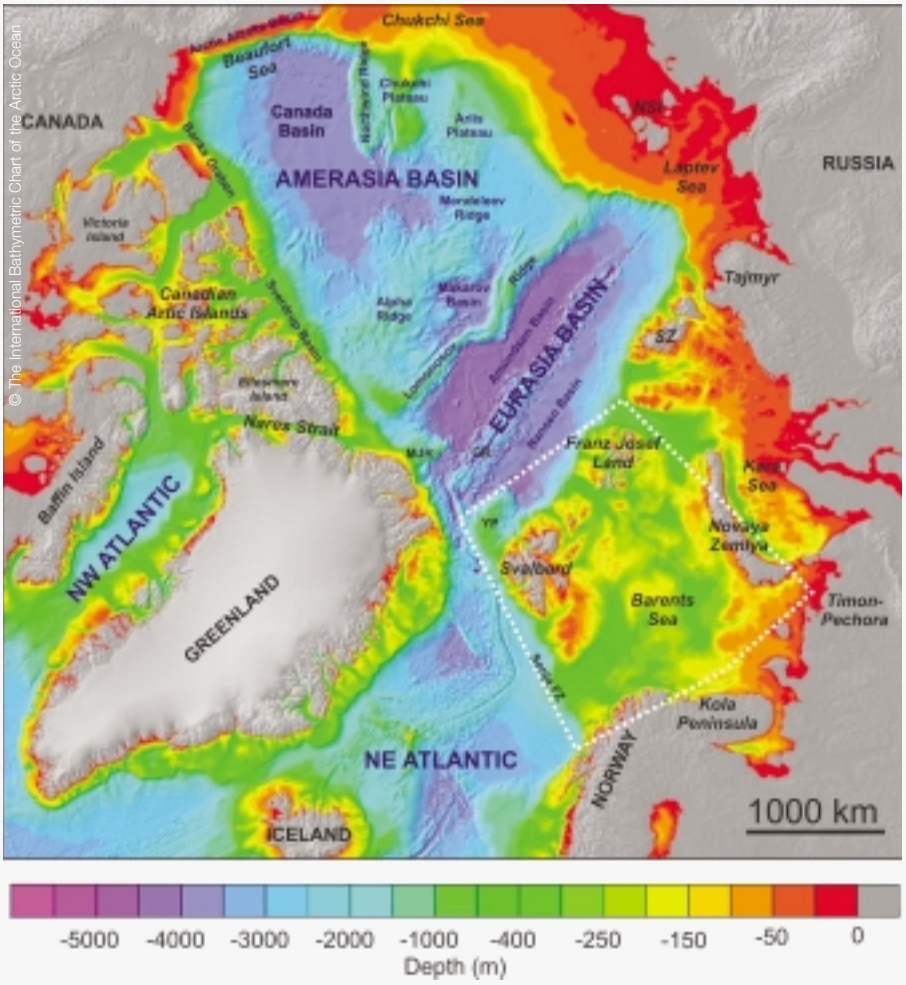
More giants to be found

Two fields are currently being developed, significant amounts of oil and gas have already been found, and geological studies indicate that this is a promising exploration frontier, possibly making the Barents Sea a major gas and oil supplier in the future.

Photo: Atle Mork, SINTEF Petroleum Research



The Barents Sea is situated between the North Atlantic Ocean to the west and Novaya Zemlya to the east. To the north, it is bounded by the Eurasia Basin that is floored by oceanic crust. The Barents Sea extends from 70°N (equivalent to the northern coast of Alaska) to 82°N covering an area of 1.2 million km^2, more than twice the size of the entire Gulf of Mexico (shallow and deep water included).

The Barents Sea is named after Willem Barents (1555-1597), a Dutch explorer and navigator who discovered Bjørnøya and Spitsbergen (the main island in the Svalbard archipelago) when searching for the Northeast Passage to Asia.

The Barents Sea is relatively warm considering its latitude. The southern and central parts of the Barents Sea are predominantly ice-free during the winter months due to warm water brought by the Gulf Stream. Drift ice will never reach the Norwegian coastline, but further to the east, north of the Pechora Basin, drift ice is common. Almost the entire Barents Sea is free of ice during the summer months. The southern limit of permanent pack ice falls within the Eurasia Basin.

Svalbard, Franz Josef Land, Bjørnøya and Novaya Zemlya, surrounding the Barents Sea and together comprising an almost complete sedimentary succession from the Lower Paleozoic to Tertiary, can all be used as field analogues for the offshore geological provinces. With daily flights from the mainland, and a mild climate, Svalbard has particularly been popular amongst geologists for several decades. Geologists from all around the world, including both the academic and oil sectors, engage in field work or take part in field trips on the island for weeks or months each summer. This particular field camp on Svalbard lies below a shale with a high organic content. The black band just below the top of the mountain is the Triassic Botnheia Formation that may prove to be a prolific source rock in the Barents Sea.

