1. Objective and sub-goals

The main objective is to model the isostatic response of Cenozoic glaciations, sedimentation and erosion on the Norwegian continental shelf, and to constrain consequences for petroleum systems.

This objective will be met by the following sub-goals, providing crucial input to the modelling:

- More complete knowledge on timing and extent of glaciations through the Plio-Pleistocene.
- Improved understanding and quantification of glacial depositional and erosional processes.
- Expanded knowledge on the interaction between the Fennoscandian, the Barents Sea, and Kara Sea ice sheets and their crustal influence through the last glacial cycle.

Two contrasting areas will be studied: the Barents Sea region, which is characterized by uplift through the late Cenozoic, and the northern North Sea, a region of late Cenozoic subsidence.

2. Frontiers of knowledge and technology

Hydrocarbon exploration in the SW Barents Sea has been rather unsuccessful so far, as the traps seem to have experienced partial or complete drainage of hydrocarbons. Glacial erosion during the Plio-Pleistocene (~2.7-0.11 Ma) is regarded to be one major cause for this. Rapid erosion and subsequent differential uplift and tilting is commonly envisioned to have lead to spillage of hydrocarbons, phase transition from oil to gas, expansion of gas, seal failure, cooling of source rocks, and slope instability. In addition to glacial erosion, repeated ice and sediment loading have had great influence on hydrocarbon migration routes and the temperature history, i.e. hydrocarbon transport and maturation. Large gradients in Plio-Pleistocene subsidence rates and overburden are also of importance for understanding the location of hydrocarbon reservoirs in the North Sea region. Such knowledge will be of specific importance when exploring for new smaller accumulations in the region. Detailed control on the glacial erosion, sediment deposition and ice load (i.e., the glacial history) is therefore an important and insufficiently utilized factor for identification of the remaining hydrocarbon resources in both regions. In the following, we detail our proposed program by synthesizing these elements within a novel, integrated approach.

Although Norwegian and foreign research groups have made great progress in terms of reconstructing the history of the Barents Sea, the North Sea and the Eurasian ice sheets during the last two decades, the application of an integrated approach including the use of industry 3D seismic data in combination with existing/new borehole, 2D seismic and onshore data as proposed here opens a new avenue for a better understanding of the history of the marine based parts of these ice sheets. With greatly improved geological boundary conditions for modeling the isostatic response of Cenozoic glaciations, a better understanding of the processes responsible for affecting the petroleum systems can be achieved.

While the extent of the last glaciation and its influence on the shorelines are mapped in some detail, relatively little is known about the precise timing and extent of older glaciations, except that the maximum Saalian glaciation (~0.140 Ma) had a larger southern and eastern extent than any of the subsequent Weichselian glaciations (Svendsen et al. 2004). Quantitative estimates show that there
has been a huge redistribution of sediment mass in Scandinavia and the Barents Sea over the last few million years, but the timing of events and processes involved are uncertain. 3D seismic data in combination with existing/new boreholes, 2D seismic and onshore data can provide more reliable information on the extent of glaciations in space and time (see tasks A & B). In addition, the processes involved can be better constrained (Fig. 1) (Larsen et al. 2003, Andreassen et al. 2004, Rise et al. 2004). The extensive use of such data in the two target areas will allow the establishment of more reliable models for older glaciations. This will provide a new baseline for modelling the isostatic response of Cenozoic glaciations and their potential impact on the stability of petroleum reservoirs.

![Figure 1: Style of maximum type glaciations within three periods of the Pleistocene (Larsen et al. 2003).](image)

Glaciers, sediments and erosion act as loads on the Earth’s surface – positive or negative. When a load is applied to the lithosphere covering the asthenosphere, part of the applied load will be supported by the elastic stiffness of the lithosphere, and part by the buoyant forces of the asthenosphere. The rate of viscous subsidence into the lithosphere is different for different size of load. The Earth's response to the last deglaciation in Fennoscandia (e.g. Ekman, 1991, Milne, 2001, 2004, Marotta 2004, Bergstrand 2005) has been modelled by using a layered viscous model overlain by an elastic lithosphere (Fjeldskaar, 1994, 1997, Fjeldskaar et al. 2000a, b). By using the strength of the lithosphere determined from the post-glacial uplift, the isostatic effect of the erosion/deposition can be calculated (Fig. 2C, from Fjeldskaar, unpubl). The isostatic movements will influence the sedimentary basins on the Norwegian continental margin. Areas overlain by thick

