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Frode Ringdal (ed.)

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6.3 The International Polar Year 2007-2008 Project “The Dynamic Continental Margin between the Mid-Atlantic-Ridge System (Mohn’s Ridge, Knipovich Ridge) and the Bear Island Region”

6.3.1 Introduction

In 2005, NORSAR submitted to the International Polar Year (IPY) Organization a proposal for a project with the title ”The Dynamic Continental Margin Between the Mid-Atlantic-Ridge System (Mohns Ridge, Knipovich Ridge) and the Bear Island Region”. The submission was made on behalf of a consortium consiting of NORSAR (lead institution), the University of Bergen, the University of Oslo, the Alfred Wegener Institute in Bremerhaven, the University of Potsdam, the University of Warsaw and the Institute of Geophysics-Polish Academy of Sciences, Warsaw.

This proposal was supported by the IPY Organization and became one part of the proposed IPY project cluster “Plate Tectonics and Polar Gateways in Earth History (PLATES & GATES)” (http://www.platesgates.geo.su.se/). In 2006, NORSAR submitted the full proposal to the Norwegian Research Council (NFR), which awarded the project as one of the 26 Norwegian IPY projects after an additional reviewing and selection process with in total 6 000 000 NOK.

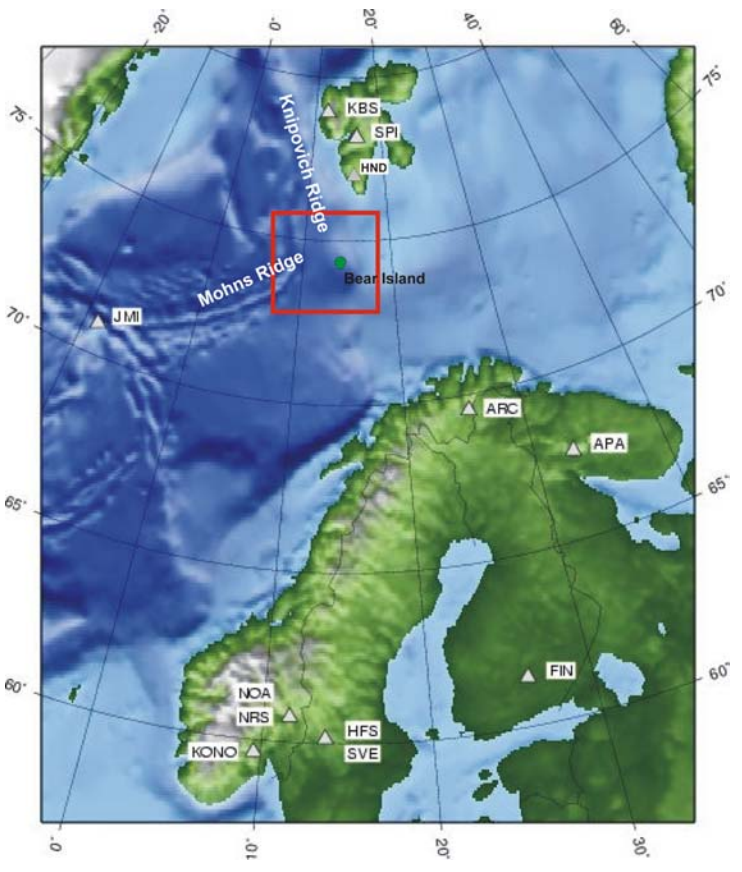

Fig. 6.3.1. Map showing the area of interest for this project (red rectangle) on the background of the main tectonic elements. Grey triangles show locations of seismic arrays and seismic stations of major importance for the project.

The project started as planned in 2007 and this contribution will give an overview on the principal project objectives and the planned or already carried out field activities. The official project webpage (http://www.norsar.no/seismology/IPY/) is regularly updated.

6.3.2 Project Background and status of knowledge

The continental margin along the northern Atlantic Ocean (Fig. 6.3.1) has been extensively studied in the past by active and passive seismic experiments (see e.g., Husebye et al., 1975; Mitchell et al., 1990, Bungum et al., 1991; Sellevoll et al., 1991; Eiken, 1994; Høgden, 1999; Bykjeland et al., 2000; Faleide, 2000, Faleide et al., 2000; Mjelde et al., 2002). These studies have shown that a complete understanding of continental margins is only possible, when also the deeper crustal and mantle architecture beneath the margins is recovered.

