Master's thesis

NTNU
Norwegian University of
Science and Technology
Faculty of Social Sciences
and Technology Management
Department of

Werner Svellingen

THE IMPORTANCE OF UNCERTAINTLY AND RISK UNDERSTANDING IN ORGANIZATIONS IMPLEMENTING DISRUPTIVE TECHNOLOGIES ROCKSOURCE - A CASE STUDY

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NTNU – Trondheim
Norwegian University of
Science and Technology

Abstract

The subject for this thesis focuses on how Rocksource, a Norwegian independent oil and gas company, evaluated prospect uncertainties and risks during the exploration phase, where the main risk is absence of commercially viable hydrocarbons. To mitigate the uncertainty and risk Rocksource implemented the disruptive technology, Controlled Source Electromagnetic Marine (CSEM). For small oil companies the success or failure can be directly related to the ability to understand and manage risks. The ability to understand and quantify uncertainties and risks, and knowing how to manage them effectively, contributes to well-founded business decisions, protects the value of projects and assets, and maximizes the value of the company's project portfolios.

To define uncertainty and risk in prospect evaluation explorationists simplify the geology into "sophisticated" models as it is not possible to be present at subsurface, it is impossible to handle all data, and even if it was possible, a good model can actually represent the reality excellent. Humans are influenced by biases when evaluating uncertainty and risk, but training and practice can improve the evaluations. The influenced biases can vary from human to human and from organization to organization.

In addition to the traditional exploration uncertainty and risk related to hydrocarbon exploration, Rocksource was explored to the risk of implementing a new technology. To mitigate the risks and uncertainties related to the new technology Rocksource developed internal processing and evaluation software. No new technology guarantees success, but the right technology, spread across a range of opportunities can significantly improve the chances of drilling the right prospects, accelerating development and reducing the environmental impact. To develop a CSEM friendly prospect portfolio Rocksource developed a work flow and acquired data on the Norwegian Continental Shelf.

Prospects and opportunities was evaluated and ranked based on the uncertainty and risk evaluations from the Rocksource risk team. In 2011 five large hydrocarbon prospects, all associated with a high chance of success, was matured for drilling through Rocksource's decisions system.

Post drilling analysis of the quality of subjective probabilistic assessments made by explorationists are an increasingly attractive way to improve the quality of risk assessment. Without a vigorous effort to encode and analyze the historical performance, expert judgment is not likely to improve.

In the study a factual and observational approach is used. Predicted uncertainties and risks pre drilling are compared to post evaluated results from drilled exploration wells. In addition pre well CSEM studies are compared to post drilling evaluations to understand how an immature technology improve over time, hence the pre well evaluation of uncertainties and risks. The observations in the data is linked theory describing decision theory, disruptive technology and escalation of commitment.

The data show a substantial gap between the pre and post well uncertainty and risk estimations. Even if large and wide ranges was used in the pre well evaluations, the post well results was overrepresented on

the negative side. CSEM data was the single most important factor in the drilling decision, without a well-defined risk management. The post well reprocessing of the immature CSEM data show how new processing techniques can change the results. The collected data and discussion show that Rocksource's uncertainty and risk evaluation was influenced by high expectations to the new CSEM technology, belief and biases within the whole organization, from the board to the employee. The consequences of misinterpretation of uncertainty and risk limited the options for Rocksource to develop a more balanced portfolio. The Rocksource portfolio was evaluated to be as *low risk-high reward*, but as the most of the prospect was located within new plays (high uncertainty and risk) the portfolio consisted more likely of high risk-low reward prospects.

Contents

1 Introduction

A simple definition of risk is “a problem that has not yet happened but which could cause some loss or threaten the success of the project if it did.” Before deploying and implementing a new technology, it is important to understand the risks, and perform a risk analyses. In order to discover possible risks of a new technology, the uncertainties must be described and understood. Risks can not only be analyzed, it must also be managed. Knowledge of risk elements is crucial to find solution for each possible (most probable) scenario in order to manage risks and lowering the chance of failure when developing and implementing new technology. In a Norwegian Parliament hearing, Helge Lund, CEO in Statoil AS, comment “*It is considerably more difficult to implement and development technology than talking about it in the newspaper.*”

The oil and gas industry is inherently high risk, requiring a dynamic approach to identifying, evaluating and mitigating a broad range of technical and non-technical risks. Strong and effective risk management is central in the industry to achieve strategic objectives and protects business, people and reputation. Ability to identify, understand and mitigate uncertainty and risk, maximize the value from business opportunities, supports effective decision making at an asset, business unit, regional and strategic level.

Uncertainties, and the associated business risks, touch all aspects of the oil and gas industry. Large oil companies have departments to analyze impact assessment, risk management, and key indicators before decisions. On the other hand, smaller companies with limited resources need to prioritize the use of a scarcity, and it became more important to be aware of procedure and techniques to perform uncertainties and risk analysis. For small oil companies the success or failure can be directly related to the ability to understand and manage risks.