The average water depth of the Barents Sea is 230 meters, and rarely does it exceed 300 meters. To the west and to the north, when entering the North Atlantic Ocean and the Arctic Ocean floored by oceanic crust, water depths increase rapidly to more than 1000 meters.
Politically, the Barents Sea region is divided into a Norwegian and a Russian sector. However, there is a large disputed area comparable in size to the Norwegian sector of the North Sea in between the two countries (shadow). While Norway claims "the median line principle", the Russians claim "the sector principle". As is evident from the map, one gas field – North Kildinskaya - has been discovered next to this area.

Halfdan Carstens and Mona Holte

The drilling rig Eirik Raude, named after the explorer who discovered Greenland in the year 982, moved north in January and spudded well 7220/6-1 on the prospect Obelix. This semi-submersible became operational in 2002 and was hailed as "the world's most extreme drilling rig" by the Discovery popular science TV channel. Along with other such high commendations, it should be well suited for the winter in the Barents Sea.

At the same time, this well marks the beginning of a new era for exploration in the Barents Sea, after nearly fifteen years of stagnation.

The first discoveries

Offshore exploration in the Norwegian sector of the Barents Sea started some 25 years ago. The first 2 wells were drilled in 1980 in the Hammerfest Basin, and in 1981 the Norwegian operator Norsk Hydro struck gas in two different prospects in Jurassic sandstones, Alke and Askeladden.

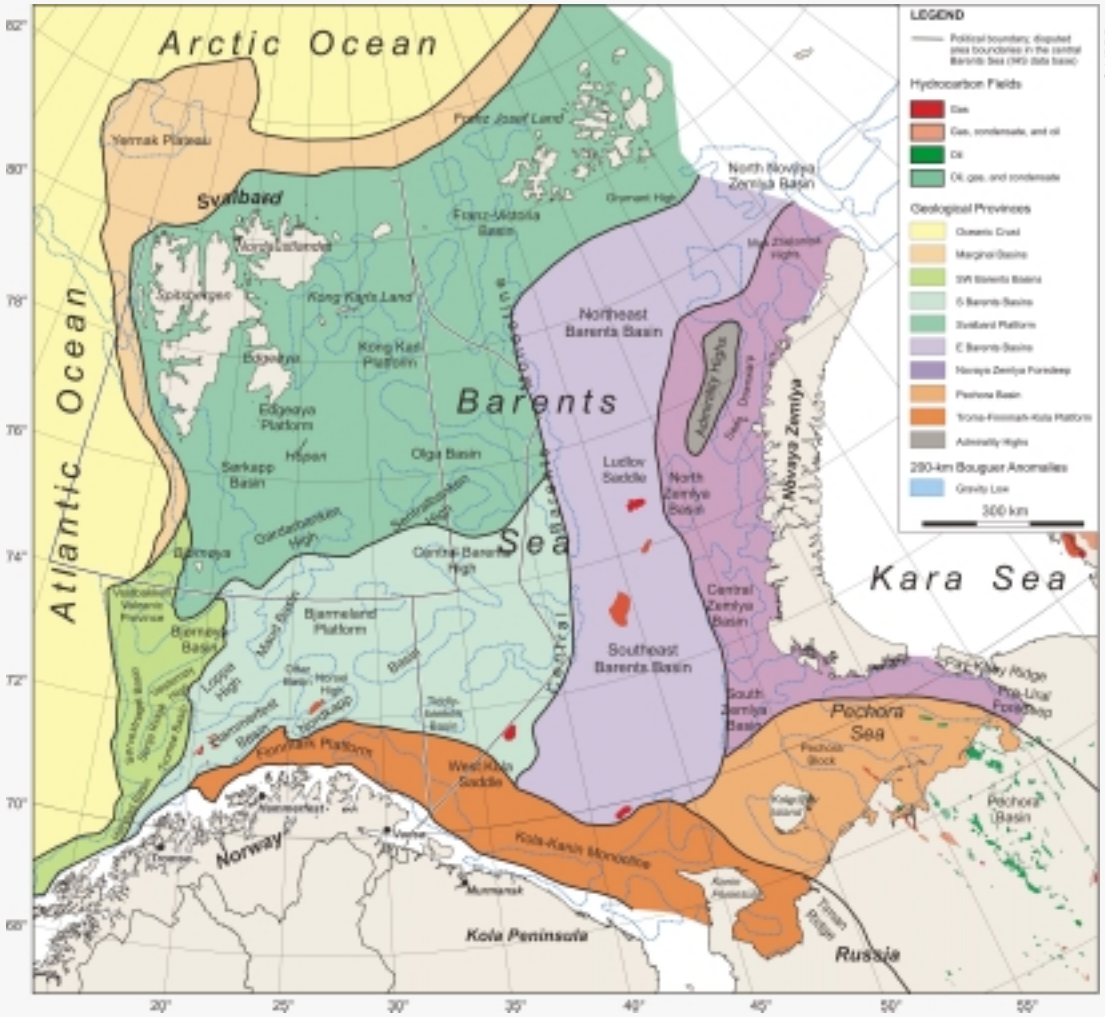
Almost 25 years later, 270,000 km of 2D and 10,000 km^2 of 3D have been shot, 61 wells have been drilled and some 30, albeit small, discoveries have been made in the Western Barents Sea. Approximately 300 billion m^3 of gas and 35 million Sm^3 of oil have been proven to date, according to the Norwegian Petroleum Directorate.

