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Gas Hydrate Drilling Conducted on the European Margin

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Jürgen Mienert and Petter Bryn

Since 1996, the Norwegian government has licensed hydrocarbon exploration in seven deep water areas on the continental slope north of the Norwegian Trough. Data acquired in this region, which is of interest to both scientists and the oil industry, provide an opportunity to improve understanding of the geology and development of the area through Quaternary times. Gas hydrates, slope stability, and geohazards are especially important topics for research near the Norwegian Trough.

Seismic reflection data revealed gas hydrates in the marine sediments. A bottom simulating reflector (BSR) is believed to represent the base of the gas hydrate stability field. Questions remain about whether the seismic expressions of gas hydrates and free gas can be confirmed by drilling, and if so, what the concentration of gas hydrate and free gas is in the pore space of the sediment. Humankind's influence on global climate is likely to initialize chain reactions that are not well understood; therefore, the probability and order of magnitude of future greenhouse gas releases from oceanic gas hydrates need to be determined.

Past and Current Research

The European North Atlantic Margin (ENAM) project, funded by the European Commission since 1996, serves as a bridge between the academic institutes and the oil industry for mapping and interpreting gas hydrates and sediment slides on the Norwegian deep water continental margin. ENAM and the Norwegian oil company consortium Seabed Project exchange knowledge and information gathered by both groups and jointly plan new field activities. The oil companies use state-of-the-art multichannel two- and three-dimensional seismic records to study the distribution of gas hydrates, and they plan to investigate further by drilling (Figure 1). A team from GEOMAR has developed and deployed a High-Frequency Ocean Bottom Hydrophone (HF-OBH) data logger to determine in situ, small-scale changes in compressional wave velocities from near-vertical and wide-angle seismic experiments (Figure 2) in areas that possess gas hydrates and slope instabilities [*Mienert and Posewang*, 1997; *Mienert et al.*, in press].

Over the past 10 years, the Universities of Tromsø, Bergen, Oslo, and Kiel have collaborated to study the Norwegian continental margin. The main focus has been on understanding the composition, distribution, and stability of the thick Quaternary deposits found along this margin, in particular, the composition and formation of the large deep-sea fans. Emphasis has also been placed on mapping the various types of mass movements, both spatially and temporally, to eluci-

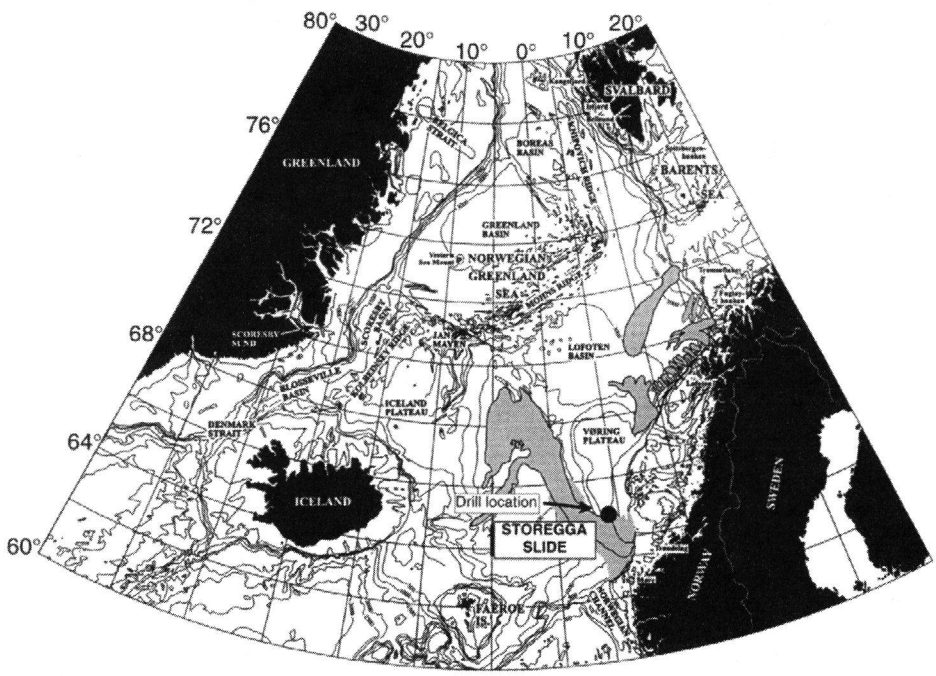

Fig. 1. The Norwegian-Greenland Sea continental margins showing the major slides on the Norwegian margin (in gray) [Vorren et al., *in press] and the location of the drill site north of the Storegga slide.*

