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Petroleum geoscience in Norden – exploration, production and organization

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Offshore exploration in Norway and Denmark—in the North Sea, the Norwegian Sea and the Barents Sea—has involved drilling about 850 wildcat wells, resulting in about 300 oil and gas finds, of which 84 are fields with production. The recoverable resources of all these finds total about 65 billion barrels of oil equivalent. Almost all these hydrocarbons come from a Jurassic source and the main reservoirs and traps are Jurassic sandstones in fault blocks and Paleocene sandstones or Cretaceous chalks in gentle domes. The article describes four major fields—Ekofisk, Gullfaks, Ormen Lange and Snøhvit—to illustrate some of the many challenges in developing and producing the hydrocarbons.

Elsewhere in Norden, there has been much less exploration. Drilling results have mostly been negative in mainland Sweden, onshore Denmark, onshore Svalbard and on- and offshore West Greenland. Minor oil finds have been made in Palaeozoic rocks in the Baltic Sea. The first wells have recently been drilled off the Faroe Islands, resulting in one discovery. No drilling has taken place on- or offshore East Greenland.

As a result of the hydrocarbon activities in Norway and Denmark, petroleum geoscience there has flourished, with 2000 geoscientists currently employed in the industry, many technical innovations made, a wealth of publically available information and a great increase in the understanding of the geology.

Introduction

Norway and, to a lesser extent, Denmark have seen their economies transformed because of the discovery and production of oil and gas from below their continental shelves. These developments have been based on a huge amount of geoscientific work and have resulted in a revolution in the understanding of the geology of those regions. Thick sedimentary basins suitable for petroleum exploration also occur to the west and east of Greenland, on the islands and shelves of Svalbard, east of the Faroe Islands and in the Baltic Sea (Figure 1). This article aims to outline the petroleum geology of the basins, to give highlights of the production geoscience for four representative large fields and to summarize how that geoscience work has been organized.

Exploration

The modern phase of exploration in Norden started in the North Sea in the 1960's prompted by the discovery in 1959 in Holland of the giant Groningen gas field reservoir in Permian sandstones and sourced from Carboniferous coals. Although the early wells in Denmark and Norway were planned for such targets, the geology proved to be different. The first well offshore Denmark found oil in an Upper Cretaceous chalk (1966, Møller group). In Norway, the first find showed oil in Palaeogene sandstones (1967, Esso) and the first giant find was oil in the chalk at Ekofisk (1969, Phillips). These early wells were in water depths of less than 100 m but in the following decade exploration extended into the northern North Sea in waters up to 350 m deep. The most prolific play—Middle Jurassic sandstones in fault block traps—was discovered in the UK in the giant Brent Field (1971, Shell). Similar giant oil finds in the adjacent Norwegian sector were: Statfjord (1974, Mobil), Gullfaks (1978, Statoil), Oseberg (1979, Statoil). The largest field in the North Sea province, the super-giant Troll gas field, was found in Upper Jurassic sandstones (1983, Shell). Exploration north of 62°N in Norway started in 1980 and discoveries in Jurassic sandstones soon followed, opening up two new petroleum provinces: in the southwest Barents Sea (Askeladd, 1981, Statoil) and offshore mid Norway (Midgard, 1981, Saga).

These four regions—the Danish and Norwegian North Sea sectors, the Norwegian Sea and the Barents Sea—have seen the great majority of all the exploration in Norden (Table 1). In West Greenland, six wells were drilled offshore between 1976 and 2000 without discovery, and in the 1990's six onshore wells targeted oil seeps in a region of Palaeogene lavas, but made no commercial discovery. In the Svalbard Archipelago 15 wells were drilled onshore between 1963 and 1991, but most were based solely on surface geology and lacked seismic data, and no discoveries were made. In Sweden, wells were drilled onshore in southern Skåne and offshore in the Baltic in the 1970's without making discoveries, whilst drilling on the island of Gotland in the 1970's and 1980's resulted in many oil discoveries, but all with tiny resources. In the Faroes, drilling started in 2001 but targeted the same type of prospectivity as in the adjacent, prolific, West Shetland province of the UK; one oil discovery has been made (Marjun, 2001, Hess).

