

Chapter 26

Exploration Strategy

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26.1 Play Concepts

The purpose of exploration for petroleum is to make oil and gas discoveries that can form the basis for commercial development and production of oil and gas fields (Fig. 26.1). The formulation of ideas or models for where to drill to make discoveries is based on assessments of the generation, migration and trapping of petroleum. Combinations of these factors are referred to as *play concepts*. At the very start of the exploration of an area within a sedimentary basin the factual basis for assessing the various necessary factors is sparse and oil companies are confronted with a wide range of possible scenarios that can lead to petroleum discoveries. An open approach is, however, needed in relation to what is the most likely scenario both in the early and later phases of exploration. The explicit knowledge can very easily shadow for the implicit potential. Exploration is a continuous learning process where the key to success is found in details that are difficult to appreciate.

The play concepts should always contain, but never be constrained by, available facts and knowledge. Awareness of the unknown will always be the main driver for generative learning. In the evaluation of play concepts a maximum number of parameters must be considered, and the limitations of current theories and technology should be appreciated. Continuously improving technology has to be applied when maturing the play types and prospects in an area. In this

context it is important to understand the behaviour reference curve for the past successes and failures of the exploration (Fig. 26.2). The successful breakthroughs can be related more to the performance of the actions rather than the predictions.

Early in the exploration phase of an area the concepts will be referred to as *frontier play concepts* (Fig. 26.3). When the models are documented by their successful application and significant follow-up discoveries are made, they are referred to as *growth plays*. When only smaller, albeit frequent, discoveries are made they are referred to as *mature play concepts*. In the frontier phase the possibilities, assessments and discovery frequency are in general less than 25%, in the growth phase these factors are between 25–50% and in the mature phase more than 50%. The resource growth for each play concept follows an S-curve. The perception of maturity is a subjective process and frequent revitalisations of mature areas are experienced.

The S-curve also reflects the knowledge creation process and clearly demonstrates that at any time one should harvest using the knowledge at hand while creating new models to obtain a stable reserve growth over time. Today's impossibilities will be tomorrow's general accepted truths. The explicit knowledge reflects the past and the future is always in the tacit domain.

The reality can only be revealed through drilling and there will in general be significant differences between the pre- and post-drill assessment of reality. The discovery wells need to be followed by delineation wells to clarify subsurface uncertainties and assess the resource potential.

All parameters of unsuccessful as well as successful wells need to be re-analysed after drilling. The main obstacle for learning is the human self-

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Fig. 26.1 Oil dripping out of a core from the Volgian reservoir in Johan Sverdrup Field. The reservoir is marine sand with multi-Darcy permeability

referencing that can only be compensated for by including all facts from many different geological disciplines. The facts available at any time and new perceptions of reality can only be corrected by drilling.

Efficient exploration of an area requires frontier, growth and mature exploration drilling to be carried out in parallel. Due to the size of the discoveries the frontier exploration concepts will be the most cost efficient over time (Fig. 26.4). A linear approach where one play type or area at a time is explored can easily abort an exploration process prematurely due to self-fulfilling prophecies. In general 1/3 of the drilling activity efforts should be spent on frontier prospects, 1/3 on growth prospects and 1/3 on mature/delineation drilling.

Successful breakthroughs become rapidly obvious. Hence, for companies to harvest on their own breakthroughs the potential follow-up acreage should be secured prior to start of exploration drilling activities. Securing acreage in clusters can also lower the reserve threshold needed for commercial development by enabling several discoveries to constitute a larger field.

Individual companies need to have prospects related to various play types in their portfolio, and a

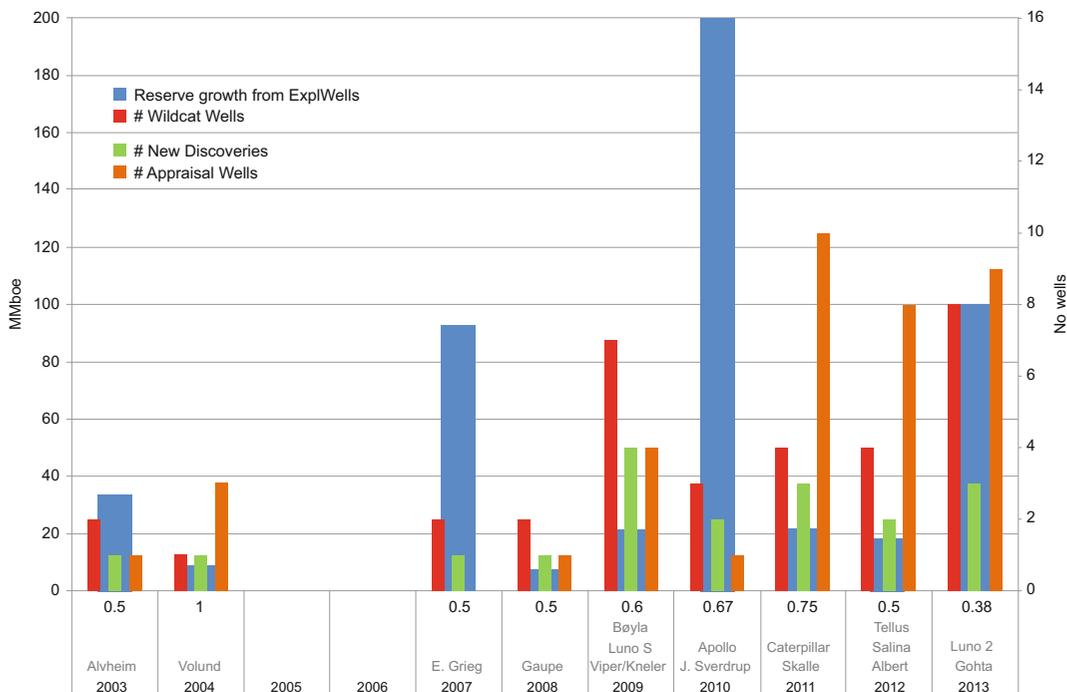


Fig. 26.2 Lundin organic growth exploration curve. The behaviour reference curve for the reserve growth shows the break-through nature of reserve growth. The reserves are referred to the time of the exploration wells

Truths and facts:

1. Thoughts are instant, thinking takes time (self-referencing).
2. Facts are the experienced parts of the truth. The truth must contain, but not be constrained by facts.
3. What is the likelihood of having experienced the truth based on facts?
4. The truth is so large that everybody can see a part of it but nobody the whole.
5. We should keep on unfolding reality by interacting with it (David Bohm).

