Petroleum Geology of the Barents Sea

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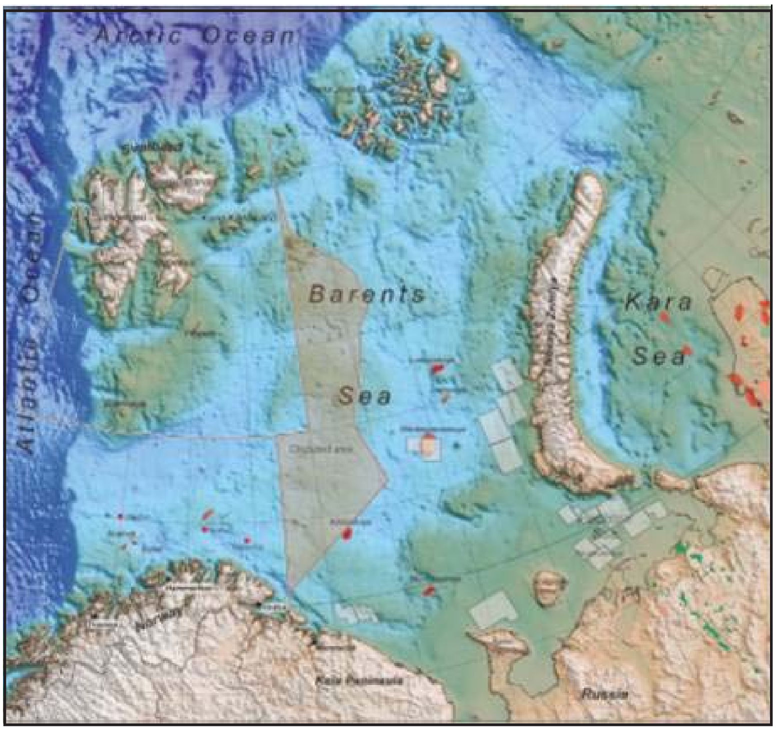

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Bachelor Thesis

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Department of Geology
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Contents

Cover Picture: Statoil takes natural gas from the Snöhvit field and produces LNG at Melkøya (pictured). This is the first major project in the Barents Sea. Production began in September, 2007. *(from Statoil 2008)*

IAN MCGIMPSEY

Petroleum Geologi av Barentshavet

Denna publikation syftar till att skapa en grundläggande överblick av prospektering och utveckling av petroleumtillgångar i Barentshavet. Den är tänkt som en överblick av regionen samt en sammanfattning av dess bassänger, reservoarer, fällsystem och källbergarter.

Prospekteringen av Barentshavet började på 1970-talet, och under 1980-talet gjordes ett flertal större upptäckter. Utvecklingen har varit långsam på grund av en större förekomst av naturgas än olja i området, lågt marknadsvärde på naturgas, geografiska avstånd till potentiella marknader samt logistik, begränsade borrsäsonger samt miljöintressen. Kring millennieskiftet ökade priserna på naturgas väsentligt samtidigt som nyutvecklade tekniker minskade framställningskostnaden av LNG (Liquid Natural Gas). Den ökade kostnadseffektiviteten ledde till utveckling av områdets första stora LNG projekt, Snøhvit, som påbörjade produktion år 2007. Ytterligare ett större projekt kommer att utvecklas inom en nära framtid då Shtokman fältet beräknas påbörja produktion år 2013.

Barentshavet uppvisar stora variationer mellan den norska regionen i väst och den ryska i öst. Den ryska regionen innehar större tillgångar av både gas och olja än den norska. Tektonik och erosion under Kenozoikum har påverkat det västra området mer än det östra, och den norska regionen har därför haft mindre gynnsamma förhållanden för bildande av oljebildande strukturer.

Den påbörjade produktionen i Barentshavet kommer att gynna infrastrukturen samt kunskapen om den regionala geologin, två faktorer som i sig kommer att kunna påskynda vidare utveckling av området. Barentshavet ses av många inom industrin som ett ”hett” område för framtida utveckling och prospektering av fossila bränslen.

Handledare: **Kent Larsson**
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IAN MCGIMPSEY

Petroleum Geology of the Barents Sea

The purpose of this publication is to outline the exploration history and development of the Barents Sea region. It is intended as an overview of the region, summarizing the various basins, reservoirs, trap systems, and source rocks.

Exploration of the Barents Sea began in the 1970s and major discoveries took place in the 1980s. Development has been slow due to the prevalence of natural gas over oil in the region, the low price of natural gas until recently, the distance to potential markets, difficult logistics, restricted drilling seasons and environmental concerns. Around the turn of the century the price of natural gas increased significantly at the same time that new technology was developed that decreased the costs associated with producing Liquid Natural Gas (LNG). Better cost feasibility led to development of the first major LNG project, Snøhvit, which began production in September 2007. The area is poised for another major development in the near future as the Shtokman field is expected to begin producing by 2013.

The Barents Sea varies greatly form the West, Norwegian, side, to the East, Russian side. The Russian side contains much larger reserves of both gas and oil. The Norwegian side has been more affected by uplift during Cenozoic times which caused massive erosion and the expulsion of oil from reservoirs.

The start of production in the Barents Sea will increase the available infrastructure and knowledge of regional geology which should facilitate an increased rate of future exploration. The Barents Sea is considered by many in the industry to be a 'hot' region in the world for future off-shore petroleum exploration and development.

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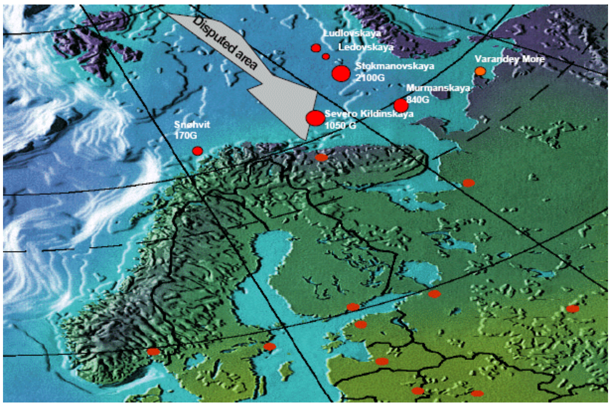


***Fig. 1**. The Barents Sea (from Haraldsen 2003)*

1 Introduction

High in the Arctic waters north of Norway and north-eastern Russia, the frigid Barents Sea has slowly become a hot zone of petroleum exploration and development and is posed to be an important source of gas for Europe and North America well into the new millennium. The Barents Sea covers an area of approximately 1.3 million km^2 and in very rough estimates is expected to contain 25.7 billion m^3 oil equivalents in the Russian sector and another 1.3 billion m^3 oil equivalents in the Norwegian sector (Geoexpro.com 2005). Most of these reserves are expected to be in the form of natural gas as opposed to oil and this has slowed interest in development of the region along with extra costs due to remoteness, lack of infrastructure, and environmental concerns. Recent marketplace changes have made natural gas more economically viable to produce and this combined with technological advancements that have lowered the cost of producing gas from this remote area in the form of LNG (Liquid Natural Gas), have allowed the first production facility in the Barents, Norway`s Snøhvit to come online. The Russian gas field Shtokman will soon follow and it appears this relatively unexplored region is at the beginning of a long maturation process.

1.1 Method

This paper is a review of the petroleum potential for the Barents Sea region. The paper outlines various geological features of the area, known discoveries, the potential for future discoveries, and difficulties unique to the area that may complicate development, such as the extreme environment, a fragile ecosystem and undetermined political bounders. Several papers were used to composite the information, as well as several websites in order to attain the most recent information. Two case studies were examined, Snøhvit and Shtokman. Each of these cases is highly representative of the varying geology and size of reserves found in the Norwegian and Russian Barents Sea respectively. The case studies also highlight the current state of development of the region, including an idea of the direction companies may undertake in the future to retrieve petroleum from the difficult settings found in the Barents.