Ability to understand and quantify uncertainties and risks, and knowing how to manage them effectively, contributes to well-founded business decisions, protects the value of projects and assets, and maximizes the value of the company’s project portfolios (Figure 1). Oil companies face uncertainty and risk at different stages in the “life cycle” from exploration to production. This thesis focus on how methodology and new technologies can reduce the uncertainties and risks in the exploration phase. The main uncertainty is presence of a functioning hydrocarbon system associated with dry hole, phase and size as the main risk parameters. The study is not evaluating risks and uncertainties related to appraisal, development or production phase (Figure 1).

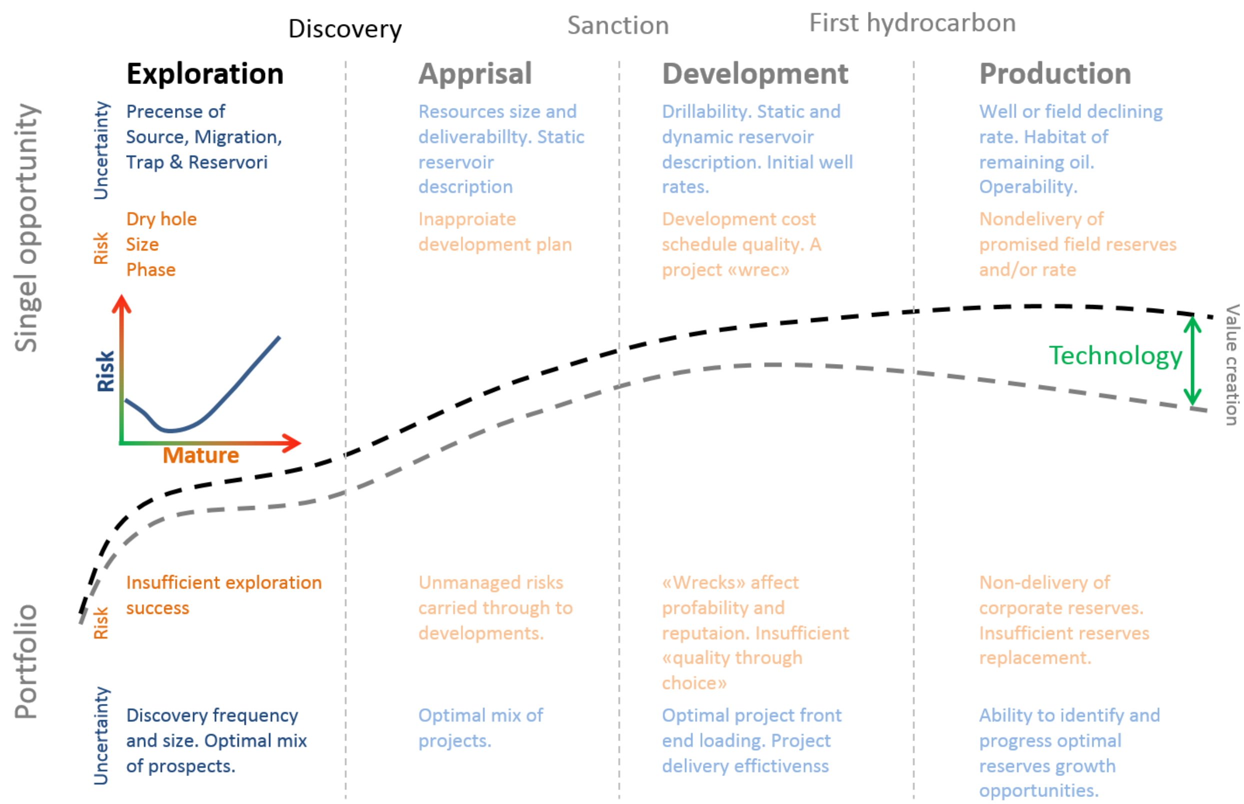


Figure 1 Typical subsurface-related risk and uncertainties relevant at different stages of field life, contrasting single opportunity and portfolios. Commercial risks are also important but are not focused on in this thesis (modified from: Smalley et al., 2008). Rocksource and the thesis are only focusing on the exploration phase.

1.1 Scope of thesis

The subject for this thesis focuses on how Rocksource, a Norwegian independent oil and gas company, evaluated prospect uncertainties and risks during the exploration phase, where the main risk is absence of commercially viable hydrocarbons. To mitigate the uncertainty and risk Rocksource implemented the new and immature technology Controlled Source Electromagnetic Marine (CSEM) technology. The study map how Rocksource, from the start-up in 2005, evaluated the prospect uncertainty and risk used for drilling decisions until 2013. The study also investigate how Rocksource applied the new and immature CSEM technology to mitigate prospect uncertainty and risk. The study data, evaluations and the applied theory can be used as a foundation to improve future decision basis for the company. The thesis is also relevant for companies, even within other industries, implementing new and disruptive technologies to improve decisions.