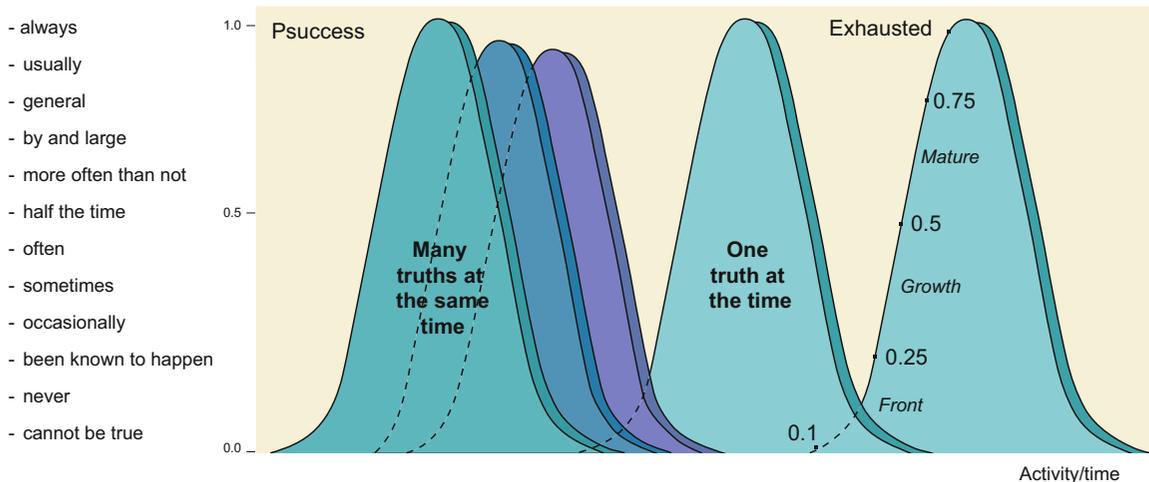


Fig. 26.3 Sustainable organic growth needs a balanced exploration. Frontier, growth and mature exploration drilling should occur in parallel

	Frontier	Growth	Mature	Stepouts	Total
No of wells	15	15	10	6	46
Expected prospect size	300	100	30	20	
Probability	0.15	0.25	0.5	0.75	
Expected reserves (mmboe)	675	375	150	90	1290

Fig. 26.4 Frontier exploration is most cost efficient. The size of the prospects compensate for the lower discovery rate

country needs a diversity of companies that secure the plurality necessary to unfold the resource potential.

26.2 Probability Analysis

Assessment of the inherent uncertainties in evaluating exploration prospects are referred to as *probability or risk analysis*. The analyses are concerned with the same parameters that define the various play types, i.e. the presence of rock sequences with organic material that have been buried deep enough to generate petroleum of various types, and assessment of porous rocks or fractures where the petroleum can migrate until it is retained in porous reservoirs of sufficient size

to be defined as drillable commercial prospects (Fig. 26.5). The critical part of the assessment process is to construct time and space relations between generation of traps, preservation of porosity, and the migration and retention of petroleum.

There will always be alternative ways of combining the parameters into equally likely scenarios. Possibility analyses need to reflect this by trying to define many alternate ways of linking the critical parameters. The alternate deterministic relations should reflect an understanding of the geological processes that can have happened.

The alternative to constructing possible scientific relations is to treat the factors as independent. The consequence of this approach results in the paradox that the more factors that are used the lower the probability of success becomes. This is however a commonly used approach and can be misleading as a decision tool, as it underestimates the value of knowledge.

Probability analysis should be based on the awareness that the available facts at any time are only the experienced part of the truth. New actions will always uncover new facts and knowledge. Hence an

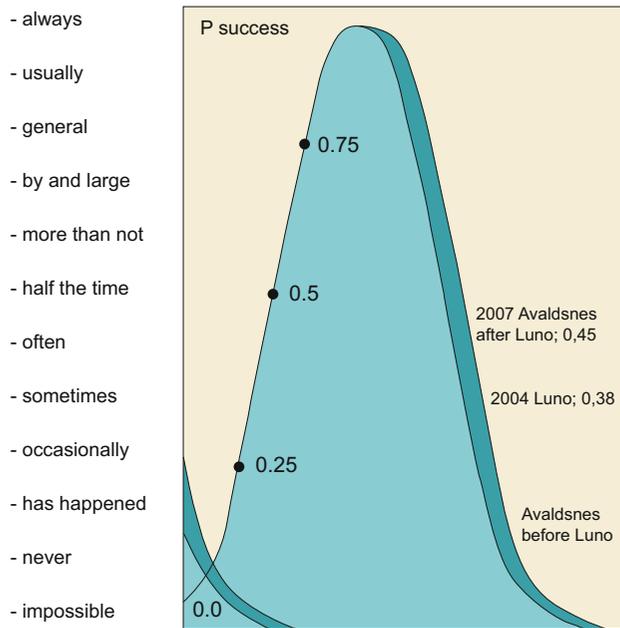


Fig. 26.5 Probability analysis is a subjective tool. The scientific relationship between the various factors related to petroleum generation, migration and trapping has to be understood.

assessment of the unknown should be included in any possibility analysis. It should be accepted that the unknown is largest in the frontier phase, but the learning process should continue and significant breakthroughs can occur after long time. The analysis should always be based on open perceptions of reality. Facts and successful ruling models will always contain the risk of shadow for the possibilities.

26.3 Operation

In implementing knowledge-based exploration strategies in frontier areas the larger prospects, preferably with stacked play possibilities, are selected first for drilling (Fig. 26.6). In addition the conditional links between alternative prospects should be assessed prior to selecting the drilling sequence. The first well on a structure will be located *so it can* test the reserve potential necessary for a commercial development. In addition it should secure as much new geological information as possible that will be relevant for a rapidly improved understanding of the whole area.

Probability assessments:

The simultaneous presence of reservoir, generation, migration and trapping of petroleum

- The same facts can support alternative possible models or scenarios
- Stochastic modelling based on independent parameters is no substitute for thinking
- Decisions reflect the input that is always insufficient in relation to the truth
- Probability analyses are time contextual

The successful Luno (Edvard Grieg) discovery changed the Avaldsnes (Johan Sverdrup) prospect to a high possibility prospect

A conscious data acquisition strategy is necessary for securing fact-based subsurface knowledge creation. The basic principles for acquisition of data should be:

- Sampling of drill cuttings
- Coring through reservoir sequences and hiatuses
- Continuous processing of all petrophysical data during drilling
- Sampling of fluids
- Production testing to understand reservoir continuity

During the operations it is important to continuously relate new data to a maximum number of parameters in relation to the models that were used as a basis for the prospect evaluation. It is imperative to continuously adapt the operation to the reality revealed during the drilling progress in order to enable corrective actions to be taken early. Changes in the perceptions of reality are most efficiently done by the people that formulated the basic concepts before drilling. These people have the necessary knowledge about the simplification process behind the volumetric models and play types used.