![Figure 2: Mapped Late Tertiary erosion (A) and deposition (B) of Northern Europe (from Amantov, unpublished; red colours indicate high degree of erosion/deposition), and subsequent theoretical isostatic response (C; from Fjeldskaar, unpublished; yellow to redish colours indicate uplift, blue to redish colours indicate subsidence).](image)
ice domes (or thick sediments) will experience more severe movements than peripheral areas, thus potentially tilting existing reservoirs. The influence of the ice load on the petroleum reservoirs has been modelled: when the lithosphere is uplifted (or downwarped) the hydrocarbon migration and trapping may be adversely affected (Sales 1992, Corcoran & Doré 2002). It was shown by Kjemperud and Fjeldskaar (1992) that as much as 30% of the closure volume might be lost during the most extensive glacial events.

3. Research tasks and deliverables

The three research tasks defined below, will address three crucial effects of glaciations for petroleum reservoirs: 1) **Timing and extent** of glaciations through the Plio-Pleistocene, 2) **Glacial erosion** has caused isostatic uplift, and 3) **Glacial deposition** has caused isostatic subsidence.

**Task A: Erosion and deposition in the North Sea.** Since the development of the ice age theory, there has been a more or less continuous debate on the possible glaciations of the North Sea. Early interpretation of the extent of the Fennoscandian and Hiberno-British ice sheets into the North Sea basin were mainly based on inferences from sites bordering the North Sea, the general morphology (bathymetry) of the North Sea, and surface sediment distribution from depth soundings and dredges (Charlesworth 1931). Some global reconstructions (e.g. CLIMAP 1981) placed an ice mass between the Hiberno-British and Fennoscandian ice sheets at the Last Glacial Maximum (LGM), while more recent ones have not (e.g. Peltier 1994, Shennan et al. 2002). Observations of deep incisions on the North Sea seafloor, and the interpretation as subglacial/ice-proximal features have been taken as evidence for glaciations of the North Sea and their distribution has been used in constructing maps of extent of grounded ice (Flinn 1967, Wingfield 1990, Huuse & Lykke-Andersen 2000). From the studies of core data and 2D seismic it has been suggested that the central North Sea has been glaciated (Stoker and Bent 1985, Sejrup et al. 1987, Sejrup et al. 1994). Recent work by one of our collaborators (Lidia Lonergan) using 3D seismic investigation of tunnel valleys in the central North Sea concludes that they are indeed subglacial meltwater channels, thus requiring an ice cover at their time of formation. Also, new research carried out along the continental margins, including recognition of end moraines and glacial fed debris flows (Bulat & Long 2001, Nygård et al. 2004), strongly suggest that the NW European margin from Ireland to Svalbard was covered by glacial ice to the shelf edge during LGM.