Petroleum systems, plays and resources

Almost all the discovered petroleum resources in Norden are in Norway and Denmark (Table 1). The petroleum system responsible for nearly all the discovered resources is derived from an Upper Jurassic source rock. Figure 2 shows that the Upper Jurassic source is known in all regions from the central North Sea to the southwest Barents Sea, and that the discovered hydrocarbons in these regions are proved to have come from this source. For example, in the central

Figure 1 Outline map showing the setting of the sedimentary basins of Norden and the zones of discovered oil and gas fields. a–h: locations of stratigraphic columns in Figure 2.

North Sea this source has supplied hydrocarbons to nine different reservoir levels ('plays'), ranging from Devonian to Eocene. In Svalbard and the Barents Sea region, a Triassic marine shale source rock is known to be present and may have given rise to a petroleum system, but no link to the discovered hydrocarbons has yet been demonstrated. The oil finds in the Baltic Sea region, on Gotland and in the Polish sector there, are probably derived from a Lower Palaeozoic source. In Denmark, the main petroleum play is in the chalk, with smaller finds in Paleocene and Jurassic reservoirs. Below we describe the plays in Norway (Figure 3).

The Norwegian Petroleum Directorate (NPD) has defined 68 different plays on the Norwegian continental shelf, ranging from Carboniferous to Neogene and covering most of the Norwegian offshore areas, with 25 plays defined in the North Sea, 20 in the Norwegian Sea, and 23 in the Barents Sea. In the North Sea 18 plays are confirmed by oil and gas discoveries. Exploration is less mature in the Norwegian Sea, where nine out of 20 plays are confirmed, while in the Barents Sea six plays are confirmed. The rest of the plays are hypothetical, based on seismic and geological mapping. NPD estimates that 9.5×10^9 bbl oe liquids and 11.5×10^9 bbl oe gas remain to be discovered

Table 1 Petroleum exploration statistics of Norden.

Country	Region	Wildcat wells	Discoveries		Total discovered recoverable resources ($\times 10^9$ bbl oe)	
			Oil	Gas	Oil	Gas
Greenland	West	12	-	-	-	-
	East	0	-	-	-	-
Svalbard		15	-	-	-	-
Norway	Barents Sea	61	3	16	0.4	1.1
	Norwegian sea	143	23	28	6.1	6.7
	North Sea	520	152	66	27.7	17.6
Faroes		5	1	-	-	-
Denmark	North sea	130	27	8	3.6	1.5
	Onshore & Baltic Sea	60	-	-	-	-
Sweden	Onshore, mainland	25	-	-	-	-
	Gotland, Öland	200	24	-	0.003	-
	Baltic Sea	17	-	-	-	-

Sources of discovery information: Denmark – Danish Energy Authority, as at January 1 2006; Sweden – IHS Iris 21 database; Norway – Norwegian Petroleum Directorate, as of January 1 2007.

Figure 2 Stratigraphy of the main sedimentary basins of Norden, indicating the source rocks, reservoirs and resources. Compiled after Henriksen (2005), Harland et al. (1997), Ramberg et al. (2006), and Evans et al. (2003).

offshore Norway: 75 % of this lies in the proven plays. In this article petroleum resources are quoted in normal oil industry units: barrels (bbl), barrels of oil-equivalent (bblo) and standard cubic feet (scf). Conversion factors are: 6.29 bbl = 1 Sm³; 35.31 scf = 1 Sm³.