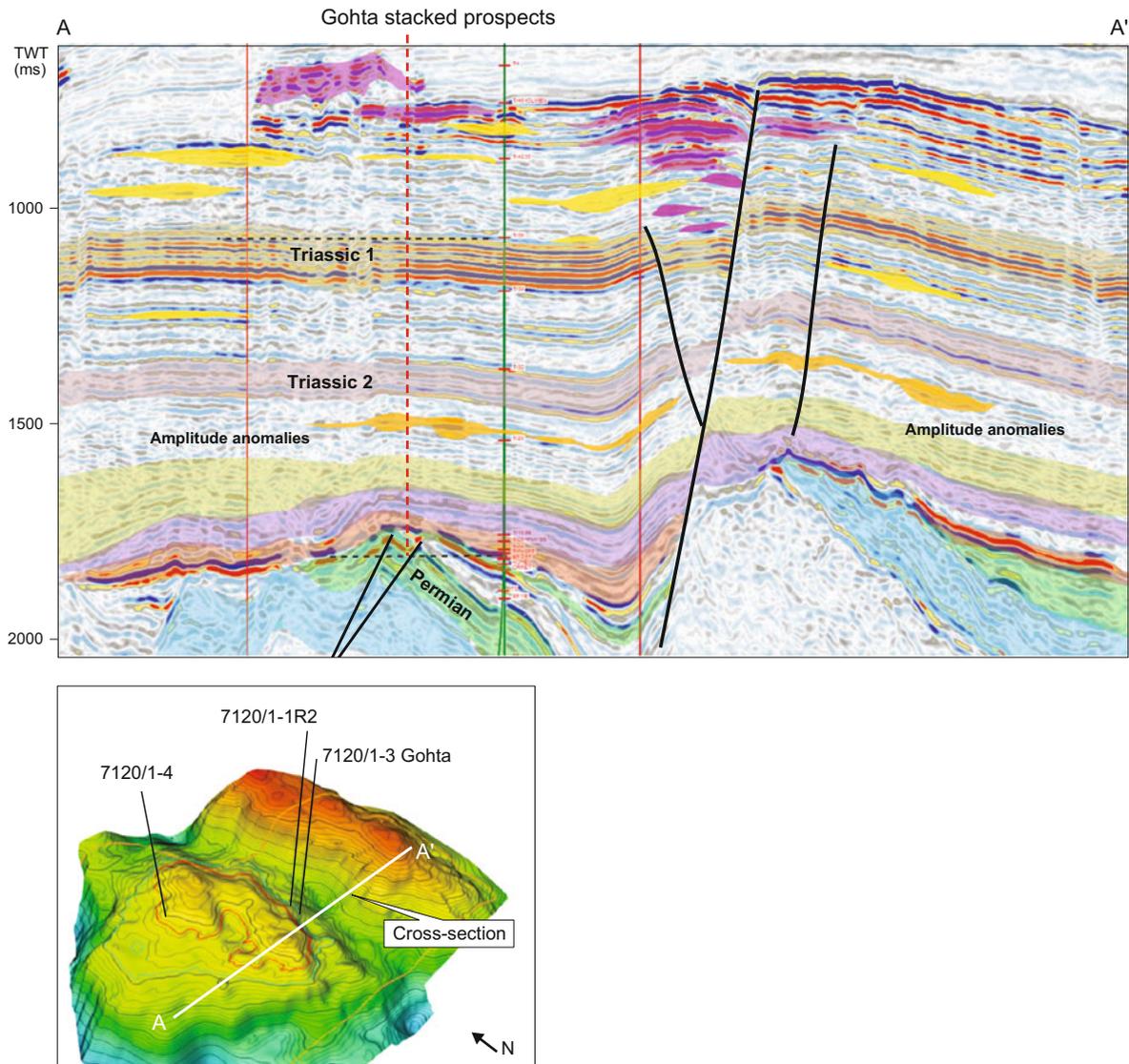


Fig. 26.6 Diversity of prospect types increases the learning speed. It is preferable to test several stacked prospective levels with the first wells in the exploration of frontier areas

26.4 Exploration Culture

Knowledge creation is a self-organising team effort that requires a common purpose for all involved (Fig. 26.7). The individuals should have the freedom to improve their specialty skills to realise the full knowledge creation potential of the team. This requires a high degree of communication and co-operation. The greater the diversity of special disciplines involved, the greater the knowledge generation potential of the team becomes. The relations

between the people involved in knowledge creation need to be based on openness and trust.

Learning is a continuous process of action and change. Knowledge changes in steps and the way forward should not be shackled by past knowledge. Continuous development of better practice is a must. The skill to act should always be combined by the strengthened will to believe in the improved concepts that form the basis for stable activities. The learning

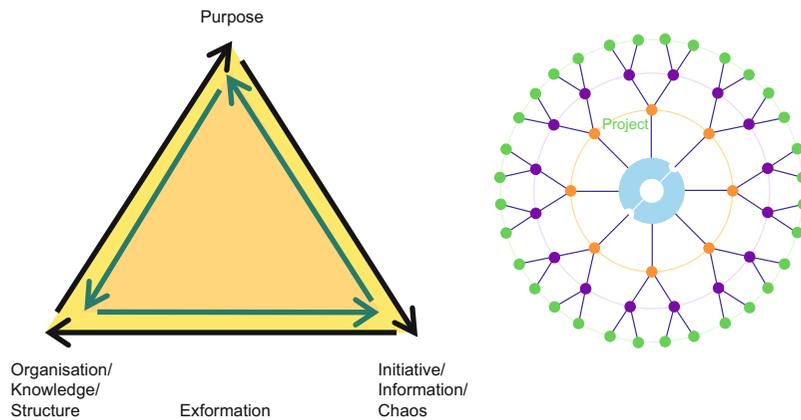


Fig. 26.7 Knowledge needs a common purpose and open network. The individual should have freedom to improve their specialty within the purpose of the team

speed of the team depends on the quality of the relations between humans.