Exploration for oil and gas in the Russian sector of the Barents Sea started more than 40 years ago and has gone through three stages. The first, from the late 1960s to the late 1970s, geological and geophysical investigations included bathymetric studies, bottom sampling, seismic surveys and the acquisition of gravity and aeromagnetic data to almost latitude 80°N. "The seismic reflection operations conducted in the 1970s did, however, produce inferior quality data due to a low technical level," according to Konstantin Dolgunov, general director of Sevmorneftegeofizica (SMNG) in Murmansk.

"The second stage, from the early 1980s to the early 1990s, was characterised by aggressively expanding volumes of seismic and drilling operations. The resulting data enabled Russian scientists to gain knowledge of the geological framework of the sedimentary cover, reveal and delineate major structural elements, and obtain qualitative and quantitative estimates of hydrocarbon potential for these vast territories. As a result of these operations, estimates of Russian Barents Sea's potential were substantially enhanced," says Dolgunov.

"The third stage, which took place in the 1990s, has been notorious for deep recession, abruptly downsized exploration, reformation of the oil and gas complex and transfer to the state licensing of offshore underground resources," says Dolgunov.

Today, more than 350,000 km of 2D seismic data have been acquired with 1-6 km spacing in the South Barents Basin and 20-40 km spacing in the North Barents Basin. Based on this, at least of 50 major structu-



The Barents Sea can be divided into eight main geological provinces with their own unique petroleum systems. Detailed mapping does reveal a number of sedimentary basins within each of these provinces. Several oil and gas fields have been discovered in the Pechora Basin, both onshore and offshore. Both oil and gas have also been discovered in the South Barents Basins (Norwegian sector), while one of the largest gas discoveries in the world – Shtokman - are found in the East Barents Basins (Russian sector).

res have been identified. In addition, 1,700 km^2 of 3D data has been acquired.

The deepest well to date has been drilled to a depth of 4524 m in Lower Triassic rocks within the South Barents Basin, while the stratigraphically deepest rocks encountered so far are Carboniferous limestones in a well northwest of Novaya Zemlya.

The first discoveries in the eastern Barents Sea region of Russia were made in 1982-1983. Two prospects were drilled, Murmanskaya and North Kildinskaya, both finding dry gas in Triassic sandstones reservoirs.

"Without doubt, an important result of the seismic studies in the 1980s in the eastern Barents Sea was a shift in exploration for hydrocarbons targeting the Jurassic sedimentary sequence instead of the thick (7-9 km) Permian-Triassic series. Due to its genesis the latter exhibits increased organic content but is uneconomic for offshore production of localized hydrocarbon reserves," says Dolgunov.

The shift in exploration strategy led to the discovery of the giant Shtockmanovskoye gas and condensate field by the very first exploration well in 1988, a field that penetrated the Jurassic sequence. "High quality data and superior seismic resolution, as well as confidence in reservoir productivity, enabled us to recommend placing a well in the most crucial parts of the expected accumulation," explains Dolgunov.

"Altogether 6 wells confirmed previous assumptions based on seismic data and the reserves are now estimated to 3200 billion m^3 of gas."

Major new discoveries on the Ludlovskaya and Ledovaya prospects were soon to follow, one and two years later, respectively. To date, about 36 wells have been drilled in the eastern Barents Sea based mainly on 2D seismic.

No wells were drilled in the Barents Sea from 1995 to 2000, neither in the Norwegian nor in the Russian sector. In 2000-2001, a new drilling campaign was initiated in the Norwegian sector based on large 3D surveys and detailed geological studies completed collaboratively by several companies. Two discoveries resulted: Eni hit oil in the Hammerfest Basin (Goliat) and Statoil found a tiny oil field in the Nordkapp Basin further east. A new drilling campaign has been initiated this winter with three wells being drilled, the Obelix, Uranus and Guovca-prospects. The first results are expected to be made public in March.

Exploration in the *offshore* Pechora Basin, now considered to be one of the most prospective western Arctic basins, began in the late 1960s. Lots of seismic data has been acquired since then, and fifteen wells have been drilled resulting in four oil discoveries, one gas-condensate discovery and one oil/ gas-condensate field. The Prirazlomnoye oil field, with estimated reserves of 607 million barrels of oil, is now being developed and is expected to start flowing in 2005.

The majority of the wells in the offshore Pechora Basin tested Lower Permian to Carboniferous carbonate reservoirs that are also productive onshore. Both the oil and gas condensate is sourced from Paleozoic (Upper Devonian) source rocks.

