Vol. 2, no. 1 – 2005

# GEO ExPro

GEOSCIENCE & TECHNOLOGY EXPLAINED

*The Blue Lagoon: Volcanic energy made available*

# The Barents Sea: Giants to be found!

Richard Selley

*An outstanding and inspirational teacher*

GEO ExPro
GEOSCIENCE & TECHNOLOGY EXPLAINED
June 2004, Vol. 1 No. 1

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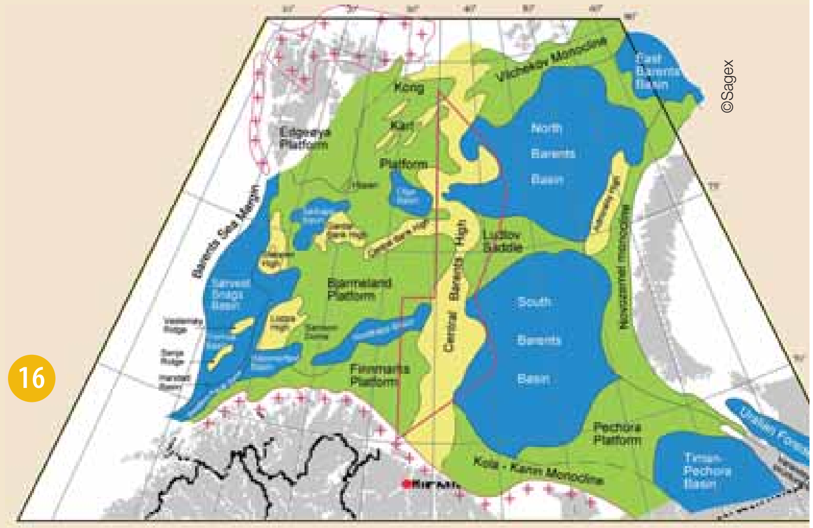
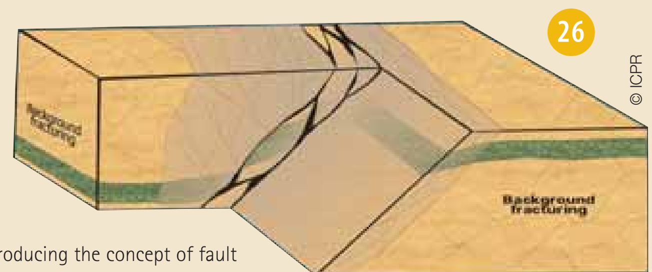
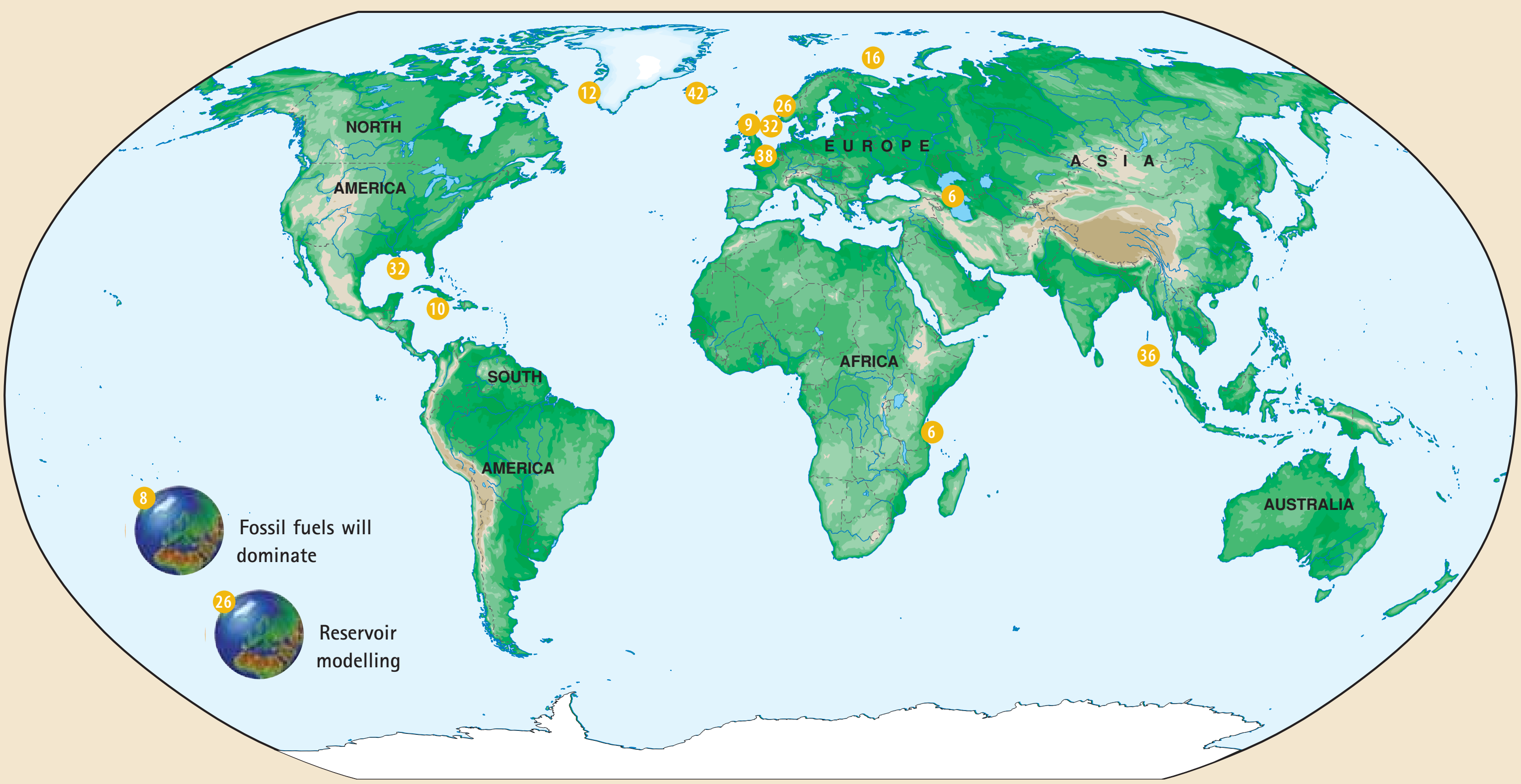



The Barents Sea is a geological province that covers an area that is twice the size of the Gulf of Mexico. Oil and gas is already proven in both the Norwegian and Russian sector, and the undiscovered oil and gas resources are estimated to be high, in particular in the Eastern Barents Sea. This is why western companies are becoming more and more interested in getting involved.




By introducing the concept of fault facies, a new research project aims to arrive at a more realistic way of representing faults and fault properties in the subsurface. The result is expected to improve our understanding of reservoir behaviour and thus improved recovery.



# New technology enhances knowledge

The workday for petroleum geoscientists have changed dramatically over the last two decades. There has been a revolution in the work process, and most of us are finding ourselves in front of a computer in our daily routines.

The reason for this is improved technology.

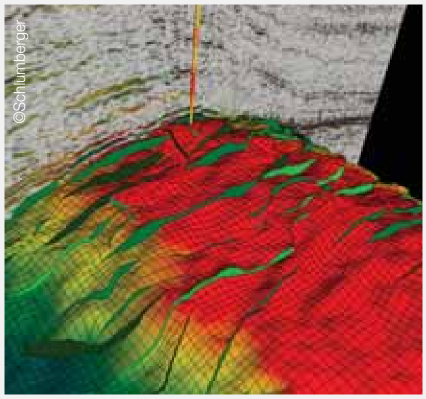
The technological advances do indeed benefit the entire workflow throughout the value chain. Some few examples illustrate this:

Airborne magnetic data with improved processing techniques may change our understanding of continental break-up and thus sedimentary basin development, deep imaging made feasible by introducing super-long seismic cables help us define new plays in mature basins, and complex structural features in producing fields are resolved by applying 4C-seismic,

The above examples demonstrate how geophysical data help the geoscientists to understand the subsurface.

However, we experience the same evolution in reservoir management: New software is available that can handle large amounts of data and display it in a way that makes interpretation easier.

Also, our fundamental understanding of geological processes has changed as we have attained vast amounts of new and improved data that can be analysed with advanced computers.



Recent developments in reservoir modelling make it easier to display complex data gathered through recent technological developments.

**Recent Advances in Petroleum Assessment**, subtitled **Implications for Value Creation**, is the theme of a petroleum conference to be hosted by the Geological Society of Norway this autumn. Through lectures, discussions and demonstrations, the overall scope is to demonstrate how recent developments in petroleum technology have enabled the geoscientists to increase our understanding of the subsurface on a local, regional and global scale.

Representatives of both oil companies and service companies will present a number of case studies applicable to the entire value chain. By starting out with regional basin studies and ending up within how to produce the last droplets in the reservoir, the conference will exemplify these advancements in subsurface knowledge.

A preliminary programme is available on the web-site www.geologi.no.

*Halfdan Carstens*
Editor in Chief

Photo: Geir Birger Larssen, Statoil

## Historical field expedition

For the first time since 1937 a group of western geologists managed to get permission to do geological fieldwork on the southernmost part of Novaya Zemlya. The expedition took place in the late summer of 2004 and was organised by VNIIOkeangeologia (St.Petersburg) in collaboration with the University of Uppsala. Other participants were the University of Stockholm, CASP, Moscow University, St Petersburg Mining University and Statoil.

Thanks to the flawless organisation, combined with excellent weather conditions, the expedition achieved nine days of successful fieldwork.

Besides being an extremely sensitive military area, Novaya Zemlya is a key area for understanding the geology of the shelf areas in the Barents-, Kara- and Pechora Seas. The well-exposed coast cliffs reveal a folded geological record that ranges from Precambrian to Permian on the southernmost part of Novaya Zemlya.

Statoil's purpose for the fieldwork was to get a better understanding of the Russian studies of the Devonian-Carboniferous succession in order to better predict facies patterns in the deeply buried carbonates in the offshore areas to the west and south of Novaya Zemlya. Given the limited access to the outcrops and the time constraints, the researchers were not able to study the entire succession, which is more than 3500 m thick. The expedition documented the depositional facies and evolution of selected, stratigraphically well-defined intervals by recording detailed sedimentological logs.

*Geir Birger Larssen*

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# More oil from the Caspian

In February, the Azerbaijan International Operating Company (AIOC), operated by BP, began oil production from the Central Azeri development, part of the supergiant Azeri-Chirag-Gunashli (ACG) field, in the Azerbaijan sector of the Caspian Sea.

It is estimated that 5.4 billion barrels of oil will be recovered during the 30 year PSA period. The field is being developed in several phases: Chirag has been producing since 1997 and has now been followed by Azeri. The deepwater Gunashli is expected to begin production in 2008.

Located in approximately 128 metres of water 100km east of Baku, Central Azeri (CA) production began from the first of ten pre-drilled production wells on 13 February. Production will increase through 2005 as the other pre-drilled wells are brought online. Production from Central Azeri is forecast to average of 93,000 barrels of oil a day.

The landlocked Caspian Sea contains a number of sedimentary basins with proven hydrocarbons. Most of its oil and natural gas reserves, however, have yet to be developed. BP estimates that the South Caspian region contains 10 billion barrels of oil equivalent of proven reserves (defined as oil and natural gas liquid deposits that are considered 90% probable), while the region's possible oil reserves (those considered to be 90% probable) range from 17 to 33 billion barrels.

For most of the 20th century the Caspian resources were developed to meet the needs of the former Soviet Union. With the dissolution of the Soviet Union in December 1991 the Caspian basin was opened to the outside world, both in terms of foreign direct investment into the region and resource exports to world markets.

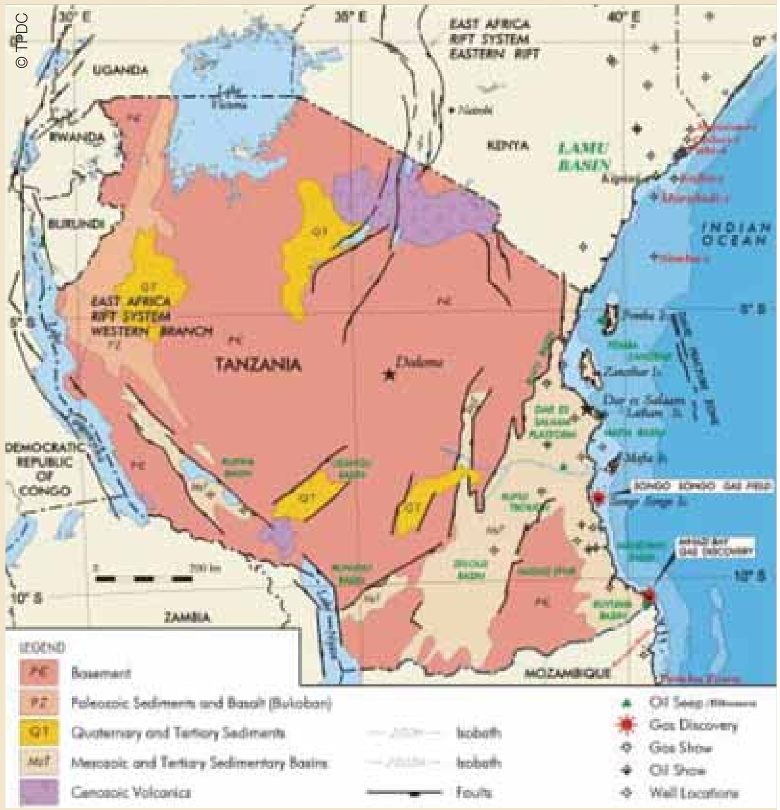
Although the littoral states of the Caspian Sea (Azerbaijan, Kazakhstan, Turkmenistan, Russia and Iran) are already major energy producers, many areas of the Caspian Sea and the surrounding area remain unexplored.




Oil from Central Azeri will be transported via a new 30 inch pipeline to the onshore Sangachal Terminal. Processed oil will initially be transported to market via existing export routes, and through the Baku-Tbilisi-Ceyhan (BTC) pipeline, once it is operational later this year. Gas produced from Central Azeri, beyond that used for reservoir pressure maintenance and fuel, will be sent to shore for domestic use.

# Deep-water blocks






Gas discoveries have been made in shallow water. Now it is time for the deep water to be explored.

Tanzania, through the Ministry of Energy and Minerals and the Tanzania Petroleum Corporation (TPDC), launched the 3rd Offshore Licensing Round late 2004 with 35 companies being present. The round, including seven deep-water blocks, will close on 25th May 2005. Onshore blocks are available through direct negotiations with the Government and TPDC.

One deep-water block is already licensed to the Brazilian state oil company Petrobras who signed a production sharing agreement with Tanzania last year. The four northernmost deep-water blocks have been licensed to Shell.

Tanzania has been intermittently explored over the last 50 years, and onshore gas discoveries were made at Songo Songo and Mnazi Bay. Songo Songo is now being produced and the gas is used for a 180 MW electricity plant.

So far, a total of 35 exploration and development wells have been drilled throughout the country, and the cumulative seismic coverage is approximately 52,000 km of which 28,000 km were acquired offshore and 24,000 km onshore. An additional 11,000 km of deep-sea non-exclusive geophysical data were acquired in the year 1999/2000. No oil has been produced until now, but "available data and geological information reveal the existence of an active petroleum system," according to TPDC representatives.

The Mafia Deep Offshore Basin (MDOB) of southern Tanzania is one of the several East African basins, which resulted from the break-up of the Gondwana continent in the Middle Jurassic.The basin occupies an area of some 75,000 km2 developed between the Tanzanian continental shelf edge and the Davie Fracture Zone 200 km east of the coast. The water depth ranges form approximately 500m to a maximum of 3300m in the southeast of the basin.

The availability of a modern Western Geophysical high-resolution seismic survey data has allowed the geological development of the basin to be interpreted in far greater detail than before. The deep-water basin, situated adjacent to the petroliferous Tanzanian Coastal Basin with known onshore oil seeps and subsurface gas discoveries, offers some of the few remaining frontier exploration opportunities in Africa. Its "multi-play potential is recognized and the possibility exists for several world-class hydrocarbon discoveries, comparable with those recently made in West Africa," report TPDC representatives.

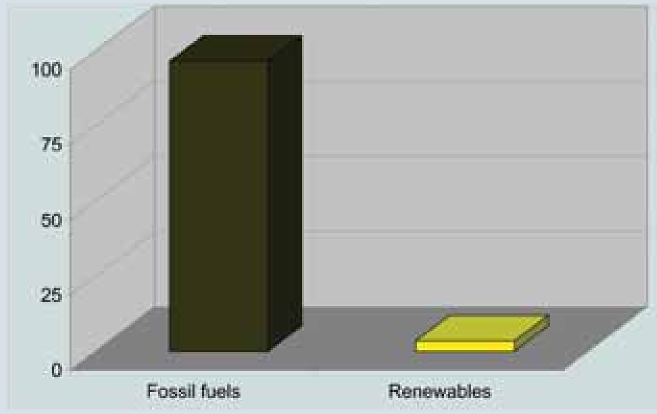

Representatives from TPDC promoted the 3rd Offshore Licensing Round at last years PETEX Conference & Exhibition in London.

## CALENDAR – SELECTED EVENTS

| | | | |
|---|---|---|---|
| **March** | | | |
| 1-3 | APPEX - AAPG Prospect & Property Expo<br>www.aapg.org | London, UK | GEO ExPro No 1 |
| | Exploration Revived, Norwegian Petroleum Society<br>www.npf.no | Bergen, Norway | |
| **May** | | | |
| 2-5 | SPE Offshore Technology Conference (OTC)<br>www.otcnet.org | Houston, USA | |
| 30-1 June | The 10th Conference on Field Reservoir Management, Norw. Petroleum Society<br>www.npf.no | Stavanger, Norway | |
| **April** | | | |
| 10-13 | 2nd North African/Mediterranean Petroleum & Geosciences<br>www.eage.org | Algiers, Algeria | |
| 10-13 | 2005 APPEA Conference & Exhibition<br>www.appea.co.au/conference | Perth, Australia | |
| **June** | | | |
| 13-16 | EAGE 67th Annual Conference and Exhibition<br>www.eage.org | Madrid, Spain | GEO ExPro No 3 |
| 19-22 | AAPG 2005 Annual Convention<br>www.aapg.org | Calgary, Canada | GEO ExPro No 3 |
| **September** | | | |
| 7-8 | The 4th HGS/PESGB International Conference on African E&P, "Path to Discovery"<br>www.pesgb.org.uk | Houston, USA | |
| 5-8 | 2nd. International Conference on Submarine Mass Movements, Geological Society of Norway<br>www.geologi.no | Oslo, Norway | |
| 11-14 | AAPG International Conference and Exhibition<br>www.aapg.org/paris | Paris, France | |
| 25-29 | 18th World Petroleum Conference<br>www.18wpc.com | Johannesburg, SA | |
| **October** | | | |
| 9 - 12 | SPE Annual Technical Conference and Exhibition 2005<br>www.spe.org | Dallas, USA | GEO ExPro No 4 |
| 18-19 | Recent Advances in Petroleum Assessment, Geological Society of Norway<br>www.geologi.no | Trondheim, Norway | GEO ExPro No 4 |
| **November** | | | |
| 6-11 | SEG International Exposition and 75th Annual Meeting<br>www.seg.org | Houston, USA | GEO ExPro No 5 |
| 15-16 | Production Geoscience 2005 - Understanding and Modelling Geological Heterogeneity<br>www.geologi.no | Stavanger, Norway | |
| 21-23 | International Petroleum Technology Conference<br>www.iptcnet.org | Doha, Qatar | |

# Fossil fuels will dominate

## BP stands for Beyond Petroleum. Group Chief Executive Lord Browne does not, however, believe that renewable energy sources will provide material supplies of energy in the next 20-30 years.




The estimate from the International Energy Agency is that in 2015 renewalbe energy will provide only 3.3 per cent of total demand. Coal, oil and gas have to meet the balance.

In an address given to The Empire Club of Canada in Toronto, Group Chief Executive Lord Browne talked about the outlook for the world oil market. Lord Browne, among other things, touched upon the subject of energy security.