Detailed investigations of core and acoustic data suggests that the first occurrence of an ice stream following the Norwegian Channel took place at ~1.1 Ma (Sejrup et al. 1994, 1995) and from Marine Isotope Stage (MIS) 12 (~0.460 Ma) the Norwegian Channel Ice Stream has apparently been active during each glacial stage (Nygård et al., in press). For the central North Sea, the first evidence of glaciations have been found within the Aberdeen Ground Bed and dated to ~0.900 Ma (Stoker et al. 1985; Sejrup et al. 1987). Mapping programs have provided a regional seismostratigraphic framework both for parts of the Norwegian sector and for the UK sector (Rise 1984, Gatliiff et al. 1995). The present project will compile new and previously published data from the northern North Sea in order to quantify erosion and deposition through the Pleistocene. An important element in this project will be to utilize 3D industrial data in order to determine genesis and geometry of the Pleistocene units in selected areas (cf. Rise et al. 2004). We will also conduct one cruise with the new well equipped research vessel "G.O. Sars", focusing on collecting high resolution acoustic data (including Topas) in order to better link new and previously published core data with the seismic stratigraphy. The work will be concentrated in two regions: 1) The Norwegian Channel, from off Stavanger to the North Sea Fan, and 2) From off Stavanger across the North Sea Plateau to the Fladen area (in collaboration with scientists from BGS, University College of London and University of Sheffield). From this work we will provide estimates of deposition (in the major depocenters in the region) and erosion for two time intervals: 1) From first glaciation of the North Sea (~1.1 Ma) to MIS
Task B: Erosion and deposition in the Barents Sea region. A compilation of timing and extent of the Barents Sea glaciations during the last glacial cycle was recently made by Svendsen et al. (2004). The reconstruction shows how erosional and depositional patterns varied during the last ~0.140 Ma. In particular, the geomorphology and sediment records both offshore and onshore in this region provides an excellent potential for the understanding the dynamics of coastal glaciation, the history and locations of fast flowing ice streams, and sedimentation through glacial periods (Vorren et al. 1991, 1998, Hjelstuen et al. 1996, Faleide et al. 1996, Laberg and Vorren 1996, Kleiber et al. 2000, Landvik et al. 1998, Larsen et al. 2003). However, to fully understand the erosion and depositional pattern in the area, it is of vital importance to obtain information on timing and extent of previous glaciations and to develop coherent glaciation models for the last ~2.7 Ma. So far, relatively little is known about glaciations older than the Saalian (before ~0.140 Ma) (Svendsen et al. 2004). The first indications for large-scale glaciations in the northern Barents Sea are ~2.7 Ma old (e.g. Eidvin et al. 1993, Knies et al. 2002), while repeated ice advances to the shelf break may have occurred since ~1.6 Ma west of Svalbard (Butt et al. 2000). A recent study of industry 3D seismic data reveals detailed images of glacially eroded surfaces and deposits at the southwestern Barents Sea margin, covering the last ~1.4 million years (Andreasen et al. 2004), and provides a new type of information about the earliest Pleistocene glaciations. The seismic structure of the northwestern margin suggests at least sixteen glacial advances during the last ~1 Ma (Solheim et al., 1996), while Sættem et al. (1992) and Laberg and Vorren (1996) found indications for five major ice advances in the southwestern part over the past 0.440 Ma. The Cenozoic erosion in the Barents Sea region has been estimated by various methods, showing that in the northwestern part ca. 1500-3000 m of sediment has been eroded, while in the southwest, erosion was apparently less than <2000 m (Nyland et al. 1992, Hjelstuen et al., 1996). As the erosion increased the sediment delivery to the western Barents Sea continental slope increased by about an order of magnitude, compared with a non-glacial environment (Fiedler and Faleide, 1996; Hjelstuen et al., 1996).

With the development of 3D seismic techniques, combined it with bore hole and 2D seismic data, it is now possible to improve the different glaciation models in the Barents Sea and to extend them back in time to cover the entire Quaternary period. An attempt was made in a pilot study from the Barents Sea region (Fig. 1, Larsen et al. 2003) indicating that the first glaciations (until 1.5 Ma) were probably limited to onshore Scandinavia, the Svalbard/northern Barents Sea area and other Arctic highlands. Most of the central and southern Barents Sea area was ice-free. After this stage, until ~0.5 Ma, there was a period with colder climate leading to glacier expansion, in which there probably was no contact between the Scandinavian and the Barents Sea ice sheets. In the youngest period (the last 0.5 Ma) glaciers grew to the maximum Quaternary size. This model needs testing and verification, and its applicability outside the region of origin needs to be explored.

The work of the present project will be concentrated on two key areas for Late Cenozoic ice sheet fluctuations in the region: 1) the southern Barents Sea, and 2) the White Sea area. Approximately 15000 km² of industry 3D seismic data will be combined with available/new 2D high-resolution acoustic and borehole data. A cruise is planned to acquire high-resolution 2D seismic data to improve ties between the results from areas covered with 3D surveys and the interpreted seismic stratigraphy. In addition, onshore stratigraphic and chronological data will be used (1) to develop coherent glaciation models for the last glaciation, and (2) to construct sea-level curves. The age constraints for the seismic stratigraphic interpretation will be addressed by adding new chronostratigraphic information from existing industry and ODP boreholes in the study area. Finally, we will provide new models for: (1) the interplay of fast flowing ice streams from various ice sheets, (2) the glacial extent and erosion patterns since the onset of glaciations in the Barents Sea, and (3) the interaction of the Barents- Kara- and Scandinavian ice sheets during the last glacial cycle. This
allows a better understanding of the influence of ice streams on ice dynamics, and a quantification of erosional and depositional products in the study area.