2 GeologIcal Setting

The Barents Sea was formed by two major continental collisions and subsequent separation. The first event was the Caledonian orogeny, some 400 Ma. The Caledonian foldbelt runs N-S through Scandinavia and the Svalbard Archipelago and mainly influences the western part of the Barents Sea. The Caledonian orogeny is responsible for a N-S structural grain in the western Barents, the NE-SW grain of the SW Barents and Finnmark Platform (Doré 1994), and possibly established the NE trends in the North Barents Basin (Lindquist 1999). The second collision event was the Uralian orogeny, about 240 Ma. Running from East Russia up along Novaya Zemlya, the Uralian foldbelt has caused a N-S structural grain in the rocks of the eastern Barents (Doré 1994). Due to erosional processes acting on the mountains created during the Uralian orogeny, large amounts of siliclastic sediments were depos-

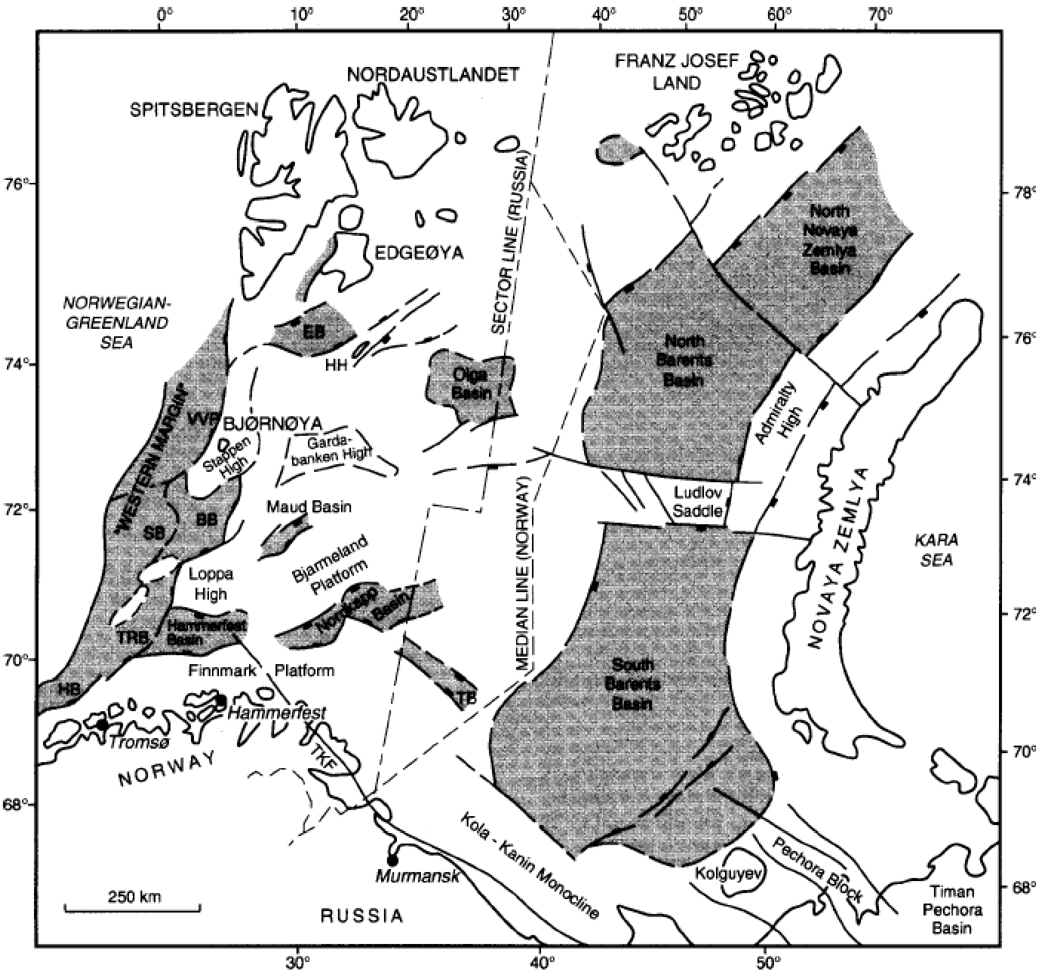


Fig. 2 Basins of the Barents Sea (*from Dorė 1994*)

ited in the eastern Barents Sea basins, creating the thick sedimentary sequences found today (Lindquist 1999). Tectonic extension started in the Late Paleozoic and Mesozoic with the collapse of the Caledonian and Uralian orogenic belts and later continued with the breakup of Pangea. These extensional events created the rift basins and series of platforms and structural highs found in the Barents Sea (Doré 1994).

Continental sedimentation was important locally but marine sedimentation was dominant. Carbonate sedimentation along with important deposition of evaporates occurred during the Devonian, Carboniferous, and Permian, during which time the Barents Sea was drifting from about 20°N latitude to about 55°N at the start of the Triassic, and then on to its present location at 75°N. During the Triassic sedimentation was dominated by clastic, sand and shale, deposits under more temperate conditions (Doré 1994).

Cenozoic uplift associated with the drifting away of Greenland and more recent ice age glaciational events resulted in regional erosion ranging from hundreds of meters up to approximately 3 kms, therefore Late Cretaceous and Tertiary rocks are thin to absent (Doré 1994, Doré and Jensen 1995).

2.1 Basins and Regions

There are several Basins and regions within the Barents Sea. The western, Norwegian section is separated from the eastern, Russian section by a gentle monocline that runs along the eastern border of the disputed territorial zone. The basins are quite different on opposite sides of the monocline with the Russian Barents Sea being characterized by a few

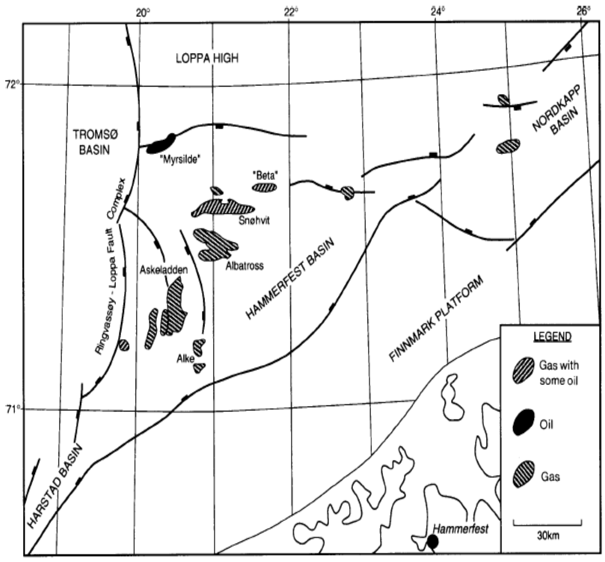


Fig. 3 Basins of the Norwegian Barents Sea. The Snøhvit , Albatross and Askeladden fields of the Hammerfest Basin have been developed by Statoil., production began in September 2007. *(from Doré 1994)*

large basins and the Norwegian side having more, but smaller basins.

2.1.1 West Barents Basins (Norway)

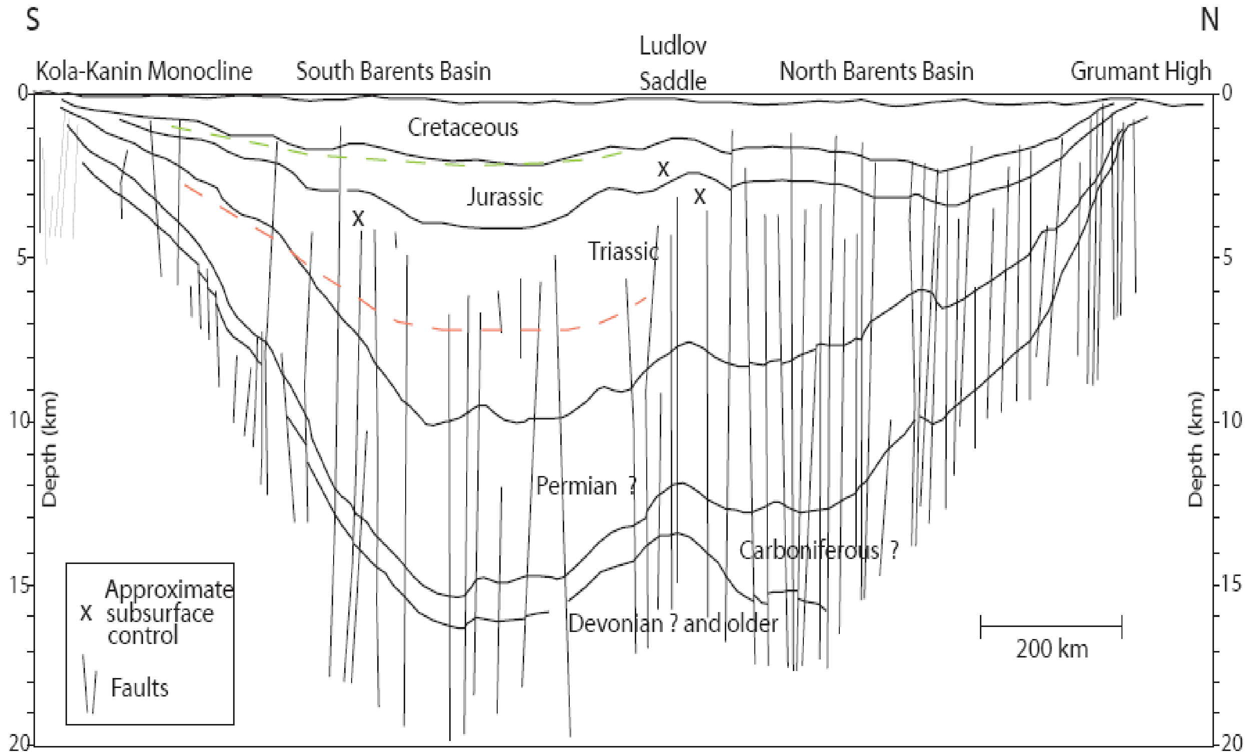
Nordkapp Basin- Found in the southeast corner of the Norwegian side of the Barents Sea, the Nordkapp Basin is a half graben, an elongated basin which is bounded on one side by a major fault. The basin follows a NE-SW Caledonian trend which was probably initiated by a late Paleozoic extension. Nordkapp is bounded on the north by the Bjarmeland platform and on the south by the Finnmark platform. The basin is dominated by massive Triassic deposits and characterized by significant salt deposits which probably were in place by the late Carboniferous-early Permian, and have created many halokinetic structures, i.e. salt domes and salt walls.