**He said that one substantive issue is about supply and demand.** "The demand for energy continues to grow, with the growth underpinned by the increase in population numbers and by the gradual spread of prosperity. The world's population grows by almost 10,000 an hour – almost a quarter of a million every day. In ten years time the world will have an additional one billion citizens – making 7.3bn in total. All those people need food, housing and all the other basic products and services which require energy."

"More and more of the world's population can afford the energy they want to buy. The spread of prosperity, especially in China, India, and parts of Latin America, adds to effective demand on a daily basis. The result is that there are tens of millions of new consumers of commercial energy every year," Lord Browne said.

The current projection from the International Energy Agency (IEA) is that global demand for all forms of commercial energy will rise from the current level of around **190 million barrels per day** of oil equivalents (mbdoe) to some **240 mbdoe by 2015**, thereby increasing almost 30 per cent.

"That forecast is made on quite cautious assumptions about economic growth rates. The numbers could turn out to be significantly higher," Lord Browne added.

### The question is then how this demand can be met.

Some place their faith in renewable and alternative forms of energy supply; that is, power from wind, waves or solar panels.

"We believe those are important sources of future supply, and they may one day provide a significant proportion of global energy demand," Lord Browne maintained, "but the evidence is that day is still a long time off."

The reason is that all the renewable and alternative forms of energy supply provide just 2.5 per cent of world demand, the bulk of which currently comes from biomass. Still, the group executive believes that "renewables will provide material supplies of energy in the long term. But the long term could be 20 or 30 or more years away. The estimate from the International Energy Agency is that in 2015 they will provide only 3.3 per cent of total demand."

The follow-up question is what sources then will meet the demand?

"Some people believe that the key lies in the potential of nuclear power. That certainly is possible. But it seems a remote possibility on the timescale of a decade. Nuclear power currently supplies 7 per cent of world energy demand. The first generation of nuclear stations is reaching the end of their natural lives."

"Last year, only *two* new nuclear stations were commissioned and public doubts both about safety and about the uncertain long term costs continue to constrain new investment. In the US, no new stations have been commissioned for over two decades, while in Europe the forecasts suggest that on current trends nuclear capacity will decline rather than increase over the next ten years.

"The mix will vary from one country to another. China, for instance, will no doubt continue to use large volumes of coal, but in terms of convenience, oil

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*"And that leaves hydrocarbons – coal, oil and gas – to meet the balance," Lord Browne concluded.*

and gas seem set to remain the fuels of choice."

In reality, energy security is about the supply of oil and gas to meet a demand that could grow to around 93 mbd of oil and 64 mbdoe of natural gas by 2015, according to the IEA figures, This would represent about a 20 per cent increase in oil demand from today's level and a 45 per cent increase in the consumption of gas.

"Can the oil and gas industry meet that demand?" Lord Browne asked his audience rhetorically. "In physical terms the answer is clearly yes. The resources are there."

"The world holds some 1,000 billion bbls of oil which have been found but not yet produced, and some 5,500 tcf of natural gas (160 trillion $m^3$) – also found but not yet produced. At current consumption rates, that is 40 years of oil supply and 60 years of gas. In addition, the U.S. Geological Service estimates that some 800 billion bbls of oil and 4,500 tcf of natural gas are yet to be found."

"In terms of physical resources, then, energy security is within reach. There is no fundamental physical reason why there should be a shortage in the next ten years, or indeed for many decades beyond that" Lord Browne, Group Chief Executive of BP concluded.

# Another competitor

EMGS, the innovators of sea bed logging (see articles in GEO ExPro Nos.1 and 2, 2004), are now facing another competitor. This is in addition to AOS Geomarine Operations (AGO) as mentioned in the last edition of GEO ExPro (No. 3, 2004).

"We want our data to look like seismic data and produce an image of the subsurface," says Leon Walker, chief executive of MTEM, to GEO ExPro. Walker, who has held a variety of senior management positions with Schlumberger, will play a key role in bringing the technology into commercial production by first half 2005.

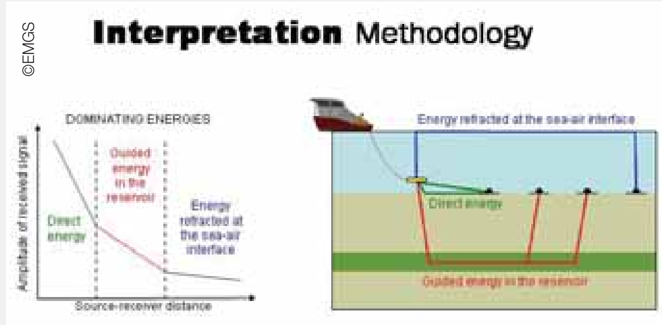
MTEM is a spin-out company from Edinburgh University and ranks as one of the largest ever spin-outs from a UK university. Scottish Equity Partners (SEP) has teamed up with Norwegian energy investment funds Energy Ventures and Hitec Vision in a £7.4 million deal that was settled last November. Stavanger-based Energy Ventures specialises in high growth technology companies in the energy sector while its other co-investor HitecVision is one of the largest private equity investors in Europe focused on the global oil and gas industry.

David Sneddon, Director of SEP's Energy Related Technologies Team, says "the potential market for this technology is around £500 million per year."

MTEM, which was founded by a team from the University's School of GeoSciences led by Professor Anton Ziolkowski, has worked on this technology since 1992. It has lately rejected the possibility of licensing its technology in favour of developing in-house teams, which can then be contracted out for a range of projects. Six years later they had not made any significant progress, but Professor Ziolkowski still thought it was possible to get something out of the data, and a clever PhD-student resolved the problems in 2001. MTEM was thus founded in 2003, and late last year the company has secured the necessary investments to go ahead.

MTEM's team now believe that they can determine whether deep underground reservoirs contain hydrocarbons before drilling. Another of their ambitions is to do time-lapse surveys and monitor the movement of hydrocarbons in the reservoir. MTEM, which includes co-founders Bruce Hobbs and David Wright, also claims to be the only company that have the technology to do electromagnetic surveys onshore.

Walker says that the first land crew - about 15 specialist geologists and technicians - will be up and running by August this year, with the second to follow soon after. The first tests have been conducted above a gas storage reservoir in France.

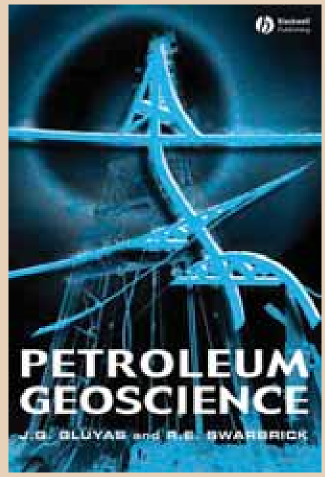



The principles of sea bed logging - electromagnetic surveying - is explained in GEO ExPro No 1, 2004.


Professor Anton Ziolkowski and chief executive Leon Walker (right) of MTEM will compete in the market of electromagnetic surveying. This technology is capable of distinguishing between oil, gas and water, and as a result could save oil companies billions of dollars in the long-term.

# For professionals and students alike

**Petroleum Geoscience**
**Jon Gluyas and Richard Swarbrick**
**Blackwell Publishing £37.50**




New textbooks have a tendency to be quite flashy with glossy paper, excellent photos and stunning colourful illustrations. This one is different. It is black, grey and white throughout, and as such the 357 pages are certainly not serving the geosciences a great favour.

In my view, geology has a lot to do with colours. This is one reason we are impressed by the Grand Canyon. In the "good old days" the seismic data came in black and white, these days everyone wants to use colours also for this purpose. The same is true for graphics displaying reservoir models, well path trajectories and production profiles. Without the colours we loose a lot. "Petroleum Geoscience" would certainly have benefited from introducing this important agent. In particular when it comes to photos and some of the graphics.

That said, this textbook has an attractive profile making it a good buy not only for students, but also for a lot of professionals that are eager to learn more about their own industry. The reason is the broad range of upstream topics it covers. After the introductory chapter, with some basic knowledge and definitions, follows "Tools", "Frontier Exploration", Exploration and Exploitation", "Appraisal" and "Development and Production". In this way the book covers the entire value chain from early exploration to tail end production. And this is exactly what makes it different from a few other textbooks and worthwhile to keep in your bookshelf for particular occasions. Geophysicists may for example want to know a little about migration (that is migration of oil and gas!). Well, here is a one-hour crash course covering primary, secondary and tertiary migration on 8 pages.

The specialists do not like such an approach. It does not give all the details and it is certainly oversimplified. That may be true, but it is better than nothing, and it will give the reader more than most of us know about the subject. And this is exactly why this book is for a broader audience.

One more thing. Numerous case histories, from (almost) all around the world, give the reader knowledge about different geological settings and petroleum systems different from the one that we are dealing with on a daily basis. That is really an asset for the petroleum geoscientist who wants to broaden his or her scope!

*Halfdan Carstens*

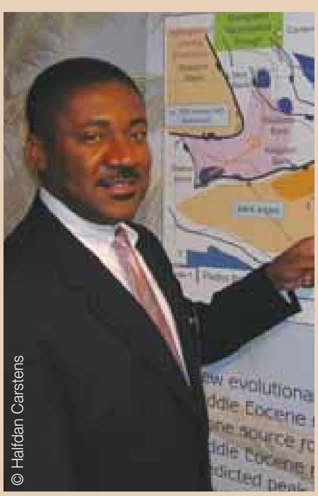
# Jamaica - 2nd try

Jamaica is entering its second phase of exploration. Altogether 22 blocks, 4 onshore and 18 offshore, can now be applied for. The round closes 15 July.

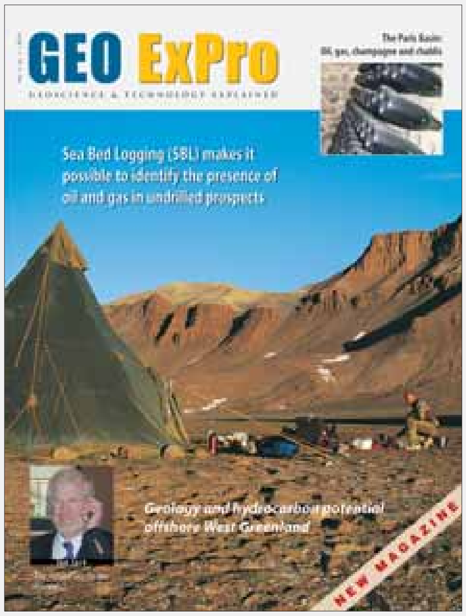
"There seems to be a tremendous interest in this licensing round from the major companies," says one Jamaica representative to GEO ExPro. His judgements were based on the interest shown in their industry presentations held both in London and Houston

There has been virtually no oil and gas exploration activity in Jamaica for more than two decades. Out of eleven wells were drilled between 1955 and 1982 onshore and offshore, ten yielded shows. In addition, there are onshore gas seeps.

More than 16,000 km of seismic were acquired up to 1983. A new 1,900 km seismic grid in deep water is being planned together with airborne magnetics and gravity.




Jamaica promoted their open acreage at last year's PETEX.




**Do you enjoy being a geotourist?**

Remember 'Paris Basin: Oil, gas, champagne and Chablis'?

# Lack of interest

Only one license was awarded in the third licensing round offshore West Greenland (see GEO ExPro No 1/2004 for a detailed account of the West Greenland offshore basins). The award was made public 20 January this year. No details about work obligations have been disclosed.

The Canadian oil company EnCana Corporation, one of the world's leading independent oil and gas companies and a key player in Canada's offshore East Coast basins, will hold 87.5% of the licence and act as operator. The publicly owned oil company Nunaoil A/S will hold 12.5%.

EnCana is also the operator of the only other licence offshore West Greenland. This licence was awarded in the 2002 West Greenland Licensing Round and is situated approximately 80 kilometres northeast of the new licence area. There has been no drilling on this license yet.

EnCana was the only applicant in the third round that closed 1 October 2004.

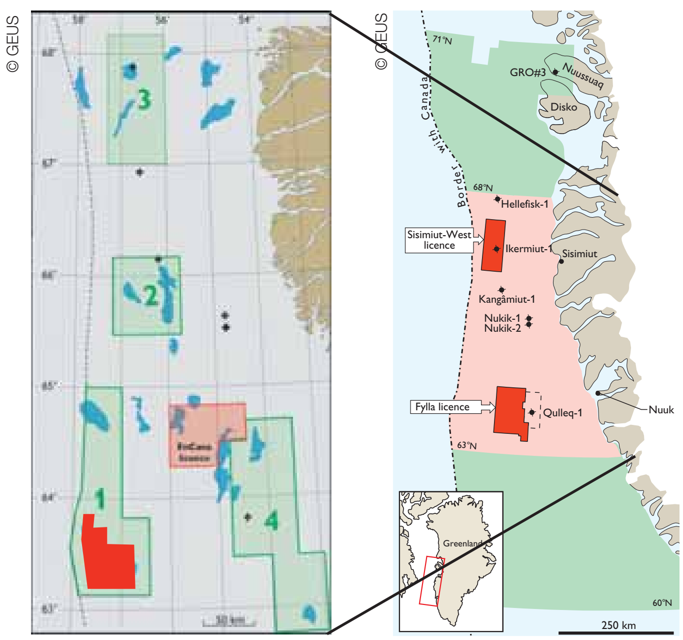
The new licence area covers 2897 square kilometres, it is located approximately 250 kilometres west of Nuuk, offshore West Greenland and covers parts of the Lady Franklin Basin. Altogether 4500 km of 2D speculative seismic data has been acquired in the area. The water depth roughly ranges from approximately 750 metres in the northern part to 1750 metres in the southernmost part. No wells have previously been drilled in the licence area.

A total of only six wells have been drilled offshore West Greenland since the first five exploration wells were drilled in the 1970s. The last well was drilled by Statoil in 2000, but it did not strike hydrocarbons.

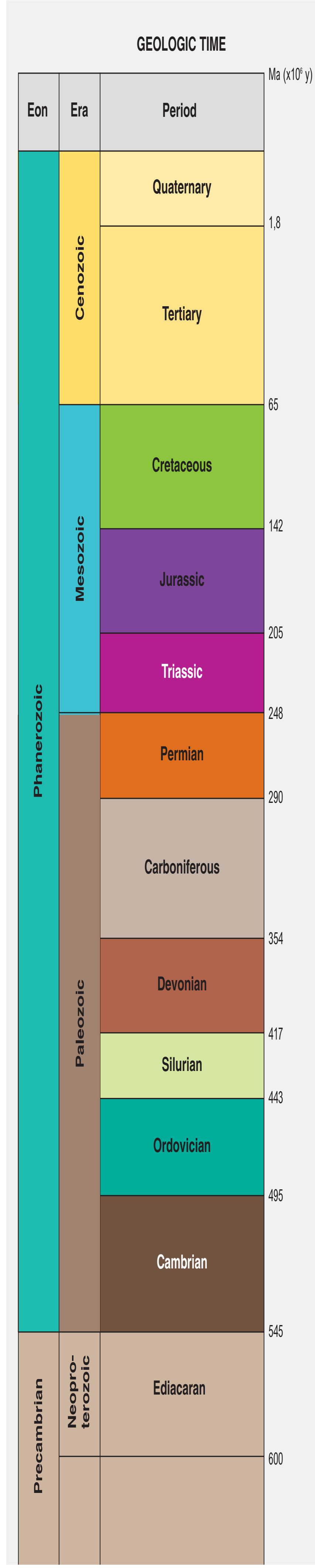
There have been three licensing rounds so far in the course of the last 10 years. Four licences have been awarded, including the last award to EnCana in the third round.

Phillips Petroleum (now ConocoPhillips) and Statoil were operators with one licence each following the first round. Only Statoil drilled an exploratory well, and it proved the existence of sandstones of Cretaceous age, which up to then were unknown from the continental shelf.

The second licensing round closed in July 2002, and EnCana was awarded a license with Nunaoil (carried partner) in the exploration phase.




The continental shelf offshore West-Greenland is divided into three areas for licensing purposes. The former open-door onshore and offshore areas in the Disko-Nuussuaq region between 68°N and 71°N (see map) are closed for applications for exclusive hydrocarbon licences from 1. January 2005 until 31. December 2006. The closing of the area follows the oil and gas exploration strategy for Greenland approved by the Greenlandic and the Danish governments in 2003. The Government of Greenland has in accordance with the strategy implemented an overall plan of action, with plans to decide the future licence policy for the Disko-Nuussuaq area before the end of 2006. The licence policy will also include selected areas of the recent licence rounds further south. To the south (green colour) oil companies can apply when they like and for whatever area they wish. This area is designated an "open door area". The two only licenses offshore Greenland are showin in the map to the left. Both are held by EnCana.



# Creating values through new technology


Through the introduction of "operation centres" and new work processes, managing the reservoir has become more efficient: increased recovery is one implication of this.

The technological breakthroughs of the onwards from the early1990's have had enormous implications for the oil and gas exploration and production industry. New methods, changing work processes and an improved understanding of the subsurface have all contributed to new exploration arenas and increased oil recovery.

Two such examples of recent technological achievements, fault facies analysis and deep imaging, are dealt with in this issue. They both result from the application of new technology in combination with innovative ideas for how to explore in mature areas and how to enhance oil recovery.

Increased understanding of the subsurface as a result of the technological revolution is the topic of an international conference to be arranged in Trondheim, Norway, 18-19 October 2005, entitled Recent Advancements in Petroleum Assessment – Implications for Value Creation. The Geological Society of Norway is the organiser.

The 2-day conference has been divided into six themes:

- Reconnaissance Studies
- Basin Modelling
- Imaging
- 4D/4C Seismic
- Electromagnetic Surveying
- Real Time Reservoir Modelling
- Risk Assessment

Each theme will emphasize how the new technological achievements improve our subsurface knowledge and its important implications for value creation. Ample time for questions and discussions will be allowed following each talk.

The conference programme may be of interest to managers, geologists, geophysicists and engineers who see a need for taking part in a forum discussing how new technology is shaping the future of the E&P-sector.

The organising committee consists of representatives of the strong technological environment in Trondheim, including Eivind Berg, SeaBed Geophysical, May Britt Myhr, SINTEF, Martin Landrø and Egil Tjåland, The Norwegian University of Science and Technology (NTNU), Ola Fjeld, Schlumberger, Odleiv Olesen, The Geological Survey of Norway and Ståle Johansen, Electromagnetic Geoservices (emgs).
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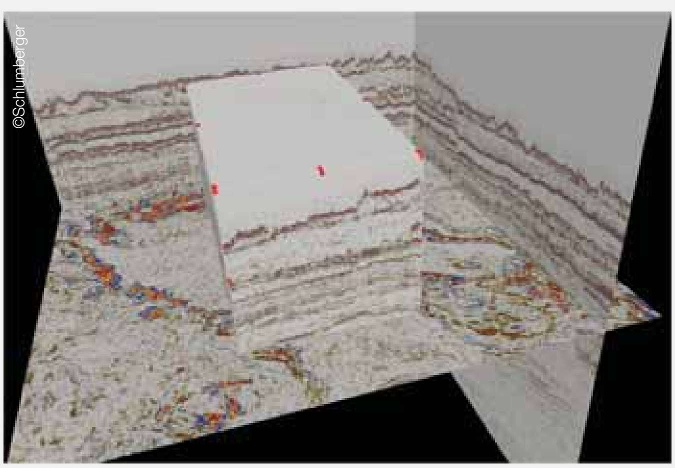
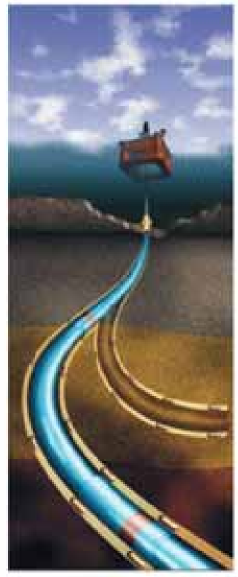


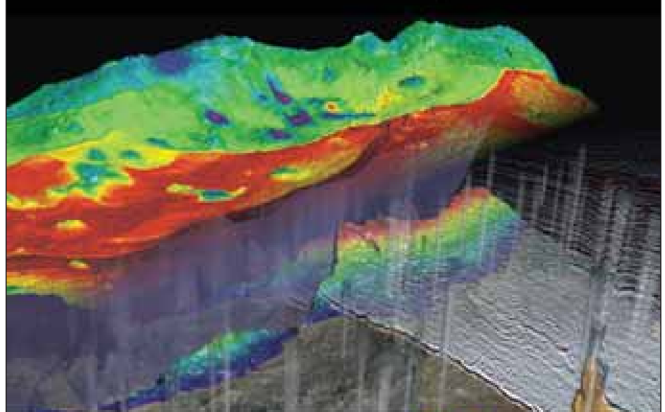

Reservoir modelling, and the demonstration of how recent developments have benefited reservoir management, will be an important subject of the forthcoming conference.


