Sea floor stability offshore Lofoten, Northern Norway (LOSLOPE)

A PETROMAKS FP by the University of Tromsø (UiT)

Main objective
The main objective of this research project is to evaluate the present-day seafloor stability of the continental slope offshore Lofoten, Northern Norway (Figure 1) for a safe and environmentally sustainable hydrocarbon exploration. The main objective will be achieved through: detailed studies of sea floor morphology, sedimentology and geotechnical properties of the sub-sea floor sediments in a key area in order to elucidate mass movements, their age and origin, and consequences for slope stability conditions.

Frontiers of knowledge and technology
The continental slope off Norway has been affected by numerous large submarine landslides including the Storegga Slide (Bugge et al., 1987; Evans et al., 1996, 2005; Forsberg and Locat, 2005; Kvalstad et al., 2005; Solheim et al., 2005), the Trænadjupet Slide (Laberg and Vorren 2000; Laberg et al., 2002, 2003, 2006; Laberg and Camerlenghi, 2008) and older, buried slides (Rise et al., 2006). One of the largest gas fields offshore Norway, the Ormen Lange gas field, lies within the Storegga Slide. In order to evaluate the risk and consequences of future mass wasting processes (including submarine landslides, landslide-generated tsunamis) that could endanger sea floor installations and pipelines, an in-depth and multi-disciplinary investigation of the slide scar morphology, resedimentation processes and age of the landslide events of the Storegga Slide were performed, to address the triggers and pre-conditional factors, but also the recurrency of submarine landslides in this particular setting (Bryn et al., 2005; Solheim et al., 2005).

Figure 1: Bathymetric map of the northern Norwegian continental margin including the outline of the study area.
Both the Storegga Slide and the Trænadjupet Slide are very large submarine landslides (i.e. wide, deep and with a large volume of sediments involved) inferred to have been triggered by low probability and very large earthquakes due to the isostatic rebound of Fennoscandia during the present interglacial (Kvalstad et al., 2005). Whereas the mechanisms leading to failure of these large events have received considerable interest (Canals et al., 2004; Sultan et al., 2004), little attention has been paid to the smaller but more frequently occurring landslides, some of which involves deformation of a weak layer only a few meters below the sea floor.

Smaller events occur on the continental slope offshore Lofoten, northern Norway. The continental slope in this area has so far received little attention and is thus hardly explored. New swath bathymetry data reveal several landslide escarpments. The slide scars vary in shape, depth and freshness (Figure 2), indicating a long record of mass wasting history.

*Figure 2:* Swath bathymetry of the study area showing the upper part of several slides. Slide A and the location of Figure 3 are indicated.
A detailed study of one of the slide scars, Slide A and the nearby areas using high-resolution deep-towed side-scan sonar, reveals a complex interplay of mass movements and resedimentation processes. In addition to a more detailed image of the upper slide scar of Slide A, side-scan sonar data illustrate that part of the surrounding sea floor is characterised by alongslope-oriented and lineated fabric (not seen on the swath bathymetry), likely indicative of sediment creep (Figure 3). Another slide scar slightly to the south-west of Slide A affects only the upper few meters of the sea floor sediments. Also here indications of sediment creep and an associated pattern of larger fractures of unknown origin has been identified (Figure 3).

The main focus of this project will be to study the past and present mass movements and resedimentation processes on the continental slope offshore Lofoten. The investigation will be based on an extensive multi-disciplinary data set, comprising multi-beam swath bathymetry, high-resolution side-scan sonar data and high-resolution seismic records, most of which are already in the data base at the University of Tromsø. In addition, gravity and piston cores will be acquired at key locations carefully selected from investigating all available geophysical data. The cores will be investigated using standard sedimentological techniques. Physical properties and geotechnical testing (ring shear tests, triaxial tests, direct simple shear and/or consolidation testing) will be undertaken at the Norwegian Geotechnical Institute. Here, special focus will be to identify, characterise and explain the

**Figure 3:** Side-scan profile MAKAT-158 (30 kHz) across the upper part of Slide A (Fig. 2) and the nearby areas. The data display several areas affected by sediment creep and large fractures of unknown origin. The location of Figure 4 is indicated.
origin of a possible weak layer located only some meters below the sea floor (Figure 4), i.e. using geotechnical properties to assess present-day regional slope stability.

**Research tasks, approach, methods and international co-operation**

Studies of selected parts of the continental slope offshore Lofoten will focus on:
- What kind of mass movement processes can be identified?
- How and why were the sediments remobilised?
- Are there any layers of weakness in this area and what is their origin?
- What are the age, frequency and volume of the remobilised sediments?

**Research approach and methods**

Based on newly acquired multibeam echo-sounder data (Figure 2) and side-scan sonar records (Figure 3) together with high-resolution seismics, a morphologic and seismostatigraphic analysis of selected parts of the continental slope will be undertaken, in order to identify mass movements, their ages and origins. These data will form the basis for the acquisition of gravity and piston core samples for sedimentological and

**Figure 4**: Part of a high-resolution seismic profile across two submarine slides. The bases of both slide scars are located only some meters below the sea floor. They are parallel to the acoustically laminated signature of this area and thus may have their origin in a regional layer of weakness. This layer will be one of the key core targets of the project. For location of the profile, see Figure 3.
geotechnical studies of the remobilised sediments and the possible so-called “weak layer” that may have acted as a glide plane (Figure 4). Based on the high-resolution seismic data, our study area should be a suitable location where the weak layer can be sampled using a conventional piston corer, as it is located only some meters below the sea-floor.

**Project organisation and management**
The project will be led by Prof. Tore O. Vorren, University of Tromsø. Together with Research scientist Dr. Jan Sverre Laberg, post. doc. Matthias Forwick, Dr. Carl Fredrik Forsberg and Dr. Maarten Vanneste they will comprise the steering group of the project. The side-scan sonar data were acquired in cooperation with Prof. M. Ivanov, Moscow State University who also will be involved in the project. One PhD student, Nicole Baeten will work full time on the project.

**References**