Jürgen Mienert, Geomarine Research Center (GEOMAR), Wischhofstrasse 1-3, Building 8C, D24148 Kiel, Germany; and Petter Bryn, Norsk Hydro, Postboks 200, N1321 Stabekk, Norway

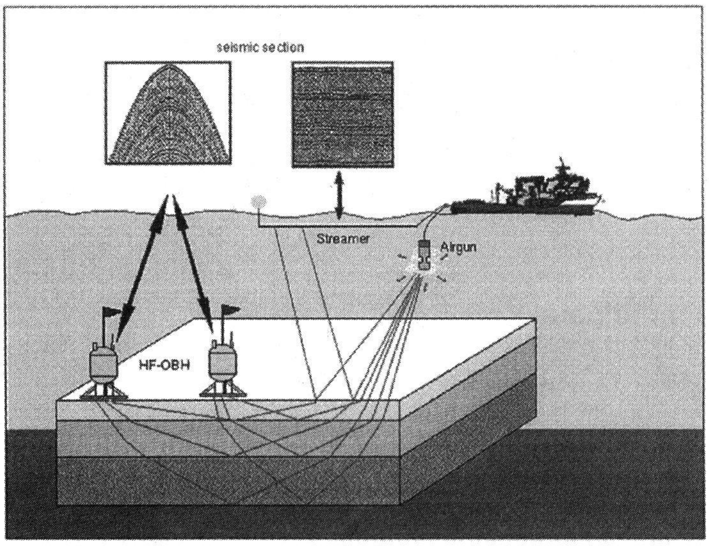

Fig. 2. Schematic diagram of the near-vertical and wide-angle seismic reflection experiments to study gas hydrates and free gas zones in sediments below the sea floor.