Four plays contain the bulk of the resources in the Norwegian North Sea. They can be grouped in relation to the important Late Jurassic rifting. The pre-rift Upper Triassic to Middle Jurassic fluvial, deltaic and marginal marine sandstone play of the northern North Sea contains several major oil and gas fields (e.g., Gullfaks). This play alone contains 1/3 of the total Norwegian petroleum resources and more than half of the resources in the Norwegian North Sea. The NPD estimates that this play still has a significant undiscovered potential. Upper Jurassic plays occur both in the southern and the northern parts of the Norwegian North Sea. Norway's largest field, the giant Troll Field (47×10^{12} scf gas + 1.8×10^9 bbl liquids) belongs to this play. The post-rift chalk play of the southern Norwegian and Danish North Sea contains important oil fields (e.g., Ekofisk). As recently as 1997, a giant field (Halfdan) was discovered in a structural low between existing chalk fields in Denmark. The Palaeogene sandstones in the central part of the Norwegian North Sea contain several significant oil and gas fields.

The Norwegian Sea is well explored in parts but also contains large under-explored regions. The Upper Triassic to Middle Jurassic continental to marine sandstone play is dominant, containing two-thirds of the discovered resources and half of the undiscovered resources. The NPD estimates that marine sandstones of Late Cretaceous age have a significant potential in the Norwegian Sea. Paleocene sandstones are also important: the largest field discovered in Norway in the last 20 years, Ormen Lange, belongs to this play.

The Barents Sea is the least explored of the Norwegian offshore regions. The Hammerfest Basin is the only well-explored basin and contains most of the discovered resources. The Lower to Middle Jurassic sandstone play contains 75% of the discovered resources. The Snøhvit gas field belongs to this play. The NPD estimates that significant undiscovered potential also exists in sandstones and carbonates of Pennsylvanian and Permian ages and in Triassic sand-

stones, both in the south and in the area not yet opened for exploration in the north of the Barents Sea.

Fields and production

Since 1971 a total of 65 Norwegian fields and 19 Danish fields have started production. Most of the fields have sandstone reservoirs, but chalk reservoirs also occur. The sandstone reservoirs have generally good qualities and hydrocarbon flow is controlled by sedimentological, stratigraphic and large-scale structural heterogeneities. The chalk reservoirs usually have low matrix permeabilities and hydrocarbon flow is enhanced because of extensive natural fracture systems. We have selected four fields from different provinces and plays to illustrate the varied production challenges and technological phases in the oil and gas industry (Figure 4).

Ekofisk oil field

The Ekofisk Field in the south of the Norwegian North Sea is operated by ConocoPhillips. Production started from four converted exploration wells in July 1971. Permanent production facilities became operational in 1975 and the field has undergone continual development since then, with current production plans until 2028.

The Ekofisk field is the largest in the North Sea Chalk play. The structure is an elongated dome (Figure 5) at a crestal depth of 2900 m TVDss. Seismic quality is good on the flanks of the structure, but is severely degraded by a gas cloud over the crest, creating a seismically obscured area. The hydrocarbons are reservoirized in originally overpressured Tertiary and Cretaceous chalks, up to 900 m thick. The productive pay interval is as much as 300 m thick. The original in-place resources are 6.9×10^9 bbl of oil and 10.7×10^{12} scf of solution gas, two-thirds of which are contained in the Danian age Ekofisk Formation reservoir. This is separated by a basal low poros-

Figure 3 Geological and seismic profiles across the petroleum provinces of Norway, modified from the following sources: A—NPD (1996), B—Blystad et al. (1995), C—Husmo et al. (2003), D—Zanella and Coward (2003). For locations see Figure 4.

ity clay-rich interval (the Ekofisk Tight Zone) from the underlying Maastrichtian age Tor Formation reservoir (Figure 6). Both reservoirs consist of pelagic and redeposited coccolithophorid chalks, with average matrix porosities of 30% and matrix permeabilities up to 20 mD. Numerous low-throw faults are interpreted from seismic and well control. Extensive sub-seismic tectonic and stylolite-associated fracture systems enhance well permeabilities up to 200 mD.