Hammerfest Basin- The home of the Snøhvit field, Hammerfest is an en echelon continuation of the Nordkapp Basin. The tectonic features that created the fault traps found in the Hammerfest basin were active during the Jurassic-early Cretaceous and the hydrocarbon reserves lay in the Early-Middle Jurassic sandstones. The basin is bounded on the north by the Loppa High which is a positive tectonic element that was active during Carboniferous and Permian times and has subsequently undergone reactivations (Stemmerik et el. 1999). On the west Hammerfest is separated from the Tromsø and Bjørnøya Basins by a structural hinge line known as the Ringvassøy-Loppa Fault Complex.

Tromsø and Bjørnøya Basins- Strung-out in a North-South line the Tromsø and Bjørnøya Basins have underwent rapid subsistence in Cretaceous times. The Tromsø Basin contains halokinetic structures that probably developed from salt deposits of similar age to the ones common to the Nordkapp Basin.

2.1.2 East Barents Basins (Russia)

There are three main basins in the Russian Barents Sea, they are the South Barents Basin, the North Barents Basin, and the Novaya Zemlya Basin, the on-shore Timan-Pechora Basin also extends off-shore into the south-eastern Barents Sea. The three off-shore basins run in a N-S line along the east coast of Novaya Zemyla and are separated by gentle highs, notably the Ludlov Saddle which separates the South and North Barents Basins.
All three basins were major catchment centers for sediments shed from the Urals and Nova Zemylan mountains during Paleozoic-Mesozoic times. Up to 12 kms of Permian and younger sediments are found in the basins with impressive Triassic deposits that locally range from 6 to 8 kms thick (*fig 4* on page 8 shows the thickness of stratigraphic layers in the South and North Barents Basins). The Basins terminate in the south-east Barents where Permian rocks rise in the subsurface to about 2-3 kms deep (Lindquist 1999)
The basins found in the Russian section are very large, the North Barents basin is approximately 106 500 km^2 and the South Barents is about 173 000 km^2. The eastern Barents basins are separated from the western Barents basins by a gentle monocline that runs N-S along the eastern edge of the disputed territorial zone of Norway/Russia.



Fig,4 Depth and age of sediments in the South and North Barents Basins, Russia. The green and red lines mark approximate oil and gas windows during pre-Cenozoic times. *(from Lindquist 1999)*

2.2 Source rocks

The main source of petroleum found in the western, Norwegian, portion of the Barents Sea is believed to be a Late Jurassic dark grey to black marine shale that is widespread throughout much of the Barents Sea. A similar shale is the source of most of the hydrocarbons in the North Sea (Dore 1994). Despite being widespread, the Jurassic shale is believed to be immature in the East (Geoexpro.com 2005) and is mostly thermally immature in the west as well due to being buried either too deep or too shallow for proper hydrocarbon production. It is, however, believed to have reached thermal maturity in a narrow belt along the western edge of the Hammerfest Basin and the Loppa High (Doré 1994).

As well as partly being sourced from these Late Jurassic shales, it is believed the Hammerfest Basin is also sourced by Early Jurassic shales and coals. There is also a shale found on Spitsbergen from the middle Triassic that is a potential source rock and equivalent units have been drilled in the Norwegian Barents offshore. This shale is believed to be widespread but of variable quality. The Triassic shales that source the enormous gas deposits in the eastern Barents Sea are also present in the western Barents and probably contribute some of the hydrocarbons found there but are not believed to be a major source (Doré 1994).

The source rocks for the eastern, Russian, section of the Barents Sea are believed to be primarily Triassic shales. These terrestrial sourced shales are medium to dark, locally coaly and contain type II, oil prone, to type IV, gas prone, kerogen (Doré 1994, Lindquist 1999) The dominance of gas in the eastern Barents is believed to originate from the presence of these gas producing prone shales as well as rapid, deep burial, that has created an advanced stage of thermal maturity for the Triassic rocks in the basins (Lindquist 1999). The extreme size of the reserves found in the

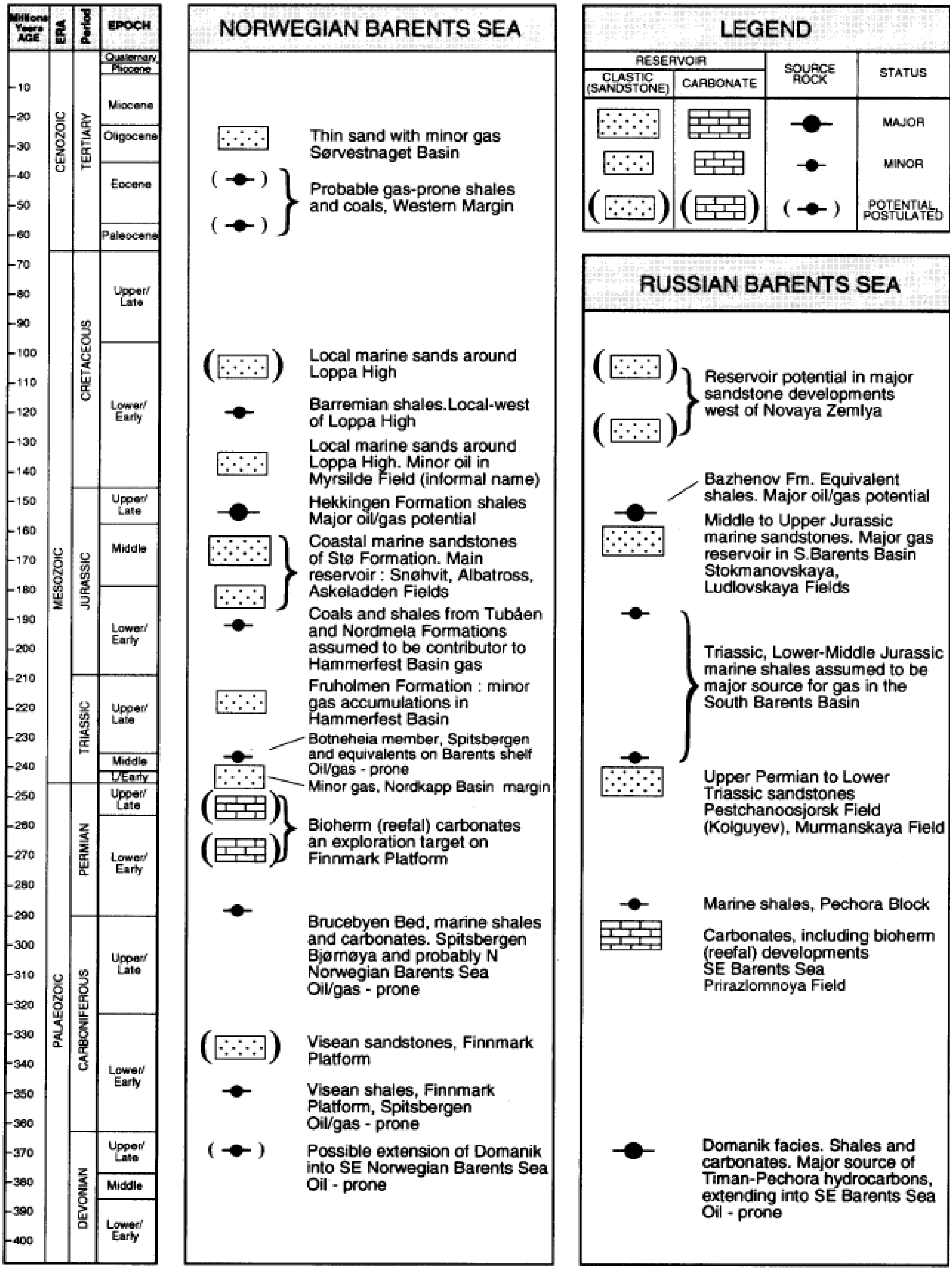


Fig. 5 Time of deposition of source and reservoir rocks in the West and East Barents Sea *(from Doré 1994)*