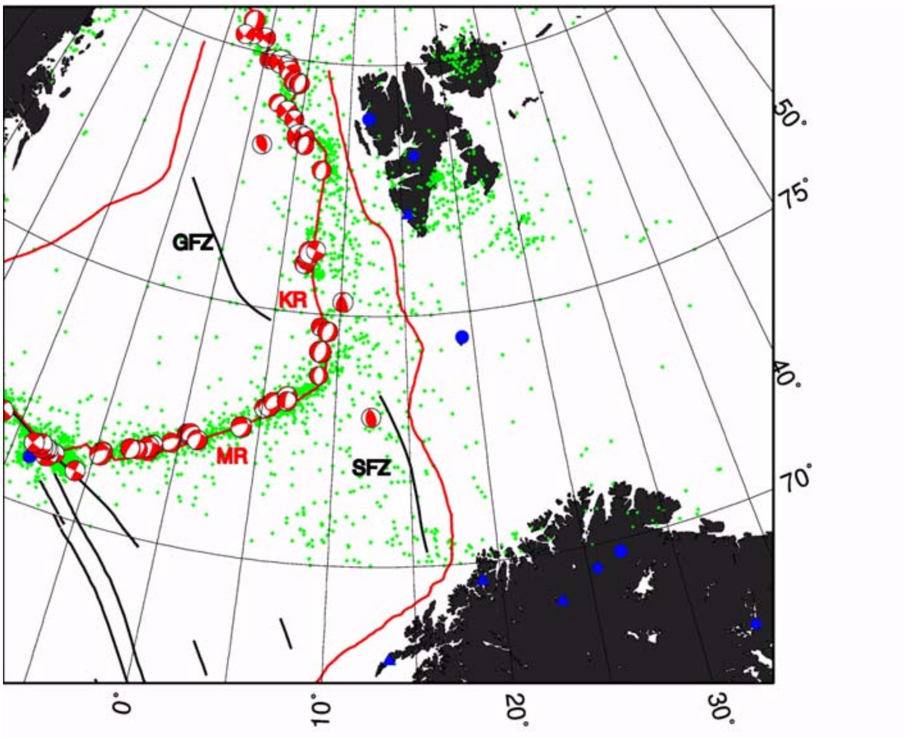

Fig. 6.3.2. Seismotectonic map of the region of interest. The red lines show the continental slope (margin) and the mid-Atlantic ridge with Mohns Ridge (MR) and the Knipovich Ridge (KR), the black lines show main tectonic fracture zones, namely the Senja Fracture zone (SFZ) and the Greenland Fracture Zone (GFZ). The fault-plane solutions are copied from the Harvard CMT Catalogue (1976–09.2001) for events with magnitude M > 4.7. The blue points, triangles and diamonds show locations of permanent seismic stations (broadband stations, short period stations, and seismic arrays, respectively) in the region. The small green dots show all locations of seismic events north of latitude 70˚, as far as they are published in the ISC catalogue for the period from 1900 until the end of 1999.

The western Barents Sea – Svalbard continental margin developed mainly as a sheared margin in response to the Cenozoic gradual northward opening of the Norwegian-Greenland Sea (Faleide et al., 1991, 1993, 1996, Breivik et al., 1999). A rifted margin segment associated with volcanism southwest of Bear Island links sheared margin segments to the south and north. Repeated tectonic and volcanic events at this margin segment reflect a complex plate tectonic evolution of the adjacent oceanic basin involving jump(s) in the spreading axis. The continentocean transition occurs over a narrow zone and is covered by a thick sedimentary wedge comprising major depots (submarine fans) along the margin.