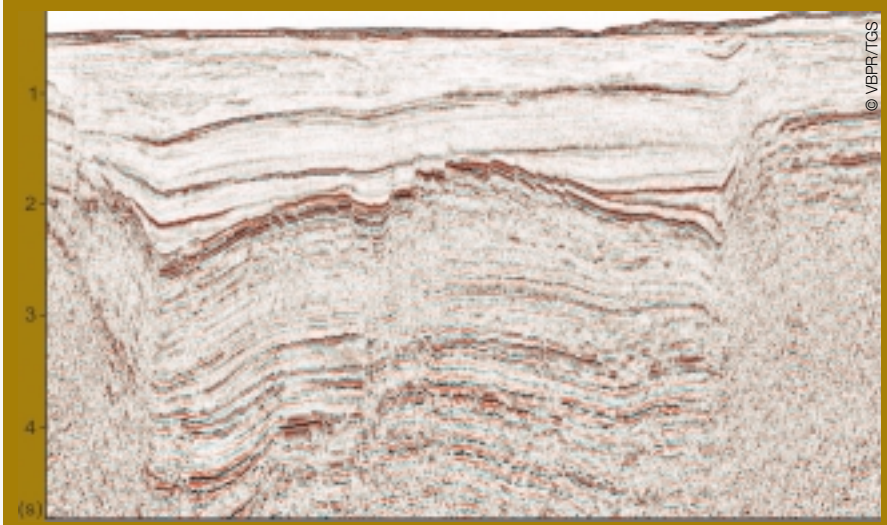
Snøhvit

The Snøhvit complex comprises three separate fields: Snøhvit, Albatross and Askeladd. Askeladd was discovered in 1981, while Albatross and Snøhvit were discovered three years later. Gas is expected to start flowing at the end of 2005 with a plateau production of 20.8 million Sm^3 per day until 2032. The first well on Statoil's Snøhvit development in the Barents Sea is under way from *Polar Pioneer*, which is due to complete this initial 10-hole drilling phase by spring 2006.

The field primarily contains gas and oil with small quantities of condensate. Recoverable reserves amount to 161 billion Sm^3 of gas, 5 million tonnes of NGL and 50 million barrels of oil.

The development does not include the 14-16 meter thick oil zone. A critical time factor is present regarding any extraction of the oil from the field because the start of gas production will lead to loss of pressure and loss of oil if oil production does not start sufficiently early. The accumulation of natural gas will be developed by a total of 21 wells.

Snøhvit is located in the Hammerfest Basin about 140 km northwest of the town of Hammerfest facing the Barents Sea.



The Snøhvit gas is trapped within Jurassic fault-bounded blocks typical of the Hammerfest Basin. The prominent reflector below the sub-parallel beds represents the base of the Cretaceous.

New optimism

There were many reasons for the oil companies to turn their back on the Barents Sea after nearly fifteen years of offshore exploration. "The expected oil discoveries failed to appear, and that was a huge disappointment. Gas was of no interest, as the technological solutions for gas transport were not developed at that time. The gas was therefore left in the ground, and it was not until the turn of the century before the Snøhvit field could be developed with gas being transported as LNG to the European and North American market", says Ørjan Birkeland, Exploration Manager for the Barents Sea in Statoil.

The unstable political relations following the collapse of the Soviet Union made it difficult for the Russians to continue their offshore exploration effort. Besides this, large scale onshore oil and gas production, with several of the largest oil and gas fields in the world in the West Siberian Basin, the need for further exploration and production has not been a matter of debate in Russia.

"Seemingly undepletable onshore reserves and a short-sighted strategy of state authorities in the 1990s have led to excruciatingly slow shelf exploration, especially when it comes to developing already discovered fields", says Konstantin Dolgunov.

The reopening of the southern Barents Sea to exploration and the forthcoming nineteenth licensing round will probably encourage new activity. Also, the development of Snøhvit and the discovery of at least 50 million barrels oil in the Goliat field have boosted optimism in the Norwegian sector.

In Russia, the high oil-price has given a growth in the economy, and combined with the stabilisation of the political relations, the Russians are moving back into the Barents Sea. "The Russians have invited western oil-companies to take part in early phases of the development of the Shtokmanovskoye field," says Ørjan Birkeland.

"Recent years have seen heightened interest in the Kola shelf of the Barents Sea, which aroused from newly obtained geological results of 2D seismic surveys. To the west, the Kola Kanin monocline extends all the way to the Norwegian sector, where it is known as the Finnmark Platform. Principal exploration targets are Permian reefal buildups, presumably up to 80 m thick and occupying a maximum area of 80 km^2, and possible Lower Paleozoic stratigraphic

traps," explains Dolgunov.

Operators in the Russian Arctic are Arcticshelfneftegaz, Gazflot and Sevmorneftegaz. Arcticshelfneftegaz actively conducts operations on its license blocks in the Pechora Sea. During the last two years Arcticshelfneftegaz drilled two wells and acquired 2D and 3D surveys.

Sevmorneftegaz acquired 1,700 km^2 of 3D on the Shtockmanovskoye field. Gazflot will shoot 3D operations in the Pechora Sea this year.