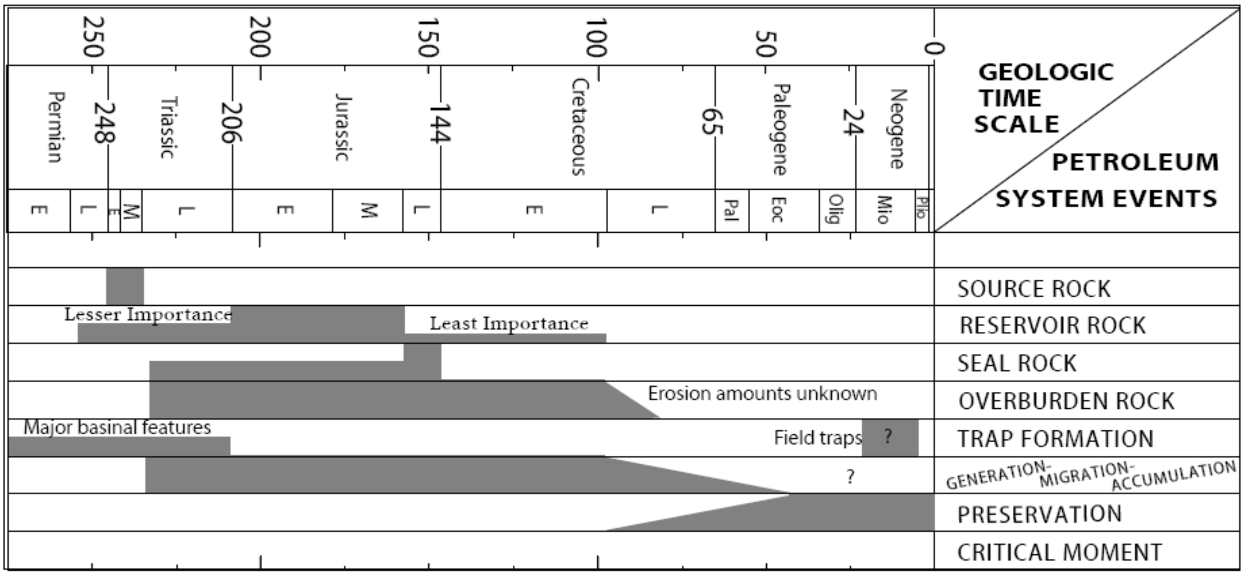


Fig. 6 Timing of petroleum system events in the East Barents Sea. *(from Lindquist 1999)*

Russian basins can be owed to the large cumulative generational potential of shale layers in the thick Triassic pile (Doré 1994).
The hydrocarbon resources of the onshore Timan-Pechora basin originate from source rocks in the Dominik Unit of Late Devonian to Early Carboniferous age (Doré 1994). The Dominik contains marine shales and carbonates that are a high quality oil source. It is believed that the Domink extends offshore and is responsible for the oil discoveries found near the cost in the extreme southeast of the Barents Sea.

2.3 Reservoirs and Traps

The reservoirs found in the Barents Sea are primarily Jurassic sandstones. Location of petroleum varies in age of strata within the Barents, with resources found in the Norwegian sector found in older Lower-Middle Jurassic strata, and resources in the Russian sector being found in slightly younger Upper Jurassic strata. The Jurassic reservoirs in the Norwegian sector are part of the Stø Formation (Doré 1994) and were deposited in a coastal, marine, setting. This formation has very favourable reservoir properties with high porosity and high permeability. It is estimated that 85% of the petroleum reserves in the Norwegian sector lie within the Stø formation, most of which is expected to be in the form of natural gas (Doré 1994). The Upper Jurassic sandstones in the Russian sector account for 97% of known recoverable reserves (Lindquist 1999). These marine sandstones contain large amounts of gas and significant quantities of condensate.
Triassic sandstones, as well as rocks from the Uppermost Permian, contain fairly significant reserves in the Russian sector. The Triassic deposits formed as a result of a series of westward prograding deltas originating from Novaya Zemlya, and because of their dynamic depositional history the reservoirs are complex, containing altering layers of sandstone and shale and sand layers are often discontinuous (Doré 1994). Triassic reservoirs are also present in the Norwegian sector but are of poorer quality because the greater distance from the terrestrial source means less sand is present.
In the extreme southeast of the Russian Barents Sea, there are also reservoirs occurring in the Paleozoic. These reservoirs are an extension of the onshore Timan-Pechora Basin,

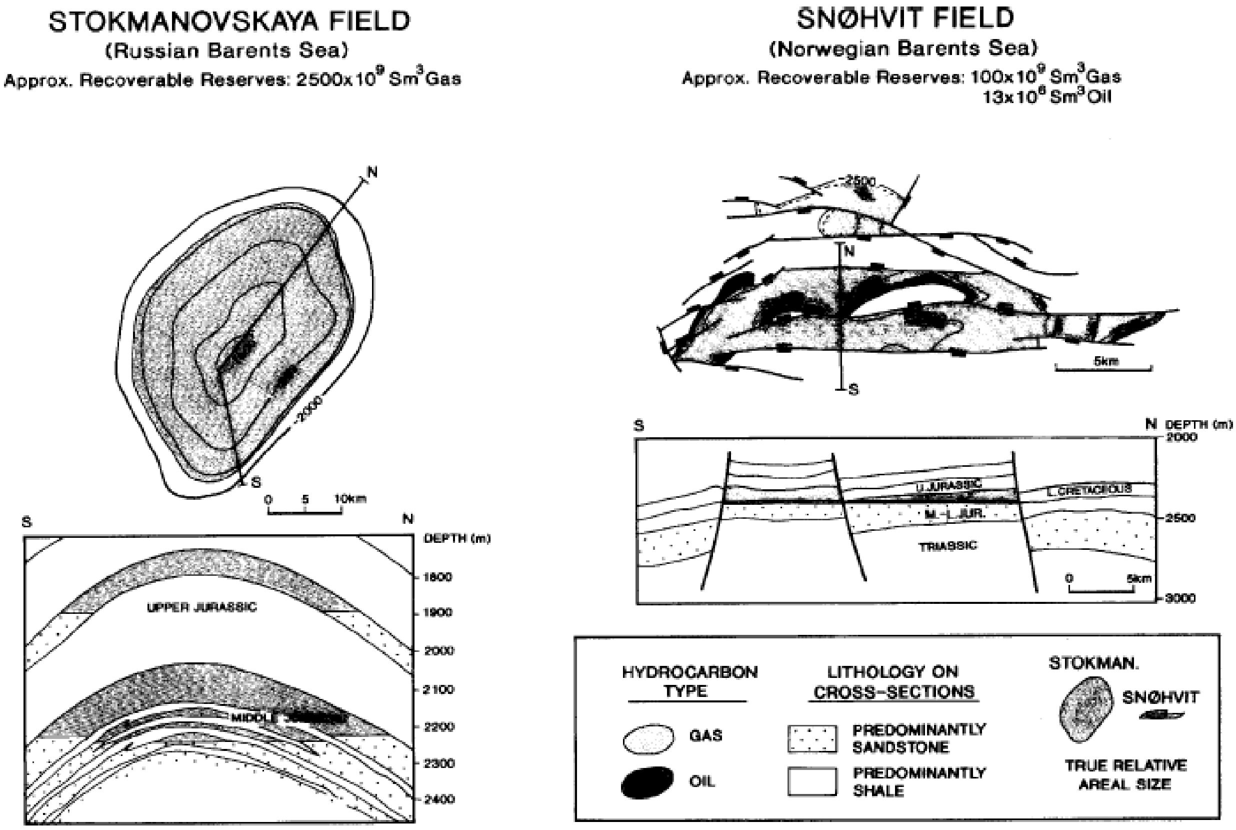


***Fig.** 7* The Shtokman and Snøvit fields, representative of the anticline and fault traps typically found in the Eastern and Western Barents Sea respectively *(from Doré 1994)*

with oil occurring in Carboniferous and Permian carbonates. (Lindquist 1999)

Both the Norwegian sector and the Russian sector have their own dominate trapping structure, however many other types of traps exist throughout the Barents Sea. There is some change depending on the age of strata as to the nature of the trap style and not all trap types have yet been tested. Drapes, onlaps, pinch-outs, stratigraphic and structural erosional traps, and diagenetic traps exist in all potential reservoir horizons in Triassic, Jurassic, and Cretaceous sandstones, but remain under-tested (Geoexpro.com 2005).
Within the Jurassic strata, generally fault bounded positive blocks are the trap type typical of the Norwegian Barents and simpler dome, or anticline structure traps are common in the Russian Barents Sea. This can be seen in the illustration below (fig) of the main deposits in both Norwegian and Russian sectors, with the Fault bounded Snøhvit field and the dome structure trap of Shtokman. Systems in both the Norwegian and Russian sectors are sealed by Upper Jurassic shales (Doré 1994).
The Triassic reservoirs that occur in both sectors include both fault bounded traps and dome traps. They are sealed by intraTriassic shales.
Found primarily in the South-eastern Russian Barents Sea, but also believed to be identified by seismic surveys in the Finnmark and Bjarmeland Platforms in the Norwegian Barents, Paleozoic reservoirs are trapped within Biotherm structures, reef-like organic build ups (Ivanova 2001).