Generative learning requires an action-oriented, bottom-up culture glued together by shared visions. The shared visions must be based on a common consciousness of how reality is perceived. The basis for perceptions of reality should honour the following:

- Possibility analyses are influenced by the ruling authoritative opinions of the time
- New knowledge is created beyond the filter of preconceived ideas
- A concept must be based on, but not limited by, all that is considered facts
- New knowledge is frequently created by actions
- Cost benefit analysis can hinder generative learning
- Efficient learning should attack uncertainties, not certainties
- New awareness relates to increased diversity of geological aspects and not more of the same of what is well known

26.5 Exploration History and Strategy of the Norwegian Continental Shelf

The initial exploration phase on the Norwegian Continental Shelf (NCS) during 1965–71 was led by a diversity of major companies with different perceptions of play concepts in the shallow water parts of the North Sea basin. The unfolding of the petroleum potential of the NCS has been a continuous learning effort that demonstrates the need for

conscious continuous drilling actions. The exploration effort started out as impossibility, and the shelf or parts of it have been considered mature at frequent intervals. Renewed drilling activities based on increased diversity have revitalised the discovery process several times. The authorities have been instrumental in relation to such revitalisations. The last revitalisation occurred around year 2000 when the authorities compensated for lack of diversity of companies by inviting new players to take part in the exploration activities. This effort has led to several new significant discoveries in earlier assumed mature areas.

The first play type to be established on the NCS was the early Palaeogene deep sea fan play that resulted in the Balder oil field and the Frigg and Odin gas fields. The first definite commercial discovery was the serendipitous revelation that the chalk in the Ekofisk Formation, considered to have poor reservoir potential, actually contained producible oil.

The initial success led to a technical national management of the resources from 1972 onwards by establishing the Norwegian Petroleum Directorate (NPD) and Statoil as instruments for the political management of the nation's offshore hydrocarbon resources. An important aspect of the NPD's resource management was the proper storage and retrieval of geological as well as geophysical data.

Areas to be allocated for future exploration drilling were from then on selected by the NPD and put up for competitive bidding and awards among the petroleum companies. Work commitments were agreed through

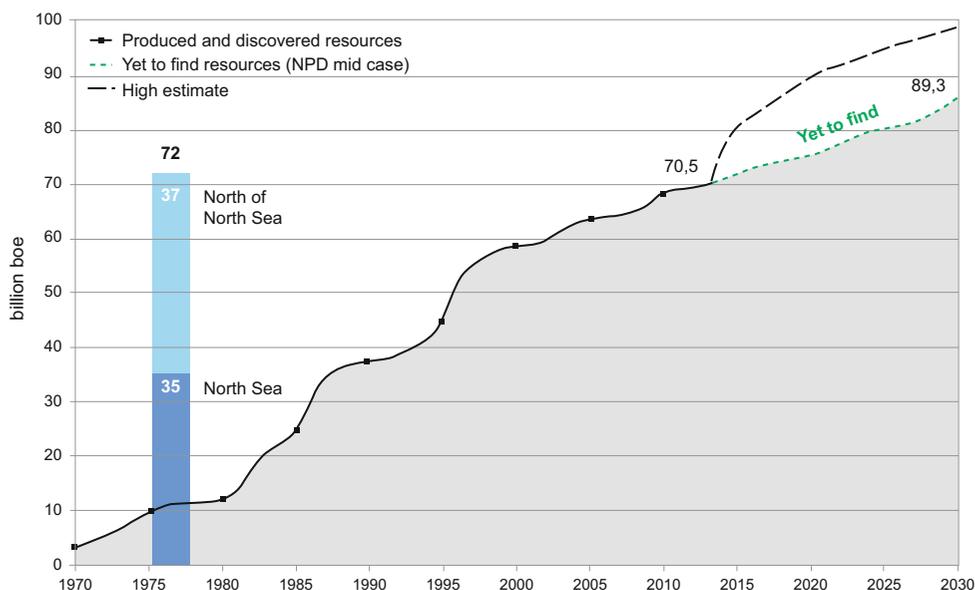


Fig. 26.8 The reserve growth of the Norwegian Continental Shelf reflects breakthroughs. The breakthroughs are related to new play types or new areas

negotiations for each new licence in order to secure the necessary funding of seismic and drilling activities considered necessary from a national point of view. A mixture of established and new plays were selected in the various allocations rounds. This early period included the Staffjord allocation, and the third, fourth, fifth, sixth, seventh and eighth concession rounds. The fourth and subsequent rounds were designed after the Jurassic had been established as the third major play type, and were based on the first total resource estimate of the shelf (Fig. 26.8). The fourth round, which followed the third round that prematurely was considered as a disappointment, was the major breakthrough round ever in relation to reserve growth on the NCS. Fields like Snorre, Oseberg, Gullfaks, Brage and Troll was the major outcome.

The opening of licence areas on Haltenbanken and in the Barents Sea in 1980, 1981 and 1982 was based on national mapping by the NPD. The chosen areas were selected to cover various play types in order to secure continuity. The same philosophy was applied on Trænabanken in 1982. The result of the initial exploration phase resulted in gas and oil discoveries on Haltenbanken and gas discoveries on Tromsøflaket, but no discoveries were made on Trænabanken.

The oil price drop in 1985–1986 resulted in a reduction of drilling activity and more focus on near-

field exploration than frontier exploration, with the natural self-fulfilling result that smaller discoveries were made and it was assumed that the NCS (Norwegian Continental Shelf) had reached maturity. At the same time an increasing number of mergers and acquisitions of companies took place, reducing the number of operators and drilling activities on the NCS. The authorities stimulated new activities in the Barents Sea by opening up acreage for strategic drilling in the 11th round phase 2 in 1987, without any major success. The 15th concession round in 1996 opened up major inverted Tertiary structures in the Norwegian Sea for exploration, which resulted in the discovery of the Ormen Lange and Åsta Hansteen gas fields. At the same time the authorities initiated the Barents Sea Project with awards in 1997 to stimulate increased activities. The main result of this project was the discovery of the Goliath oil field.