The two reservoirs contain a 39°API black oil in pressure communication. Solution gas drive, partial gas injection and reservoir

compaction were the primary drive mechanisms. The average field pressure was depleted about 2,500 psi over the first 16 years, with an accompanying decrease in production. Water injection was first started as a pilot project, since there was limited experience of water injection into a chalk reservoir. Full scale water-flooding commenced in 1987 and has been the dominant and highly successful secondary recovery strategy since then (Figure 7). Average field pressure has been pushed up by about 1000 psi and the oil production rate has increased significantly. Reservoir compaction has also acted as a significant drive mechanism, caused by initial reservoir

Figure 4 Oil and gas fields of Denmark and Norway.

pressure loss and porosity reduction, with further matrix weakening and compaction through water-flooding. As a consequence, the seabed above the field has subsided by a total of 9 m.

Geoscience work has focused exhaustively on understanding reservoir compaction and waterflood management, particularly the mechanical, drainage and imbibition properties of chalks under both oil and water-flooded conditions. Studies also continue to address the seismic and sub-seismic fracture systems that both aid water injectivity, yet also complicate prediction of water-flood movement. Current reservoir management strategy is focused on exceeding a 50% recovery factor, by exploiting 4D seismic data and extended reach drilling and completion technologies so as to enable optimal water injection management into the foreseeable future.

Figure 5 Ekofisk Field: depth map of the top of the Ekofisk Formation. The crest is at 2900 mss and vertical closure is about 350 m. The crestal area inside the white line has poor seismic imaging.

Figure 6 Ekofisk Field: cross section through the geomodel showing porosity and initial water saturation. The main reservoir (Ekofisk Formation) is separated by a tight zone from the underlying reservoir (Tor Formation). The oil-water contact is highly gradational due to the low matrix permeabilities and the high capillary pressure of the chalk.

Figure 7 Ekofisk Field: production and water injection rates and average field pressure from 1971 to 2006. Note the decline in production rates and field pressure over the first 16 years, due to limited pressure support. The start of full-field water injection in 1987 reduced the pressure decline and increased oil production rates, while the reservoir was still compacting due to water weakening of the chalk. The subsequent build-up of field pressure increased the oil production, while reservoir compaction was reduced from 30–40 cm/yr to about 10 cm/yr after 1999. Total sea bed subsidence, due to reservoir compaction, amounted to 9 m by 2006.

Gullfaks oil field

Gullfaks is a giant oil field in the north of the Norwegian North Sea. The field came on stream in 1986 and the production up to June 2007 amounted to 2.09×10^9 bbl, which represents ca. 93% of the base reserves, assuming today's expected recovery factor of 61%. The ultimate goal is to achieve a recovery factor of 70%, and 4D seismic interpretation is a key element in locating the remaining oil to achieve this.

The field is trapped in a series of rotated fault blocks defined by major N-S trending faults, with throws up to several hundreds of metres (Figure 8). A secondary fault system trends E-W, with smaller throws of up to 100 m. The reservoirs consist of Cretaceous, Jurassic and Triassic sandstones. The sandy parts of the Cretaceous

Figure 8 Gullfaks Field: production wells from three platforms target multiple intervals in the complex, faulted Jurassic reservoir.

Kyrre Formation are interpreted to be a marine beach deposit fringing the Gullfaks structure. The Middle Jurassic Brent Group contains deltaic strata. The Cook Formation consists of marine to marginal marine deposits, while the Statfjord and Lunde Formations are mainly fluvial/alluvial. Most of the reserves are found in the Brent Group, within which the reservoir quality is generally good, with porosities up to 35% and permeabilities in the Darcy range.

The use of repeated seismic surveys (4D seismic/time-lapse seismic) has contributed significantly to improving oil recovery. Four repeated streamer seismic surveys have been acquired over the field, in addition to the baseline survey in 1985 prior to production start. Figure 9 shows a seismic line from 1985 and the corresponding geologic sketch illustrating the fluid contacts then. There is a strong seismic response from the top of the Brent Group reservoir when this contains oil and a very weak response down-dip when it contains water. There is also a strong reflection from the oil water contact. The corresponding seismic line acquired in 1996 shows significant changes in reflectivity on the dipping top reservoir surface; the earlier oil-water contact has more or less disappeared, whilst on the crest of the structure we still observe a strong response from the top reservoir level. Repeat saturation logs acquired from this location over the same time period show that water has displaced oil on the flank of the structure, with high initial oil saturations confined to the crest. Repeated saturation logs in numerous wells prove that changes in seismic response are often associated with changes in the saturation of different reservoir fluids. Sixteen development wells have now been drilled where interpretations based on 4D seismic data have played a major role in the decision making process.