The development plans for the Shtockmanovskoye field and the expected oil production from the Prirazlomnoye field shows that the Russians are moving forward. "The Ministry of Natural Resources of the Russian Federation have adopted a long-term programme for licensing the Arctic subsurface resources. It is provisioned to hold predominantly open rounds and attract investors from every country and with every form of ownership," Dolgunov says. Russian authorities are therefore expected to announce and award several offshore production licences in the next few years.

Change in structural style

"As a petroleum province, the Barents Sea has a very interesting potential. A great variety of trap and sealing mechanisms exist, and several different play models have proven hydrocarbon accumulations", says Dr. Sverre Planke, head of Volcanic Basin Petroleum Research, (VBPR). In collaboration with geophysicist Reidun Myklebust in TGS, Professor Jan Inge Faleide and Asbjørn Breivik at the University of Oslo, he has recently published a "Geophysical Atlas of the Barents Sea", written for petroleum explorationists.

The Atlas is based on the integrated seismic-gravity-magnetic (SGM) interpretation method. "This type of integrated studies gives an overview of the different geological provinces, the regional basin configuration and the geodynamic development", says Sverre Planke. "This knowledge is essential for understanding the petroleum systems, and to give priority to which basin provinces and structures to explore".

"There is a major change in structural style and basin configuration from the western to the eastern Barents Sea," explains Professor Jan Inge Faleide. "The eastern part is characterised by very broad and deep sedimentary basins, while the western part, separated by a monocline, is

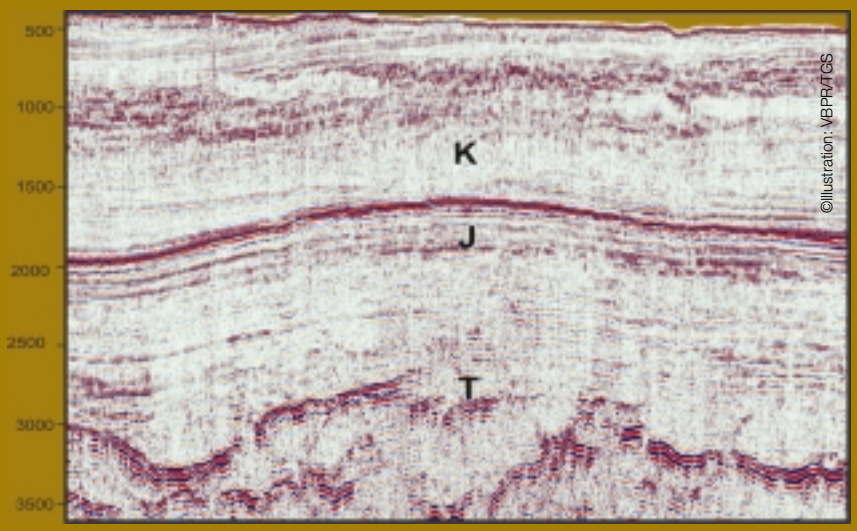
Shtockmanovskoye

Following a drilling campaign in the *eastern* Barents Sea that was initiated in 1982, the giant Shtockmanovskoye gas and gas-condensate discovery was made in 1988. Almost 2 decades have past, but it is still highly uncertain when gas production will start.

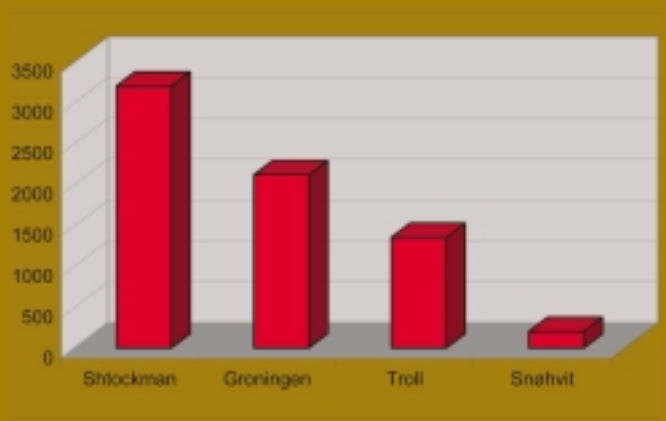
In 2003 Sevmorneftegaz (holder of the development licence for Shtockmanovskoye) acquired 1,700 km^2 of 3D survey. This year it is planned to drill an appraisal well.

Shtockmanovskoye is located in the South Barents Basin about 650 km north of Murmansk on the Kola Peninsula. Shtockmanovskoye is one of the largest offshore gas fields in the world. "Recoverable reserves are estimated to 3205 billion m^3 of gas and 226 million barrels of gas condensate. The field is considered unique in terms of reserves," says General Director Konstantin Dolgunov of SMNG in Murmansk. As such, it is more than two times the size of the Troll field in the North Sea and also larger than the Groningen field in the Netherlands. To put it into perspective, the estimated gas reserves of Shtockmanovskoye exceeds the remaining gas reserves of most countries in the world, with only some 10 countries having higher gas reserves than this particular field.