The Senja Fracture Zone (SFZ) extends from the Norwegian mainland to the area west of Bear Island, and is generally interpreted as a sheared margin segment resulting from the Early Eocene opening of the North Atlantic (Fig. 6.3.2). The present-day active oceanic spreading ridge, the Knipovich Ridge (KR), gradually approaches the West Spitsbergen sheared margin obliquely northwards, and we consider the study area as a key region for revealing the continental breakup processes. Furthermore, the area is essential for understanding the interplay between accretion of oceanic crust and passive (sheared) margin formation further north, where the eastern part of the ridge crest is covered by a thick sedimentary wedge.

On the western side of the KR the Greenland Fracture Zone (GFZ) can be addressed as a similar structure. However, this fracture looks simpler than the SFZ because it does not define in addition the border between continental and oceanic crust.

Mohns Ridge (MR) (Fig. 6.3.2), which is nearly perpendicular to the KR and the SFZ, has a strike pointing directly to the continental margin. Therefore, it has been proposed that the MR is migrating further to the east and possibly into a relatively weak continental lithosphere. Recently achieved surface-wave-tomography results show relatively low S-wave velocities in this region (Levshin et al., 2005; 2007). A detailed knowledge of the lithospheric margin dynamics, from its top to its bottom, is needed there, and our experiment will focus on this.

The very slow spreading KR shows an active but diffuse seismicity pattern and no clear alignment of earthquakes along active segments or transform faults (Fig. 6.3.2). In addition, the deep sea between the mid-Atlantic ridge system and the continental margin of the Barents Sea show an unusually high but diffuse seismicity. It is unclear if this is an artefact due to location uncertainties of the events or an expression of the interaction of the ridge with the nearby continental margin. The observed seismicity appears to correlate with the distribution of young (< 2.3 mill. years) sediments in the major fans along the NE Atlantic margins (Byrkjeland et al. 2000).

Because of the large distances between this seismically active area and the installed seismic 3C broadband stations and arrays in the region (ARCES, Apatity, BJO1, JMIC, KBS, KEV, SPITS) (see Figs. 6.3.1 and 6.3.2) and the relatively high noise level at many of the stations due to the ocean generated microseisms, the epicenter locations of the events in the region around Bear Island are currently associated with relatively large errors. Moreover, there is little control on the event depths and in addition the regional seismicity reported by the ISC has a relatively high cut-off magnitude at about M = 4. Therefore, new well-located (lower magnitude) events will dramatically improve our capabilities to understand the seismicity and seismotectonics of this region.

Only a few earthquake source mechanisms have so far been estimated for this region. They all come from larger events for which moment-tensor solutions could be estimated from globally distributed stations. More and better focal mechanism solutions, either estimated with standard methods or full moment tensor inversions, are necessary to characterize the active structures near the ridge, in the oceanic crust between the ridge and the shelf region and in the shelf region itself. Of particular interest is here the northern “tip region’’ of the SFZ. It is not known whether the SFZ intersects with the narrow margin near Bear Island and whether it may be somehow connected with the Knipovich-Mohns-Ridge system. If so, a seismogenic stress release on this fracture zone could bear a major potential for the triggering of submarine slides. In fact, major slides have been identified along the southern part of the Barents slope and the Lofoten-Vesterålen slope (Dehls et al., 2000). Focal solutions are also important to understand the crustal stress field in the region. To a first order, stress is extensional along the ridge system and compressional on Svalbard (Mitchell et al., 1990). The state of stress on Bear Island is however not known and moreover it is unknown if the transition from extensional to compressional stress may be occurring in the region of our experiment. Mitchell et al. (1990) have proposed that ridge push forces are controlling this stress transition.

6.3.3 The project objectives

Within the PLATES&GATES consortium, the proposed project will aim at improved understanding of the structural architecture, the stress conditions and sources, and the dynamics of the continental margin near Bear Island. This will be accomplished by:

- Improved determination of earthquake hypocenters along the mid-Atlantic ridge system (Mohns Ridge, Knipovich Ridge), within the oceanic basin between the ridge systems, and along the continental margin to identify active tectonic structures.
- Investigation of possible migration of seismicity along Mohns Ridge towards the continental shelf, and to investigate the reactivation potential of the Senja Fracture Zone.