The three Norwegian companies Statoil, Norsk Hydro and Saga Petroleum were conducting 80% of the drilling activities on the NCS in the 1990s. When these companies were merged into first two and then subsequently one company, due to a perception that the Norwegian shelf was too mature to sustain many companies, the authorities revitalised the diversity strategy pursued in the 1970s. This diversity strategy has been a success, both in the North Sea, Norwegian

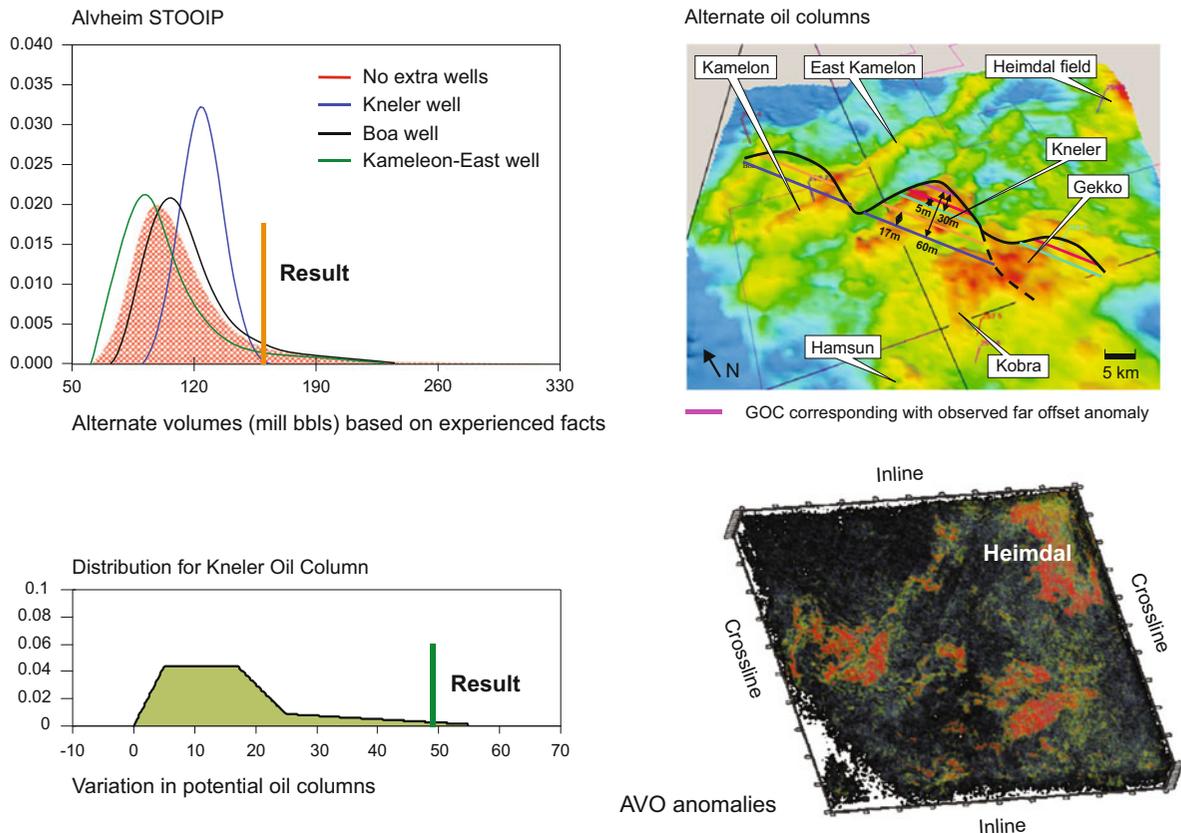


Fig. 26.9 The Alvheim Field is the story of gas satellites that became a large oil field. The exploration drilling proved oil reserves beyond two standard deviations in the pre-drill model for the prospects

Sea and Barents Sea. In all areas fourth generation exploration has resulted in new successful play types that clearly demonstrate that the maturity of the shelf was fiction due to lack of exploration drilling. Examples of new discoveries are the Alvheim, Edvard Grieg, Ivar Aasen, Johan Sverdrup, Johan Castberg, Wisting and Gohta fields and discoveries.

Prior to the Alvheim oil field discovery in 2003 the prospects were assumed to be gas tie-in satellites to the Heimdal field (Fig. 26.9). The exploration drilling resulted in a significant standalone oil field consisting of three discoveries that became the hub for other oil tie-in satellites. This demonstrates the importance of defining the resource potential in a subsurface-based context and not in relation to what could be nice to have from a production point of view. The drilling of the Kneler prospect within the Alvheim Field proved an under-saturated non-biodegraded oil discovery amidst the saturated Gekko and Kameleon and later Boa oil discoveries. The discoveries were drilled on

seismic indications interpreted as gas AVOs. The post-drill results demonstrated the shortcomings of a single method. Additional oil discoveries were the spinoff of rapid learning from these results.

The Haugaland High (Utsira High South) was explored for 40 years before the breakthrough discovery was made (Fig. 26.10). The first well, Esso's 16/2-1, was drilled in 1967 and had good oil shows in the Tor Formation and Basement. These shows were later referred to as the Ragnarrock discovery and delineated by Statoil in 2007 by the drilling of 16/2-3 and -4 wells. The delineation concluded that the chalk and basement reservoirs in this area have limited commercial potential.

The prolific hydrocarbon nature of the Haugaland High area was demonstrated by the Luno 16/1-8 discovery (Edvard Grieg) in 2007, the Draupne 16/1-9 discovery (Ivar Aasen) in 2008, the Avaldsnes 16/2-6 discovery (Johan Sverdrup) in 2010 (Fig. 26.11) and Luno 2 16/4-6 discovery in 2013.

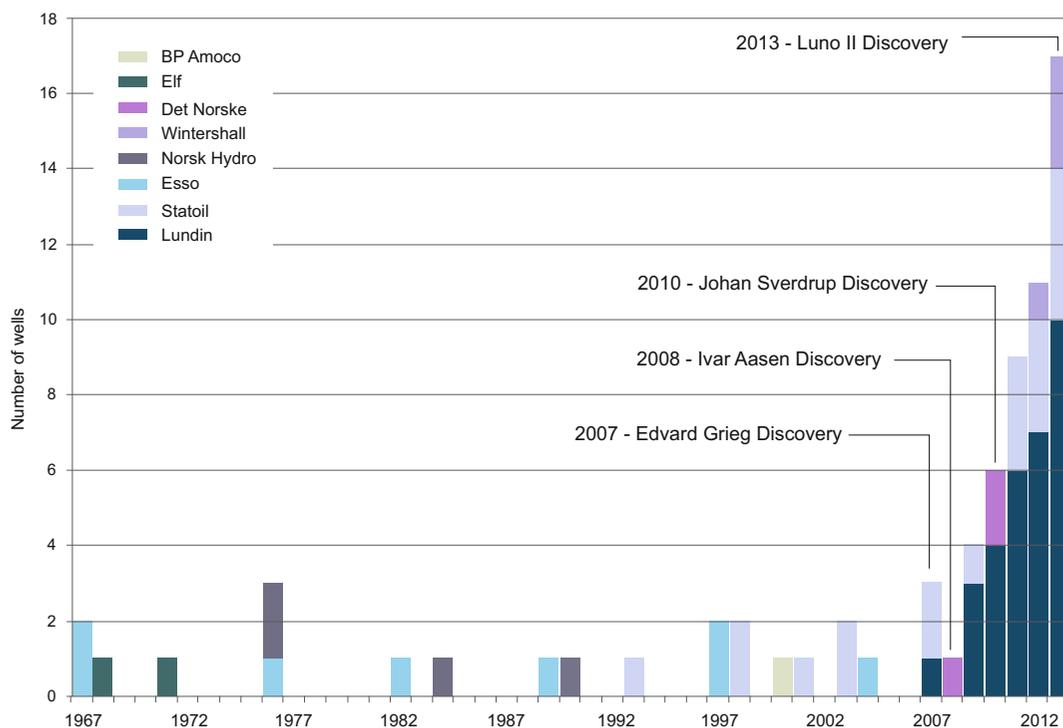


Fig. 26.10 The learning curve demonstrates 40 years of disappointments before the first discovery on the southern Utsira High. The result from the first well in 1967 was encouraging

with the presence of oil in basement. The Edvard Grieg discovery 2007 opened up for the discovery of the Johan Sverdrup discovery in 2010