"Shtockmanovskoye is associated with a large dome-shaped fold covering an area of 1,200 km^2. The larger part of the reserves is related to gently folded thick competent sand beds in Middle Jurassic strata with 15-27 % porosity and 200-800 mD permeability," explains Dolgunov. The discovery was presented outside Russia for the first time at a conference in Norway in 1989.



This seismic line of the Shtockmanovskoye field shows Jurassic beds (J) in a dome structure overlying an extensive volcanic sill complex in Triassic strata (T). The development of these dome structures is still under debate, but there is a consensus that they are associated with widespread magmatic activity.



Gas reserves in Shtockmanovskoye and Snøhvit compared to Groningen (The Netherlands) and Troll (Norway).

Vast amounts of gas

Following 25 years of intermittent exploration, both oil and gas have been proven in significant quantities in the Barents Sea. So far it has shown to be a gas-dominated region, even if oil has also been encountered and is soon to be produced in Russian waters. The larger Barents Sea must be looked upon as a very promising exploration frontier that will attract a lot of interest in the future.

Geologically speaking, only half of the geological provinces that have been defined have been drilled, and few of the envisaged play concepts have been tested. The latter is true for both the Norwegian and the Russian sector. With less than 100 wells in an area equivalent to more than twice the size of Gulf of Mexico, this huge geological setting is by all accounts underexplored. With the present pace in exploration it will take multiple decades to mature the area.

Few wells have been drilled in the eastern Barents Sea region of Russia, but enough gas has been found to classify this region as a world-class petroleum province.

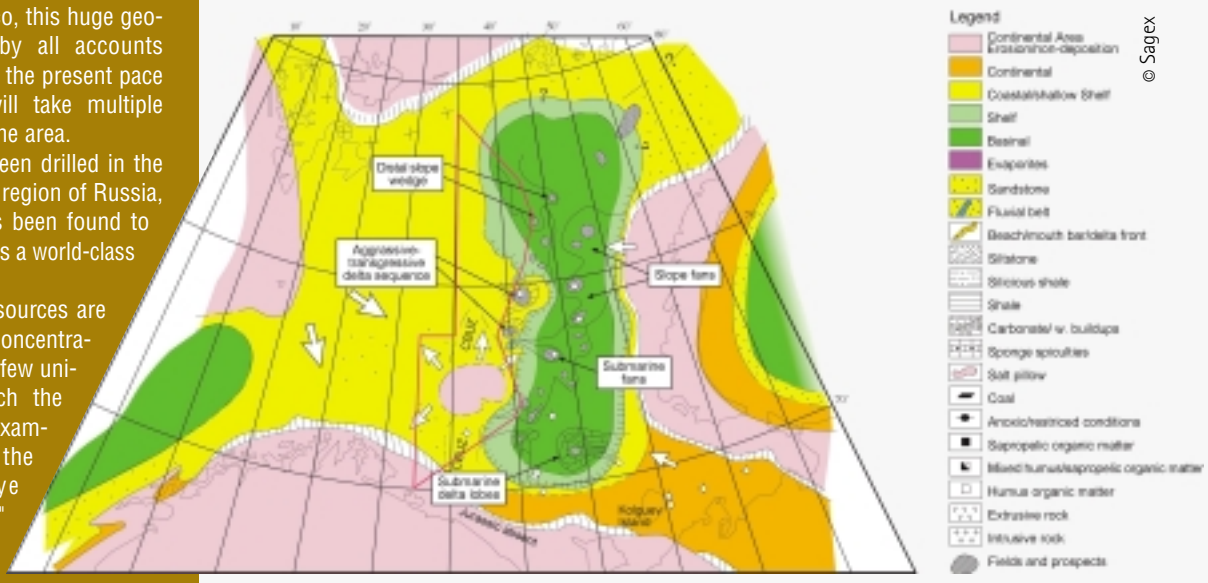
"The identified resources are characterised by a concentration of reserves in a few unique fields, of which the most remarkable example is certainly the Shtockmanovskoye gas/condensate field," says Dolgunov.

The oil and gas reserves of the Eastern Barents Sea are certainly speculative, but according to Dolgunov the Russians have estimated the total natural gas reserves of the Barents Sea to 25,7 billion m^3 oil equivalents. "This is mainly gas in Jurassic strata," he says. Other experts outside Russia have presented numbers that are considerable higher.

In the western Barents Sea region of Norway the petroleum resources are significantly smaller. According to the Norwegian Petroleum Directorate (NPD), 300 million Sm^3 of oil equivalents (mainly gas) have already been identified as recoverable reserves. It is estimated that another 1 billion m^3, (o.e.) of which 60 % is gas and 40 % is oil, may be discovered in the future.

Konstantin Dolgunov is General Director of Sevmorneftegeofizica, the largest marine geophysical company in Russia with a 25-year track record. SMNG operates five seismic vessels worldwide and has three processing centres in Murmansk.

