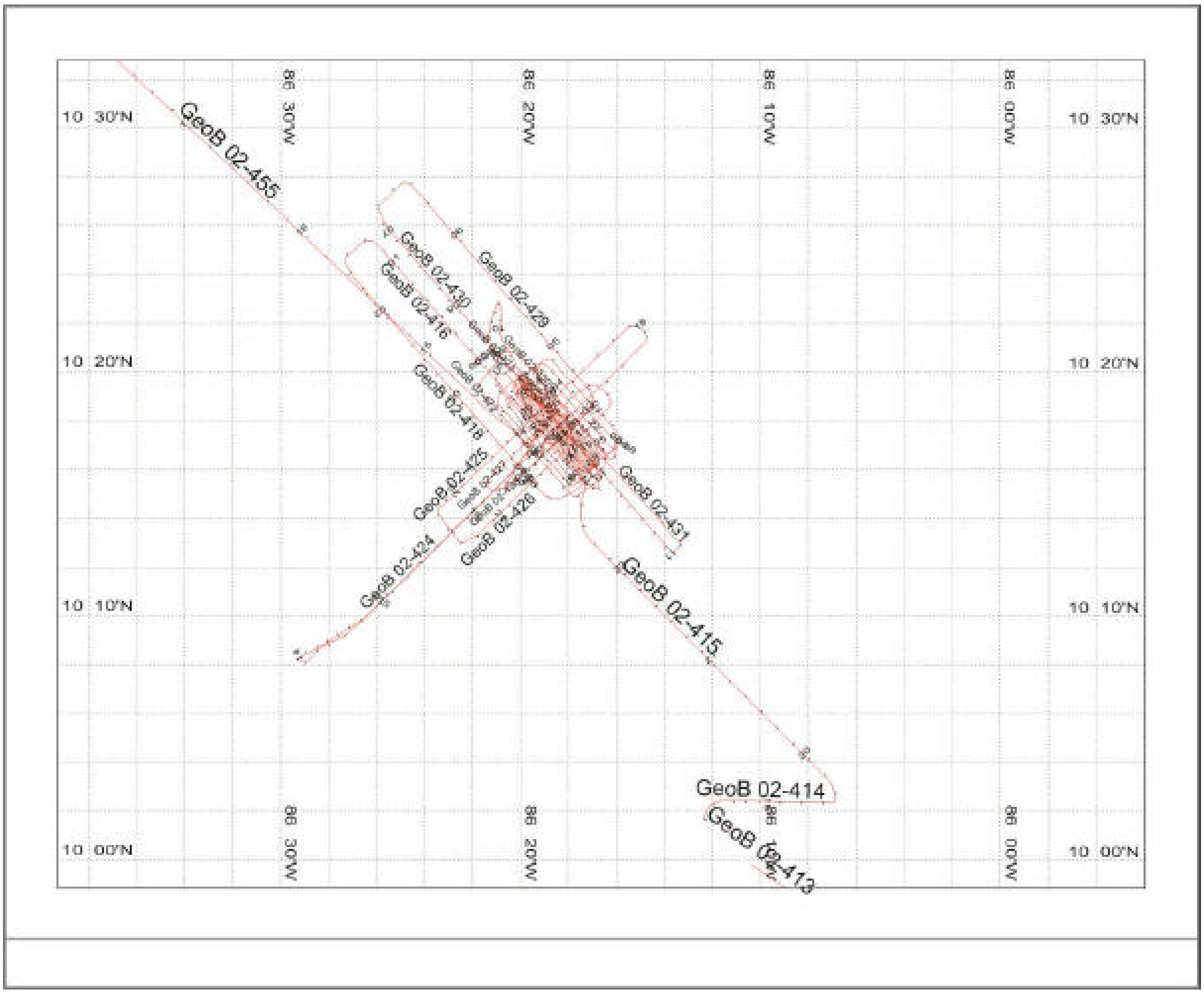

Figure 13: Seismic track chart of the Mound Culebra area.

At August 8th, we retrieved to ocean bottom systems successfully, to continue with seismic profiling into Nicaraguan waters towards the Northwest and across the subduction zones onto the oceanic plate. The track was crossing a number of assumed mound structures, which we often found associated with indications for recent activity also in the seismic data. The final target were the graben of the subduction zone, which is more than 5000 m deep, and the numerous normal faults on the oceanic plate, which would also be the first target for the subsequent M54/2 cruise to look for fluid flow from the oceanic crust.

Just 24 hours before the final port call of the cruise, we finished the seismic survey work in the morning of August, 9th. On August, 10th, we reached Caldera, to finish a very successful cruise in this region, which hopefully has also provided sufficient new information for the subsequent cruises to find appropriate sampling and sea floor investigation sites.