In this study a factual and observational approach is used. Predicted uncertainties and risks pre drilling are compared to post evaluated results from drilled exploration wells. In addition pre well CSEM studies are compared to post drilling evaluations to understand how an immature technology improve over time, hence the pre well evaluation of uncertainties and risks.

Before identifying a plan to manage uncertainty and risks, it is important to know the company's definition of paradigms, and used common approach for risk analysis. Generally regard as company sensitive information and rarely shared externally. It is also useful to know the backgrounds of those implementing the risk assessment, tools used for the analysis, reasons for the preferred methods and available data. In the study all necessary information is collected to evaluate Rocksource's approach to assign uncertainties and risk to the drilled prospects, including the understanding of uncertainties and risk related to the new and unproved CSEM technology.

In the discussion around a model-based approach to evaluate exploration opportunities Duff & Hall (1996) suggest a distinctive approach to play definition and modelling emphasizing a closed style. At the same time the importance of post mortem evaluation of model performance is emphasized. The information is used to correct biases and adapting new information to define uncertainty intervals with specific descriptions of the type of data supporting assignment of a geologic event to an interval. Post analysis of the quality of subjective probabilistic assessments made by explorationists is an increasingly attractive way to improve the quality of risk assessment in larger oil companies. Without a vigorous effort to encode and analyse the historical performance, expert judgment is not likely to improve – which is the main goal for the study.

1.2 Thesis structure

The thesis is composed of Sections. As a short introduction to the oil industry, the different characteristics of uncertainties and risks, in addition to challenges related to implementation of new technology is presented in Section 1. The section also present the aim and outline of the study. In Section 1 Rocksource's history, business plan, strategy and expectations to the company is presented. Perspectives to Rocksource's ambitions is presented in Section 1, together with an overview of the oil business on the Norwegian Continental Shelf (NCS) to improve the overall understanding of challenges and opportunities. The chapter gives a brief overview of how the oil industry have developed on the NCS and future exploration potential. For how long exploration and production can be maintained on the NCS depends on several factors, including resources, technological advances, cost developments, the player picture, political operating parameters and the price of oil and gas in relation to other energy carriers. In the past Rocksource invested large amounts of resources to develop the new and immature CSEM technology in order to de-risk high valuable hydrocarbon prospects (Section 1). The introduction in Section 1 and 1, and the large amount of collected data provides the foundation for many topics to be discussed in the thesis (Section 1). To limit the content of the thesis it is necessary to narrow the used theoretical framework and context for the discussions. Section 1 give a brief introduction to the theoretical context of implementing a new technology in the decision evaluated to be the most relevant for the study. The methodology used for the thesis is given in Section 1 together with limitations and research questions. Data and findings is presented in Section 1, including presentation of the organization, Rocksource Risk Team (RRT), and working processes. For the five drilled prospects pre well uncertainties and risks evaluations are presented and compared to interpreted well results and post CSEM analyses. Section 1 present discussions and conclusions, before references are given in Section 1.

2 Rocksource ASA – the vision and history

Rocksource is an independent oil and gas company established in 2004 and stock listed at Oslo Børs a year later (2005). Rocksource's competitive advantage was to use the new CSEM technology, a technology believed to prove more hydrocarbons quicker and to a lower cost than conventional explorers. To achieve the goal new work processes had to be developed to deal with all aspects of the CSEM technology from initial screening to fully integrated analyses. To identify CSEM suitable areas Rocksource undertake a global screening of offshore sedimentary basins. Based on screening results the business development activity was focused on the most prolific areas where Rocksource's proprietary exploration technology could be applied to de-risk high potential prospects to low risk drillable prospects. An introduction to the company's vision, strategy, decisions and business model, based on the new CSEM technology, is presented through excerpts from the Annual Reports (2005-2013).

The 2005 annual report define the business model and strategy as: *Rocksource's objective is to develop its own license portfolio. We have defined growth ambitions as a focused E&P company using our insight in CSEM technology as a basis for project selection. This will be accomplished through licensing rounds and co-operation with other oil companies that are interested in exploiting the advantages of our CSEM technology and expertise to increase the probability of success in predicting hydrocarbons and thus reduce exploration costs. This co-operation may in part be expressed through joint applications for licenses in open areas and in part in the form of farm-ins to already allocated blocks. Rocksource participates as partner and covers its share of the partnership's license costs. In addition, Rocksource shall contribute with its CSEM technology and expertise in the licenses to reduce risk and increase value creation. The pre-condition for applying for new exploration licenses and entering into farm-in agreements is that our CSEM technology and expertise may be employed. Rocksource entered into co-operation with Statoil, Shell and Interaction in a "Joint Industry Project" with the objective of developing software tools and work processes for use in the respective oil companies' activities. Rocksource also entered into an agreement with DNO participation in a license in UK.* Onshore production in US secured cash flow and Rocksource continued development of technology to include exploration activities onshore applicable for our own production and exploration leases onshore USA, and in co-operation with other oil companies with suitable onshore exploration activities (Annual report 2005).