2.4 Cenozoic Uplift

The major dominance of gas over oil in the Norwegian Barents Sea has been the primary factor slowing the development of the region (Doré 1994). The lack of oil has often been attributed to a major uplift and erosional event during Cenozoic times that affected the Norwegian Barents Sea, especially the far west, removing as much as 3 kms of sediment (Doré 1995 and Geoexpro.com 2005). Although it is widely believed that Cenozoic uplift is the cause for the missing oil, Dore and Jensen (1996) point out that many of the world's petroleum basins, especially those on-shore, have undergone major and rapid, uplift, implying therefore the possibility other factors could be in play in the Barents that contribute to it being a mainly gas province.

Around 30 to 40 million years ago Greenland moved west and the north Atlantic widened creating new areas of seabed. As this happened the top layers of sediment were scraped off and the decreased pressure from above allowed lower layers to rise. This process happened again during recent ice ages when the sea level in the Barents rose and fell (Forskningsradet.no 2007).

During uplift the cap rocks could have fractured over large areas allowing oil to escape from the reservoir rocks below them (Sintef.no 2006). At the same time the decreased pressure from above allows dissolution of gas from the oil and the expansion of the gas forces the oil out of the reservoirs (Doré 1994, Doré and Jensen 1995) Not only has the uplift expelled most of the original oil, it raised the source rocks to a position where they were no longer in under the proper temperature and pressure constraints to produce new oil. It is believed that much of the oil that was expelled during the Cenozoic is still somewhere in the Barents (Forskningsradet.no 2007), in fact the Goliat field, discovered in 2001, is believed to contain oil that is at least partially migrated oil from the Snøhvit field.

Despite the negative effects of Cenozoic uplift being well documented in the Barents region, it is possible that the uplift had some positive effects as well. Some known positive effects of uplift that have been documented in other major petroleum basins in the world include the redepositing of eroded material to adjacent areas whose petroleum generation benefits from the increased pressure, also thermally mature source rocks are raised to levels above the expected oil producing constraints and are thus able to produce reserves closer to surface than would otherwise be expected. Methane gas can also be expelled from formation water when pressure is relieved due to uplift, and this is considered a possible factor in the large gas accumulations of the Eastern Barents, like Shtokman. Since reservoir rocks are typically less competent than cap rocks, it is possible that during uplift fracturing can occur in the reservoir, increasing permeability and porosity, thus increasing reservoir quality, while leaving the cap rock intact. Finally, if seals are broken and oil escapes as a result of uplift, this leaves open the possibility that the oil may migrate into shallower adjacent structures where it may be more economical to extract (Doré and Jensen 1996).

Future exploration in the Barents Sea will be greatly influenced by the ability of geologists to understand the role of Cenozoic uplift to this specific region and much research is under way on this subject.

3 History of Exploration and Development

Exploration in the Barents Sea began on the Svalbard Archipelago in the mid 1920s by the Norwegians and also the Russians, who had rights under the 1920 Svalbard Treaty to explore the area. The first well was drilled on Spitsbergen in 1963 and since that time a total of 14 wells have been drilled on the island. These early wells found frequent shows of oil and gas but only minor amounts of producible gas. Exploration on the Svalbard islands continues today but it has been limited by a restricted drilling season, permafrost, and ice that covers much of the main islands (Doré 1994).

Exploration on Spitsbergen led geologists to believe that thick successions of Mesozoic and Cenozoic sandstone could be present offshore. This belief combined with exploration success in the North Sea during the 60s led to initial geophysical mapping beginning in 1969 in the Norwegian Barents. At the same time the Russians were following onshore oil reserves in the Timan-Pechora Basin into coastal regions which led to research and geophysical surveying identifying 20 prospects for drilling by 1980 (Geoexpro.com 2005).

The 1980s saw the first exploration wells being drilled offshore in the Barents Sea. Success soon followed with the Alke and Askeladden fields being discovered in Norway's Hammerfest Basin in 1981 and oil and gas being discovered in Russia off the coast of Kognyev Island that were known to exist in the same succession on land, as well as gas discoveries in the Murmansk Basin in the extreme south of the Russian Barents.

The mid to late 80s saw two of the most important discoveries to date, Norway's Snøhvit field in 1984, and Russia's enormous gas field, Shtokman in 1988. Since then, however, discoveries have been slow due in part to the most likely targets in Norway's Hammerfest and Tromsø Basins being drilled first and political unrest in Russia during the 1990s slowing exploration there.

Exploration in the Barents Sea is further slowed by a restricted drilling season in place to protect fish spawning grounds during the summer as well as being complicated by ice flows, the generally harsh climate, and the discovery that the Barents Sea is primarily a gas province not an oil one and gas has been much less attractive before the turn of the century than it is now. That being said, exploration continues to move forward and is encouraged by the discovery in 2000 of Goliat, an estimated 60 million barrel oil field in Norway (Forskningsradet.no 2007 and Doré 1994) and the start of production on the Snøhvit project combined with building momentum on the development of Shtokman mean that infrastructure will be inplace making future discoveries more economical.

4 Case Studies

4.1 Snøhvit

Snøhvit is the first major discovery of petroleum in the Norwegian sector of the Barents Sea. Discovered in 1984, it has taken 23 years of development, technological innovations, and increased market demand to begin producing from the Snøhvit field in 2007. During the development of Snøhvit, Statoil over came many problems relating to the fragile arctic environment and the cost feasibility of recovering the gas and processing it. The success of Snøhvit is a strong indication that technological advances will allow for increased development of petroleum fields in this remote and difficult environment.

The Snøhvit project actually consists of three fields, Albatross, Askeladden and Snøhvit itself. The fields are believed to hold some 193 billion cubic meters of natural gas and 113 million barrels of condensate (Statoil 2008). The deposits are found within the Hammerfest Basin in the south-eastern section of the Norwegian Barents Sea, where geophysics work, starting in 1969, identified the Hammerfest Basin as having similar geology to proven finds in the North Sea. It was because of this similarity to known North Sea deposits that the Hammerfest Basin was drilled first (Geoexpro.com 2005). Since these major discoveries, new discoveries have been slow to follow as the most attractive deposits have already been drilled. The reservoir rock consists of Sandstone from the Lower to Middle Jurassic, it was deposited in a costal-marine setting and is called the Stø Formation. The hydrocarbons have been trapped in fault-bounded positive blocks and sealed by overlying Upper Jurassic shales. There are various theories as to the source of hydrocarbons in the Barents Sea. The most widely distributed potential source in the Norwegian Barents Sea is called the Hekkingen Formation. The Hekkingen Formation is comprised of dark, organic rich shales similar to those found in the North and Norwegian Seas. In much of the Barents Sea the Hekkingen Formation is not believed to have reached full maturity for the production