Inexpensive seismic data covering large area in a short time-span has been used in both exploration and production. The conference will highlight how improved data has benefited our understanding of the subsurface.









# 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.**

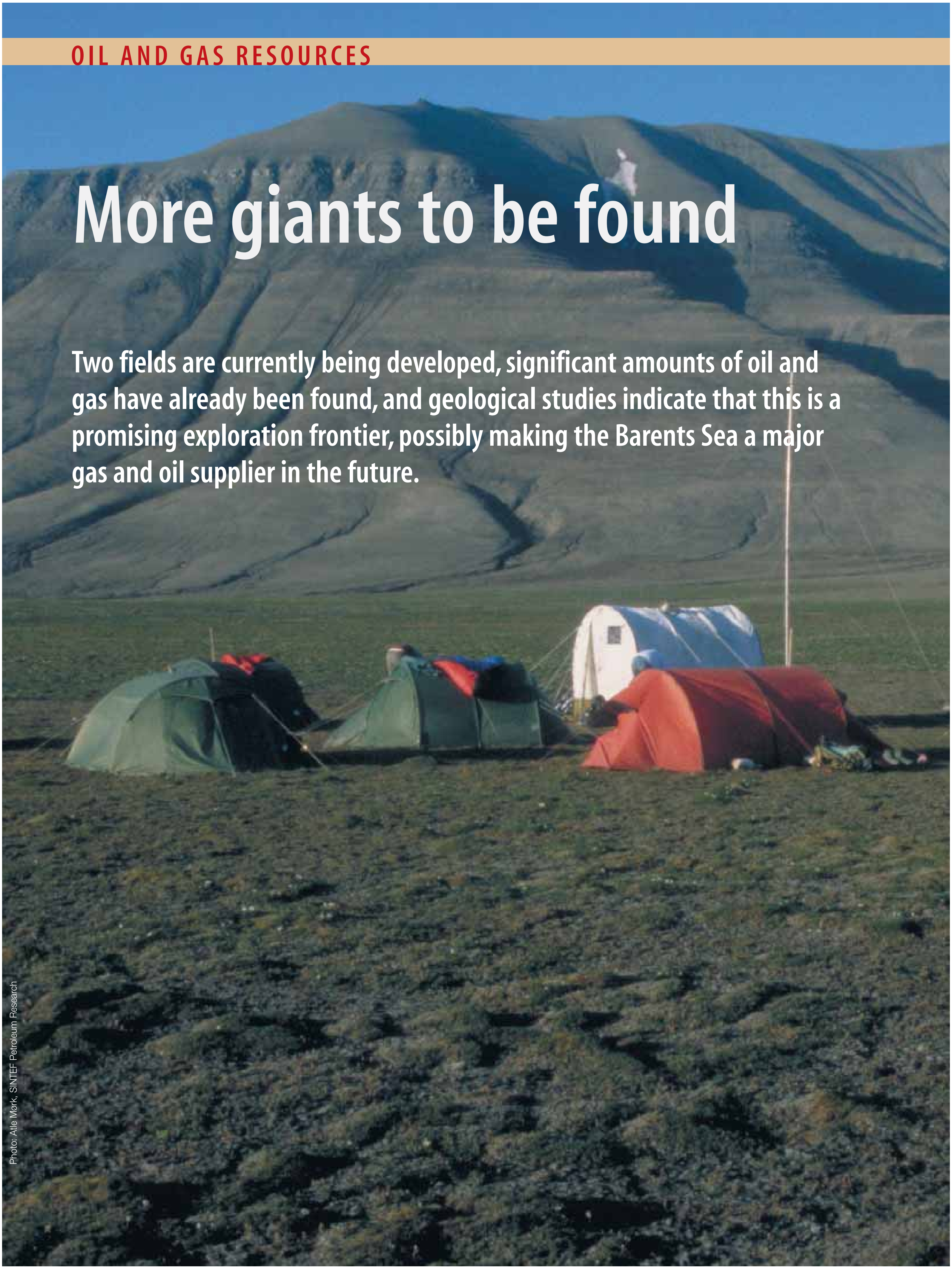
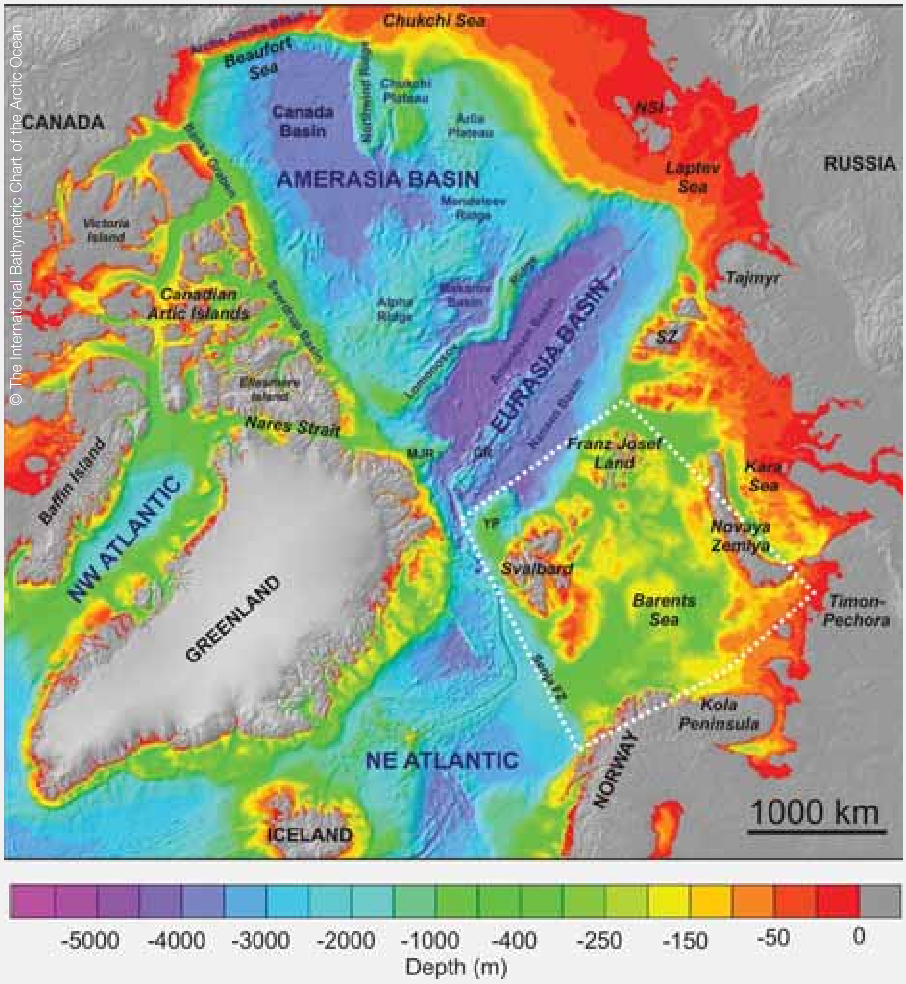
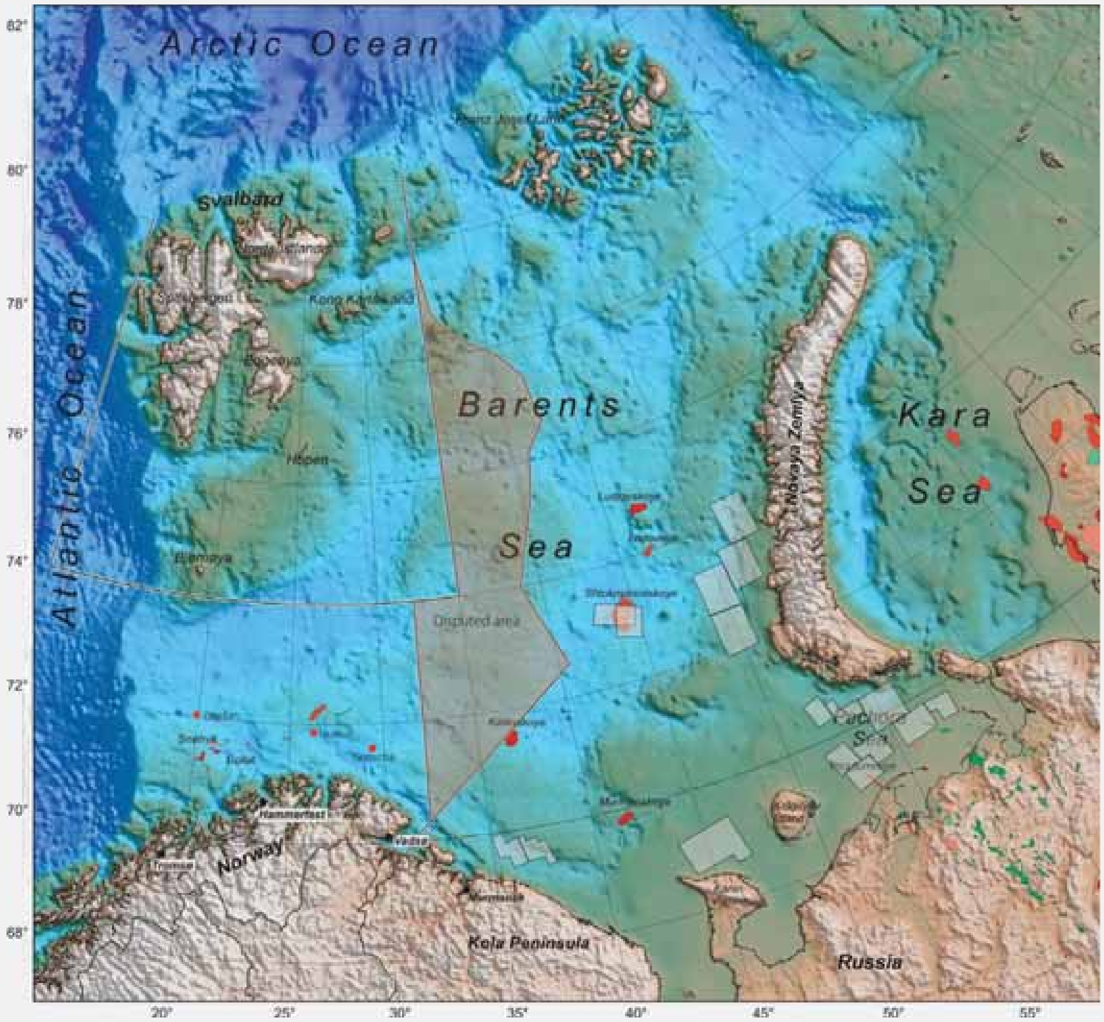


Photo: Atle Mørk, SINTEF Petroleum Research




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.

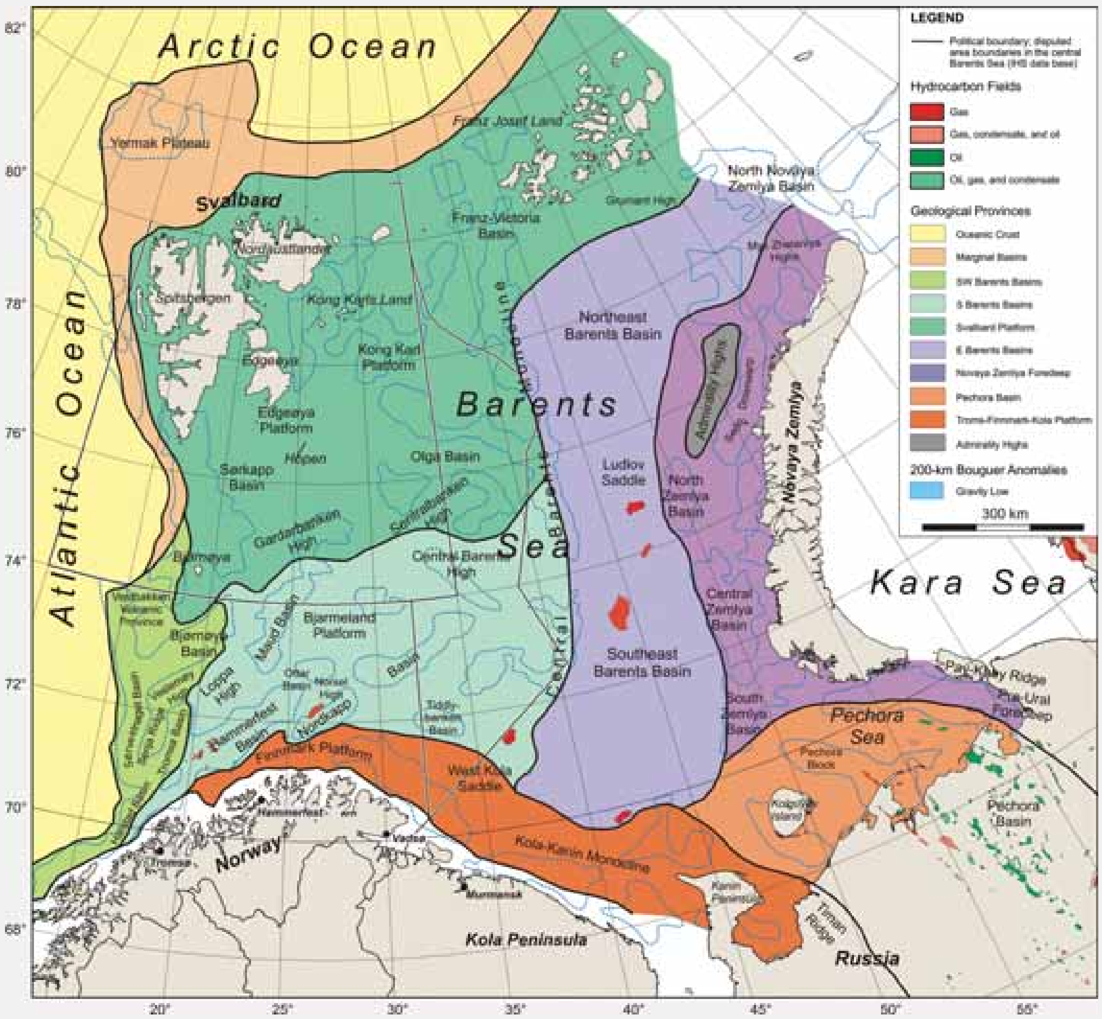
Exploration for oil and gas in the Russian sector of the Barents Sea started more than 40 years ago and has gone through three stages. The first, from the late 1960s to the late 1970s, geological and geophysical investigations included bathymetric studies, bottom sampling, seismic surveys and the acquisition 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.

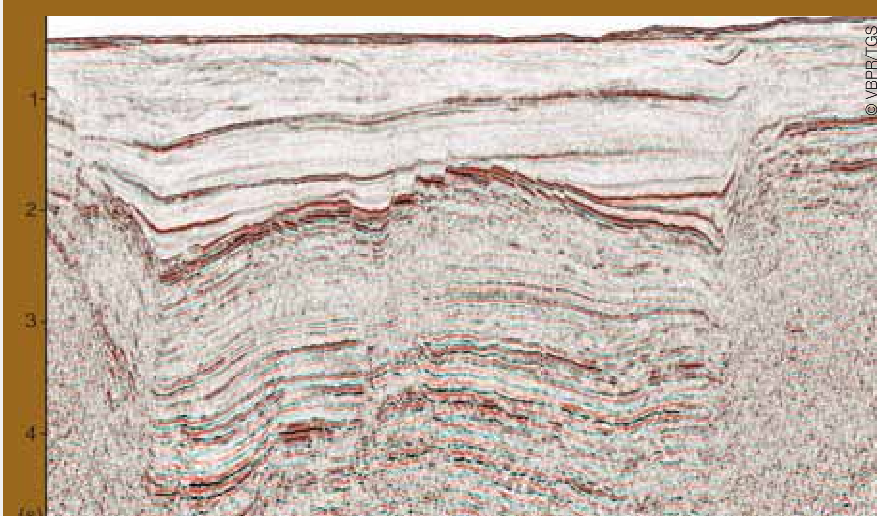
## Snøhvit

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 Shtockmanovskoye 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

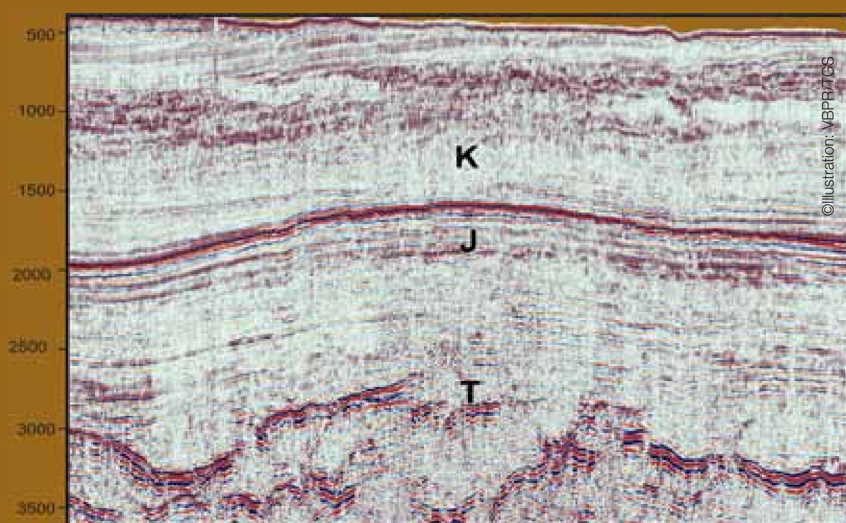
## Shtockmanovskoye

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.

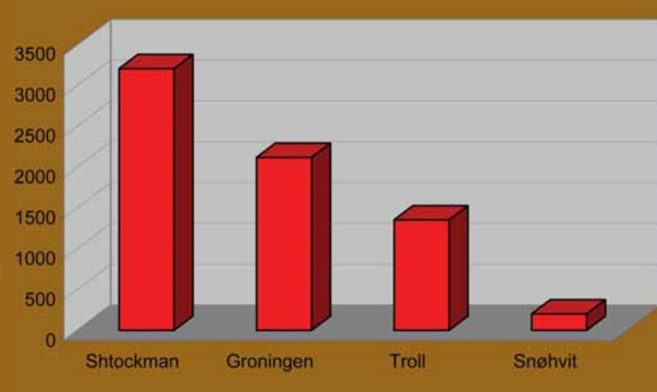
Shtockmanovskoye is located in the South Barents Basin about 650 km north of Murmansk on the Kola Peninsula. Shtockmanovskoye is one of the largest offshore gas fields in the world. "Recoverable reserves are estimated to 3205 billion m$^3$ of gas and 226 million barrels of gas condensate. The field is 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.