Foto: SMNG



Palaeofacies map showing the depositional environment during Middle Jurassic time. The Jurassic sandstones are the most important hydrocarbon reservoir rocks of the Barents Sea.

more like the North Atlantic area with classical rift basins and highs".

The geological variations within these two basins make it suitable to further subdivide the east and west into several geological provinces. "We have subdivided the larger Barents Sea into eight main provinces. These provinces also act as different types of petroleum systems," says Faleide.

Uplift with negative consequences

The most significant exploration problem in the western Barents Sea, seen from the Norwegian side, relates to the severe uplift and erosion of the area that took place during the Cenozoic in response to the opening of the North Atlantic. "The uplift is highest in the west and decreases to the east, and as a result Triassic and Jurassic rocks were eroded and transported westwards in Oligocene-Miocene times. The uplift may have resulted in failure of the cap rock and leakage of reservoired oil, thereby explaining the lack of success," says Nils Ræstad of Sagex.

Adds Jan Inge Faleide: "This is probably the main reason for the lack of significant discoveries during the eighties and nineties. The quantity of sediments removed, and the timing of the removal, is still a matter of

debate. But it is generally agreed that the uplift and erosion have had important implications for oil and gas exploration in the western segment of the Barents Sea."

"Residual oil columns found beneath the gas fields in the Hammerfest Basin indicate that the structures were once filled with oil. The removal of up to two kilometres of sedimentary overburden from the area has had severe consequences for these accumulations. Gas is separated from the oil, and expansion of the gas due to the decrease in pressure, resulted in migration of most of the oil from the traps", says Sverre Planke.

"A further consequence of these late movements was the cooling of the source rocks in the area, which effectively caused hydrocarbon generation to cease. Thus, little new oil was available to fill the trapping space. These mechanisms may explain the predominance of gas over oil in the Norwegian sector of the Barents Sea."

Source, reservoir and traps

The most significant proportion of the proven hydrocarbon resources in the Barents Sea is contained within Jurassic strata. The gas discoveries within the Norwegian sector that are now being developed all have a reservoir consisting of Lower to Middle Jurassic sandstones. The reservoir is somewhat younger in the giant Russian gas field Shtockmanovskoye and the two large fields Ledovoye and Ludlovskoye, where the hydrocarbons are trapped in marine sandstones of Middle Jurassic age.

"Usually, the number of prolific source rock intervals are sparse in oil provinces, but this is not the case for the eastern Barents Sea. There are source rocks at many levels, and this is one of the real advantages of exploring in this area", says Professor Faleide.

The best eastern Barents source rocks are probably Early and Middle Triassic in age deposited when the eastern Barents region drifted from about latitude 40° to 60° N. Eastern Barents Triassic source rocks are oil-prone to gas-prone shales with total organic carbon (TOC) content of typically 2-8 weight percent. Gross shale thickness ranges from hundreds to thousands of meters. This petroleum system is thought to be gas dominated because of the abundance of gas-prone kerogen, the rapid burial, and the relatively advanced stage of thermal maturity for large areas.

A Late Jurassic warm and humid climate

The disputed area

Politics is an important aspect in the Barents Sea region where environmental movements are also strongly involved. Due to the North Atlantic drift, the Barents Sea has a high biological production, and it is therefore said to be more vulnerable compared to other oceans of similar latitude.

Another, and certainly more challenging, dispute is the border between Norway and Russia, which is far from being clarified. Norway and Russia have been negotiating rights to certain areas of the Barents Sea for more than 30 years.

Geologically, a gentle monocline separates the enormous gas fields identified on the Russian side from the modest oil and gas discoveries on the Norwegian side. Roughly, this geologic boundary also follows the political border the Norwegian Government maintains. The Russians adhere firmly to the sector-line principle, while Norway advocates the median-line principle.

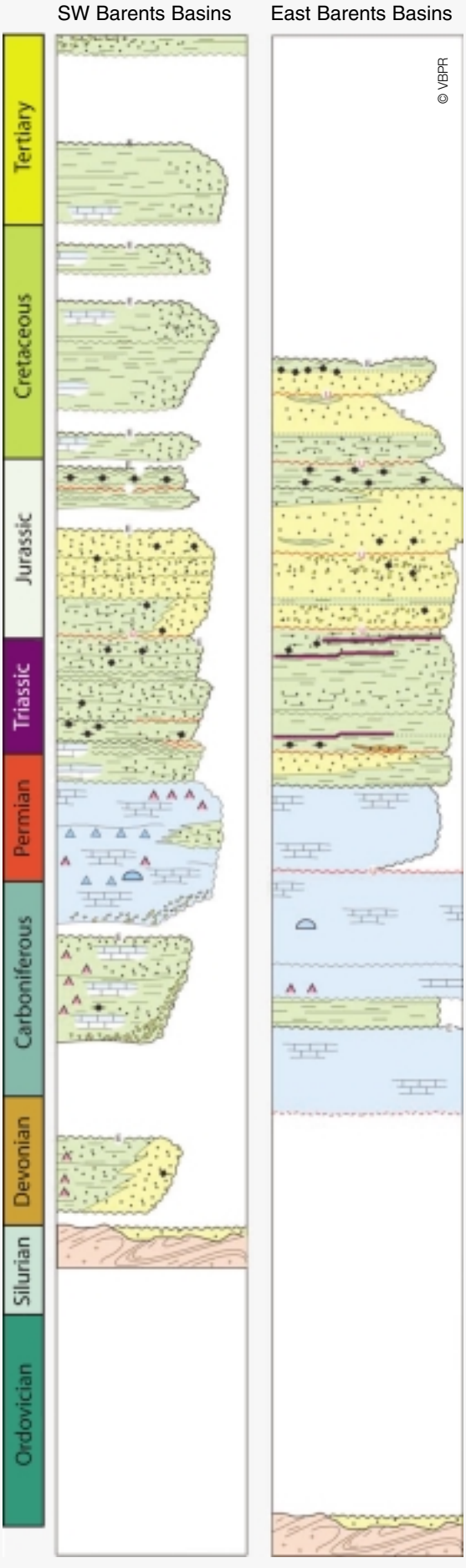
The consequence of this disagreement is a disputed area that covers 150,000 km^2, comparable in size to the North Sea Central Graben, Viking Graben and Moray Firth combined.