The Edvard Grieg and Johan Sverdrup discoveries on the Haugaland High contain under-saturated non-biodegraded oil originating from the same Draupne formation source rocks. These discoveries flank the saturated biodegraded Ragnarrock discovery at the crest of the high.

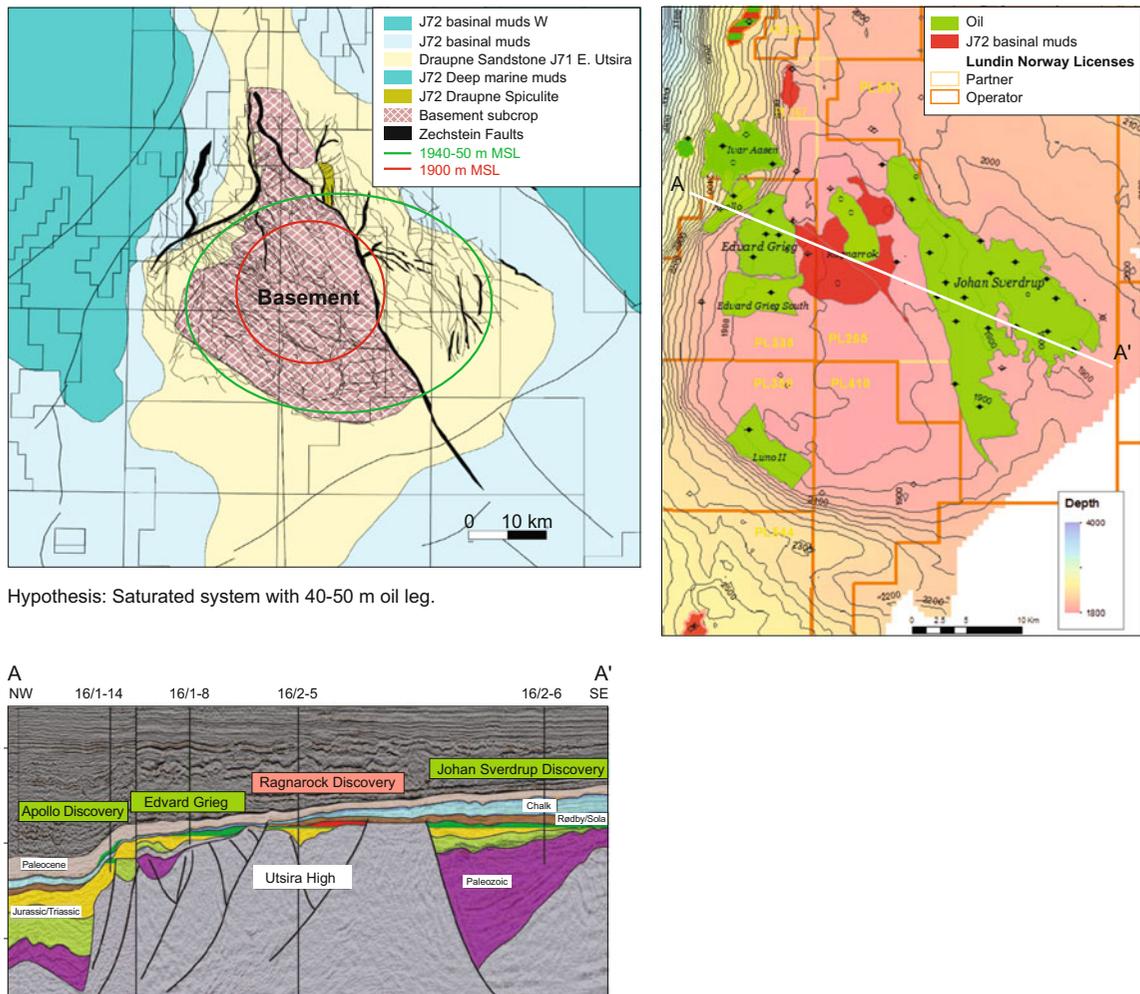
The pre-drill possibilities for oil in the Johan Sverdrup discovery were considered remote by most companies, but the possibility of an oil-filled reservoir was backed up with seismic indications of hydrocarbons venting vertically into the overlying Utsira Formation followed by lateral migration updip in a westward direction. This observation linked the Edvard Grieg and Johan Sverdrup prospects. Following the discovery of Edvard Grieg in 2007 the Johan Sverdrup prospect became a high probability prospect which was proven in 2010.

The initial play model employed on the Haugaland High was based on the presence of a thin veneer of Volgian sand, older inlier basins and fractured porous basement shallower than 1940 m MSL on the high itself. In addition, structural and stratigraphic traps

fringing the high in the west were defined. The prospects and leads were assumed to be filled by saturated light oil similar to the 16/1-7 West Cable discovery.

Following the discovery successes the strategy has involved the application of continuously improved geophysical and geological databases and interpretation techniques to refine the new play concepts. New 3D seismic acquisition techniques used in 2008, 2009 and 2012 have given continuously better pictures of the subsurface (Fig. 26.12).

The Edvard Grieg discovery might have been overlooked without coring and testing, due to the feldspar-rich nature of the reservoir rocks (Fig. 26.13). The increased understanding of the hydrocarbon habitat of the southern Utsira High implies a reassessment of the geological history from Palaeozoic to Pleistocene. The main learning concerns recent and on-going oil migration. The Johan Sverdrup structure (Fig. 26.14) obtained its current structural position during the last 1.5 million years, which constrains the time available for migration and



Hypothesis: Saturated system with 40-50 m oil leg.

Fig. 26.11 The basic assumption was sufficient. The drilling demonstrated under-saturated and saturated oil in new reservoir types on the NCS. The oil fill of the reservoirs is late and is still ongoing

trapping of the same oil type into both fields. The varying oil/water contact between 1922 and 1935 m MSL and deeper residual oil in the Johan Sverdrup discovery demonstrates the effect of glacial down warping and rebounds during the Pleistocene.