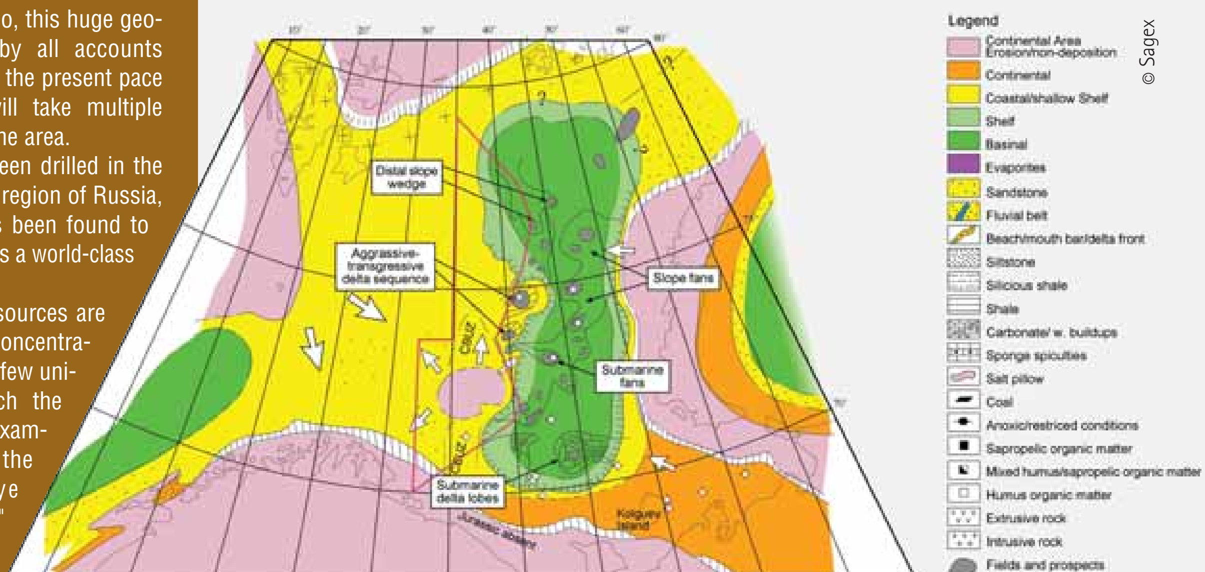
Few wells have been drilled in the eastern Barents Sea region of Russia, but enough gas has been found to classify this region as a world-class petroleum province.

"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.




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.

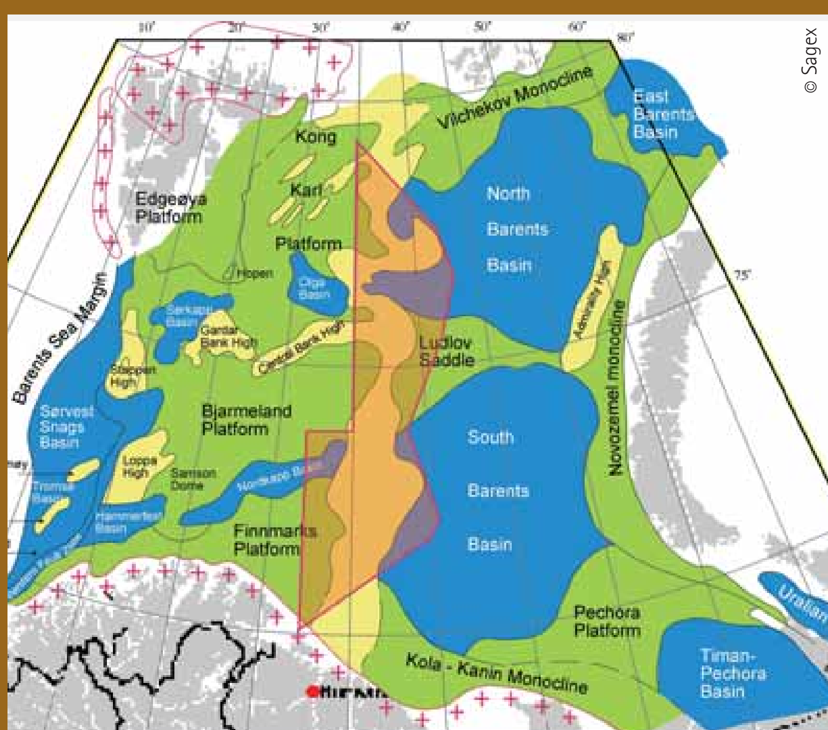
The consequence of this disagreement is a disputed area that covers 150,000 km$^2$, comparable in size to the North Sea Central Graben, Viking Graben and Moray Firth combined.

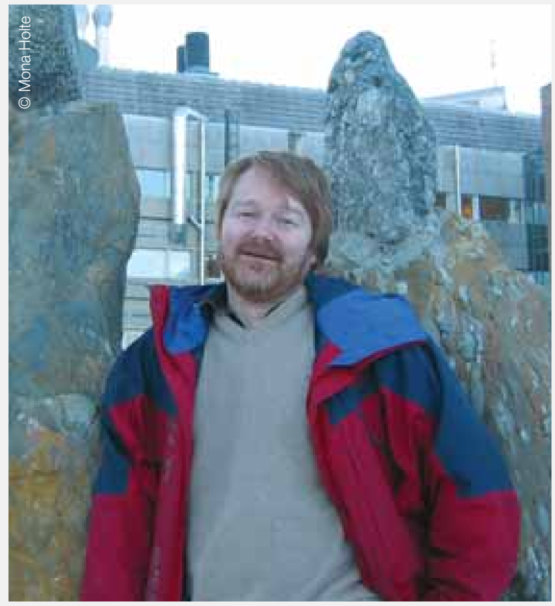
"The excellent continuous Jurassic reservoir rocks may be absent on the crestal part of the monocline making up the disputed area. However, while generally of poorer quality, Triassic reservoirs are likely to be present, says Nils Ræstad of Sagex "The gas field North Kildinskaya is straddling the median 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.

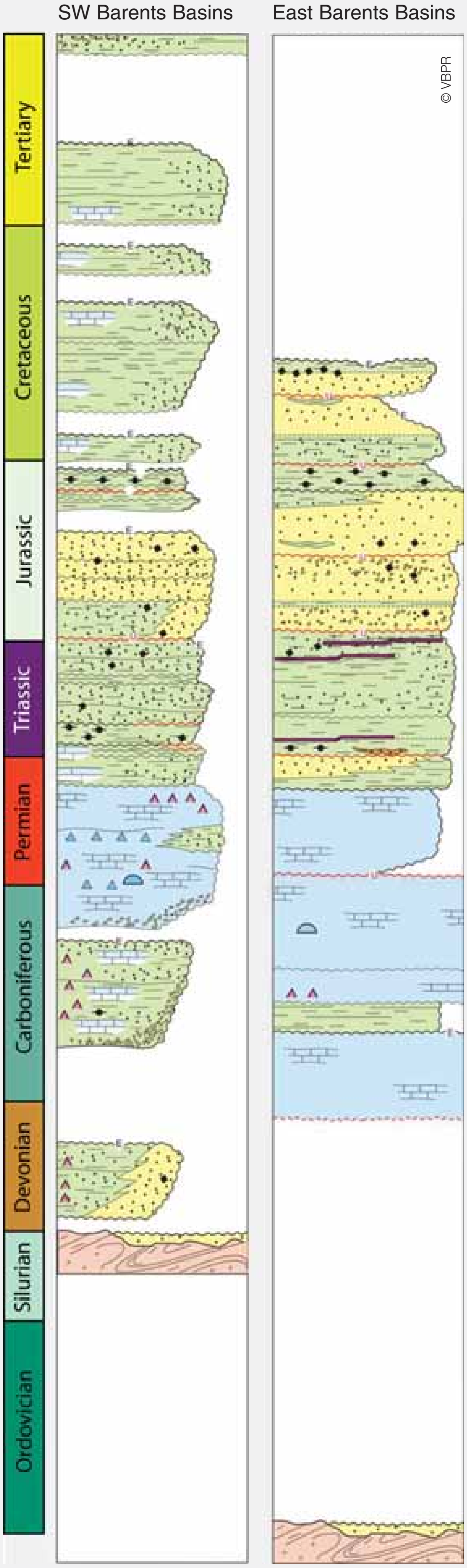
The presence of Devonian Domanik-equivalent, oil-prone, shaly basinal carbonate source rocks is proven much north of the coastline in the Timan-Pechora Basin Province

"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.

# Understanding fault facies improves reservoir modelling

**By introducing the concept of fault facies, a new research project aims to arrive at a more realistic way of representing faults and fault properties in the subsurface. The result is expected to improve our understanding of reservoir behaviour and thus improved recovery.**

Photo: Halfdan Carstens

Halfdan Carstens

Most petroleum reservoirs include faults. However, present reservoir modelling methods encounter serious problems when trying to capture the fact that faults represent three dimensional rock bodies with complex internal architectures and petrophysical properties that are intrinsically linked to the forces that acted on the rock during fault movement.

Faulted reservoirs are more complex to drill, they are more difficult to produce and the behaviour of fluid flow is hard to predict. "Not understanding fault impact on reservoirs has a multi-million dollar price tag," claims Dr. Jan Tveranger at the Centre for Integrated Petroleum Research (CIPR) in Bergen, Norway.

A research project has therefore been initiated with the aim of improving the geological understanding of fault facies. The project is currently in the process of adapting existing modeliing software to to handle fault rock volumes for reservoir modelling purposes.

## Fault complexity

Faults are displacements of rock layers in the stratigraphic succession. On the surface, faults are identified by inspection of rock sequences by experienced field geologists, while in the subsurface; faults are identified from seismic data, well logs or core samples by a multitude of experts on geology, geophysics and petrophysics.

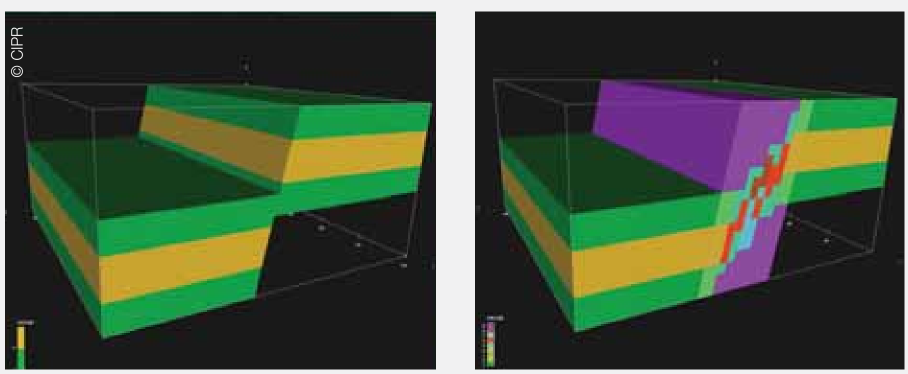
The usual and simple way of demonstrating the presence of a fault is by drawing a line on a map or on a cross-section (e.g. seismic lines), or by illustrating it as a plane in a 3D volume. The entire asset team will be familiar with this approach. Regrettably, this way of illustrating faults does not reflect reality. Faults are much more complex as a result of their genesis.

"A fault is not a line or a plane. A fault represents a three-dimensional rock body. Moreover, the petrophysical properties are changing as a function of strain that originates during fault movement, meaning that the impact of a fault is not restricted to the fault itself, but extends into the adjacent rock volume. A faulted reservoir will therefore exhibit different production characteristics compared to the same unfaulted rock," says Tveranger who acts as coordinator for the research project.

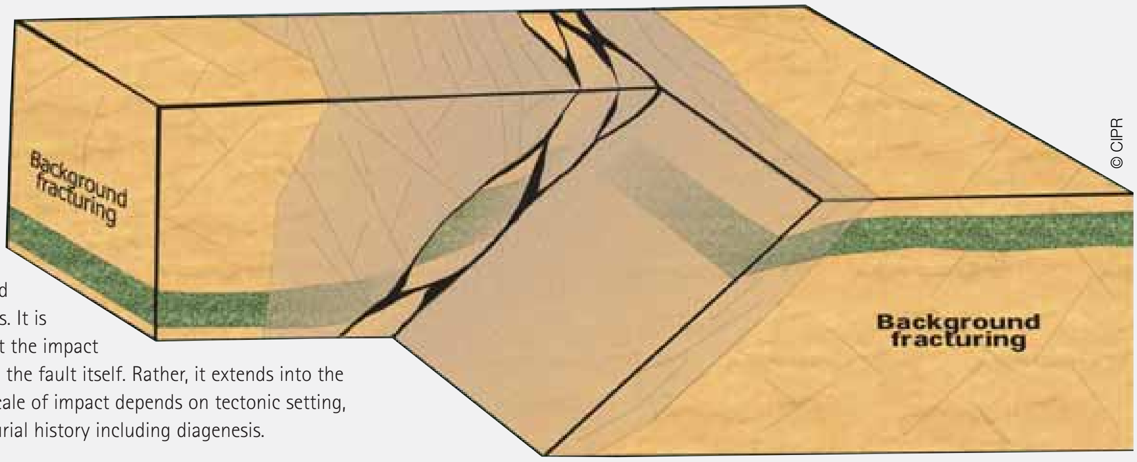
## Modelling the reservoir

"Over the last ten years, three-dimensional modelling using "ultrafast" computers has become the standard way of compiling, manipulating and presenting geological, geophysical and engineering data. It has proven an invaluable tool for arriving at a better understanding of reservoir dynamics and the effect of sedimentary architectures and property distributions on flow. As a result, there are a number of software packages allowing users to build sophisticated 3D geological models that serve as input to fluid-flow simulators," explains Tveranger.

However, there is one major built-in drawback with these tools that relates to how faults are treated. "Traditionally 3D reservoir modelling software tools emphasize the impact of sedimentological features over structural ones for two reasons: First, most geologists involved in reservoir modelling are sedimentologists, and second, reservoir simulators were not originally designed to include faults. The produ-




A fault causes both displacement and modification of the petrophysical porperties of the surrounding host rock. As can be appreciated from comparing a conventional fault model (left) with a conceptual fault facies model (right); the conventional approach only captures half the story.




A fault is a displacement of rock layers resulting in a modification of the petrophysical properties in a volume of host rock. Structures that appear as a single fault from a seismic section will typically comprise several faults with more complicated geometries and tectonically induced petrophysical heterogeneities. It is evident from this sketch that the impact of a fault is not restricted to the fault itself. Rather, it extends into the adjacent rock volume. The scale of impact depends on tectonic setting, fault throw, lithology and burial history including diagenesis.

cers of modelling tools have consequently not seen the need for a complicated fault zone design for geological 3D grids, and tectonic features are still modelled in a very simplified way: as planes and curved surfaces. This is in spite of the fact that the capabilities of modelling programs have improved significantly over the years," says Tveranger.

The need for capturing effects caused by tectonic deformation has been recognised long ago. Norwegian oil companies pioneered the fault modelling effort in the early 90's resulting in a number of specialised applications for modelling fault properties. However, these tools have not become an integral part of the standard modelling workflow. "In practice, most reservoir engineers still claim their right to apply history matching rather than geological data," says Tveranger.

Standard reservoir modelling tools and methods largely ignore the volumetric aspects of fault impact and implement faults as surfaces along which displacement and peremeability reduction take place. The 3D volumetric architecture of faults as well as changes to petrophysical properties of the rocks surrounding faults remain unadressed.

It follows that current 3D modelling techniques and tools fail to incorporate the full impact of tectonic deformation on host-rock petrophysical properties and thus its effect on fluid flow in faulted reservoirs," says Tveranger.

## The project

"Considering that most petroleum reservoirs include faults, we think that the present way of including tectonic features in reservoir modelling does not adequately help us understand reservoir behaviour," says Tveranger. CIPR has therefore launched a project in cooperation with Roxar (a leading software company supplying reservoir-modelling tools), the Norwegian Computing Centre and the departments of Earth Science and Mathematics at the University of Bergen, with the aim of predicting spatial variability of petrophysical properties in sedimentary rock-volumes affected by fault zones.

*Fault Facies* (FF) is a proposed new 3D modelling concept that addresses the lack of realism in existing methods of representing faults in petroleum reservoir models.

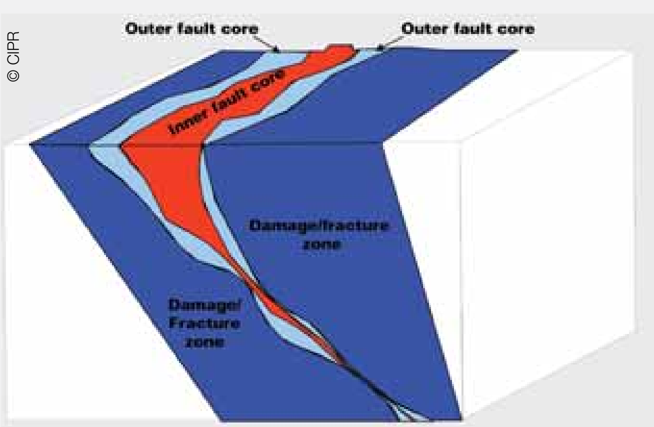
The three-year project has a budget of roughly 3 million dollars and will involve experts on sedimentology, structural geology, rock mechanics, seismic interpretati-

## Fault Facies - definition

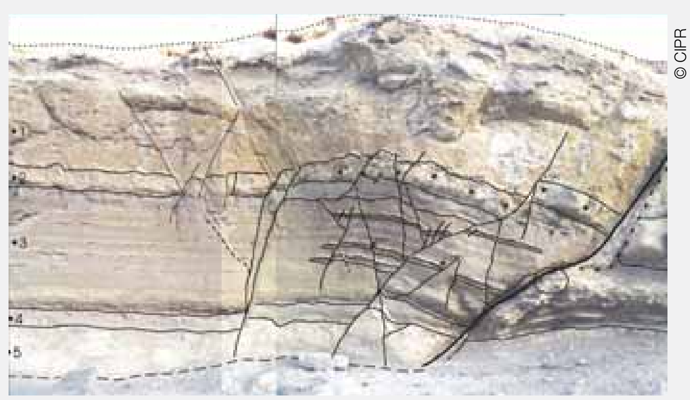
The concept of sedimentary facies has shown itself to be both useful and easy to implement in reservoir modelling. It serves to describe depositional reservoir architectures and property distributions.

A similar approach to describing rocks affected by tectonic deformation is introduced by the *Fault Facies* project. A fault facies is thus informally defined as any feature or body of rock with properties derived from tectonic deformation.

Lithologi, burial history, diagenesis and the stress field govern fault facies.




Terminology used to describe the deformation zone elements or fault facies.




The conventional method of describing faults as simple planes, or curves in cross-section, is evidently misleading.

on, reservoir simulation, programming, mathematics and geostatistics.

"The ultimate goal is to employ fault facies as an integral part of future 3D modelling of hydrocarbon reservoirs in the oil industry. This will allow users to capture and predict the effect of faults and other tectonic features on hydrocarbon flow in three dimensions with significantly higher accuracy and realism than is presently possible."

The aim of the proposed project is to arrive at a model that includes more realistic way of representing faults and fault properties. This will ultimately allow tectonically modified rock bodies to be modelled with the same kind of precision and flexibility as sedimentary architectures are modelled at present, and allow a better understanding of fluid flow dynamics in faulted reservoirs.

The project intends to publish results continuously throughout the project peri-

## CIPR

The Centre of Integrated Petroleum Research (CIPR) at the University of Bergen intends to increase recovery from existing oil reservoirs by expanding the understanding of multiphase flow in porous media. Geology, chemistry, mathematics and physics are combined in order to establish new reservoir models for quicker and more accurate simulations.

CIPR's partners comprise the Institutes of Geoscience, Mathematics, Physics, Chemistry and Microbiology at the University of Bergen. 150 persons work full or part time at CIPR, totalling about 50 man-years each year. The Centre attempts to meet industry's need for qualified candidates by educating 200 master and 100 Ph. D. students the next 10 years.

Sixty percent of CIPR's budget is covered by the oil industry, and the new status as a Centre of Excellence ensures an annual funding of approximately two million dollars from the Norwegian Research Council.

"If we manage to increase oil recovery by only one part per thousand, the investment in CIPR will be covered," says centre leader Arne Skauge, who is a petroleum engineer with long experience from the oil industry, research and education. "We want to contribute to increased recovery in existing oil fields, as well as to make new, economically marginal discoveries profitable, he says."