Figure 9 Gullfaks Field: time-lapse seismic, 1985 compared with 1996, and schematic illustrations of the changes in fluid content within the reservoir that have occurred over time—see text for explanation.

Ormen Lange gas field

The Ormen Lange Field lies 120 km west of the coast of mid Norway and is the second largest gas field on the Norwegian shelf, with estimated recoverable resources of ca. 14×10^{12} scf and an areal extent of 350 km² (Figure 10). The field was discovered in 1997 by Well 6305/5-1, finding gas-down-to (GDT) the base of the Paleocene Egga reservoir. In 1998, the southern part of the

Figure 10 Ormen Lange Field: depth map of the top of the Paleocene reservoir. The white line outlines the area containing gas.

field was drilled by Well 6305/7-1, which penetrated a free water level (FWL). In 2000, Well 6305/8-1 penetrated a hydrocarbon contact and established a FWL. Finally in 2002, Well 6305/4-1, drilled 4 km to the northwest of 6305/5-1, revealed a GDT situation in the lower part of the Egga reservoir.

The outline of the field is clear on seismic data from direct hydrocarbon indicators: a flatspot and frequency and amplitude changes. The field is heavily faulted and the faults generally juxtapose sand-rich reservoir rocks in the upper part against more clay-rich reservoir rocks towards the base. The Paleocene reservoir comprises the Egga Member, dominated by turbidite sandstones in a submarine fan (Figure 11). This sits upon an extensive shale, the “Våle Tight”, which overlies the sand/shale alternations of the “Våle Heterolithic” and the “Jorsalfare sands”. The Egga sandstones have good reservoir qualities and consist of upward-coarsening, massive, amalgamated or weakly separated sand/sandstone bodies, divided into three reservoir units.

The Ormen Lange Field is being developed as a subsea-to-land concept. This is challenging. The field is located beneath a depression on the sea bed left by an enormous submarine slide 8000 years ago (Storegga Slide). The sea bed is 800–1100 m deep and is very uneven, with 30–60 m high peaks. Also, the interface between the Gulf Stream and cold polar waters create exceptional currents that set particular demands on the installation work in the field. The same currents also cause below-zero temperatures in the water around the pipelines and installations for most of the year.

Two Templates (A and B) are currently installed on Ormen Lange. By May 2007, two pilot wells—one from each Template—and two production wells, in addition to the original exploration wells, had penetrated the reservoir section. So far the well results are in line with the geological interpretation of the field. The field has been operated by Hydro in the development phase, but Shell will take over as operator at production start-up, scheduled for October 2007.

Snøhvit gas fields

The Snøhvit development in the southwest Barents Sea comprises three separate discoveries (Figure 12). Albatross and Askeladden contain gas and condensate, whereas Snøhvit comprises a gas cap over a thin oil leg. The recoverable reserves of the three fields are estimated to a total of 6.8×10^{12} scf gas and 113×10^6 bbl condensate (light oil). Gas production will commence in 2007, involving the drilling of 20 production wells over a planned 30 year period. Gas production will be driven by pressure depletion and the produced CO_2 will be re-injected below the hydrocarbon zone. Snøhvit is the first offshore development in the Barents Sea and is being developed with sub-sea wells remotely operated from land. Gas will be piped up to 200 km to the shore, to Europe’s first liquefied natural gas (LNG) export facility. Due to remoteness and complexity, it has taken 25 years from discovery to first production.

The hydrocarbon play comprises Lower–Middle Jurassic sandstones within rotated fault blocks and horsts of Late Jurassic– Early Cretaceous ages. Overlying marine shales form the seal, whereas Upper Jurassic organic-rich shale forms the principal hydrocarbon source. The central part of the basin (Snøhvit and Albatross) is characterized by E–W master faults; to the west (Askeladden), the structural grain is more N–S.

