GEOPHYSICAL, ORGANIC GEOCHEMICAL, BIOGEOCHEMICAL AND MICRO-BIOLOGICAL STUDIES OF THE BARENTS SEA SEABED

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Since 2007 Lundin Norway has developed an extensive seabed investigation program focusing on seabed morphology and its relation to mapped subsurface geology, habitats for different life-forms, geohazards that might be relevant to future drilling, but also features that can be directly related to petroleum exploration and high-grading deeper hydrocarbon reservoirs. The main study area in this context has been the Barents Sea, especially around current Lundin-operated exploration licenses. To date Lundin Norway has collected several thousand km^2 of multibeam echosounder data, high resolution interferometric synthetic aperture sonar data (HISAS), millions of black and white and colour photographs of the seafloor, hundreds of drop cores and dozens of biological, carbonate crust and physical gas samples.

The seafloor data collected during a number of surveys spanning the period 2008 to 2016 have yielded important observations about the nature of the seabed such as pockmarks, iceberg plough marks, glacial prod marks, carbonate crusts, bacterial mats and ongoing/past gas seepage. These observations have provided the basis for interpretation of seabed morphology and its relation to mapped subsurface geology, habitats for different life-forms and geohazards that might be relevant to future drilling, but also features that can be directly related to petroleum exploration and mapping of deeper hydrocarbon reservoirs. The data acquired provides an overview of the seabed state before any field development has taken place. This provides an important snapshot in time that can be used to assess how the area is responding in terms if fauna damage/change to the field development and ensuring that when installation decommissioning occurs in the far future the area is restored to original faunal conditions.

Seafloor samples (gravity cores, grab samples, carbonate crust) from inside and outside pockmarks have been studied using an interdisciplinary approach by applying geophysical, organic geochemical, biogeochemical and microbiological methods. Most observations indicate that the majority of seafloor features related to gas or liquid seepage are inactive at present. Their origin is presumably connected to gas hydrate decomposition during the last ice-sheet retreat, involving unloading of the sedimentary sequences and temperature increase. Detailed examination and sampling of active gas leakage sites (identified by sonar and high resolution seabed mapping) using remotely operated vehicles (ROV's) has revealed strong thermogenic gas leakage occurring today. In such sites the carbon isotopic signals obtained from carbonate crusts indicate that they were formed by metabolisation of the gas via anaerobic methane oxidation. Thus, carbonate crusts can be used to identify and distinguish sites of thermogenic vs. biogenic gas leakage. Thermogenic gas-derived carbonate crusts have additionally been dated using the Uranium-Thorium method, and ages between 8 and 15 thousand years dominate, but also younger ages occur commonly. These results point towards multiple episodes of gas leakage in the (geologically) recent past.

Sites of active thermogenic gas leakage were found by an initial study targeting areas based on seismic evidence of shallow gas or gas leakage avenues (gas chimneys, faults, bottom-simulating reflectors indicative of gas hydrates). In many cases, seafloor depressions were identified in close spatial relationship to shallow gas pockets, such features were then targets for hull mounted multibeam echosounder surveys which often managed to identify gas flares in the water column. However, sonar-identified gas flares were not always visible as gas-bubbling features when investigated by ROV, indicating possibly an episodic nature of these features.

Sites of active gas leakage are characterised by abundant macro- and micro-fauna, as well as extensive occurrence of microbial mats. Such sites are hot-spots of biological activity, as also evidenced by abundant fishing related trawl marks on the seafloor. Repeated investigations of exploration well sites before and after drilling operations revealed a rapid re-colonisation of the seafloor which had been disturbed by e.g. anchor chain placement and removal or disposal of drilling returns to seabed. Geochemical analyses (GC, GCMS) of shallow sediments at such sites are characterized by the occurrence of both thermogenic and recent organic matter signals. Sites with associated petroleum prospectivity (mapped prospects) and seismic anomalies, but lacking evidence of active seepage, tended to show strong signals of the occurrence of hydrocarbon oxidizing bacteria in shallow sediment samples (drop cores, grab samples).

It is our belief that this approach of integrating seafloor data with more traditional geophysical tools as well as biological sampling significantly enhances our understanding of the dynamic processes occurring in and controlling present and past petroleum seepage in an arctic environment.

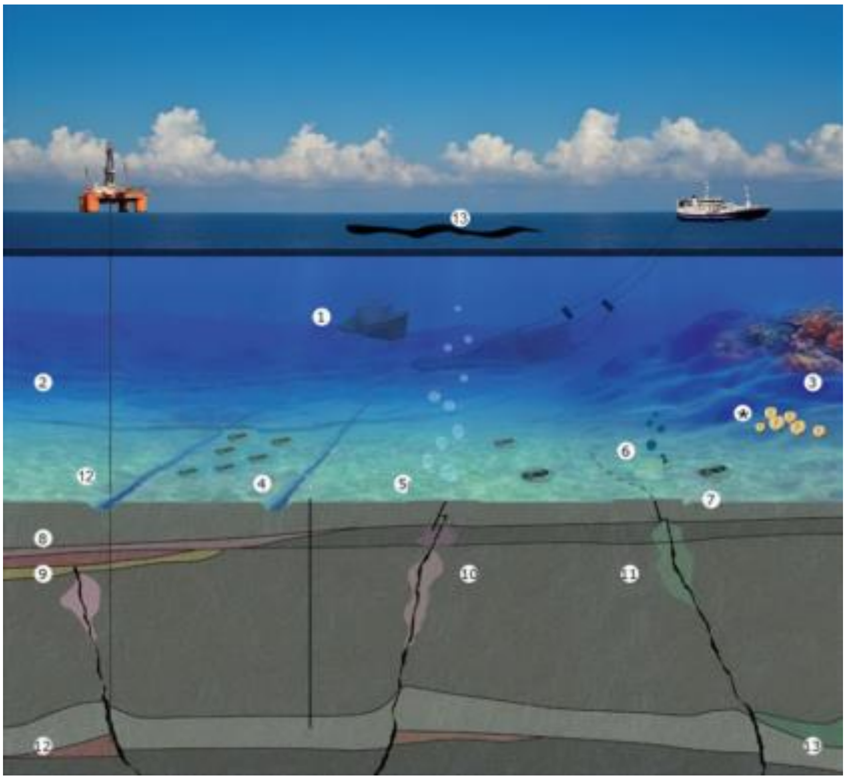

Figure 1 *Study objects of the seabed investigation program: 1. Ship wrecks and disposal sites. 2. Bottom trawling marks. 3. Deep water reefs. 4. Plow marks. 5. Gas seeps. 6. Oil seeps. 7. Pock marks. 8. Gas hydrates. 9. Shallow gas. 10. Migration of gas along faults. 11. Migration of oil along faults. 12. Old boreholes. 13. Oil slicks.*