Photo: Jan Tveranger, CIPR

Fault within the Suez graben, Sinai, showing downfaulted sandstones and Eocene pre-rift carbonates in the hanging block. The damage zone caused by faulting is clearly evident.

od in refereed national and international journals. Considering the number of PhD and researchers participating in the project, 35-50 papers are expected to be published from project start-up to two years after its termination.

The project addresses a fundamental aspect of how geological information is included in models. As these models serve as standard tools for many aspects of exploration and hydrocarbon production, results of the proposed project are expected to add to both improved recovery (improved reservoir simulation models) and exploration (mapping of faults and fractures as well as prediction of reservoir properties).

> "Current 3D modelling tools fail to incorporate the full impact of tectonic deformation on host-rock petrophysical properties and hence on fluid flow in faulted reservoirs.

## Improved recovery

Several oil and gas fields that are currently being produced have experienced significant problems with fault related features in the reservoirs. Current reservoir modelling tools are not able to realistically capture the impact of tectonic deformation of fluid flow. This is a serious obstacle to optimising production strategies and recovery. The project aims to provide an improved methodology and tools to solve this problem.

Also, relevant to exploration, prospects have been deemed too risky to drill, as sealing properties of faults within these prospects could not be established with sufficient reliability.

"It is a stated aim of the project to develop these tools and methods within the framework of existing standard modelling application in order to ensure a speedy practical implementation. The net result will be improved understanding of reservoir behaviour and thus improved recovery," concludes Jan Tveranger.

## Reservoir modelling

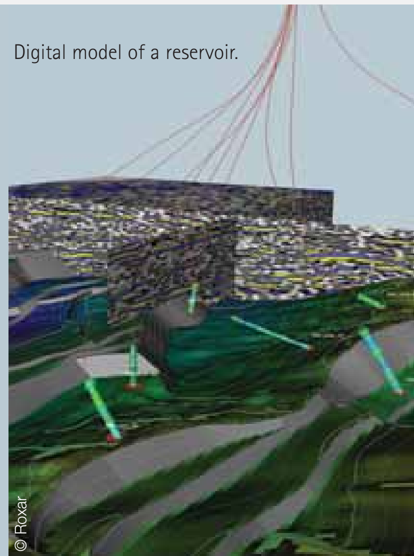
Three-dimensional digital modelling of reservoirs has become a standard in the petroleum industry. The purpose of such modelling is to describe the geometry and the petrophysical properties of the reservoir in order to calculate the volume of oil and gas present, and to predict how the reservoir performs during production.

Reservoir modelling has thus become a necessity to determine if it is economically feasible to produce the reservoir, and- if so –how to produce the fluids to get the most out of the reservoir.

Reservoir models are built by combining information from seismic and well data. The seismic data primarily gives input to understand the geometry, while the well data is essential to what kind of properties should be assigned to the reservoir rock. In between the wells, it has become common practice to fill the gap by applying field analogues. Geologists look for analogues that have comparable depositional environments to the reservoir.

Modelling requires that the reservoir be divided into blocks or cells. Such cells are typically 50x50x1 m. A reservoir model will thus consist of tens of thousands of cells that each have an assigned value as to fluids, porosity and permeability. Altogether these cells constitute a 3D grid.

Digital model of a reservoir.

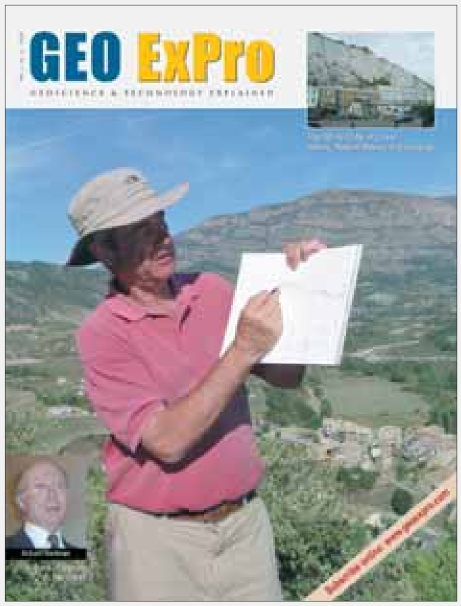


© Roxar

The reservoir model is built in two steps. First, a geological model is built based on the knowledge gathered from seismic data, well data and field analogues. The next step is to transfer the data to a flow simulator that will give knowledge on how the fluids flow through the reservoir. The results are used to determine where both production and injection well should be placed and how the production and injection should be regulated to get optimal production and maximum recovery.

Photo: Halfdan Carstens

Field analogues are important in reservoir modelling for interpolating detailed petrophysical properties between wells. The Ainsa Basin in the Pyrenees is widely used for several depositional facies, including deep-water sediments.




**Richard Hardman: "Hierarchy is the enemy of exploration." Agree?**

'Billions of barrels to his credit'

# Chasing deeper targets

**Deep imaging has improved significantly, and deeper prospects can now be identified by using very long streamers that record data to more than 10 seconds two-way travel time.**

*Halfdan Carstens*

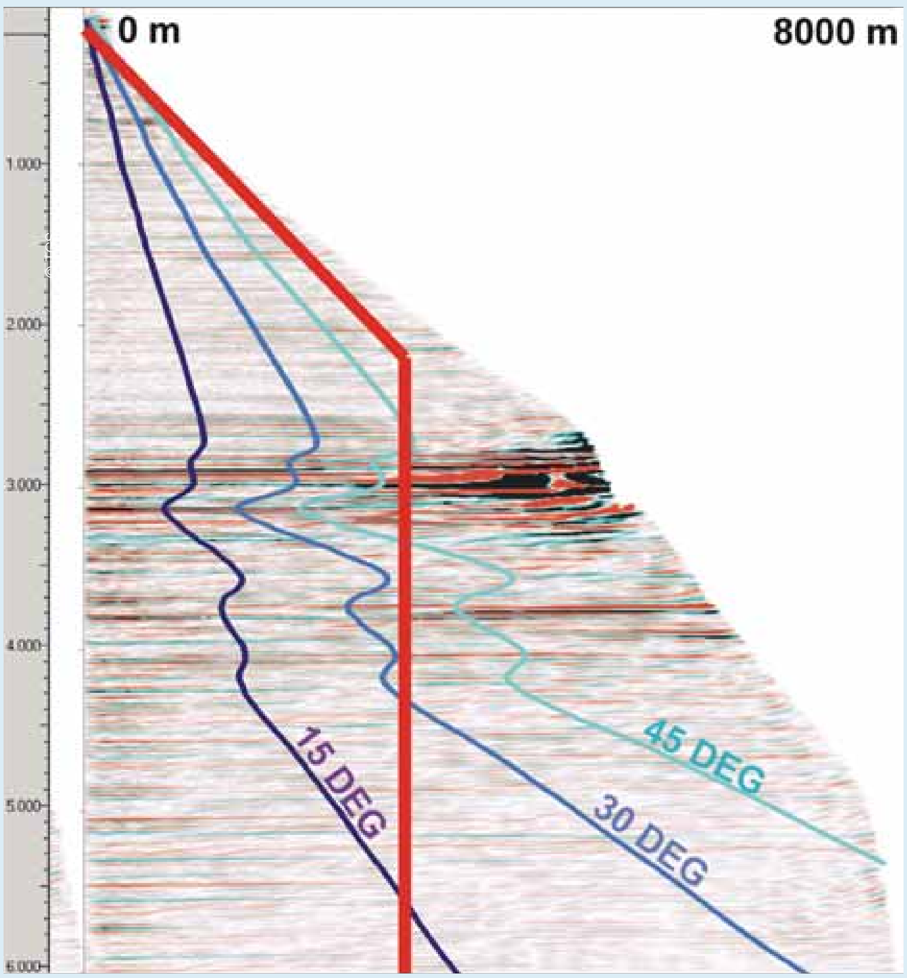
The days of 2D seismic data have certainly not come to an end. Long regional lines - recording deep data with extra long streamers - have become the preferred choice in both the Gulf of Mexico and the North Sea. The purpose is to uncover deeper reservoirs that have not been reached with conventional seismic.

## Slow start

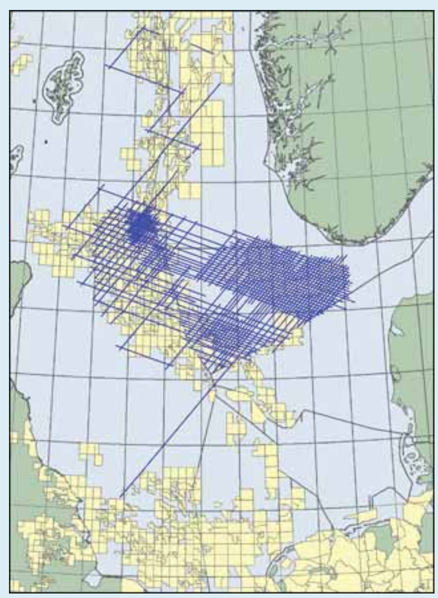
The geophysical company TGS first came up with the idea of re-shooting the North Sea with 2D seismic 3 years ago. "Long offset acquisition with an 8,000 m streamer that offered high quality processing and Amplitude Versus Offset (AVO) capabilities was our sales pitch. This would provide the interpreters with improved deep imaging to analyse rock properties and pore fluid fill," says Jørn Christiansen, Vice President of Business Development.

"Analysis of AVO has only in recent years become a standard exploration tool. Most of the 2D and 3D data recorded over the years for this reason does not have the sufficient offset to be used as a conclusive AVO analysis tool," adds Bent Kjølhamar in TGS.

Unfortunately, the industry response to the long offset recording was miserable. A road show, including a visit to almost every oil company working in the North Sea, turned out very negative. Says Christiansen: "After six months of marketing we had received absolutely no pre-funding from the industry to embark on our ambitious




NMO corrected North Sea Renaissance (NSR) gather with eight km streamer. The gather is dominated by a strong reflector at the top of the high velocity chalk layer with refraction and total reflection energy beyond critical angle. Superimposed in blue are the corridors for the angle stacks and in red the typical offset limit for a vintage North Sea survey. Note the high energy on pre Cretaceous events appears at offsets 3500-6500m at reflection angels > 45 degrees.



North Sea Renaissamce (NSR) covers the entire North Sea and parts of the North Atlantic margin. So far 20,000 km has been aqcuired, and 15,000 km more is in the pipeline.

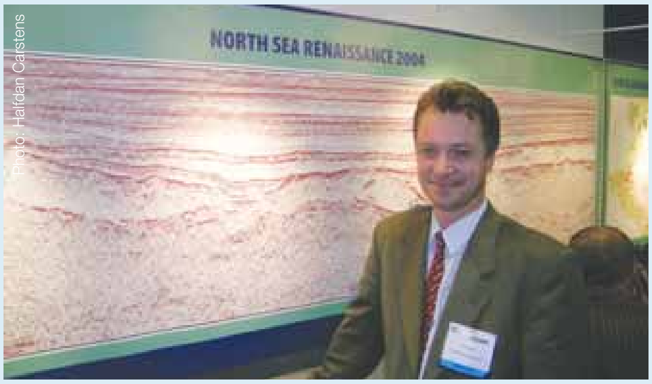



Photo: Halfdan Carstens

Bent Kjølhamar of TGS marketing North Sea Renaissance at last year's PETEX Conference & Exhibition in London.

plan. Their argument was simply that we were ten years too late. The leads had already been covered with 3D and most of the oil and gas had been found long time ago. Also, the geophysicists persisted that for the North Sea long offset would be of no use, since all the energy is refracted in the Chalk."

"That was pretty devastating. The only encouragement they gave was to welcome us back whenever we would have improvements to show", Christiansen explains.

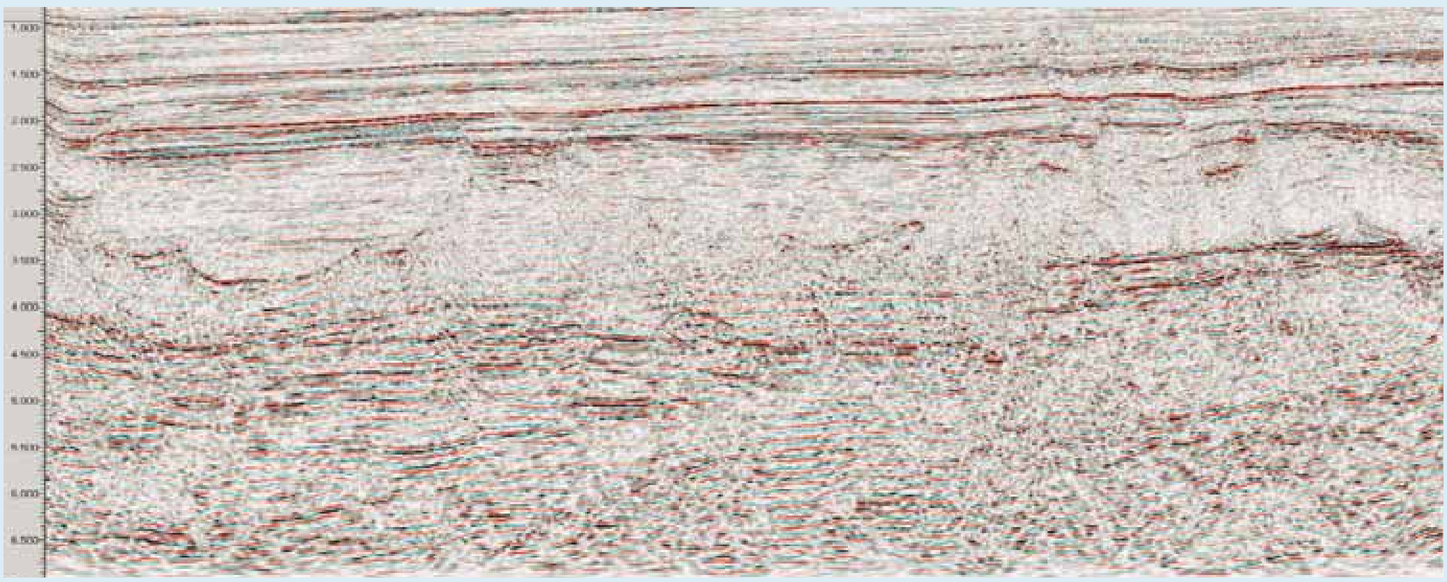
Curiously enough that did not stop TGS from continuing their planning for a 160,000 km survey to be acquired over several years. Without oil company support, TGS teamed up with Fugro, and in the spring of 2003 acquired a pilot programme of some 3,300 km long offset 2D seismic. The programme covered the producing fairway of the UK and Norwegian North Sea in an open 40 x 40 km grid.

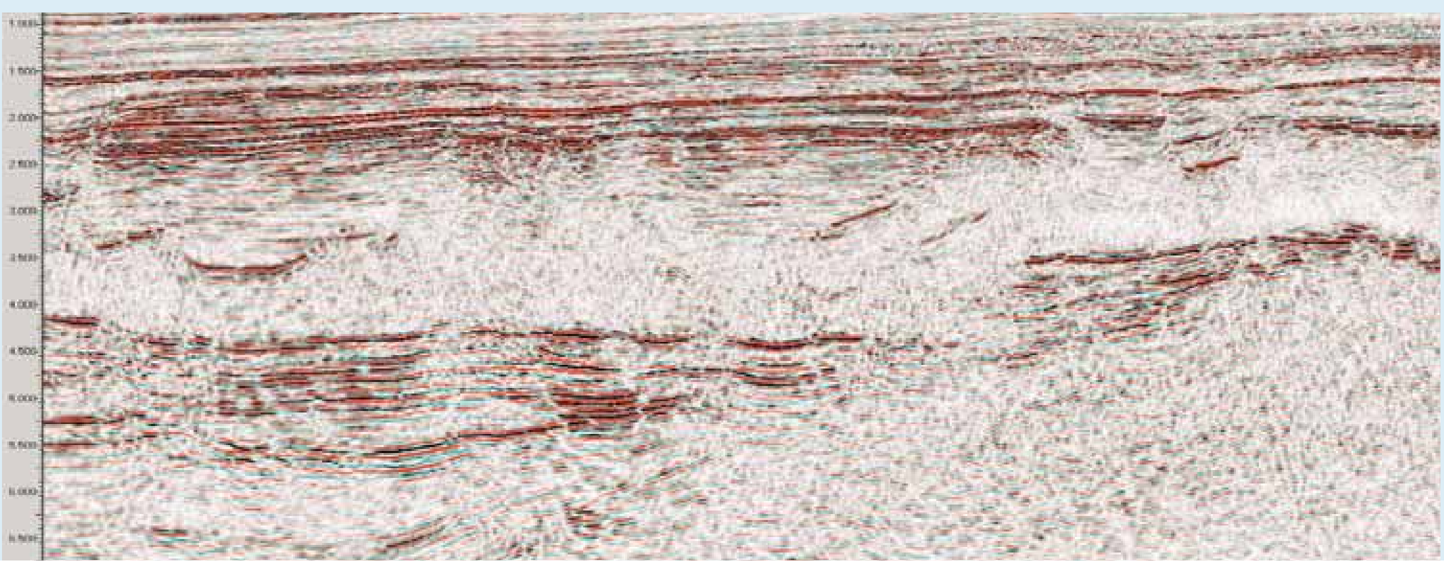
## Happy end

Towards the end of 2003 the first data had been processed and was available for review. "The new long offset 2D data, recorded to 9 seconds two-way travel time, showed deep events that we could not see on our vintage data. Suddenly, pre-salt reflectors of Permian and Carboniferous age could easily be interpreted in many areas where this was previously unheard of. Also, the data had a much better signal to noise ratio, and the long offsets appears valuable for AVO purposes," says Christiansen.

Some portions of the new North Sea Renaissance (NSR) lines are by coincidence acquired in the same location as vintage data owned by TGS-NOPEC. This provides a unique opportunity to compare data quality. The above illustrations compare data from NSR04 and a survey acquired eight years ago. Evidently multiple removal and penetration is much better on NSR, providing a cleaner seismic section, in particular in Permian and deeper strata.

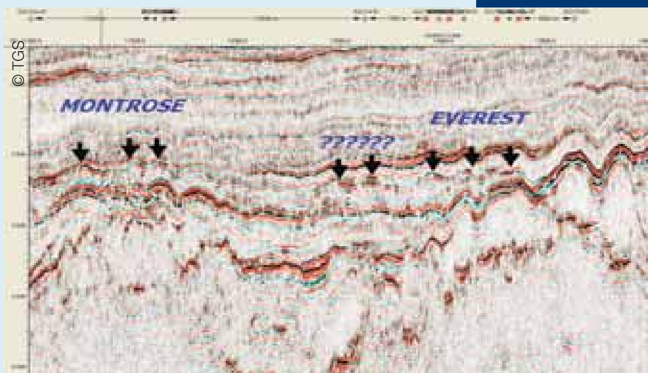
© TGS





"Our next visit to our customers was appreciably more pleasant. They liked what they saw, and several oil companies ended up supporting our 2004 campaign by pre-funding surveys in the Central Graben and the Egersund Basin. This data set is now already in active use in the blocks awarded in the Norwegian 18th licensing Round for companies exploring for deep targets in Permian and Carboniferous below the extensive salt."

The regional seismic programme North Sea Renaissance has already grown to more than 20,000 km, and TGS is presently preparing for another 15.000 km extension in 2005. "We do believe that North Sea Renaissance will live up to its name and serve as valuable tool for explorationists in the years to come," concludes Christiansen.




One of the main objectives with the North Sea Renaissance (NSR) survey is to provide a consistent dataset with special focus on amplitude preservation and AVO processing. Some NSR liens cross already discovered fields providing an unique opportunity to observe the long offset stack and gather data from NSR with respect to AVO effect in hydrocarbon baring and non hydrocarbon baring strata. Above is a line crossing the Montrose and Everest Fields in the UK North Sea. Note the high energy on the far offsets on the fields

## Deeper than 10 seconds

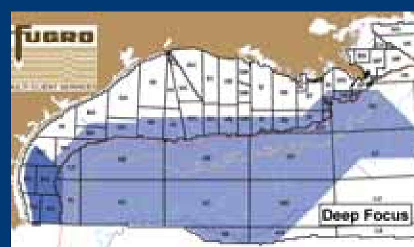
"Deep Focus is a new long offset 2D seismic survey across the Gulf of Mexico that links the shelf expansion trends with current deep water sub-salt exploration plays. By utilising 10,000m offsets and maintaining acquisition specifications, imaging of deep geology with good signal-to-noise is achieved," says Michael Davidson with Fugro in Houston.