**Task C: Modelling.** 1) The Earth’s response to the deglaciation in Fennoscandia (e.g. Ekman 1991, Milne, 2001, 2004, Marotta 2004, Bergstrand 2005, Martinec 2005) is relatively well known, by previous modelling (Fjeldskaar 1994, 1997). This modelling has given information on the rheology of the Earth’s uppermost layers - the effective elastic thickness of the lithosphere and the viscosity of the asthenosphere and the mantle. Thus, the post-glacial period will serve as a model for the way the system works. An important parameter (in addition to the glacier extent) needed for modelling, is the glacier thickness. Different thickness models can be used, and the calculated shoreline response will be calibrated with observed shorelines, to establish models of glacier thickness. When the glacier extent and the glacier thickness are established for selected periods during the Cenozoic, the effect on potential reservoirs will be calculated. This information together with knowledge about older glaciations will be used for determining the isostatic deflections for various glaciation phases in the Barents Sea and North Sea. It was shown by Kjemperud and Fjeldskaar (1992) that as much as 30% of the closure volume may be lost during the most extensive glacial events, because of tilting of the reservoirs. The method that will be used to calculate the tilting of the reservoirs is described in Kjemperud and Fjeldskaar (1992). The modelling will be done in 3D, and the results presented in map view, i.e., more detailed maps of spatial and temporal variability of glacial erosion and deposition. These syntheses will be used as input to a realistic modelling of crustal movement in the two regions through the Plio-Pleistocene.

**Deliverables**

- Georeferenced maps of ice sheet extents in the Barents and North seas during the Plio-Pleistocene and their modelled dynamic response.
- North Sea: Estimation of deposition/erosion for the eastern and central northern North Sea for two time windows (~1.5-0.5 Ma, and <0.5 Ma) and subsidence rates for the northern North Sea during the Plio-Pleistocene.
- Barents Sea: Estimation of deposition/erosion in the southern Barents Sea for the periods ~2.5-1.5 Ma, 1.5-0.5 Ma, <0.5 Ma, and Plio-Pleistocene uplift rates for the central Barents Sea.
- Modelling: Isostatic response of the ice load and deposition/erosion for the Plio-Pleistocene on maps for the central Barents Sea and the central northern North Sea, and on selected 2D cross sections covering the entire basin evolution.

**4. Research approach, methods**

**A. Empirical approaches**

The spatial coverage of industry 3D seismic data is ~15000 km² in the Barents Sea, and ~60 000 km² in the North Sea. These data sets have the potential for providing detailed plan view images of large-scale morphology. The data sets will be used in our target areas and combined with available/new 2D seismic data and borehole information to establish time frames for glaciations and calculations of erosion/deposition. Integration of different types of 3D seismic volumetric and horizon attribute maps with vertical seismic profiles and illuminated shaded relief images of buried horizons are powerful tools for identification and mapping different sedimentary facies (Andreassen et al. 2004). As an example, Figure 3 shows how the combination of different geological approaches can be applied to construct conceptual models of glaciation and erosion.