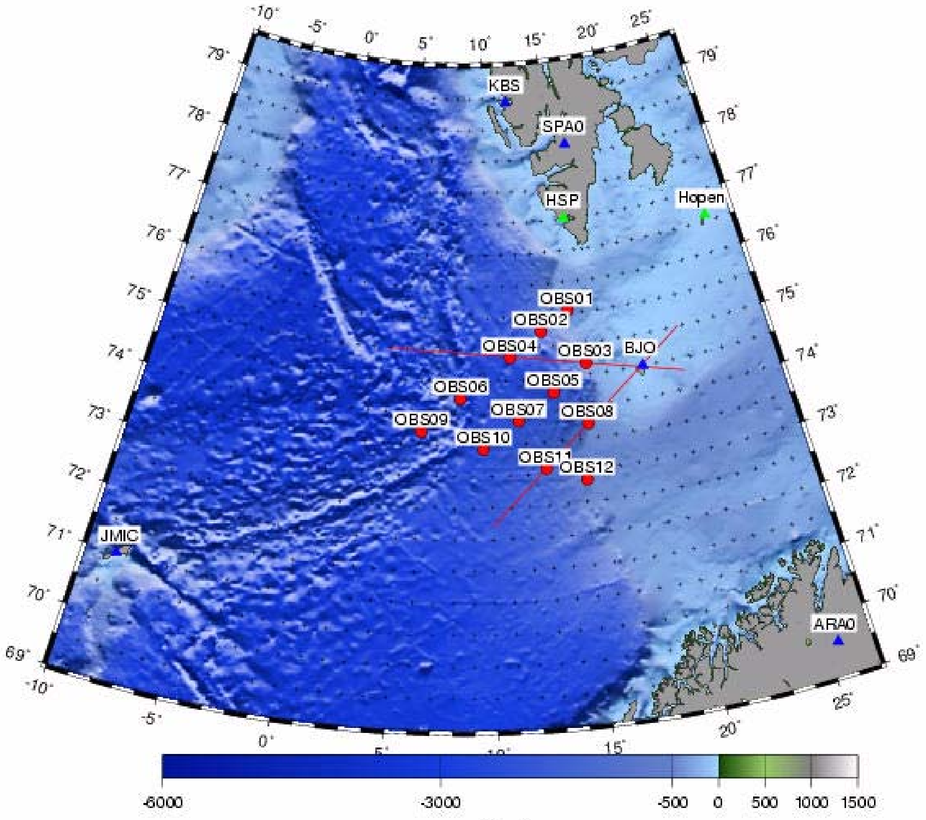

Fig. 6.3.3. Positions of the different instrumental (planned) installations during the field experiment: Red points OBSs, green triangles broadband stations on Hopen and at Hornsund, near the blue triangle the Bear Island array, and red lines the reflection/refraction profiles.

- Mapping of crustal deformation of the continental margin in a region of steep slopes with a high potential for geohazards such as submarine slides.
- Detailed recovery of the lithospheric structure from active experiment data, surface wave analysis, receiver-function methods, and S-wave anisotropy assessment.
- Calculation of focal mechanisms (standard methods and full moment tensor inversions) to investigate details of the faulting processes and to understand better the complex regional stress field in this region.
- Contribute to more detailed knowledge of seismic velocities to advance our understanding of the crustal composition and to improve the accuracy of existing and future earthquake locations in the region.

6.3.4 The (planned) project

This project is divided into two main parts. The first phase is the active / passive experiment and the second phase will be devoted to data processing and interpretation. The combination of active and passive experiments and the data from the distributed seismological arrays and stations will provide a unique opportunity to study the region of interest.

The passive experiment will monitor the seismic activity and thereby the actual tectonic stress field of the region by mapping regions of active seismicity and estimating the needed fault plane solutions.