"The excellent continuous Jurassic reservoir rocks may be absent on the crestal part of the monocline making up the disputed area. However, while generally of poorer quality, Triassic reservoirs are likely to be present, says Nils Ræstad of Sagex "The gas field North Kildinskaya is straddling the median line to Norway, and maps shown by Russian authorities in several occasions clearly show that there are additional prospects of considerable size within the disputed area," Ræstad says.

Statoil believes there are huge untapped reserves of gas and oil in the zone claimed by both Russia and Norway. Talks since 1974 have failed to result in a border treaty, so reports of promising prospects may further complicate matters. In December of last year, Statoil estimated the undiscovered resources to approximately 2 billion m^3 of oil equivalents.

"We do not have a specific estimate about how much oil may be located in the border area. The figures we have earlier mentioned were culled from various sources and is just an illustration of the area's potential," Statoil spokesman Kristofer Hetland said to the Norwegian newspaper Aftenposten in January of this year.

Other sources claim that the undiscovered resources may be significantly higher than 2 billion m^3 (o.e.), with the Triassic being gas prone and the Paleozoic possibly oil prone. The Norwegian Petroleum Directorate, which supervises exploration on the Norwegian continental shelf, does not have an official estimate.



Dr. Sverre Planke, head of Volcanic Basin Petroleum Research (VBPR) says that regional geology is a keyword when studying the Barents Sea. Integrated seismic, gravity and magnetic data gives important knowledge and overview of the different geological provinces in the study area, the regional basin configuration and the geodynamic development.

coincided with localized conditions of restricted bottom-water circulation in the Arctic region. Dark grey to black, bituminous marine shales tens of meters thick were deposited in several-hundred-meter water depths. In the central and southern Barents subsurface total organic carbon can reach 15-25 weight percent, but with thickness of just 20-30 m. Norwegian Barents Sea thickness approach 100 m.

The Upper Jurassic shale is thought to be the source for most of the discoveries in the Southwestern Barents Sea, but these source rocks are largely thermally immature in the Eastern Barents basins. An early-oil stage of thermal maturity is possibly reached at Upper Jurassic level in the deepest basin areas," says Faleide.

The presence of Devonian Domanik-equivalent, oil-prone, shaly basinal carbonate source rocks is proven much north of the coastline in the Timan-Pechora Basin Province

"Another advantage of the eastern Barents Sea is the many geological structures. The traps that form the Norwegian Jurassic fields are generally fault-bounded blocks. The dominant traps to the east are large rollover anticlines, which can easily be mapped seismically on the Tithonian (Upper Jurassic) base Cretaceous level. Until now, more than 50 dome structures have been mapped, and many act as traps for hydrocarbons. The challenge now is to determine which of these domes to be drilled first", says Faleide.

Bright or bleak?

Three wells will be drilled in the Norwegian sector of the Barents Sea this winter. The first is already under way, and the two next will follow immediately. If the results are positive, the future looks bright and the oil companies will flock back to this geological province. If negative, pessimism will again settle and the future may look bleak.

On the Russian side, the oil companies are eager to get moving with both exploration and drilling, but political constraints make it difficult to predict what happens next. There are, different from the Norwegian sector, a considerable optimism as to the prospectivity. The future therefore definitely looks bright, even if it may take lots of time before exploration and development is on track.

The Barents Sea is underlain by a thick succession of Paleozoic to Cenozoic strata. The basins are characterized by Upper Paleozoic mixed carbonate, evaporate, and clastic rocks overlaid by Mesozoic-Cenozoic clastic sedimentary rocks. The Mesozoic is dominated by clastic sand and shale sequences, containing both good source rocks and reservoir rocks. The most significant proportion of the proven hydrocarbon resources in the Barents Sea is contained within Jurassic strata.