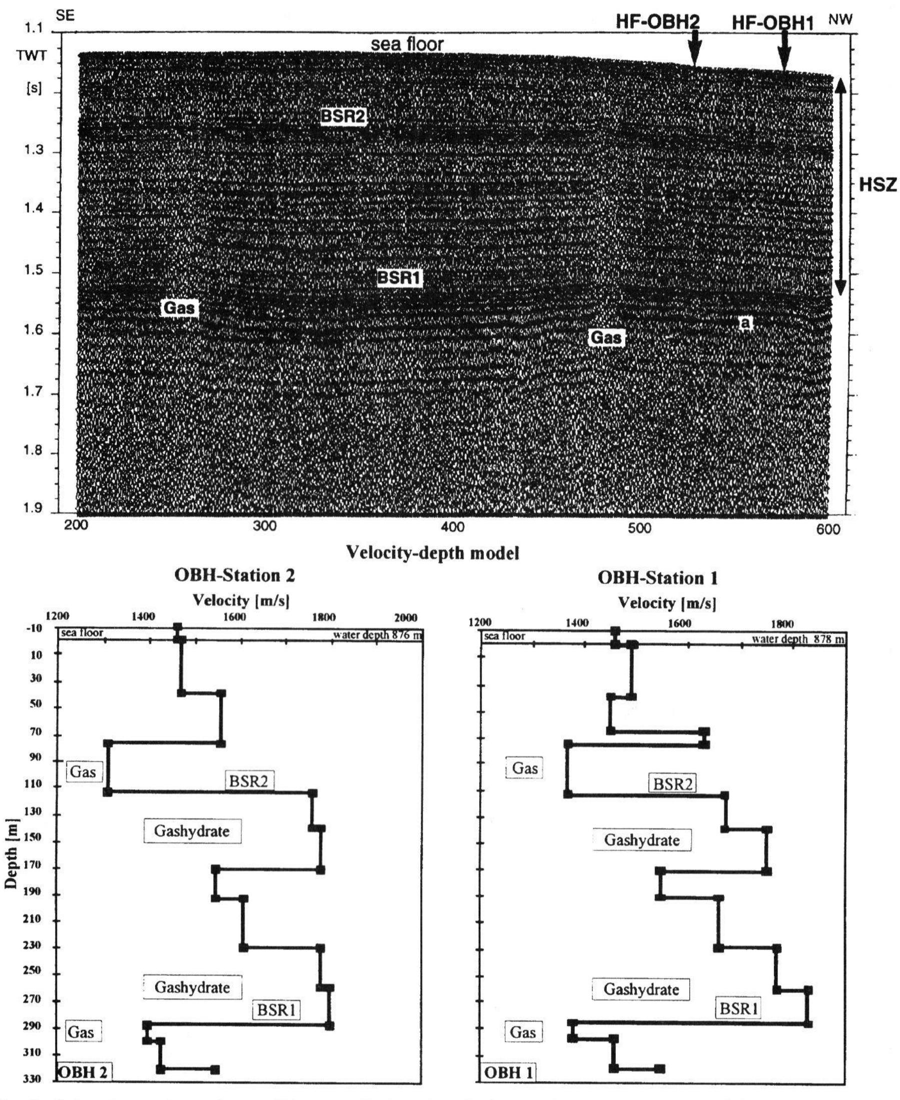

Fig. 3. Seismic section of a profile recorded with a 6-channel streamer using a 2-liter airgun as a sound source and changes of compressional wave velocity versus depth for HF-OBH stations 1 and 2. Studying changes of compressional wave velocities in marine sediments is one way to detect free gas (velocity below the speed of sound in water) and gas hydrates (velocity above the "normal velocity") in the sediment column.

date their mechanism and the frequency of downslope movement.

With regard to slope stabilities and hazards, the distribution and destabilization of gas hydrates are particularly important to study. Previous gas hydrate studies on the Vøring Plateau show that gas hydrates and fluid escape features occur in patchy fields [*Andreassen et al.*, 1990; *Mienert et al.*, in press]. Their level of stability or instability is still unknown.

A key to understanding the causes of patchy distributions of oceanic gas hydrates and how they influence continental slope stability and rapid climate change is the reaction of gas hydrates to temperature and pressure changes. This reaction leaves behind an image in the sediment that can be deciphered and traced back to past changes in the environment. The present location of oceanic gas hydrates is directly determined by temperature and pressure changes since the last ice age. Currently, we do not understand how specific changes in temperature and pressure cause natural gas hydrates to dissolve or the rate at which this occurs. Some correlations have been noted, however, and new models have been proposed [*Mienert and Posewang*, 1997; *Hovland et al.*, 1997], but additional field work is needed to test these models.

Preliminary results demonstrate that during the Quaternary, high sediment was periodically input to submarine fans along the Barents Sea margin and outside the North Sea [e.g., *Laberg and Vorren*, 1996; *King et al.*, 1996; and *Vorren et al.*, in press]. These fans, which are essentially built from debris flows, formed in association with the glaciation of the adjacent shelf areas. Areas between the fan are characterized by hemipelagic sedimentation with extensive mass movement, like the Storegga and the Traendjupet slides. In these areas, gas hydrates have been observed on seismic records. HF-OBH deployments within these areas show clear indications of gas hydrates and free gas within the gas hydrate zones (Figure 3).

Objectives of the Project

The project has four goals:

- to improve the understanding of chronology, paleoenvironment, and stability of Quaternary sediments along the Mid-Norwegian continental margin;
- to determine the distribution of gas hydrates and their destabilization in relation to margin instabilities;
- to develop numerical models for submarine slides regarding mechanics;
- and to establish close contact with oil companies working on this margin for the exchange and interpretation of data.

To maximize the use of existing and forthcoming results, current studies must be consolidated and the interpretation of ENAM and industry acoustic data must be expanded. This will particularly focus on mapping, mass movements, fluid/gas escape features, and other geological processes that are reflected in the upper sedimentary layers. Coordinated geophysical surveys will investigate sediment cores from the same area and three-dimensional seismic profiles from the upper sediment layer obtained by industry, which will involve compiling and reducing multibeam and high-resolution side-scan sonar data.

Project Organization

The project is a cooperative effort between ENAM and the oil industry. Focus on the continental margin and slope stability along the Vøring Plateau and outside the Norwegian Trough is planned.