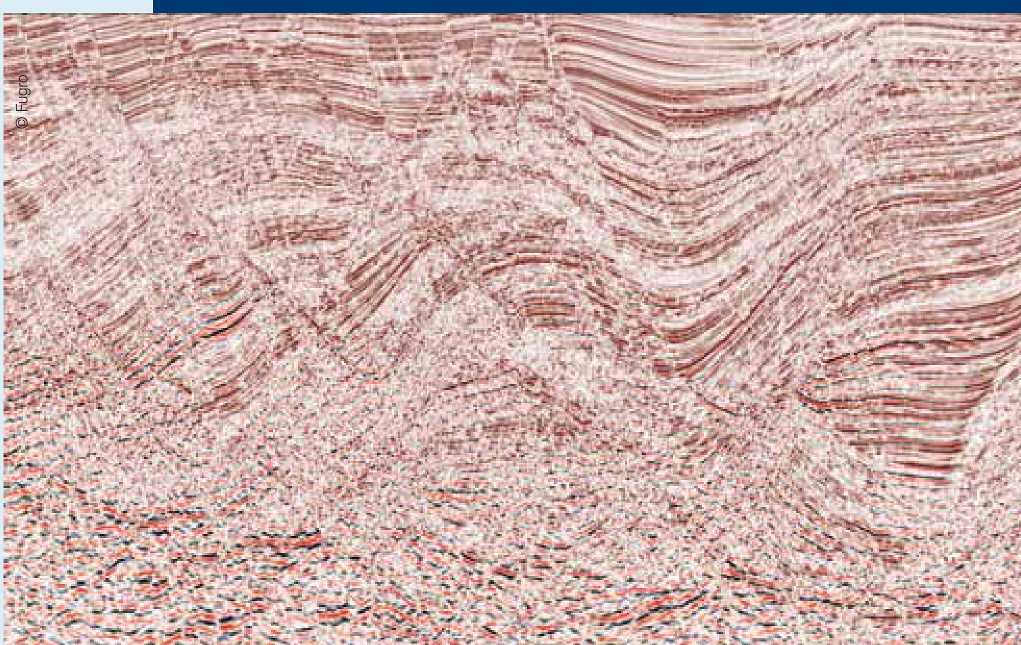
The 2D seismic grid is meant to cover all the deep-water acreage of this petroliferous oil and gas province. "The Gulf of Mexico has a unique setting. Along with only a few other basins around the world, the sedimentary sequence is very thick and extends down to more than ten seconds two-way time. To get data at such depths it is necessary to integrate quantity (3D) with quality (2D). That is why we have embarked on a programme to acquire a 2x2 mile 2D seismic grid in the Gulf in which we focus on quality," says Kenneth Mohn, Exploration Vice President of Fugro Multi Client Services.

Fugro began acquisition in 2002, and has presently acquired 80,000 km. The total survey size is 135,000 km and when completed will be the largest 2D survey in the Gulf of Mexico.

Gravity data is also being recorded on the survey and full 3D gravity modelling supports the wave equation pre-stack depth migration process in determining allochthonous salt thickness and constraining the deeper crustal model.

"The seismic and gravity data can be further augmented with high resolution aero-magnetic data to provide companies with complete and integrated geophysical datasets and tools to aid exploration efforts in the Gulf of Mexico," Davidson says.




Example of Deep Focus data from the Gulf of Mexico.

# Oil and gas operations escape damage

**The oil and gas operations in Southeast Asia were largely unaffected by the earthquake and the following tsunami that hit December 26.**

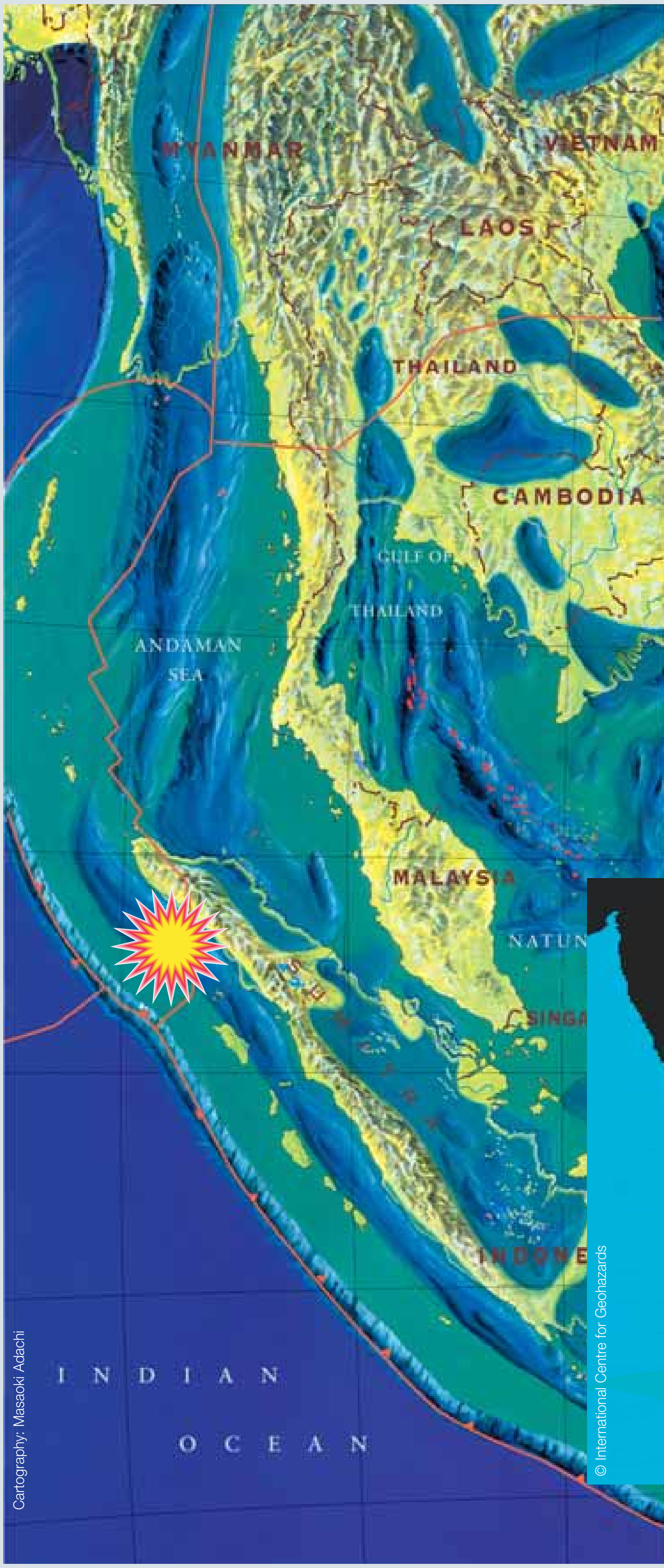
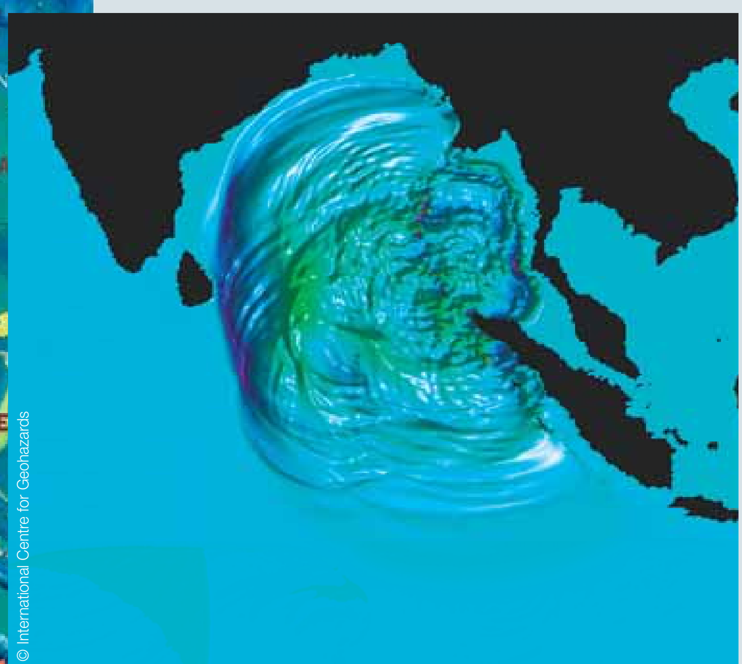



Plate boundaries, sedimentary basins (3D relief rendering) and oil and gas fields of Southeast Asia. Note that the there are no oil and gas fields on the west Sumatra coast that was hardest hit by the tsunami that followed the earthquake. Fields in the open ocean were not subject to damage, as a tsunami only generates great wave heights in shallow water close to the coast.




Surface elevation after 90 minutes of wave propagation as calculated by mathematicians based on an earthquake that originated along a 1200 km fault. The focus has been located below the Sunda trench, and from there it propagated northwards with a speed of 2-3 km/s

*Halfdan Carstens*

It took everybody by surprise. The earthquake as well as the tsunami. Seismologists around the world are said to have registered the tremors on their seismographs. But the Indian Ocean region has no tsunami warning system in place, meaning that scientists in Hawaii for example had no way of sending a warning about an incipient tsunami.

## No damage

Nevertheless, the oil and gas operations of Southeast Asia were largely unaffected by the December 26 earthquake that generated a tsunami killing some 250,000 people.

Only a few days after the event ChevronTexaco said that its substantial "oil and gas production facilities and operations in Indonesia and Thailand were unaffected by the tragic earthquake and tsunamis that struck South Asia." The company also reported no damage to downstream facilities.

In the Bay of Bengal the tsunami did not impact oil and gas exploration work or refineries on the east coast. This apparently applies to ONGC, Cairn Energy of UK as well as Reliance Industries that are all prospecting for petroleum in this province.

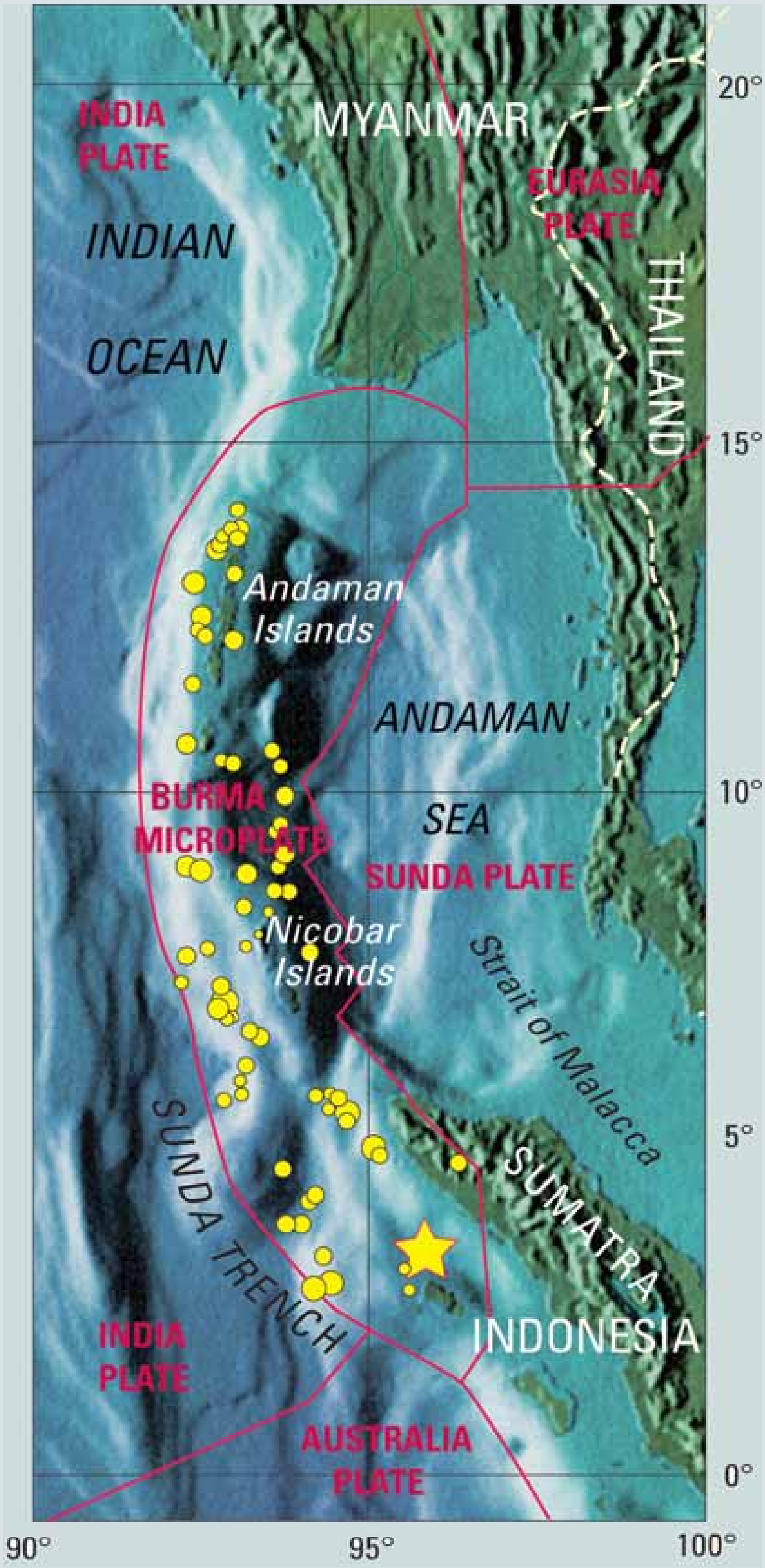
The Natuna Sea, including operations in Malaysian waters, and the Gulf of Thailand were not subject to damage by the tsunami as these areas are both protected by the Malaysian peninsula.

## Moving fast

The 9.0 earthquake is the fourth largest earthquake in the world since 1900. It is also the largest since the 1964 Alaska earthquake in Prince William Sound that had a magnitude of 9.2 on the Richter scale.

Last year's tsunami caused more casualties than any other in recorded history, although direct damage from smaller earthquakes , such as have occurred in China, may have resulted higher death rates.

The India and Australian plates move toward the north-northeast with respect to the interior of the Eurasia plate with velocities of about 60 mm/y. This results in oblique convergence at the Sunda trench. The oblique motion is partitioned into thrust-faulting, which occurs on the interface between the India plate and the Burma microplate, and strike-slip faulting, which occurs on the eastern boundary of the Burma microplate.




Cartography: Masaoki Adachi

The devastating earthquake of December 26, 2004, occurred on the interface of the India and Burma plates and was caused by the release of stresses that develop as the India plate subducts beneath the overriding Burma plate. According to U.S. Geological Survey, the locations of larger aftershocks following the megathrust earthquake show that approximately 1200 km of the plate boundary slipped as a result of the earthquake. All the details about the earthquake can be found on this web-site: www.usgs.gov

# Serving both academe and the industry

Professor Richard Selley describes himself as " one of the geologists of the old school - tweed-suited, bearded, pipe-smoking, whisky-drinking individuals with bodies full of interesting tropical diseases and more knowledge of wilderness-survival than office-survival."

**He is known throughout the oil industry as an exceptional petroleum geologist and to his many university and professional students as an outstanding and inspirational teacher. Few people are as well qualified as Professor Richard Selley to comment on the interplay between the academic world and the oil industry and the dependence they have on each other.**

*Jane Whaley*

"Why did I become a Petroleum Geologist? To see the world at someone else's expense, wander around in the outdoors and gamble with other people's money. What more could you ask for?"

So says Dr Richard Selley, Emeritus Professor of Petroleum Geology at Imperial College, London, Consultant, eminent teacher, distinguished public speaker and renowned viticulture enthusiast!

The author of 5 comprehensive and well respected textbooks and more than 70 papers on sedimentology and petroleum geology, this entertaining and multi-faceted geologist has also appeared on the 'Big Breakfast Show' where, magnifying glass in hand, he had the arduous geologically related task of interviewing the all-girl pop group 'The Brownstones.'

But has petroleum geology changed over the years? Professor Selley believes so, and has some fascinating insights into both the positive and negative impacts of the changes in his chosen profession.

## Revolutionary Geologist

Prof. Selley obtained his first degree from the University of London and followed this in 1963 with a PhD from Imperial College, London, studying the Torridonian in West Scotland, where his enthusiasm for field work in all weathers was satisfied by spending six months of each year in a tent. On returning to London, he persuaded the Geology Department secretary to type up his thesis for him, but realising "I didn't have any money to pay her, I offered her marriage instead!" She accepted, and many field trips, foreign postings and beautifully typed manuscripts later, they are soon to celebrate their 40th wedding anniversary.

Scottish mists were swapped for rather warmer climes with post-doctoral work in Jordan, the United Arab Emirates and then Libya, where he studied the different depositional environments of Libyan Miocene sediments in the Sirte Basin. This proved to be the beginning of Dr. Selley's involvement in the oil industry. Subsequently this work led to the offer of a posting as a petroleum geologist with Oasis in Libya, where the Selley family, (including by this time two young daughters), were originally due to fly out to Tripoli on the very day the Ghadaffi revolution began. Since most of Dr. Selley's time was spent out in the desert, where he had the enviable reputation of never drilling a dry hole, much of the political and military excitement passed him by - although his wife may well have a different story.

In 1971 Dr. Selley joined Conoco to work in the newly-opening North Sea, where he was part of the team which discovered the Hutton, Lyell and Murchison Fields, although he admits that for a while he was known as 'Dry-hole Dick' – whenever he moved onto the rig, the shows dried up! "This was an exciting time to be a petroleum geologist in the North Sea. You could work up a prospect in the office, sell it to management and then go out to the rig and drill it – even though the poorer quality seismic of the time meant that one could only identify petroleum traps, and not, as today, see if they contained anything.

## Academe Beckons

Eventually, Dr. Selley was lured back to the academic life by the freedom it offered, both to undertake research and to explore new places, while he also discovered a flair for teaching. He returned to Imperial College in 1975 to teach the MSc Petroleum Geology course and over the years also became heavily involved in Continuing Professional Development (CPD), teaching short courses on a variety of topics to industry professionals. In order to keep abreast of developments in the sector, he undertook consulting projects around the world. "I took the view that if you were teaching people how to find oil, you'd better be doing it yourself."

In 1988 the experienced geologist was appointed Head of the Geology Department at Imperial College, a job at which he proudly claims to have been "an abject failure!" He says: "On appointment I was told to cut one third of both staff and students and when I finished 5 years later we had exactly the same number of both!" The 'lost' staff had been replaced by new oil-industry funded posts. Not so much of a failure, then!

## Industry/Academe Interplay

So, after a lifetime straddling the academic/industry divide, how well does Prof. Selley feel the academic community serves the hydrocarbon industry? This is a topic on which he is somewhat equivocal. He points out that "very few institutions now offer a single honours Geology course, preferring 'mix and match' courses with combinations of Geology, Earth Sciences, Geophysics, Engineering, Environmental Studies, Geography – probably even Ballroom Dancing!" As a result students have more I.T. knowledge than previously, with graduates gaining at least some idea of the basic requirements of a petroleum system and the methods used when looking for hydrocarbons. Unfortunately, the development of these 'pick and mix' courses has two main disadvantages. First, the potential employer when recruiting geoscientist graduates has to try to determine the difference between these multifarious courses and then needs to decide which course suits the position offered.