Three main sandstone reservoir units persist throughout the basin. The Tubåen Formation comprises fluvial and deltaic sandstones that will be used for CO_2 re-injection. The overlying Nordmela Formation comprises fine, micaceous tidal sandstones with limited reservoir potential. The Stø Formation is a transgressive, wave- and tide-influenced shoreface deposit; the principal reservoir zones are in the basal part; the overlying sandstones are extensively bioturbated, and related to the deposition in the lower shoreface and offshore transition zone; better sandstones occur in the upper part, recording new shallowing and possible shoreline regression. Abundant quartz cementation and common stylolites testify to extensive diagenetic alteration of the sandstones, involving exposure to high temperatures at depths exceeding 3–3.5 km. Subsequent Neogene to Recent uplift of 1.5–2 km has placed the reservoirs at their current depths (1.8–2.5 km). Accordingly the porosity in the main reservoir is low (12–18%).

Figure 11 Ormen Lange Field: depositional model of the Paleocene submarine-fan reservoir.

Figure 12 Snøhvit Field: structure diagram at Middle Jurassic level. The blue lines show the outlines of the hydrocarbon pools.

Organization

This article could have contained information just on geoscience. It would be wrong, however, to leave out all mention of the human side of the petroleum activities. The exploration and production work has led to the creation of a huge, highly talented work force, currently numbering about 2000 geoscientists. Here we briefly explain the ways in which the geoscience work has been organized, using examples mostly from Norway.

Authorities

In Norway, petroleum activities are the responsibility of the Ministry of Petroleum and Energy, a government department which oversees the work of the sector, making sure it is carried out in the best national interest (Bækken and Zenker, 2007) [www.regjeringen.no/oed]. Since 1973, the government has had a technical advisory division staffed by geoscientists, engineers and economists—the Norwegian Petroleum Directorate [www.npd.no]. It carries out independent assessments of the exploration and development, advises government on petroleum resources and on licensing round applications, oversees the oil companies' work on licenses and receives all technical information produced by the companies during that work. It currently has a scientific staff amounting to ca. 120. In Denmark, the equivalent work is undertaken by the Danish Energy Authority [www.ens.dk], which is a unit under the Ministry of Transport and Energy.

Oil companies

Most of the large international oil companies have had activities in Norway. The first well was drilled by Esso (1966), the first giant field was discovered by Phillips (Ekofisk, 1969), and the largest field in the province was discovered by Shell (Troll, 1983). Nevertheless, when it became clear in the late 1960's that major petroleum finds had been made, Norway decided to create a state oil company (Statoil, founded 1972) to ensure the development of native competence in all aspects of petroleum work. For long there was a restricted list of companies allowed to operate in Norway, mostly the super majors and majors and the native companies—

Statoil, Norsk Hydro and Saga. In recent years, the authorities have recognized the importance of widening the mix of companies. Since 2000, about 50 companies have been 'prequalified' as operators or licensees, including completely new companies and companies entering the country for the first time.

Licensing

In Norway, there have been regular licensing rounds since 1965, and by 2006 some 540 licenses had been awarded. These have been based on 'blocks', of which there are 12 in each degree quadrant. Awarded licenses have had one company nominated as the 'operator', to carry out the technical work, and normally others as partners. Each license has had management and technical committees, with representatives from all the partners and the NPD: they are the fora in which the geoscience work has been planned, results discussed and further actions agreed. During their exploration period, licensees have carried out the agreed work programme in phases, each of several years duration, involving seismic data acquisition and drilling, followed by partial relinquishment, and then a new phase. Following a potentially commercial discovery, 'appraisal wells' have been drilled to more precisely estimate the recoverable resources and plan the optimum development scheme. Government approval, involving the NPD, has been needed before any field development could go ahead. Development and production of hydrocarbons from a field has involved a dedicated team of geoscientists in the operating company, monitored by others in the partner companies and reporting regularly to experts in the NPD.