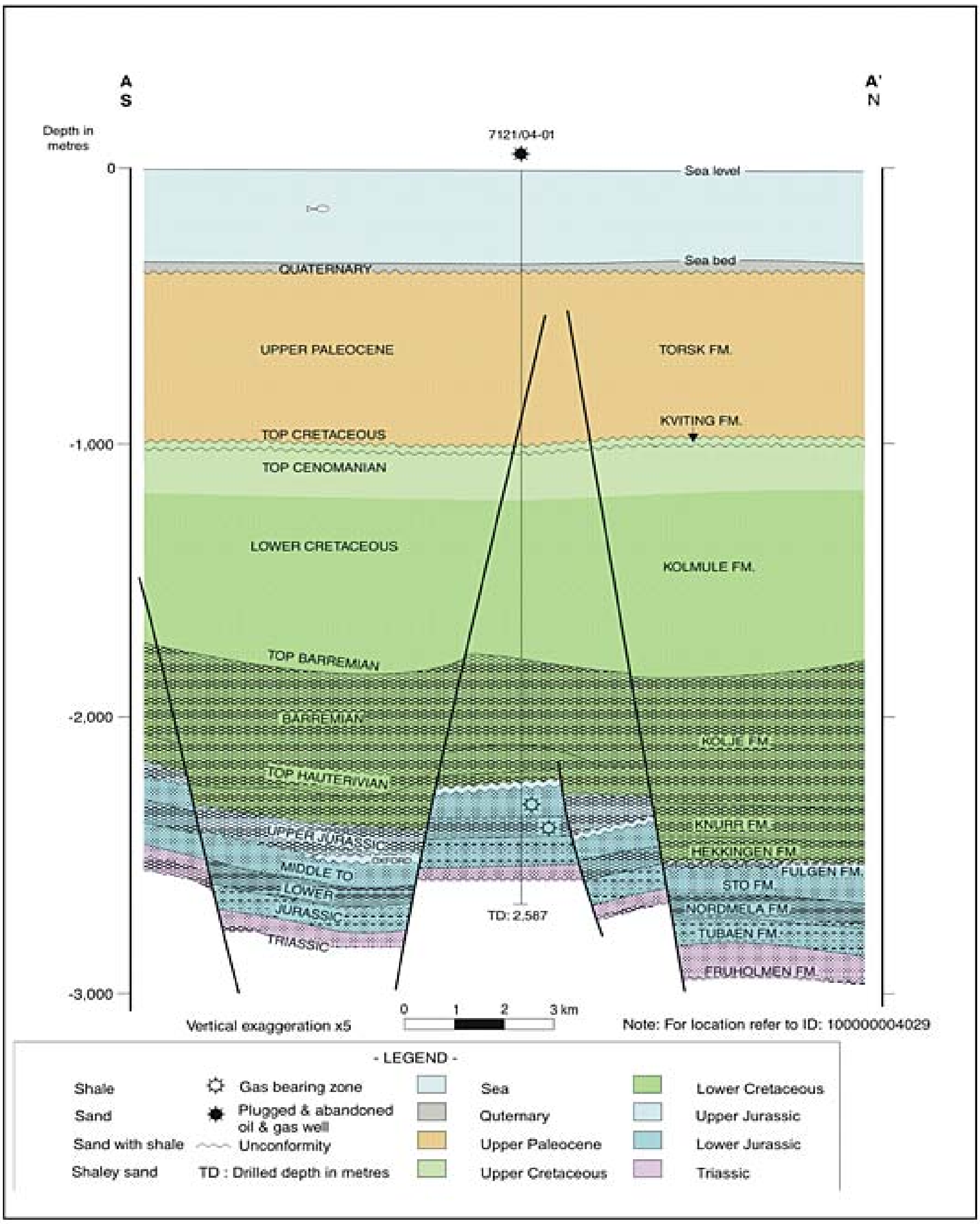


Fig.8 *(left)*
Field section for Snøhvit *(from Energy.ish.com 2008)*

Fig. 9 *(below)*
Melkøya LNG processing plant *(from Statoil 2008)*

Fig.10 A subsurface wellsystem retreives natural gas from the Snøvit field and transports it 143 km by multiphase pipe to the Melkøya LNG production plant *(from Statoil 2008)*

of hydrocarbons, but it is believed to have reached maturity along the western edge of the Hammerfest Basin (Doré 1994). It is also believed that hydrocarbons in the Hammerfest Basin could have come from Upper Jurassic shales but some also believe the gas in the deposits comes from underlying Lower Jurassic shales and coals. It is believed that the dominance of gas over oil in the Norwegian side of the Barents Sea is due to severe uplift and erosion during the Cenozoic. The Cenozoic uplift caused exsolution of gas from oil and the expansion of gas due to the decreased pressure caused the expulsion of oil from the traps. Uplift also cooled the source rocks so that they stopped producing new oil to refill the reservoirs (Doré 1994, Doré and Jensen 1995).

There are several reasons why it took so long to begin production from the Snøhvit field the biggest initial obstacle was that the deposit is largely made up of natural gas with very small oil reserves. Evaluations of the oil reserves by Statoil led to the determination that it was uneconomical to retrieve the oil and now that gas retrieval has commenced it will be impossible to reverse this decision (Statoil.com 2007). Gas appears to be the common petroleum product found in the Norwegian sector, with increasing oil reserves found to the east in the Russian sector. To produce natural gas the costs are much higher than with oil, especially if there is not a pipeline that can be used to take the gas to market, as is the case in the remote costal areas bordering the Barents. Without a building a pipeline, which has very high expenses, the other option is transporting the natural gas as LNG, liquefied natural gas. Creating LNG requires that the gas be cooled to -163°C, which liquefies the gas. In a liquid state, the gas has been reduced in volume by 620 times. Once the gas has been liquefied the LNG can be transported by ship in specialized containers that keep the gas below -163°C. Once the LNG reaches its destination port it is warmed back to a gas state and sent by pipeline to market. Transportation by sea allows gas from Snøhvit to be sent to southern Europe and the United States where the demand for natural gas is expected to increase in coming years. Although LNG solves transportation problems it does come at a cost, the facilities required to cool the gas, store the cooled gas and then reheat it add a considerable amount of cost to the gas. The costs associated with LNG made it unattractive to develop the Snøhvit field for some time, but rising natural gas prices throughout the 90s and into the new millennium and improvements in the technology used to liquefy the gas have made production of LNG from Snøhvit economical. One of the few benefits of the cold climate is that it reduces some of the energy needed to cool the gas. The cold climate and technological improvements to the LNG process developed by Statoil and the German engineering company Linde mean that the LNG facility in Melkøya is the most energy efficient and environmentally friendly facility of its kind in the world (Statoil 2008).

The costs associated with converting natural gas to LNG were not the only problems associated with Snøhvit. The actual gas fields lay some 2040-2375 meters underground below 250-345 meters of sea. At this sea depth a fixed drilling platform was not possible and instead subsea production installations have been developed to retrieve the gas and then transport it by a subsea pipeline 143 km to the Melkøya LNG facility not far from Hammerfest. The subsea solution has practical and environmental benefits. It saves costs by allowing the operations to be managed offsite from control rooms in Melkøya. It also means not infrastructure can be seen at surface and fishing boats can troll the entire area. The subsea method also helps avoid the dangers of floating ice and icebergs in the northern sea (Statoil 2008).

In further efforts to reduce the environmental impact in this fragile and unindustrialized area of the world, CO^2 is removed from the gas stream and pumped back into the reservoir to be stored. This removes 700 000 tonnes of CO^2 per year that would otherwise be burned off and released into the atmosphere (Statoil 2008).

4.2 Shtokman

The Shtokman, or Stokmanovskaya field as it is sometimes referred to as, is by far the largest gas discovery in the Barents sea and in fact one of the largest of its kind in the world. Sitting in the northern part of the South Barents Basin in the Russian section of the Barents Sea, the Shtokman field contains an estimated 3.8 trillion cubic meters of gas and 37 million tonnes of condensate (Gazprom 2008). At this size the Shtokman field has gas reserves more than twice the size of the largest Norwegian field, Troll, in the North Sea, and is larger than the Groningen field in the Netherlands.

The oil equivalent deposits of the South Barents Basin are somewhat younger than in the eastern Barents Sea. The stockman deposit is located in primarily Upper Jurassic sandstone with minor amounts of the deposit found in Middle Jurassic sandstone. The trap structure is also different. At Shtokman the oil is trapped under a dome structure, or anticline, the trap structure is again believed to be Upper Jurassic shales. The source rocks are believed to be different in the west Barents than in the east as the Hekkigen Formation, a highly organic shale, is thought to be thermally immature in the western Barents. Instead, it is believed that several layers of Triassic shales provide the source for gas found in Shtokman. The shales are rich in terrestrial organic mater, and their deep burial has caused them to produce mainly gas as opposed to oil. It is the accumulation of all these thick layers of organic rich shales from the Triassic and possibly even in the Lower Jurassic, that is believed to have built Shtokman into such an enormous gas deposit (Doré 1994, Lindquist 1999).