Secondly, and more importantly, Prof. Selley laments the decline in the single honours Geology degree because he feels strongly that the lack of a traditional geological training leaves young graduates woefully unprepared for identifying rocks in the field. "The graduates of 40 years ago were not very numerate. They had, however, spent hours in the laboratory, working with rocks, thin sections, minerals and fossils, and many weeks in the field, including several weeks of solo field mapping." The latter is an exercise which Prof. Selley considers "a physically and intellectually challenging task that provided ample opportunity for students to acquire the core skill of a geologist: the ability to envisage rocks in three dimensions, and to integrate the fourth dimension, time." Financial pressures and health and safety issues have curtailed fieldwork in general, and solo mapping in particular.

As a result, Prof. Selley considers that the petroleum industry is paying a high price for the decline in field work and practical rock and fossil identification. He can cite many cases where poor training has resulted in ridiculous mistakes, such as the well in the West Shetland Basin which continued drilling into granite basement for nearly 100 metres because the geologists on the rig could not tell the difference between granite and sandstone, or the guidebook to Indonesian petroleum geology, written by expatriate geologists, where all the synclines were actually anticlines and the anticlines were synclines.

## Industry and Government Input

Prof. Selley believes that underfunding is still a major issue. "In the past, government funds were sufficient to cover staff salaries and the cost of teaching, but now research contracts must be sufficient not only to pay for the research, but are needed to cover even the basic costs of a department, including subsidising the undergraduate courses." He wonders if "oil companies sometimes should remember that they were all originally started by a geologist with a good idea. Now many companies do not have professional petroleum geologists on their permanent staff, preferring to buy in the expertise when it is needed. Oil companies used to run world-class research facilities, but most of these were closed and the universities were asked to take up the research topics, with oil company money."

Recent years have shown a considerable decrease in the financial support coming directly from oil companies for research, he considers, although there has been an increase in funding through petroleum industry consultancy firms. In Prof. Selley's opinion, it is relatively easy to get funding for IT, software and technological research, but there is not enough money for field-based training and research. "Information Technology is very important, but the data fed into it has to be correct, or it is useless. Petroleum exploration can be described as an inverted triangle with geologists at the base. If we don't produce enough good geoscientists who can view the world in 3D and 4D, skills learnt through field mapping, the base will crumble."

10 years ago there were 7 oil industry staff-funded posts at Imperial College – now there are only 3. Only 7.5% of the 40 students on the MSc Petroleum courses in IC are sponsored by the UK industry, with another 20% (8 students) receiving UK government grants, although a further 22.5% receive overseas industry or government funding.

Does he think the government be doing more? Prof Selley laughs, somewhat ruefully. "When you think that the whole economic success and wealth of this country for the past 40 years has been based on what geologists have found under the North Sea, they shouldn't just be funding us better – there should be a solid gold statue of a geologist outside the Houses of Parliament!"

## What lies in the future?

Prof. Selley considers "Petroleum exploration is not as exciting, nor as much fun or, well, as romantic as it used to be." On a more optimistic note, however, he points out that the quality of modern seismic techniques has given us the ability to image actual petroleum contacts and migration in 4D, which one would not have even dreamt about 40 years ago.

In the future Prof. Selley thinks that we will have a greater reliance on nuclear energy, but there will also be a developing market for alternative hydrocarbons, such as gas hydrates, oil-shale and shale-gas, and he considers that this is an area where government encouragement could make an impact.

Prof. Selley has a particular interest in shale-gas which, with the introduction of horizontal drilling and the development of artificial fracturing to increase productivity, is cheap to produce and could be viable for small-scale domestic and industrial consumption. Shale-gas resources may occur at several stratigraphic horizons in a number of basins throughout the UK and could form a useful future energy source. Production may develop on a much smaller 'cottage industry' scale than conventional petroleum production and is unlikely to be of interest to the multinational energy companies, so developmental and taxation assistance and concessions could be important. However, the disparity in concepts, methodology, environmental issues, technology and rewards between traditional and alternative hydrocarbon extraction mean that there will be many hurdles ahead, so that, as Prof. Selley puts it, "both geologists and engineers will need a cerebral retread."

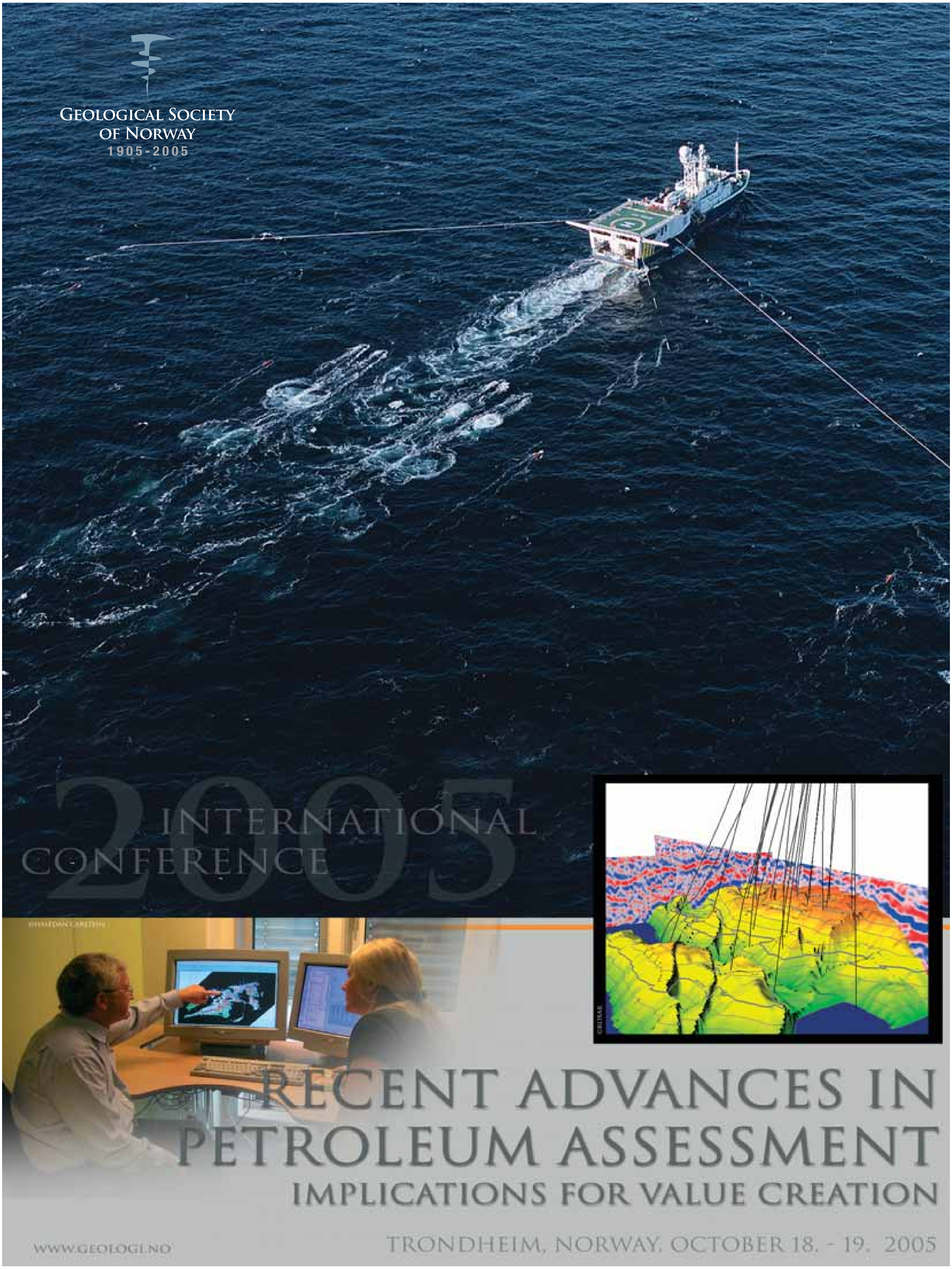
## Viticulture and collateral conviviality

Having retired from full-time academic life and with his main research area, the application of sedimentology to petroleum exploration, "largely superceded by advances in seismic imaging", Prof. Selley is now free to explore new avenues of research. In recent years this has chiefly concerned the impact of geology and climate change on viticulture, an interest which developed because "while travelling the world at other people's expense I felt obliged to explore the geology of the vineyards of the countries I visited". He frequently lectures on the subject, is much in demand as a consultant to vineyards and viticulturists and has recently published 'The Winelands of Britain: Past, Present and Prospective', an entertaining book written with wit and enthusiasm.

In fact, enthusiasm is a word that springs to mind frequently when talking to Prof. Selley. He has a great passion for all aspects of geology, for the petroleum industry, for the professional development of his industry colleagues and for his many students. His interest in the various professional bodies he has faithfully served over the years is obvious, as is his keenness on viticulture and the "collateral conviviality that such demanding research entails." In fact, he exudes enthusiasm for life in general.

## Gambling with other people's money

Prof. Richard Selley describes himself as one of the geologists of the old school 'tweed-suited, bearded, pipe-smoking, whisky-drinking individuals with bodies full of interesting tropical diseases and more knowledge of wilderness-survival than office-survival." So would he advise a young person to study geology now? "That depends what they want from it" is the tactful, if somewhat evasive reply. "If they want to have the outdoor experience, then I'd probably suggest that they try Forestry. If, however, someone is curious about the world we live in, is interested in the future of the planet, imaginative, good at critical evaluation - particularly with inadequate data (an invaluable training for business!) - and likes the idea of gambling with other people's money, then surely they will want to study geology!"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# Rifting – the geological foundation for a major tourist trap

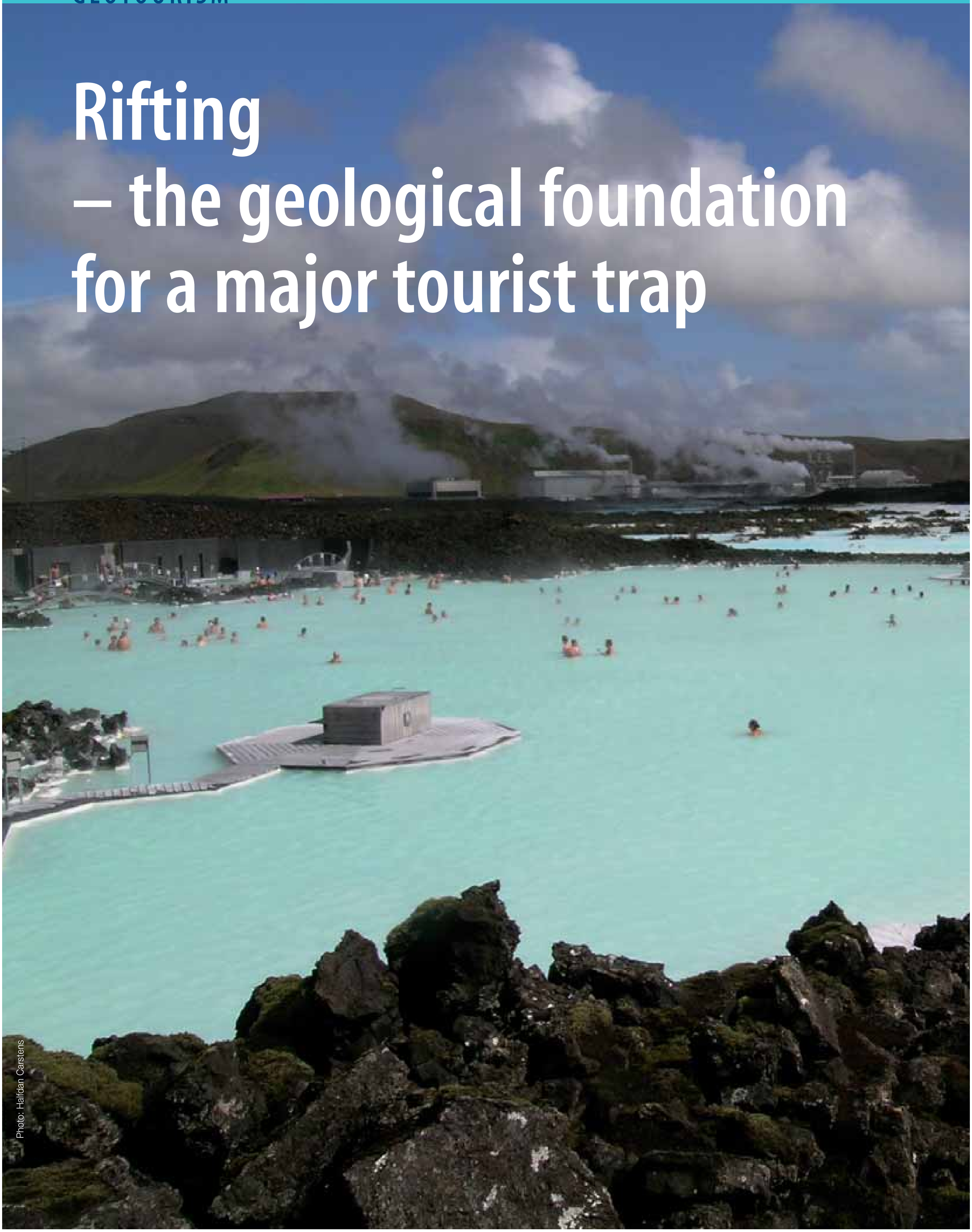
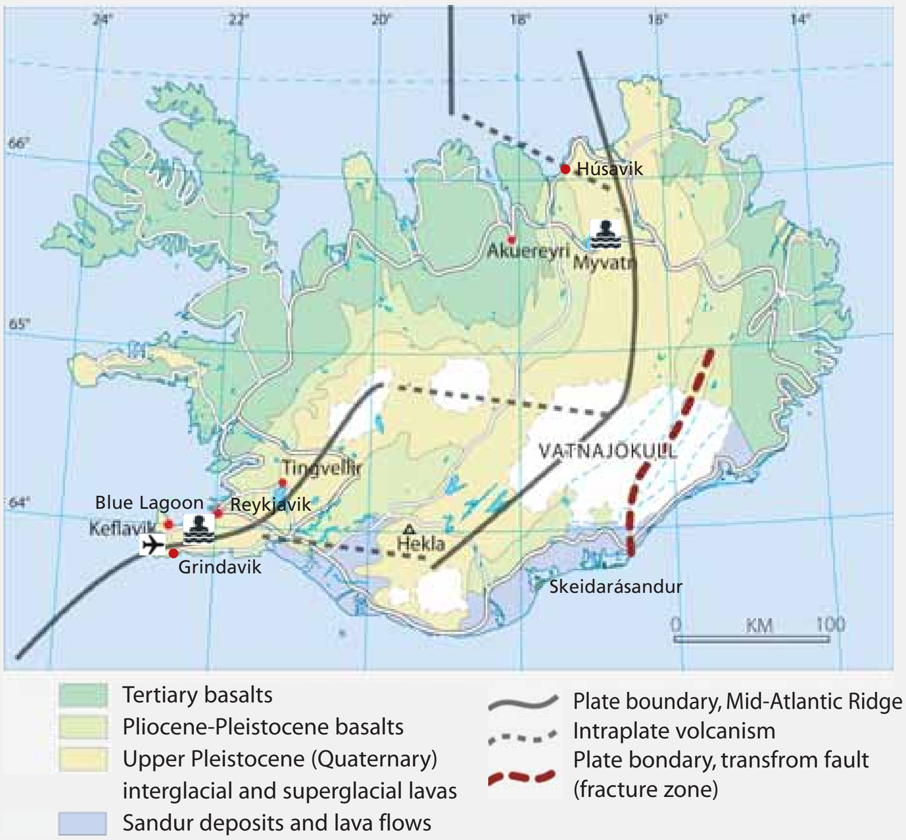


Photo: Halfdan Carstens

**The Mid-Atlantic Ridge crosses Iceland and splits the country between the American plate and the Eurasian plate by means of a geological process called rifting. The vast amount of energy released by the moving plates is made available to anyone – from tourists who want relaxation, to those who seek relief for skin maladies – in the form of a huge geothermal spa.**

Surrounded by lava fields only some few hundred years old, the Blue Lagoon outside Reykjavik in Iceland attracts tens of thousands of tourists each year. Warm (37-39 °C), bluish water coloured by cyanobacteria and the sheets of steam that blow across the surface create a fascinating recreational facility that few tourists visiting Iceland miss. Active ingredients such as mineral salts and silica are said to nourish and soften the skin. For this reason, the Blue Lagoon is a haven for those suffering with skin maladies like eczema and psoriasis. Deep-seated energy below the rift axis provides the heat source for the Svartshengi Geothermal Power Plant, which is visible in the background of the lagoon. It is spill water from the Plant that provides the warm water for the hot pots.

Cartography: Masaoki Adachi




Iceland, being located in the North Atlantic Ocean at the junction between the Reykjanes Ridge in the south and the Kolbeinsey Ridge in the north, is part of the Mid-Atlantic Ridge. As such, Iceland is part of the oceanic crust forming the floor of the Atlantic Ocean. The surface expression of the plate boundary is the 20-50 km-wide belts of active faulting and volcanism that extends across the island. This plate boundary is the only section of the Mid-Atlantic Ridge exposed above sea level and explains why geologists from all over the world flock to Iceland to study rocks, fractures, faults, volcanoes, geysers and other spectacular geological phenomena so common in Iceland. The Blue Lagoon on the south-western end of the Reykjanes Peninsula, where the Mid-Atlantic Ridge rises out of the sea, utilises hot water heated by magma that come close to the surface where the two plates split apart.

*Halfdan Carstens*

The Blue Lagoon has surpassed both Tingvellir and Geysir as Iceland's most popular tourist attraction. Between lava flows only a few hundred years old, it is situated just a few minutes drive from the international airport in Keflavik and less than one hour bus ride from the capital Reykjavik.

With virtually no geological information presented at the entrance gate, it is a shame that only few tourists will be aware that this exotic spa complex with waterfall, steam bath and silica mud owes its existence to superheated seawater drawn from the underground through a series of deep boreholes drilled into the lava fields.

The steam that is produced from the boreholes is utilised in the Svartshengi Geothermal Power Plant that is situated next to the Blue Lagoon. After the steam has passed through the turbines to generate electricity, huge condensers convert it back into the artificial lagoon that permanently hovers at 37-39 °C.

## Oceanic crust onshore

Iceland is geologically speaking very young and all of its rocks have been formed within the past 25 million years. The oldest rocks exposed at the surface, however, are only 14-16 million years old.

Iceland is also one of very few places where we can directly observe the Earth's dynamic processes in action. The island is in fact an exceptional laboratory, and nowhere on Earth is the architecture of sea floor spreading better exposed.

The formation of Iceland follows the opening of the North Atlantic Ocean about 70 million years ago and the break-up that lead to the separation of Greenland from northern Europe. As the continents on either side of the rift drifted apart, a new plate boundary was formed. This plate boundary is where active spreading and plate growth take place. The crust is being pulled apart and molten rock wells up from below. As spreading continues, more magma wells up to seal the cracks and gradually produces the crust that forms the ocean floor. The spreading rate has by various means been estimated to approximately 2 cm/year - or 1 cm/year in each direction.

The spreading rips apart the brittle crust and results in the formation of cracks and faults that are oriented perpendicular to the spreading direction. Vertical dykes are formed as magma cools in these pathways leading to the surface. These fractures appear as swarms of linear volcanic fissures confined to narrow belts, 20-50 km wide, known as volcanic zones; Svartshengi is situated in such a zone.

## Hot spot

The mid-ocean ridges do not normally build-up above sea level. Iceland is an important exception because it is underlain by a "hotspot" that gives rise to a lot more eruptions than is usual for a divergent plate boundary.

The concept of "hotspots" was introduced in 1963 by the Canadian geophysicist J. Tuzo Wilson who also discovered transform faults. According to his theory hotspots are localized sources of high heat energy (thermal plumes). Wilson specifically hypothesized that the distinctive linear shape of the Hawaiian seamount chain resulted from the Pacific Plate moving over a deep hotspot in the mantle, located beneath the present-day position of the Island of Hawaii.

The structure beneath Iceland, often referred to as the Iceland mantle plume, has been active for at least 65 million years. During this period unusual amounts of magma have been brought to the surface, and the series of volcanic regions that have been formed stretch across the Atlantic.