Both the Edvard Grieg and Johan Sverdrup discoveries contain reservoirs that are new on the NCS. In both discoveries Volgian reservoirs are the main reservoirs that are overlying older reservoirs by a major regional unconformity. The unconformity was created by large-scale tectonic epeirogene basin inversion. Renewed weathering and erosion sourced the various Volgian sandstone reservoirs in the two discoveries. The Volgian inversion on the Haugaland High is superimposed on the thermal-driven early

Middle Jurassic inversion that stripped off the Lower Jurassic and older sequences down to basement over large parts of the high. There are also marked tectonic events in the Callovian and Kimmeridgian that have influenced the presence of reservoir sequences.

The main Volgian reservoirs in the Edvard Grieg discovery are proximal continental deposits and consist of high quality eolian sand, good quality braided river and alluvial fan sands. There are also proximal coarse sandy conglomerates of Triassic age, weathered basement gravel and Valanginian shell fragment sand. All the reservoir types have been production tested.

The main reservoir in the Johan Sverdrup Field is the shallow marine Volgian sand with extreme

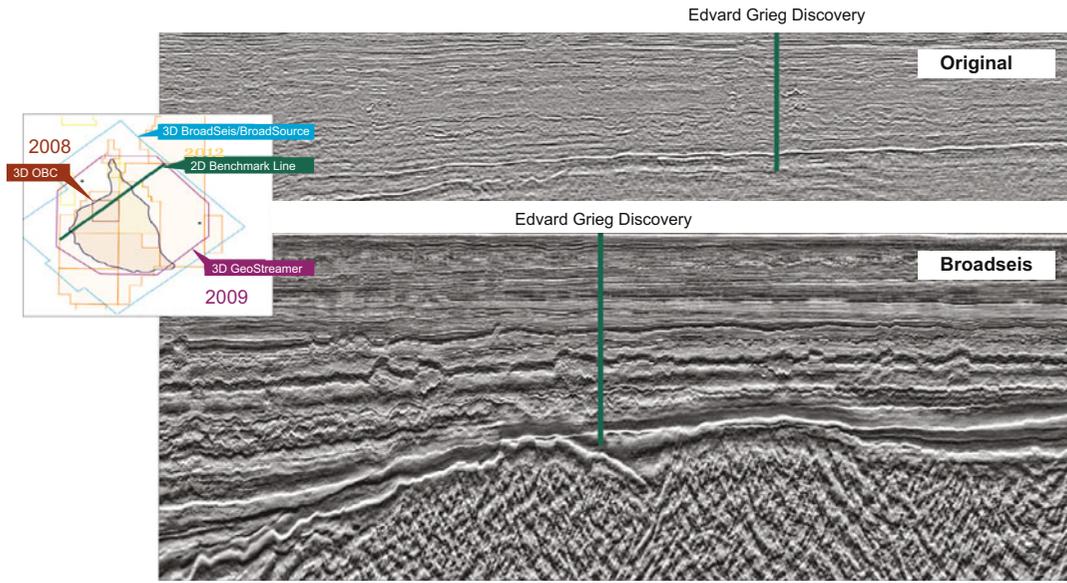


Fig. 26.12 The vintage 3D has been replaced by broadband 3D after the discoveries. The broadband 3D seismic gives a holistic picture of the shallow and deep geology simultaneously

16/1-8 formation evaluation

Logs read 40% shale in 100% sand

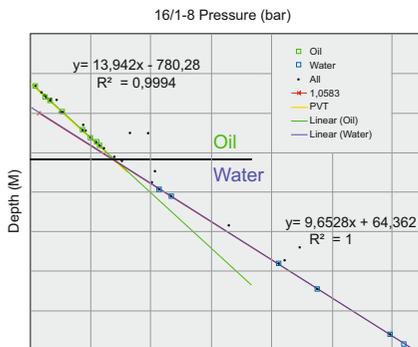
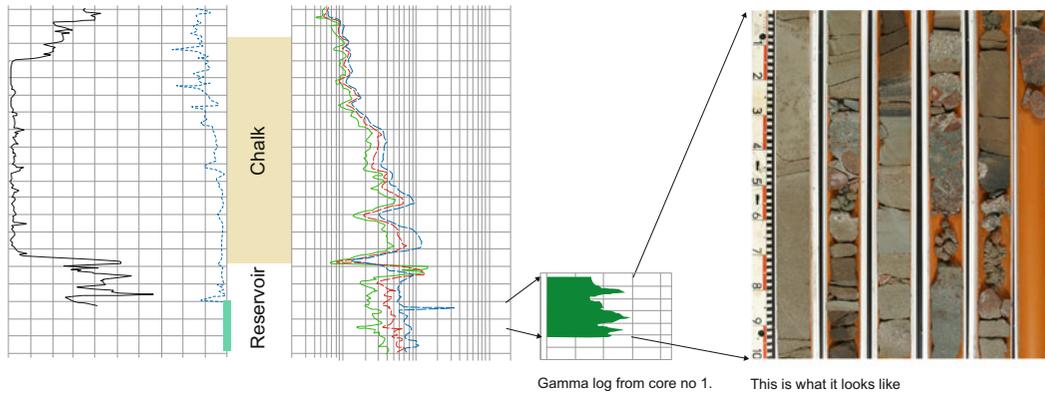


Fig. 26.13 Coring was a necessary trigger for the discoveries on the Utsira High. Indirect data types (wireline logs) need to be calibrated. Without cores the Edvard Grieg discovery could have been overlooked