Other Related Studies

Other studies have been undertaken from the Norwegian to the Celtic Margin (not shown in Figure 1) in cooperation with a number of universities from other European countries. The overall objectives are to quantify and model large-scale sedimentary processes and material fluxes and to assess their relationship to the variability of oceanic and cryospheric processes. Determining the timing, causes, and flow behavior of mass wasting events and the relationship between mass wasting events and deep-sea fan developments will help us better understand the spatial and temporal variability of marine systems from the shelf edge to the continental slope and the deep sea. The work areas involved in these studies encompass, from north to south, four margin sectors: Spitsbergen to the Vøring Plateau, Vøring Plateau to the North Sea fan, Faeroes/Shetlands to Hebrides, and Porcupine Bank to the Celtic Sea Margin. Basic morphodynamic features and sedimentary processes of the ocean margin at these key features allow high-resolution studies of the formation and timing of the processes and their products.

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Expedition Gathers New Data on Crust Beneath Mexican West Coast

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J. J. Dañobeitia, D. Cordoba, L. A. Delgado-Argote, F. Michaud, R. Bartolomé, M. Farran, R. Carbonell, F. Nuñez-Cornu, and the CORTES-P96 Working Group

During the spring of 1996, scientists explored the North American plate boundary of southern Mexico and the Gulf of California through the Crustal Offshore Research Transect by Extensive Seismic Profiling (CORTES-P96) experiment (Figure 1a). Through dense sampling of the plates, the new data provides images that unravel the style of deformation along and across the subduction zone and in the Gulf interior, the dimensions of the accretionary prism, and the geometry of the subduction zone, which is well constrained by the reflection and refraction records. The subduction process along the south coast of Mexico, in spite of the high seismic risk that it represents, is poorly constrained due to the lack of high-resolution data. This project is aimed at resolving the crustal architecture in a zone of confronted plates.

For more information, contact J. J. Dañobeitia, Consejo Superior de Investigaciones Científicas, Institute of Earth Sciences, "Jaume Almera," Lluís Solé i Sabarís s/n, 08028, Barcelona, Spain.

The Spanish R/V *Hespérides* was responsible for multichannel seismic profiling (MCS) and the coordination of three research vessels and land crews. The Mexican R/Vs *Altair* and *Humboldt* were in charge of Ocean Bottom Seismometers (OBS) and explosive source deployment, respectively. More than 3000 km of MCS, 3700 km of potential field (gravity and magnetic), swath bathymetry, and backscattering data were acquired. A 10-airgun array shooting every 30 s was the source for the MCS, recorded with a 2400 m streamer. Moreover, 35 OBSs and 50 landstations provided a densely sampled (one trace every 80 m), wide-angle seismic reflection data imaging the oceanic-continental transition zone. Just south of the mouth of the Gulf of California, the Pacific margin of North America is defined by active subduction.

From south to north, the tectonic setting changes from a pure subduction regime (Cocos plate) throughout a transpressive system along the Gulf of California to a pure transform setting (the Pacific plate and North America slide along the San Andreas fault system). MCS profiles perpendicular and parallel to the Middle American Trench offshore between Zihuatanejo and Manzanillo reveal a smooth dip-angle of subduction and relatively thick sediment (0.5 s) in the Cocos plate at the trench (Figure 1b). A high amplitude reflection indicates the top of the subducting slab at 7 s. The base of the inner wall shows a poorly developed accretionary prism. Approaching the trench, the ocean floor displays structural directions slightly different from the trend of the actual oceanic spreading center, suggesting that the subducting plate was not accreted at the spreading center.

Offshore Puerto Vallarta, between 20 and 20.5 N, 11 OBSs were deployed for three weeks to detect microearthquakes associated with the edge of the Rivera plate (Figure 1a). A preliminary stacked section of MCS profile 203 over the OBSs shows an apparent truncation of the gently dipping oceanic crust east of the trench axis (Figure 1c). A clear image of the oceanic plate was obtained between 6 and 7 s for more than 10 km beneath the Jalisco Block (Figure 1c). At 200 to 300 m beneath the sea floor, the image of a strong subhorizontal reflection appears along the platform and the slope of the margin. The shape and characteristics of this reflection are typical of bottom simulating reflectors, representing hydrates, which are observed in most of the East Pacific margins. The wide-angle data from profile 205 also shows the top of the oceanic crust at a mean depth of 4.5 km beneath 1 km of sediments (Figure 2). The dip angle decreases from 12°, measured at the south of the area, to about 7° to 8° at the northern edge where subduction seems