The centre of the Icelandic plume is below the glacier Vatnajökull. It has been modelled as a 200-300 km wide zone of highly viscous material that is hot and buoyant rising from depths of 400-700 km.


The Blue Lagoon is a natural geothermal spa with milky blue waters that are rich in blue green algae (cyanobacteria), mineral salts and silica mud. The mud is used to cleanse, exfoliate and revitalize the skin, leaving it "silky smooth," according to advertisements. "There is no doubt that the lagoonal water and its minerals have a positive effect on skin diseases," says Norwegian dermatologist Kristin Ryggen (right). Between the years 1994 and 2003, the number of treatments provided had risen from 2000 6100. While popular among Icelanders, the Blue Lagoon treatment also attracts psoriasis sufferers from all around the world.


Less than one km from the Blue Lagoon is a geological information centre named Gjáin (the Rift). Surrounded by natural rock walls, geoscientists and other visitors get an introduction to the geology of Iceland and the wonders of geology. The exhibition features 18 screens where guests have access to intriguing information ranging from the creation of the earth's mantle to videos on volcanic eruption. Visitors may also watch a video explaining the origin of the hot water supplied to the Blue Lagoon.


The Blue Lagoon is situated on the Mid-Atlantic Ridge. Close to the spa, this rift is expressed as a set of small grabens with steep cliffs.


"The Mid-Point." The crest of the Mid-Atlantic Ridge delineates the spreading axis. The North American plate (to the left) and the Eurasian plate (to the right) are actively being pulled apart by forces of plate motion.

## Heat from below

Southwest Iceland, including the Reykjanes Ridge, is a young geological province whose formation spans only slightly more than 3 million years. With outcrops everywhere and virtually no vegetative cover, Southwest Iceland is a seventh heaven for geologists interested in volcanism and tectonism.

Nowhere on Earth is a mid-ocean ridge better exposed: In Reykjanes, to the extreme southwest, the Mid-Atlantic Ridge rises out of the sea. The ridge crest – the rift valley – is defined as a distinct fault zone delineating a shallow graben structure trending northeast.

The youngest volcanic formation at Reykjanes is about 800 years old and formed during the Reykjanes Fires between 1210 and 1240. In 1226 an explosive eruption occurred that caused widespread tephra to fall. This tephra layer is an important time marker.

This volcanic belt supplies the energy that feeds the Svartshengi Geothermal Power Plant. In turn, the Plant supplies hot water for domestic use, building heating and the Blue Lagoon.

## Geothermal energy in Iceland

During the past century Iceland moved from poverty to plenty. The harnessing of the island's inherent energy resources, hydroelectric and geothermal power, and the use of this energy for industrial and public consumption, has played a significant role in the country's development. Today, about a hundred years after a farmer north of Reykjavik first used hot spring water for home heating, primary energy consumption in Iceland ranks highest in the world.

Imported petroleum and coal accounts for only 30 % of the energy consumption and is used largely for fishing and transportation. The majority of the country's energy needs is thus provided for by hydroelectric and geothermal power, owing to Iceland's geological setting that encompasses both a series of glacial rivers (meaning rapid runoff and fillup of water magazines) and an active spreading ridge (securing a high geothermal gradient and hot water close to the surface).

Geothermal power provides more than half of the country's primary energy; hence, nowhere else in the world is the share of geothermal energy anywhere near that which is in Iceland. This energy comes both from low-temperature areas, where the water is below the boiling temperature, and high-temperature areas. Low-temperature sources are used mostly for heating, while high-temperature water is transformed into electricity

From the earliest times, geothermal energy has been used for bathing and washing, and by the 20th century geothermal sources were used to heat greenhouses. In 1930, Reykjavik began large scale use of geothermal energy for space heating. Today 90 percent of geothermal heat is used for space heating.

While hydroelectric plants produce roughly 80 percent of the electricity, geothermal electricity generation has increased significantly in recent years. The first geothermal power plant came into use more than 30 years ago (1969). Since then four more plants are put into production using steam to drive the turbines. The capacity is presently x00 MW, equivalent to a production of ++ barrels of oil per day.

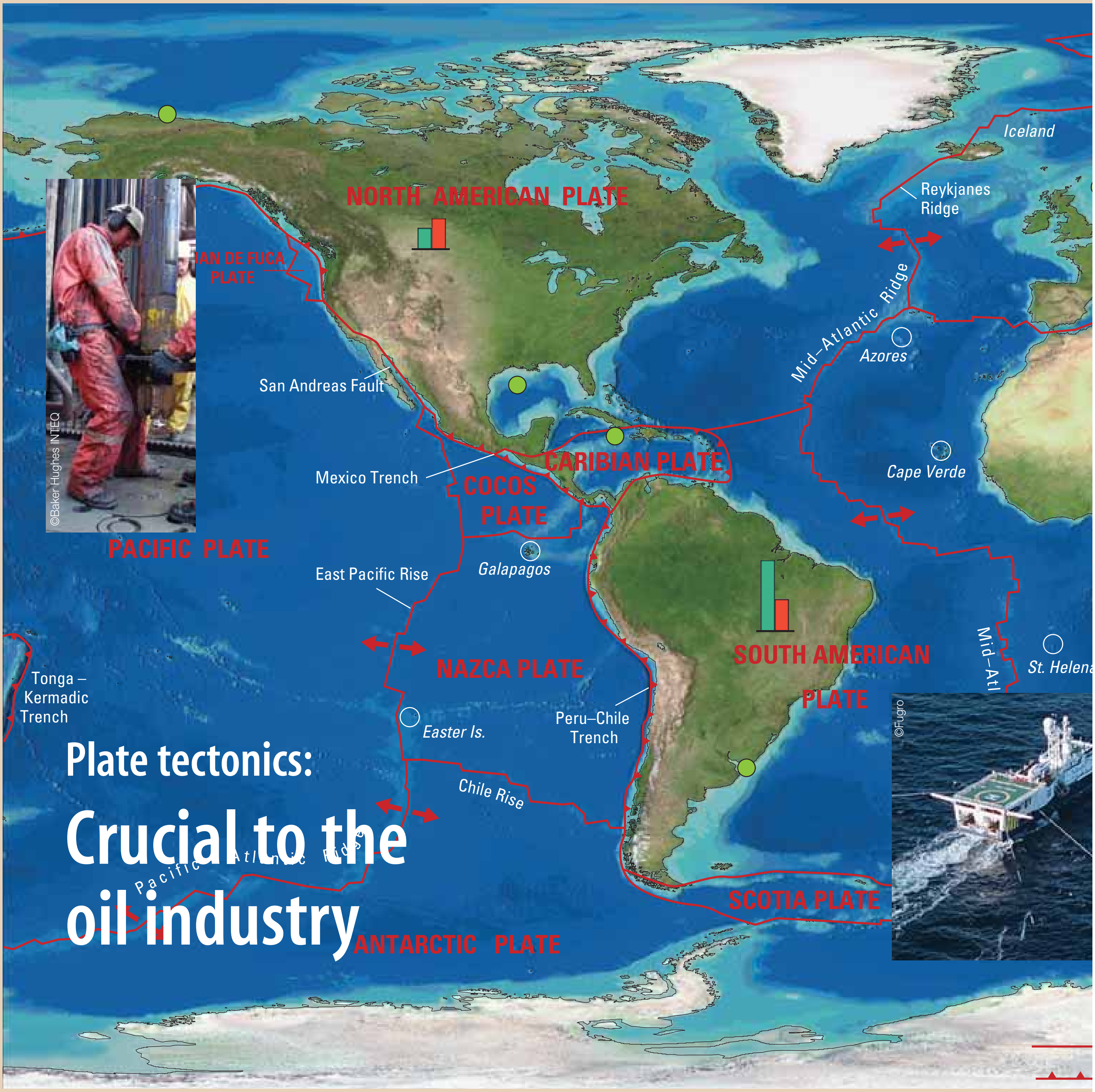
A new plant in presently under construction and there are plans for others.

The potential for producing more geothermal electricity is significantly higher and can probably be increased tenfold. This estimate might still be considered conservative because it does not include superheated geothermal waters, which Iceland is now researching.

The Svartshengi Geothermal Power Plant, in addition to providing hot water to the Blue Lagoon, supplies both steam for the production of electricity and hot water for domestic use in nearby communities on the Reykjanes Peninsula southwest of Reykjavik. The hot water is pumped through a heavily insulted pipeline system that is designed to minimize energy loss..

# Plate tectonics:

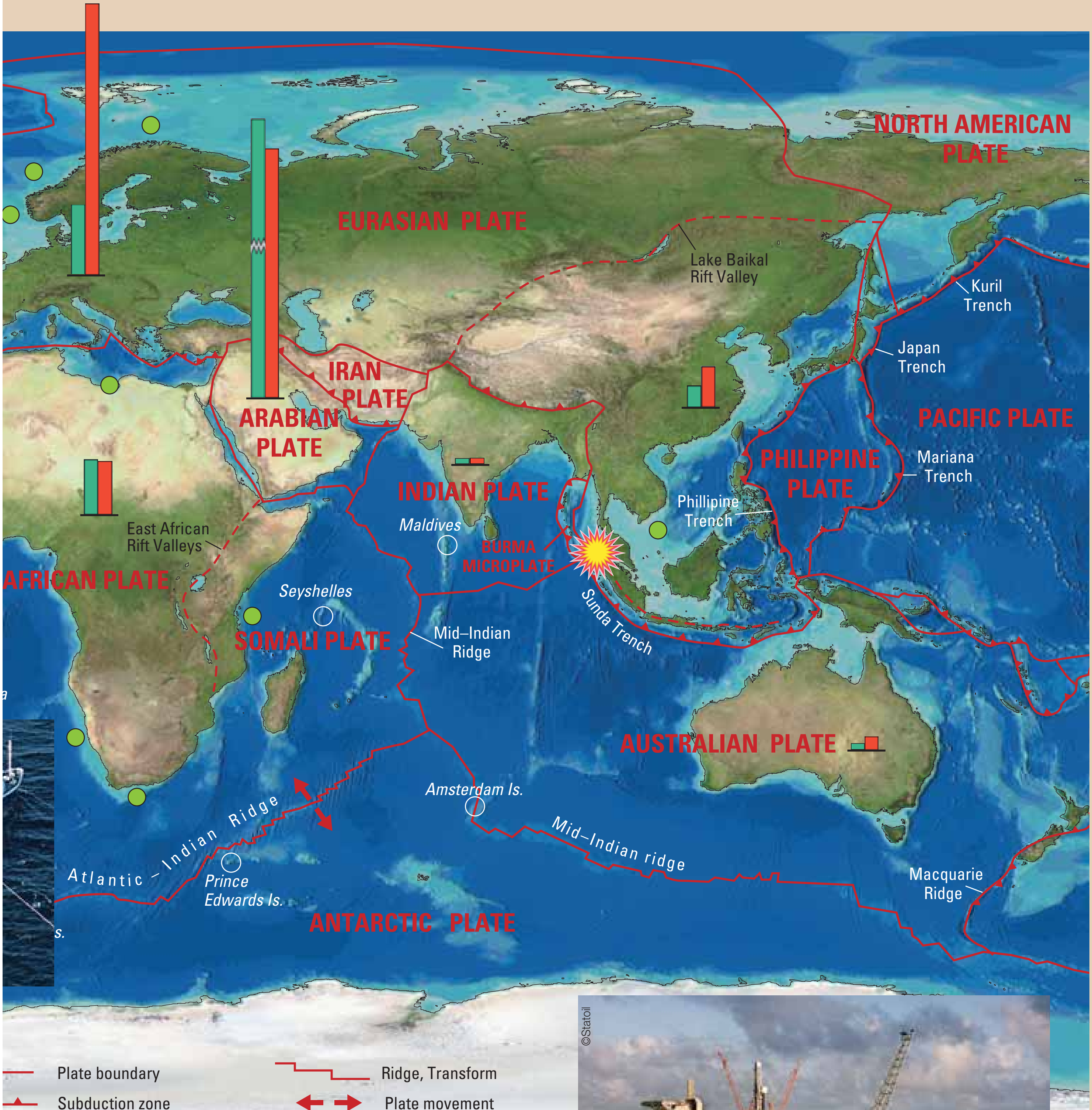
# Crucial to the oil industry




The theory of plate tectonics has revolutionised geological thinking since its introduction in the 1960's. The theory, and our understanding of the geological processes that relate to the break-up and drift of continents around the world, has also been crucial to the oil industry, and it plays a vital role when exploring for oil and gas in remote as well as mature areas.

In this map oil (green) and gas (red) reserves (BP Statistical Review of World Energy) have been plotted as per tectonic plate instead of per country or per region. Note that the oil reserves on the Arabian Plate are so much higher than on the other plates that the scale has been modified. Note also that the Eurasian Plate has been split into two plates along the Lake Baikal Rift Valley for the purpose of this presentation. Most of the reserves are located to the west of this rift. The huge gas reserves of the Eurasian Plate are predominantly located within Russia.

With the exception of the Antarctic Plate and a few small plates, exploration is taking place on all the larger plates, and licensing rounds have been announced "all over". Some of the countries that will be included in 2005 licensing rounds are shown here.




On 26 December last year the forces involved when plates move showed their strength in the fifth largest earthquake in 100 years. The earthquake had its hypocenter in the Sunda Trench, but it propagated northwards with tremendous speed where the India plate subducts beneath the Burma microplate and gave rise to the damaging tsunami.

# The deep-water success

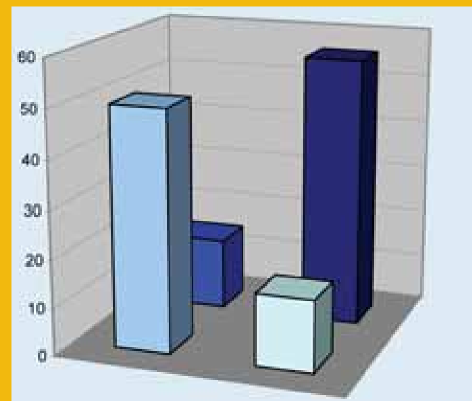
Deep-water (>300m) oil production in the Gulf of Mexico began in 1979 with Shell's Cognac field that was discovered in 1975, 30 years ago. Since then, deep-water exploration and production has grown with tremendous advances in technology. As a result, deep-water oil production grew from less than 100,000 bopd in the early 1990s to approximately 1 million bopd in 2004. The trend is the same for deep-water gas production that increased more than tenfold between 1992 and 2002.

Minerals Management Service (MMS) has estimated that the Gulf may contain as much as 136 billion barrels (21 billion $m^3$) of oil equivalents, shallow- and deep-water (>200m) combined (compare graph). More than 40% may come from deep-water. In comparison, according to BP Statistical Review of World Energy, the proven oil and gas reserves of the United States are slightly in excess of 60 billion barrels oil equivalents.

The overall oil production in the Gulf of Mexico (shallow- and deep-water combined) is currently 1.5 million barrels of oil per day (bopd), which is roughly equivalent to the daily output in countries like Brazil and Nigeria. The larger part of the oil production is now from deep-water with approximately 1 million barrels of oil being produced every day. Shallow-water production is on decline and is now only slightly in excess of 500,000 bopd. Deep-water production overtook shallow-water production in 2000.

Based on incentives under the President's Energy Plan, oil production is set to increase to 2 million bopd next year, and it could rise further in the years to come according to predictions made by MMS. This increase is expected to come from deep-water plays.

Exploration last year proved another 12 deep-water discoveries in the Gulf of Mexico. According to Chris Oynes, Gulf of Mexico MMS Regional Director, "some of these new deep-water discoveries are opening up new areas for natural gas development in the eastern Gulf." The 2004 success comes in addition to the 13 discoveries in deep water in 2003, 17 in 2002 and 32 in 2001. The exploration success rate has been estimated to 25 percent.




The back row (dark blue) shows deep-water Gulf of Mexico reserves already discovered (left), in billions of oil equivalents, and what remains to be discovered (right). The front row (light blue) illustrates that most of the shallow water oil and gas have already been discovered. The data are from the Minerals Management Service.

© MMS


The geological setting of the Gulf of Mexico is unique as the majority of the producing reservoirs are in young sedimentary rocks. Minerals Management Service says that 99% of the oil and gas reserves are in Miocene, Pliocene (Upper Tertiary/Neogene) and Pleistocene (Quaternary) formations. The geological province is also quite unique in terms of discovered and undiscovered oil and gas resources, which according to the same source, is more than 100 billion barrels of oil equivalents.

## CONVERSION FACTORS

### Crude oil
1 $m^3$ = 6.29 barrels
1 barrel = 0.159 $m^3$
1 tonne = 7,49 barrels

### Natural gas
1 $m^3$ = 35.3 $ft^3$
1 $ft^3$ = 0.028 $m^3$

### Energy
1000 $m^3$ gas = 1 $m^3$ o.e
1 tonne NGL = 1.9 $m^3$ o.e.

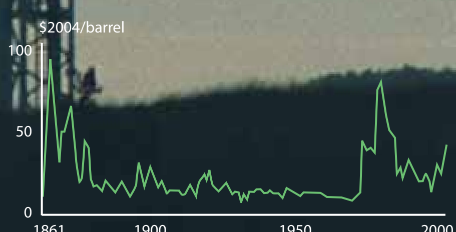
### Numbers
Million = 1 x $10^6$
Billion = 1 x $10^9$
Trillion = 1 x $10^{12}$

### Supergiant field
Recoverable reserves > 5 billion barrels (800 million $Sm^3$) of oil equivalents

### Giant field
Recoverable reserves > 500 million barrels (80 million $Sm^3$) of oil equivalents

### Major field
Recoverable reserves > 100 million barrels (16 $Sm^3$) of oil equivalents

### Historic oil price



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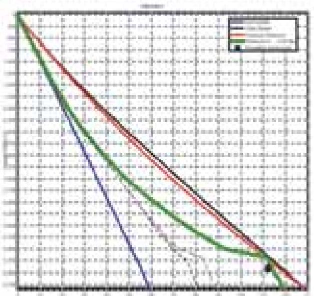
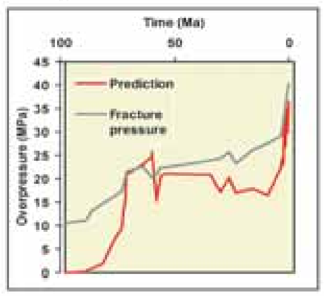
**Fobos Pro** is a new generation basin modeling package with unique pore pressure prediction capabilities. Being the only tool in the market which calculates pressure from both mechanical AND chemical compaction, Fobos Pro gives the user a realistic pore pressure model. Furthermore, it can be used in ANY basin, even in the absence of pressure data.

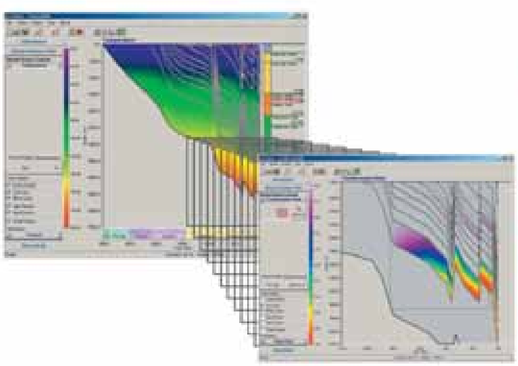
### Advantages

- Calculates extra pressure contribution from chemical diagenesis (quartz cementation/ smectite illitization)
- Flexible in creating lithology mixes and in modelling heat flow variations
- Fast calculation times
- Uses basin modelling to calculate predicted pressure at any location.






*The above example from a North Sea well shows the importance of modelling chemical compaction in order to achieve a closer fit to the measured RFT data and assess integrity of the seal above the study horizon.*



### Basin Modelling Features

- Advanced heat flow, maturation and expulsion analysis (3 possible heat flow contributions)
- Full fluid pressure history
- Seal integrity analysis
- In-built **Exemplar** enigine calculates porosity & permeability loss through time

Robust defaults make **Fobos Pro** an ideal tool for the general petroleum geologist, while calibration with observed data gives the expert user endless options for fine tuning of models and for solving specific basin analysis problems.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