Discovered in 1988, the Shtokman field is just beginning its developmental era. The development has been slow for many of the same rea-

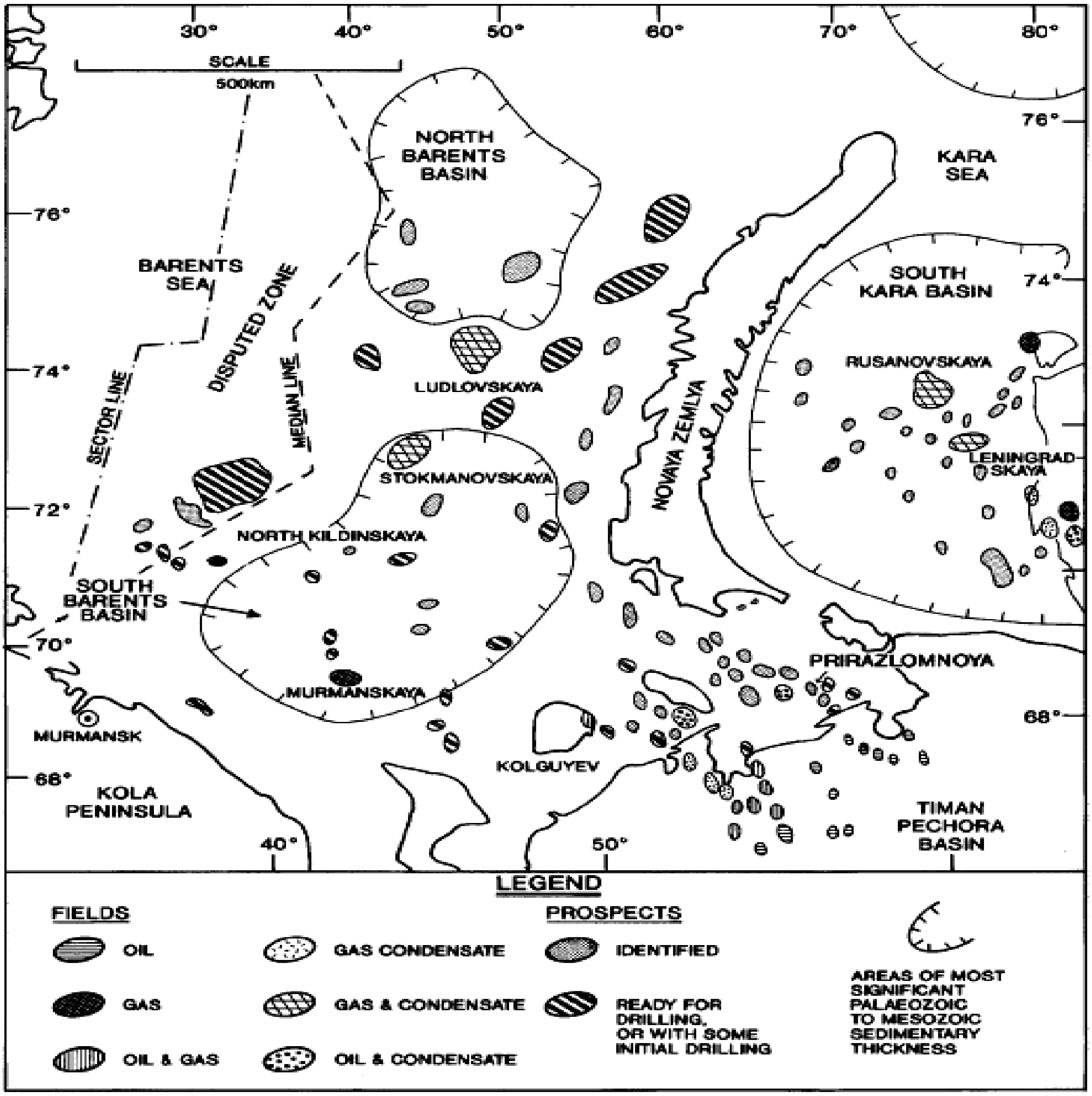


Fig.11 Known fields and prospects in the Eastern Barents Sea *(from Doré 1994)*

sons as the Snøhvit field, namely low gas prices, a hostile climate, large distances from markets, and environmental concerns. Shtokman's development has also been hindered by other issues specific to Russia. Russian political instability throughout the 90s scarred off foreign investment and stagnated domestic investment. As development in Russia began to pick up again, the easier, cheaper to develop onshore fields were first to be developed. Large projects such as Shtokman are still difficult to get off the ground in Russia- due to Russia's difficulty financing, lack of technological know how that is necessary to develop such a field, and reluctance to seek partnerships with the large multinationals. Now, however, finalized in the fall of 2007, agreements have been made between Gazprom, Total, and Statoil, to work together to develop a plan to move Shtokman into production (NewEurope 2008). The addition of western money and Statoil's previous experience of developing a project in the Barents Sea should be exactly what is needed to overcome the difficulties with exploiting this enormous resource.

The Shtokman Development Company (Gazprom 51%, Total 25%, StatoilHydro

Fig. 12 The Shtokman field (Stokmanovskoe). Dotted lines represent possible wellstream pipe to an LNG plant in Terberka, a proposed natural gas pipeline to Western Europé, and shipping of LNG to North America. Solid lines are current pipelines *(from Gazprom 2008)*

24%), is in the midst of the initial planning phase which they hope to complete by the second half of 2009, before deciding on future investments. During this time they will have to resolve some of the problems associated with Shtokman and way the costs vs. the benefits to see if it is economically viable. One major issue is that Shtokman lays some 600 km from shore. It remains to be seen if a subsea installation similar to the Snøhvit setup will be possible because the 143 km wellstream pipeline to land for Snøhvit is already the longest of its type in the world (Statoil 2008). If the subsea solution is not an option then a floating system of rigs may be needed because similar to Snøhvit, Shtokman is situated under 320-340 m of sea. An above sea setup would then have to deal with more problems with the hostility of the climate as ice flow and ice bergs would become a concern. There also could be more risk of pollution to the environment with an above sea setup.

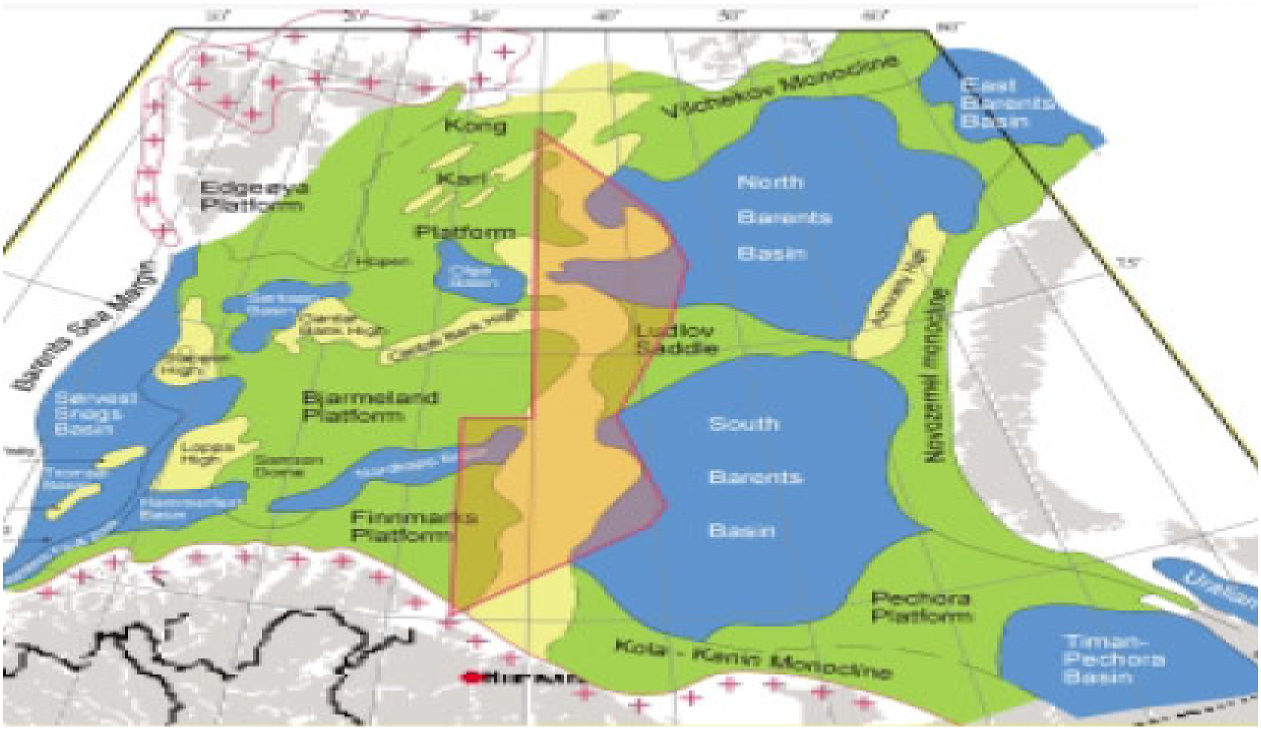


Fig 13. The disputed zone (center, in orange) and the basins (blue) in the Barents Sea *(from Geoexpro.com 2005)*

Shtokman's problems that must be overcome, and the extra expense associated with them, will be offset by some of the things Shtokman has in its favour. The Russian shores on the Barents Sea quite a lot more developed than those of Norway. Already plans are calling for a technical and transportation complex to be created in Terberka, near Murmansk, a city with highly developed infrastructure. An additional plus for development in the Russian section of the Barents is the natural gas pipeline currently being constructed via the Baltic Sea direct from Russia to Germany. Along with gas sent by pipeline to market, the more expensive method of creating LNG will also be implemented, LNG can then be sent to other North Atlantic markets including the United States. The ability to shift volumes of supply between markets based on demand is a very attractive option for such an enormous

5 Geopolitical Considerations

The development of a significant part of the Barents Sea is complicated by the inability of the Norwegian and Russian governments to settle a long standing border dispute. The Barents Sea is divided roughly in half between Russia and Norway, but in the middle, the two governments have been unable to agree on where the border should lie. The Norwegian government believes in the Median Line principal which was founded in 1958 by the Geneva Convention. The Median Line principal dictates that the border between countries should lie and equal distance from their costal shores. The Russians promote the Sector Line principal, developed in 1926 by a Soviet Decree. The Sector Line principal states that boundaries should extend northwards, following a line from the onshore border to the North Pole (Doré 1994).