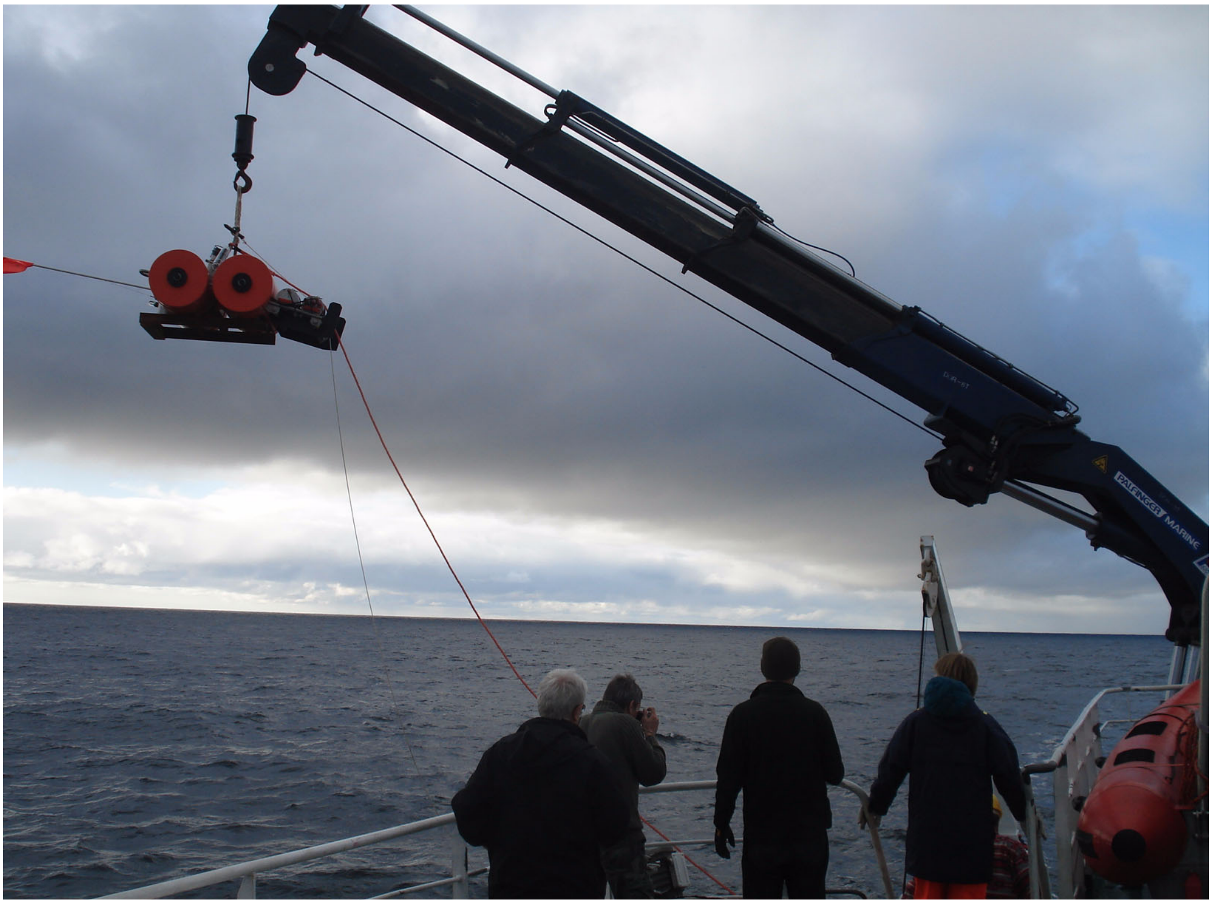

Fig. 6.3.4. Watering of one of the 12 OBSs (Photo: Frank Krüger, University of Potsdam).

The active profiling experiment will provide detailed information about the velocity structure and the distribution of major geological and tectonic elements down to the upper mantle. This information will then be utilized in (re)locating all seismic events in the region on the basis of a new, improved velocity model for the region.

First Phase: The Field Activities (2007 – 2008)

1) Installation of 12 broadband ocean bottom seismometers (OBSs) provided by the German pool for amphibian seismology (DEPAS, http://www.awi-bremerhaven.de/php/GPH/link-web.php?page=obs). The 12 OBSs have been installed at the end of September 2007 in the deep sea from the mid-Atlantic ridge system (MR, KR) to Bear Island, and along the continental margin to the north to form a profile of stations together with the new broadband station at Hornsund and the existing stations on Svalbard (see Fig. 6.3.3). The OBSs have been deployed by colleagues from the University of Potsdam, the Alfred Wegener Institute, KUM (Kiel), and the staff of the polish vessel HORYZONT II, which had been hired by the Polish Academy of Sciences, Geophysical Institute. The disassembly of these 12 stations is planned for autumn 2008 after the planned active experiment. Fig. 6.3.4 shows the deployment of one of the 12 OBSs.