The 3D seismic surveys (available from Norsk Hydro, Statoil, and Petroleum Geo-Services (PGS)) will be tied to borehole information and stratigraphic framework by using dense grids of
regional 2D seismic data (cf. Fig. 3). The stratigraphic framework for the onset of glaciation, the Northern Hemisphere large-scale glaciation at ~2.7 Ma and the Mid-Pleistocene Revolution between 1.5 and 0.5 Ma will be improved by additional sedimentological (e.g. grain sizes, clay minerals) and chronostratigraphic (stable isotope, paleomagnetic) data from ODP sites 910, 911, 986 and exploration wells 7216/11-1 and 7316/5-1 as well as other published data from the Barents Sea (e.g. Ryseth et al. 2003). For the North Sea, a detailed stratigraphic framework exists that is based on investigations of a number of shallow cores and gravity cores within the two target areas. Especially the BGS cores 81/26 and 77/2 from the Fladen area, B1002 from Sleipner and 8103 from Troll will be of importance. Offshore data will be tied to onshore data from bordering land areas by 2D seismic data. It is especially important to obtain an improved glacial geological model for the entire last glacial cycle based on investigations in NW Russia, and to tie this to the offshore data. The land data give a better resolution than the data from the shelf, and the area selected contains sediments in sections from the Scandinavian, the Barents Sea and the Kara Sea ice sheets that cover the entire last glacial cycle. Focus in the field will be on obtaining stratigraphic and chronological control, estimating former sea-levels (crustal influence), and estimating ice thickness in the different phases. The latter can be addressed by using lower limits of block fields and pre-consolidation of sediments that have been overridden by ice (e.g. Nesje et al. 1987; Larsen et al 1995).

Figure 3. Diagram illustrating that interpreted 2D seismic lines (A) can be tied to interpreted 3D-seismic horizons that are representing buried glacial surfaces surfaces (B). The glaciated surfaces can be used to reconstruct glacial events, that for the younger part of the record is validated by onshore data (C). Three main glacial erosion phases (D) are inferred from the conceptual glaciation model (Fig. 1). E is an example of a buried surface showing glacial lineations. From Larsen et al. (2003).

B. Modelling approaches
Methods and input data. When a load is applied to the lithosphere, part of the applied load will be supported by the elastic stiffness of the lithosphere, and part by the buoyant forces of the asthenosphere. Loads of short wavelength are supported by the lithosphere so that the lithosphere acts as a low pass filter. The characteristics of this filter depend on the elastic strength of the lithosphere. The isostatic model that will be used simulates how the lithosphere supports load through flexure as well as by buoyancy (Fjeldskaar and Pallesen, 1989). An analogue for the lithosphere is a thin elastic plate overlying an inviscid substrate. The thin elastic plate is characterized by its flexural rigidity D, or equivalently by its effective elastic thickness (EET), which we believe represents the mechanically
strong part of the lithosphere in a depth-averaged sense (e.g. Burov and Diamant, 1995). This thickness varies around the Earth from approximately 0 to several tens of km’s mainly caused by variations in heatflow and age of the load (visco-elastic properties). Input data needed for the modelling include the quantified extent and thickness of glaciers in the selected time intervals, and maps of erosion and deposition. The maps for erosion/deposition will be developed in reasonable detail for smaller areas, and with low resolution for the entire region.

Methods and calibration data. For calibration of the Earth model, data on sea level changes (and possibly gravity) will be used. Dated shoreline curves from the time of glaciation will be important for estimation of ice thicknesses, and for quantification of the elastic properties of the lithosphere.

Implications for petroleum systems. The influence of the ice load on the petroleum reservoirs will be modelled. When the lithosphere is uplifted (or downwarped), the hydrocarbon migration and trapping may be affected. The various Plio-Pleistocene stages of erosion and deposition (that will be mapped in the project) will affect the reservoirs in similar ways as the glaciers, but will, generally be of less regional nature than glacioisostasy. The isostatic effect of the mass movement will be modeled in 3D, and the results presented in map view (cf. Fig. 2). Results for areas of particular interest for petroleum prospectivity will be presented in 2D geoseismic cross sections.

5. Project organisation and management

Project organisation and management

The project will be headed by professor Eiliv Larsen (NGU and UiB). Larsen has extensive experience in glacial reconstruction, mainly from onshore Norway and Russia, but also from offshore work in the Barents Sea and the North Sea. He also has extensive experience in coordinating large research programs. Dr. Jochen Kries (NGU) will act as a daily manager and PI, working closely with professor Larsen. The three remaining PI's and heads of partner groups, professor Hans Petter Sejrup (UiB), associate professor Karin Andreassen (UiTø), and professor Willy Fjeldskaar (RF and UiS) holds extensive experience in 2D/3D seismic interpretations, glacial reconstruction and modelling (see enclosure on Professional Competence). Frontier studies as proposed in this project can only be carried out in close alliance with a major oil company, in this case Norsk Hydro ASA (NH), since many of the data sets are not in the public domain. In addition, Statoil and PGS will kindly provide access to 3D seismic surveys. The project will be managed through a steering committee consisting of all PI's and the Norsk Hydro representative. The steering committee will meet twice a year, and is responsible for the overall strategic, including economical, dispositions. A project secretariat at NGU, run by Larsen/Knies, is responsible for daily management, the project database, the reporting to NFR, organization of work-shops/meetings, and contact with the industry partner.