Licensing in Denmark has followed a different pattern. In 1962, the onshore and offshore area was granted as a sole concession for 50 years to the ship owner A. P. Møller, who joined with oil companies to form a group which over the next 20 years discovered 13 chalk oilfields. In 1984, this license system was replaced by competitive licensing rounds for 'blocks', of which there are 32 in each degree quadrant.

How much geoscience work has been expended on a license? A license with only exploration work, e.g. seismic acquisition and interpretation and one exploration well, has only needed a total of a few man-years of geoscience work. At the other end of the scale is the Statfjord field. Work there has comprised 15 exploration and appraisal wells, 272 production wells, a production history from

1979 to today, a total of up to 11 partner companies and—because it stretches over the Norway/UK median line—several major reviews of the resource distribution ('unitizations'). The geoscience effort of all organizations involved has probably reached 1000 man-years on this one field.

Contractors

The exploration and production work in the last 40 years has been achieved by cooperation between the authorities, oil companies and contracting companies. Great innovations have been made by contracting companies involved with seismic data. The first 2D seismic (single streamer, dynamite source) was acquired in the UK-Norway-Danish parts of the North Sea by Geophysical Service International in 1964. Since then, advances in acquisition technology have gone on continuously. 3D surveys began in the 1980's and have involved survey ships with more and more streamers. Repeated survey acquisitions over the same areas at different time periods ('time-lapse' or '4D seismic') have revealed changes in seismic reflections, caused by temporal changes in rock and fluid properties. Surveys involving permanent ocean bottom cables began in about 2000, giving the ability to monitor changes in reservoirs at intervals shorter than previously practicable.

The seismic contracting industry is worldwide in scope, but whilst in the 1960's there were no Norwegian companies involved, several have formed (e.g., Geco—now Schlumberger/WesternGeco; Petroleum-Geo Services; TGS-Nopec). Also, major technology breakthroughs have been made—for example, the development of 'sea-bed logging' to directly detect hydrocarbons below the sea floor by Electromagnetic Geoservices (www.emgs.com). Similarly, many geology-based contractors have developed in Norway—for mud logging, biostratigraphy, geochemistry, reservoir analysis, resource estimation (e.g., Geoknowledge—www.geoknowledge.com)—and even a geology-based exploration news magazine (Geo-expro—www.geo365.no/geoexpro).

Publications

Petroleum geoscientists in the North Sea have, since the early 1970's, had a tradition of publishing, to make available information that would otherwise be hidden away within company archives and official agencies. This publication effort has taken many forms. There have been six major conferences in London covering the North Sea and, later, northwest Europe (e.g., Doré and Vining, 2005). A five-year project involving societies, government institutes and companies resulted in the first consistent, published, overview of the central and northern North Sea petroleum provinces (Evans et al., 2003). The Norwegian Petroleum Society has arranged 22 conferences on petroleum geoscience themes since 1975 (e.g., Wandås et al., 2005) (www.npf.no). The Norwegian Petroleum Directorate has published data books on well stratigraphies, official overviews of stratigraphic and structural nomenclature (e.g., Gabrielsen et al., 1990; Blystad et al., 1995), assessments of petroleum plays and annual synopses of resources (e.g., NPD, 2007). The Geological Survey of Norway, although principally responsible for geoscience work onshore, has issued maps covering the structure and geology of the offshore basins (e.g., Sigmond, 2002) (www.ngu.no). The Geological Survey of Denmark and Greenland (GEUS) has issued compiled maps of the Danish on- and offshore areas (Britze, Japsen and Andersen, 1995) as well as major publications on Greenland (Ineson and Surlyk, 2003; Henriksen, 2005) (www.geus.dk).

Data

All well data become available for public inspection and purchase after two years in Norway and five years in Denmark. In Norway, this process is administered by the Diskos Database, currently operated by Schlumberger (<http://192.23.12.6/diskos/pex/default/index.html>). Summaries of well data are available from the NPD (<http://www.npd.no/engelsk/cwil/pbl/en/index.htm>).

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