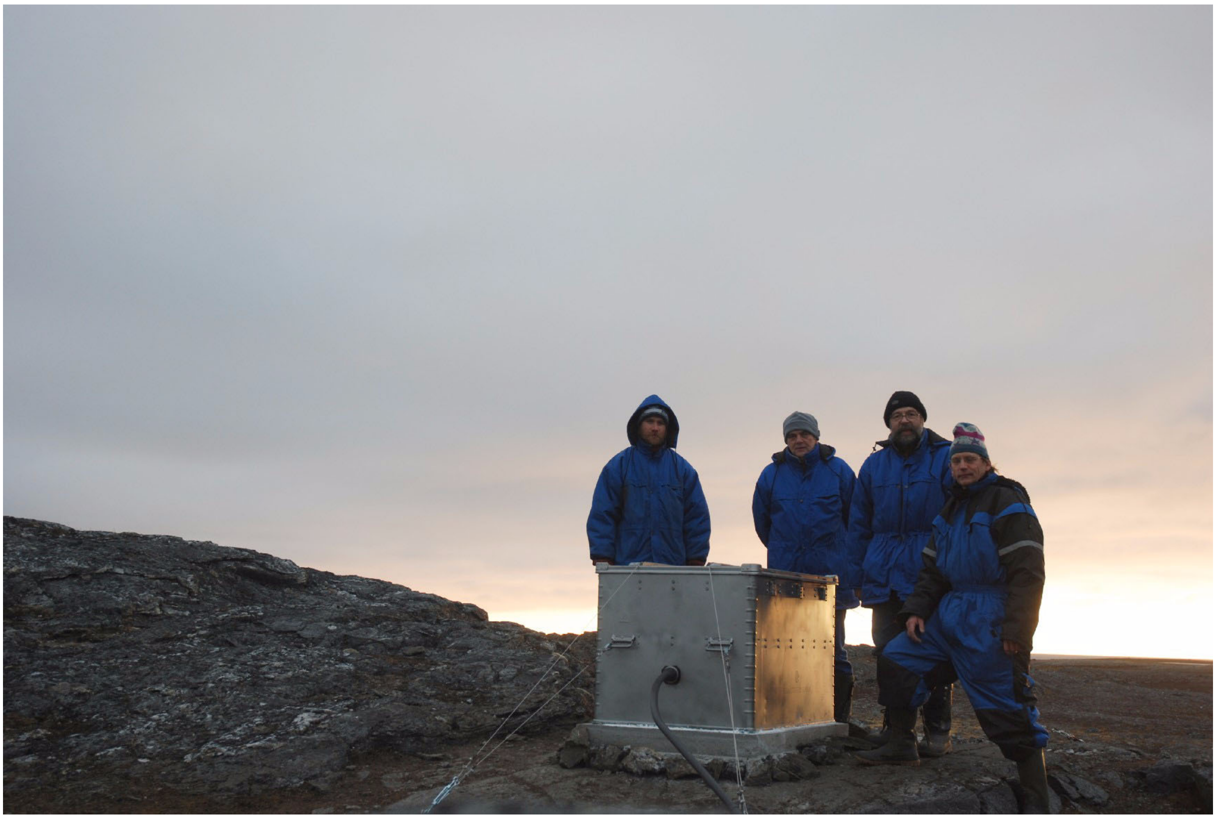

Fig. 6.3.5. The new STS-2 site at the Polish Polar Station Hornsund with the installation team (from left) Michal Sawicki, Andrzei Skizynski, Jerzy Suchcicki (all Geophysical Institute of the Polish Academy of Sciences, Warsaw), and J. Schweitzer.