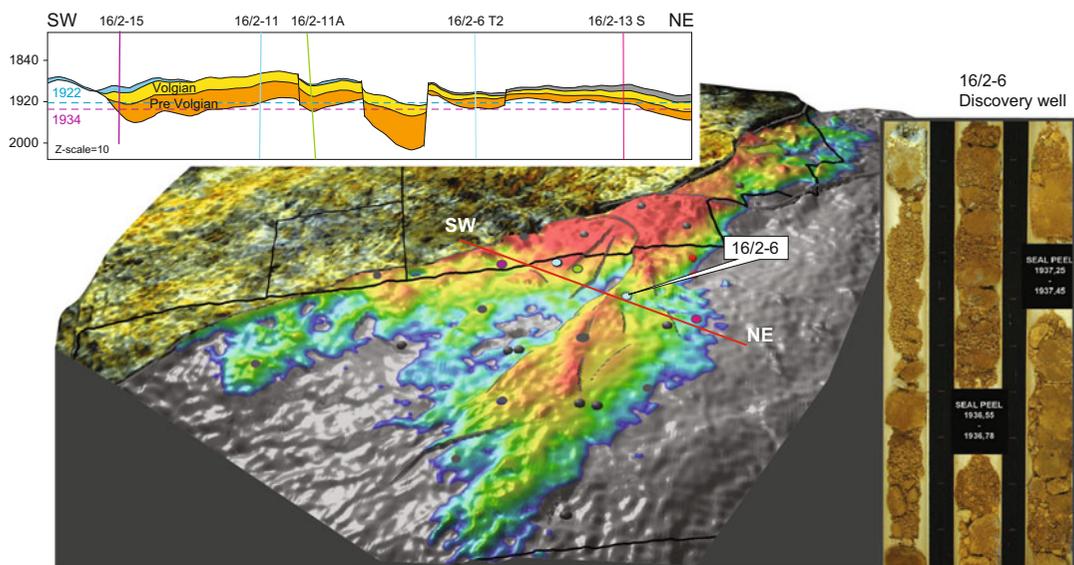


Fig. 26.14 The Johan Sverdrup Field was found by well 16/2-6 in 2010. The discovery well was located to give a maximum amount of information. The delineation drilling took place in 2011, 12, 13 and 14

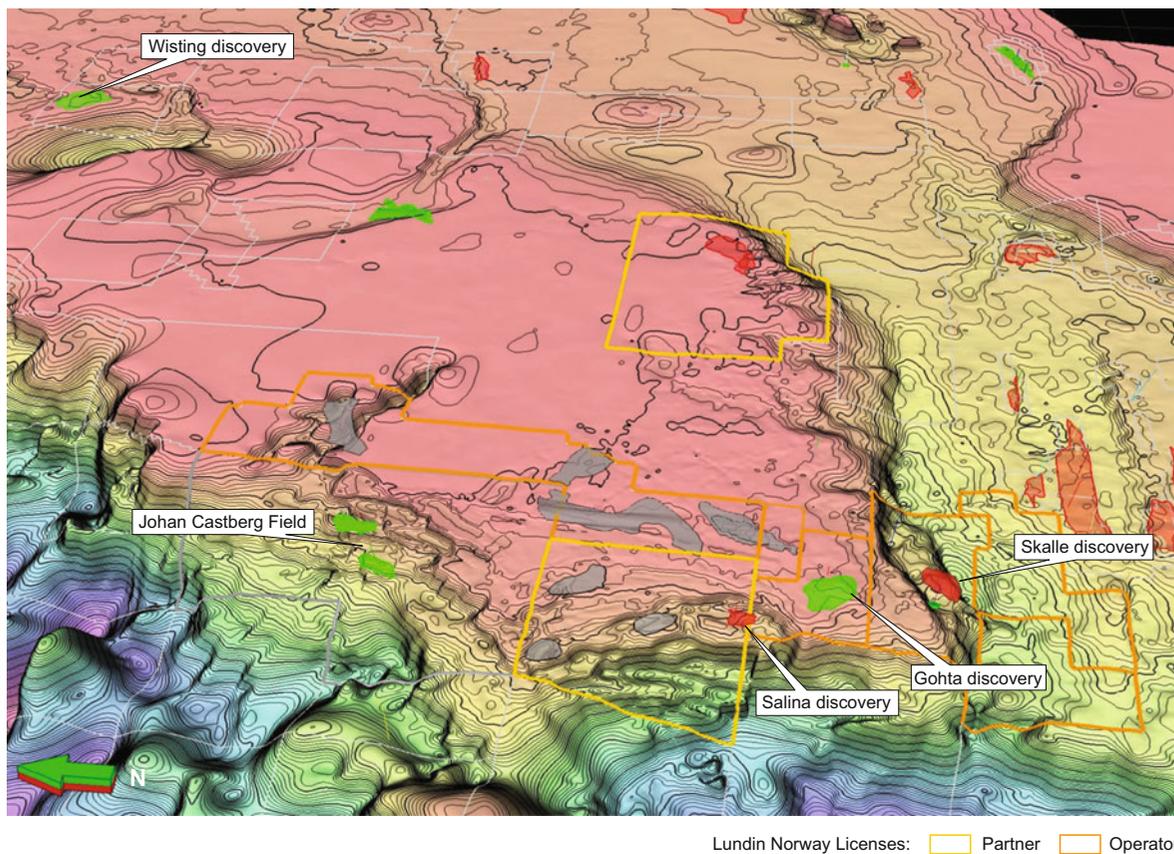


Fig. 26.15 The Barents Sea has experienced breakthrough in relation to oil potential. The ongoing oil filling is compensating for the leakage during the ice ages

permeability documented by the seven production tests. Beneath the Volgian unconformity there is Middle to Upper Jurassic estuarine to fluvial sand sequences with good reservoir qualities. Beneath the base Middle Jurassic unconformity there are marine to continental Lower Jurassic sands of very good quality. Zechstein karstified limestone and dolomite are also present as reservoirs.

The Luno 2 discovery is a Late Triassic/Jurassic inlier basin with reservoirs in fluvial facies sandstones. This oil discovery is sourced from the Heather/Draupne formations.

The Volgian inversion on the Haugaland High is reflected regionally on the NCS and formed the Mid North Sea High, Utsira High, Tampen High, Manet High, Frøya High, Nordland Ridge, Loppa High and Fedinsky High. Hence analogue plays have and will be found around these highs. This demonstrates the importance of having a regional geological perspective in formulating efficient exploration strategies.

Renewed exploration of the Barents Sea resulted in the discoveries of the Johan Castberg field in 2011 and the Gohta and the Wisting discoveries in 2013 (Fig. 26.15). Common for all these light oil

discoveries is ongoing active oil migration that compensates for leakage of oil during the glaciation periods. The indication of this process has been there for a long time, but the possibilities were shadowed for by the ruling view that focused on the leakage problem and not on the active ongoing petroleum migration which has been documented by sampling. The reservoirs are Late Triassic to Middle Jurassic except for Gotha with karstified Permian carbonate reservoirs.

The new discoveries on the NCS related to both old and new play concepts since 2003 demonstrate that the exploration process should always be open in relation to which parameters are necessary. The seed for new knowledge will always be outside the bandwidth of preconceived ideas and the truth can never be voted on by majority or size. Diversity and not more of the same is needed in generative knowledge creation. The following wording of Piet Hein is a good guidance for exploration; "To know what thou knowest not is in essence omniscience".

Updates on the petroleum discoveries and production are found on: www.NPD.no (Norwegian petroleum directorate)