Between the Median Line border and the Sector Line border is a "grey" zone. This "grey" zone of disputed waters is of no insignificance. The area makes up 1/7 of the entire are of the Barents Sea, some 175 000 km^2 (Geoexpro.com 2005).

Geologically, the area in dispute lies over a gentle monocline which divides the two basic geological styles of the west and east Barents

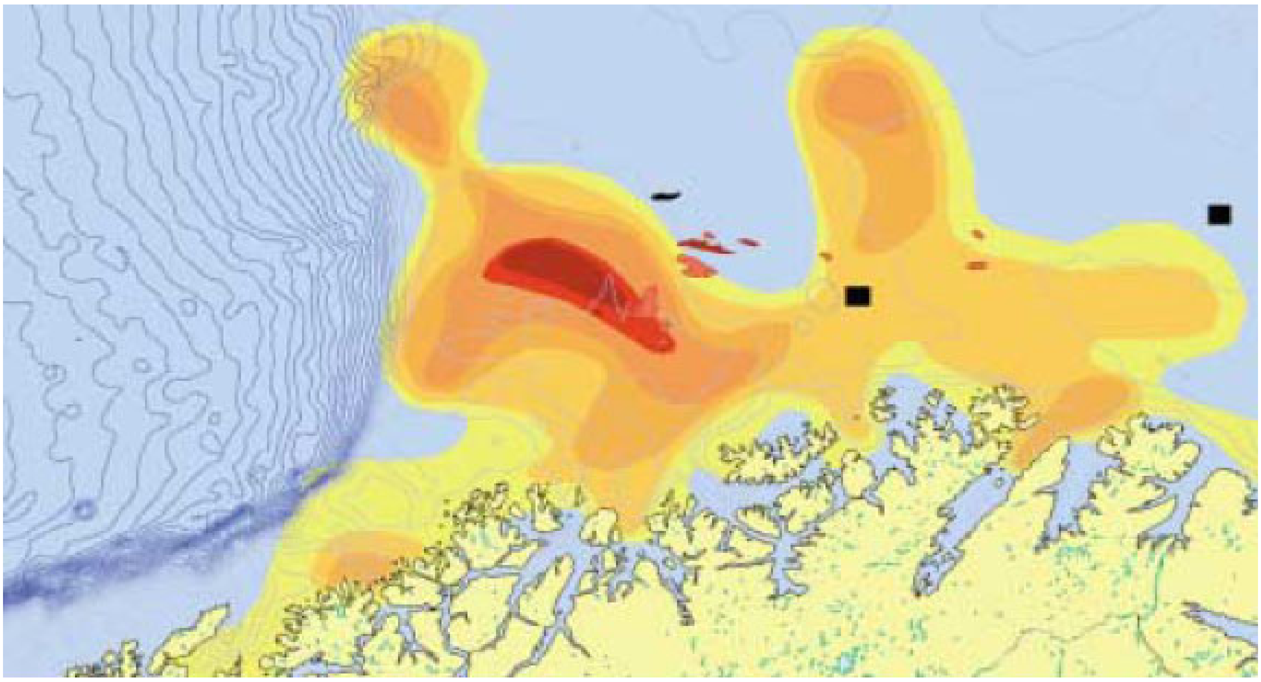


Fig. 14 Areas of high cod spawning activity in orange and Snøhit gas fields in red *(from WWF 2001)*

Sea, separating the prolific Russian gas reservoirs from the more modest Norwegian discoveries. The monocline roughly follows the border sought by the Norwegians, so no mater where the border is agreed to lay it is unlikely that Norway will gain access to the large, continuous Jurassic reservoirs found in the Russian Barents Sea. However, it is believed that Triassic reservoirs, though of poorer quality are present and may contain significant amounts of gas and oil equivalents. The Russians have drilled wells near the Median Line with some success and have also identified several large prospects within the disputed zone. Based on the size of the region and some of the limited information available, StatoilHydro gives a very rough estimate that approximately 2 billion m^3 of oil equivalents are present within the area (Statoil 2008).

Negotiations on a border treaty have been taking place since 1974, but show little signs of progress. So far the Norwegian government is yet to award any acreage near the disputed waters, but in Russia the state-owned gas company Roseneft, has promised to spend 10-12 trillion RUB on exploration within the zone by 2050 (BarentsObserver 2008).

To further complicate the signing of a treaty, this is not the only area in the Arctic that contains disputed waters. In fact much of the Arctic Ocean is up for grabs in a race between northern nations anxious to assert claims to an area of the world that is becoming increasingly accessible do to global warming and is believed to contain enormous wealth through minerals, shipping lanes, and energy. Any settlements made between Norway and Russia would likely have an effect on future treaties for both countries with Canada, the United States and Denmark and thus a definite border between the East and West Barents is not likely in the immediate future.

6 Environmental Concerns

Due to a rare combination of relatively shallow warm and cold waters the Barents Sea is extremely ecologically diverse. A home to many marine mammals, sea birds, an important fish spawning ground for many commercial species, development of the Barents Sea has been under high environmental scrutiny. Environmentalists fear that the fragile ecosystem will be under threat during exploration, production, and related shipping during the development of petroleum resources.

There are concerns on the effects of small amounts of oil and chemicals used during drilling accumulating throughout the course of exploration and production. Perhaps a greater concern is the possibility of a large scale spill from a ship or pipeline. Though a large scale oil spill is devastating wherever it occurs, the WWF believes it would be even more devastating in the Barents where the extreme cold temperatures could make the chemicals used to clean spills less effective and the oil thicker and harder to retrieve. An oil spill near or on the seasonal pack ice would be especially hazardous as the ice would absorb some of the oil and then deposit it over time and in various locations, increasing the time and size of toxic exposure to life in the sea.

Shipping is also seen as a concern, due to the possibility of running a ground or collisions between ships, and also due to an increased risk of transport of foreign species to the sea in the ballast water of tankers. Once both Snøhvit and Shtokman come online the level of shipping in the Barents will significantly increase and will continue to do so as further projects are developed in the area (WWF 2001).

7 Conclusion and Outlook

The Barents Sea has been a known petroleum region for some time but has undergone very slow exploration and development. Despite some very large discoveries, changes in market place demands and advances in technology have been the driving factors in turning this region into a "hot" zone for future petroleum exploration and development. With the development of the Snøhvit field and encouraging progress in the initial phases of the development of Shtokman, a large increase in exploration of the region can be expected.

To date, apart from the Goliat oil field discovered in 2001, no major discoveries have taken place since the 1980s. Also a number of dry wells have been drilled that have shown evidence that oil was once there but now is gone. The role of Cenozoic uplift, especially relevant to the Norwegian sector, is still poorly understood and requires much attention to increase the success rate of future wells. This might seem discouraging, but it is important to remember that only a fraction of the area has been explored. The on-shore West Canada Basin is approximately the same size of the Barents Sea at 1 300 000 km^2, but the West Canada Basin has over 200 000 wells drilled into it compared to less than 100 in the Barents Sea (Doré and Jensen 1996). Russia alone has identified 450 interesting structures in their portion of the sea and 100 of them have been prepared for exploration drilling (BarentsObserver 2008). As more wells are drilled, more discoveries are sure to follow.

Production from the Snøhvit project is expected to last 25-30 years and Shtokman is expected to have steady production for 25 years starting in 2013. The long-term presence of these projects will do much to increase infrastructure in the area as well as increasing knowledge of the geology and development of production techniques. This should reduce the costs associated with future projects in the area, making them more economical. The hindrances of exploration and development in the Barents Sea seem to have been overcome by developments in the marketplace, technology, and successful models for future development projects. It would appear that the Barents Sea will be a major site of petroleum exploration and development in the next few decades.

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