2) Installation of two new STS-2 broadband seismometers (green triangles, Fig. 6.3.3) one at the Polish Polar Station Hornsund on Spitsbergen (HSP) and one on Hopen Island. Both new stations are operating in parallel to the 12 OBSs since late September 2007.

The STS-2 broadband seismometer at Hornsund has been installed in close co-operation with colleagues of the Geophysical Institute of the Polish Academy Sciences. Fig. 6.3.5 shows the new broadband site at Hornsund, which had been especially prepared for minimizing the influence of the temperature changes and protecting against humidity and Fig. 6.3.6 shows the recordings from this site of a small (NORSAR ml = 2.6) event at an epicentral distance of about 60 km close to the southern tip of Spitsbergen (2007/11/30, 12:14:03, 76.602° N, 16.967° E).

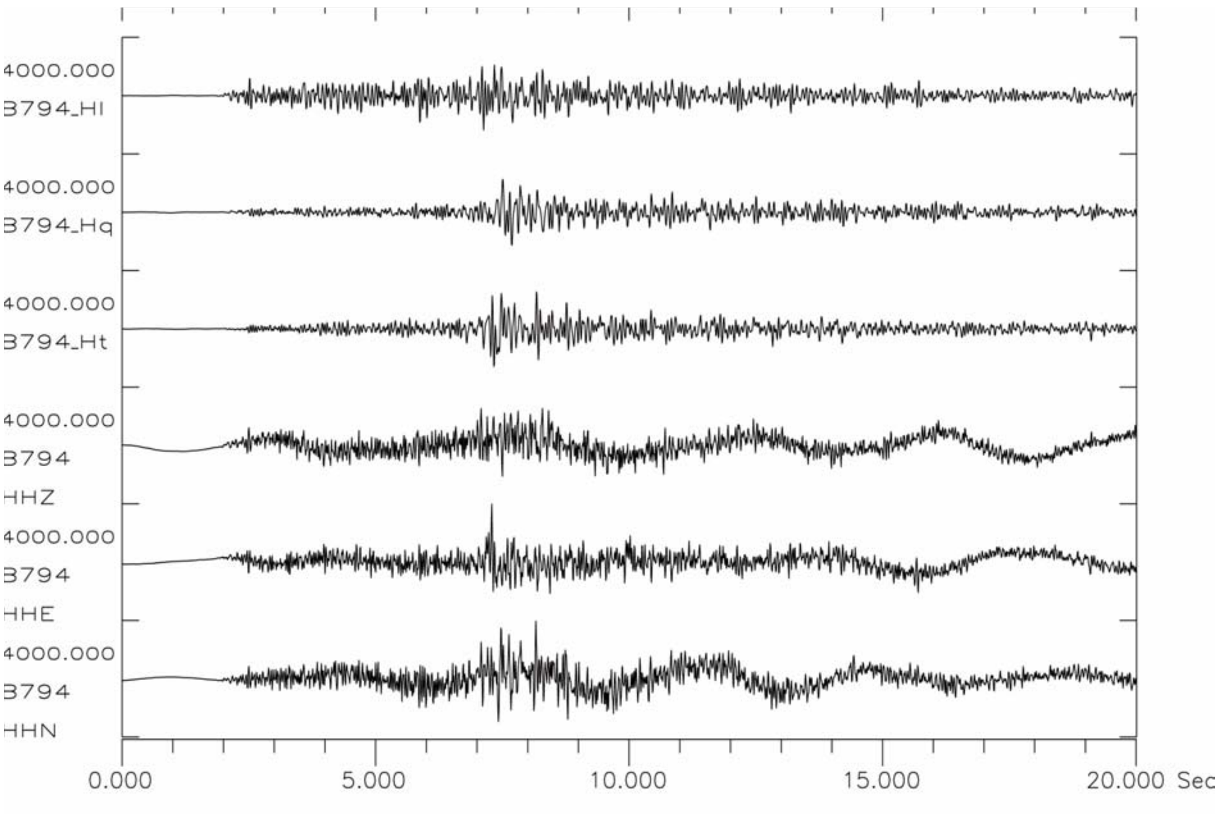

Fig. 6.3.6. STS-2 records from the newly installed broadband station at the Polish Polar Station Hornsund. The plot shows as lower traces the original three-component recordings and on top ray-oriented rotated and Butterworth bandpass filtered (1 - 20 Hz) components.