The project will arrange workshops every year for the entire project group, and invited international collaborators. Towards the end of the last year, we will arrange an international meeting, also with partners for the industry, both to present the total outcome of the project, and to put it into an international perspective. Between meetings, the activities will be largely cross institutional, e.g. between Bergen and Tromsø in 3D seismic techniques, between Bergen, Tromsø and Trondheim in geological correlations and interpretations, and between all groups in modeling.
Project group
Geological Survey of Norway (NGU): Eiliv Larsen (PI/Project leader – Regional glacial geology, stratigraphy), Jochen Knies (PI/Project secretary - shelf stratigraphy/evolution), Liv Plassen (2D seismic correlations), Erik Lundin (Tertiary uplift, Scandinavia), Kari Grøsfjeld (Biostratigraphy), Dag Ottesen (shelf stratigraphy), Maria Jensen (Post.doc applied for – Glaciations Russia/Barents Sea, sea level estimates).
University of Bergen (UiB): Hans Petter Sejrup (PI/Member steering committee – regional glacial geology), Hafldi Haflidasonn, (shelf stratigraphy/evolution), Atle Nygård (glacial processes, 3D seismic) and Berit Hjelstuen (margin evolution).
University of Tromsø (UiTo): Karin Andreassen (PI/Member steering committee – 3D seisms, glacial processes), Tore Vorren (shelf stratigraphy, glacial processes), Jan Sverre Laberg (mass movement processes, 2D seisms).
Rogaland Research (RF): Willy Fjeldskaar (PI / Member steering committee – modelling).
Norsk Hydro: Espen Andersen (Norsk Hydro Global Exploration), (Member steering committee)
Norsk Hydro: Ole Martinsen (Norsk Hydro Research Centre) (Member steering committee).

Motivation for post.docs/Ph.D
Task A, UiB: One post-doc is planned for 3D seismic investigations in the North Sea. A special focus for the post.doc will be to tie the 3D seismic results with information from shallow cores by using new and existing high-resolution acoustic data.
Task B, NGU: One post-doc (2x2 years) is planned for sedimentological and stratigraphical investigations in northwestern Russia, and correlations between onshore and offshore stratigraphies. Maria Jensen, University of Copenhagen is our preferred candidate for this position. She is completing her PhD thesis in the spring of 2005. She has worked on sea-level changes and their relations to glaciations in NW Russia.
Task B, UiTo: One post-doc/Ph.D is planned for 3D seismic investigations in the Barents Sea.
Task C, RF: One post-doc /PhD is planned for glacio-isostatic modelling.

6. International co-operation
The persons below are all active partners in the project that have committed time/expertise to this collaboration:
*Dr. Lidia Lonergan, Imperial College London, Department of Earth Science and Engineering, UK (Task A, glaciation, North Sea)
*Prof. Chris Clark, University of Sheffield, Department of Geography, UK (Task A, glaciation, North Sea and Task B, glaciation Barents Sea)
*Dr. Martyn Stoker, British Geological Survey, Edinburgh, UK (Task A, glaciation, North Sea)
*Dr. Igor Demidov, Russian Academy of Sciences, Petrozavodsk, Russia. (Task B, glaciation, Russia).
* Dr. Andrew V. Zayonchek, Geological Institute Russian Academy of Sciences, St. Petersburg, Russia (Tasks B, erosional/depositional processes Barents Sea)
* Dr. Slawek Tulaczyk, University of Santa Cruz, CA, USA (Tasks A/B, ice-stream processes, Barents and North seas)
*Dr. Kurt H. Kjær, Copenhagen University, Denmark (Task B, glaciation, Russia).
*Dr. Jens Matthesessen, Alfred Wegener Institute for Polar and Marine Research, Germany (Task B, Core correlation, biostratigraphy).
*Aleksey Amantov, VSEGEI, All-Russian Geological Research Institute, St.Petersburg, Russia (Task C, isostatic modelling).
* Prof. Larry Cathles, Cornell University, New York, USA (Task C, isostatic modelling).
Important international research initiatives:

* VNIIOkeanologia, Ministry of Natural resources, St. Petersburg, Russian Federation is, together with University of Tromsø asked by a Russian-Norwegian cooperation initiative to develop a plan for a joint project on *Late Tertiary and Quaternary uplift and erosion in the Barents Sea area*.

* The research proposed herein is a core project in a newly proposed European Science Foundation program, APEX – Arctic Paleoclimate and its Extremes.

* The research proposed herein will cooperate closely with two proposed projects to the International Polar Year: 1) NICE-STREAMS (Neogene ice streams and sedimentary processes on high latitude continental margin) lead by University of Tromsø, and 2) Late Mesozoic-Cenozoic tectono-magmatic history of the Barents Sea shelf and slope as a clue to paleodynamic reconstructions in the Arctic Ocean, proposed by the Russian Academy of Sciences.

* The research proposed herein will be suggested as a core project in a European Science Foundation program that is under development, TOPO-EUROPE, which as one of it's themes, will have the development of the North Atlantic continental margin with NGU as a leading partner.

7. Progress plan – milestones

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8. Costs incurred by each research performing partner

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<td>676,000</td>
<td>100,000</td>
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*Running costs all partners: Meetings, cruises, laboratory work, computing etc. In addition, co-ordination (NGU), joint-cruise with UiTø, field work Russia, steering committee meetings.*
9. Financial contribution by partner

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<th>Partner</th>
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<th>2007</th>
<th>2008</th>
<th>2009</th>
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<td>NGU</td>
<td>228.000</td>
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<td>Norsk Hydro</td>
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<td>4.600.000 (24.3%)</td>
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<td>3.026.000</td>
<td>3.076.000</td>
<td>1.654.000</td>
<td>12.561.000 (66.5%)</td>
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<td><strong>Total</strong></td>
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<td><strong>4.649.000</strong></td>
<td><strong>4.599.000</strong></td>
<td><strong>2.382.000</strong></td>
<td><strong>18.886.000</strong></td>
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</table>

10. Relevance for knowledge-building areas

There is a considerable lack of knowledge about the influence the Quaternary glaciations on petroleum systems on the Norwegian continental shelf. A main motivation for this project is to contribute to successful hydrocarbon exploration and development. This may imply large revenues through more focussed exploration strategies by the oil companies. By building new models for the influence of glaciations on hydrocarbon reservoirs, this can be obtained through the proposed research project by the group with complementary expertise.

11. Importance to Norwegian industry

Norsk Hydro has great interest in the project and will actively participate and contribute with financial support (see attached letter of support by Pål Haremø, Chief-Geologist, Global Exploration). Leif Lomo, director of Norsk Hydro's Research Center in Bergen has also expressed strong support to the project. This ensures that in addition to assisting with provision of data, the project is kept in line with industry research and exploration aims, and thus that results are immediately tested and implemented through company strategies. Petroleum Geo-Services (PGS) will contribute to the project by providing free access for the University of Bergen to the shallow column of the MegaSurvey, a mega-scale 3D seismic merge, covering large parts of the North Sea.

12. Relevance for Innovation programmes

The most important contribution of this "Petromaks" - KMB project is within the area of optimal exploration, with special focus on a better understanding and quantification of geological processes for basin development, sedimentation and fluid flow at basin scale both in the North Sea and the Barents Sea. In addition the project will contribute to the understanding of the critical effects of glaciations on petroleum reservoirs.

13. Environmental impact

The project is not expected to have any environmental consequences.

14. Information and dissemination of results

The results will be disseminated to the participating partners in reports and workshops. The results will also be shared with a larger audience through conferences and papers in peer reviewed international journals.

References

Knies, J. et al. (2002). Boreas, 31 (82-93).
Shennan, I. et al. (2002). Quaternary Science Reviews 21, 397-408.