3) The broadband seismometer on Hopen Island has been installed as an upgrade of the existing Norwegian National Seismological Network (NNSN) short period seismometer by the University of Bergen. Fig. 6.3.7 shows the new installed STS-1 at the Hopen site.

4) Installation of a small seismic array (13 three-component seismometers) on Bear Island (close to the blue triangle on Bear Island in Fig. 6.3.3) for the summer season 2008 (University of Potsdam). It is planned to install the array in late May, 2008. However, because of the snow and ice conditions on Bear Island, the installation of this array may be delayed until late June, 2008. We plan to operate the array until September / October, 2008, depending on access possibilities of the island.

Fig. 6.3.7. The newly installed STS-2 broadband sensor at the NNSN station Hopen (Photo: Helge Johnsen, University of Bergen).

5) An active seismic refraction/reflection experiment along two profiles crossing the margin and Bear Island (see the red lines in Fig. 6.3.3). The plan is to observe the airgun shots and small yield explosion sources fired along these two lines with about 50 short period seismometers temporaly installed along the costa of Bear Island (University of Warsaw and Polish Academy of Sciences), a 3 km long digital multichannel streamer, and 10 – 15 OBSs (both provided by the University of Bergen). The active experiment is planned for late summer / autumn 2008. Both profiles of about 450 to 500 km length will start about 20 to 30 km east of Bear Island and continue in a westward direction from the island. In addition, gravity and magnetic data will be acquired.

The first profile is planned to the northwest, crossing the continental margin and the KR at about 75˚ North. The second profile will go to the southwest in direction of the sedimentary wedge covering the (unknown) continuation of the SFZ. In addition, all active sources along these two profiles will be also observed with the temporary small aperture array on Bear Island, the ocean bottom network, the about 50 Polish mobile stations on Bear Island, and depending on the source yield with the arrays and the single three-component stations on Hopen, Spitsbergen and in Northern Fennoscandia.

Second Phase: The Data Processing and Analysis (2008 – 2010)

The groups in Bergen and Warsaw have a long tradition and expertise in collecting and interpreting refraction and wide-angle reflection seismic data. Standard analysis tools for modelling and travel-time tomography will be used to analyze the data. Gravity and magnetic data will further constrain the density model and help to identify structural anomalies.

In addition, the observation of the active sources with seismic stations will give us valuable data to calibrate the installed seismic network, but also the permanent stations, which observe these sources (Taylor, 1999; Schweitzer, 2000). It is known (e.g., Schweitzer, 2001) that backazimuth and slowness observations of seismic phases as recorded by small aperture arrays, have to be calibrated. The calibration of the Bear Island array will be a special part of the planned data analysis at NORSAR.

One main goal of the analysis is to obtain a 3D structural and geological picture of this continental margin. Therefore, the data from the passive experiment will be analyzed using seismological techniques like receiver function analysis for P and S waves, S-wave splitting, and surface wave dispersion analysis, to map in more detail the crustal thickness in the area, to investigate the stress distribution in the lithosphere, and to retrieve mean S-velocity models outside the profiles of the active experiment, in particular along the continental margin.

All new data will be integrated with the existing geophysical and geological data that the University of Oslo has compiled and interpreted during more than 25 years of margin studies in the region. The goal is to build a 3D geological model for the study area. High-resolution bathymetry data and high-resolution shallow seismics are important tools to study the neotectonic structures on the seafloor.

Efforts will also be made to identify and study potentially unstable sediment masses along the continental slope, as expressed by shallow micro-earthquakes indicating neotectonic faults. In the geological past giant debris avalanches have occurred in the area of investigation. Such events may potentially re-occur today, leading to flood catastrophes (tsunamis) and other geohazards. In this context the two reverse-faulting earthquakes, as reported in the Harvard catalogue, are of special interest. They may have occurred at shallower depths than estimated by the seismological data centers, thereby indicating larger movements in the sedimentary cover of the oceanic crust.

Johannes Schweitzer
The IPY Project Consortium Members

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