The 2006 annual report describes a company building the foundation for long term growth as an oil and gas company. The driver for the value creation is the *development of proprietary technology enabling Rocksource to handle CSEM data for exploration purposes. Rocksource Discover version 2 was launched and implemented a number of important new functionalities. Rocksource Discover is the Group's proprietary system for handling CSEM data in all stages of the exploration work flow. Several new algorithms have been developed to ensure proper processing. The speed of processing data has been increased significantly as well. This allows for more rapid modelling and inversion. Finally, a completely new system for implementing results from analyses of CSEM data into the decision processes has been established. It is a major advantage for an oil company to have the ability to handle uncertainties involved in dealing with CSEM data. Failing to recognize this and not having the necessary knowledge in-house, may lead to erroneous interpretations and results. In most cases where erroneous results have been produced* *it is not the CSEM technology in itself that fails, but the ability to correctly interpret the data. An integrated approach is a competitive advantage and improves the chance for successful results. Based on analyses of 14 survey lines to date, Rocksource has a 100 percent (%) correlation between the interpretation of CSEM data and available well data and seismic data.* In addition to develop the CSEM technology, Rocksource also become qualified as license holder on the NCS and started to acquire licenses around the world (UK and Colombia): *2006 was a successful year for Rocksource in building our exploration portfolio. This includes a large number of prospects that can be tested by Rocksource CSEM technology, spanning multiple play types and levels of acreage maturity, from near field tie back to frontier exploration. The portfolio of exploration prospects represents net risked reserves of 9.22 million stander cubic meters of oil equivalent* (M Sm^3 o.e. (conversions: 6.29 barrels oil ≈ 1 Sm^3 o.e. = 1000 Sm^3 gas)) *which significantly adds to the value to the Company. The Company also clearly proved its business model by using its technological strength as a farm-in tool and as a means for generate strong partner Groups* (Annual report 2006).

In 2007 Rocksource's experience and expertise lead the Norwegian authorities to qualify the Company as an operator on the NCS and the CEO wrote: *I am proud to say that Rocksource delivered above expectations for the year 2007. From establishing the framework of an innovative and fast growing E&P company in prior years, 2007 has been all about making it happen while establishing a sound foundation for further growth.* A growth based on a new technology: *During 2007 Rocksource established a portfolio of exploration licenses which provides an excellent growth platform for CSEM led exploration. The Company also conducted the first large-scale CSEM campaign, where 1200 M Sm^3* o.e. *of unrisked exploration potential was tested in unlicensed acreage on the NCS. This was part of the preparation work for the upcoming 20th Licensing Round on NCS in 2008 and future rounds.* The expectations to the technology were high: *With this new and innovative exploration model, backed by our business strategy, we will only apply for licenses that have positive CSEM anomalies, and hence will have a significantly higher probability of success than conventional exploration. In addition we will only apply for those licenses that have the highest chance of containing commercial volumes of hydrocarbons.* In addition Rocksource increased the net risked exploration resources by 9 awards licenses in the UKCS 24th Round and the 2006 NCS APA *from 0.8 M Sm^3 o.e. to a multi-prospect portfolio with over 16 M Sm^3 o.e. potential.* To prove the hydrocarbon potential *the Group has an ambition to drill its first CSEM-based well in 2008, and to drill a minimum of 2 CSEM-based wells per year starting in 2009. Achieving this means that the portfolio will have to continue to grow, and that a significant part of the portfolio will be relinquished prior to drilling (negative CSEM results). This will result in fewer dry wells and a level of exploration success higher than the industry norm.* Rocksource also secured a credit facility for exploration on the Norwegian continental shelf for the first time (the facility has been renewed every year thereafter) (Annual report 2007).

By the end of 2008 Rocksource had *gained access to a number of quality exploration opportunities in Norway, the UK, West Africa (Ophir Energy) and India (ONGC). Highlights from 2008 annual report is that the subsidiary Rocksource Geotech is continuing to develop software tools and work processes that deliver unique insights. We see a tremendous potential in the application of CSEM as part of the exploration tool kit, and will utilize our position to create shareholder value. An external environment characterized by long-term growth in demand and short-term fall in prices will drive the need to improve exploration decisions in the industry.* Rocksource continued the development of "Rocksource Discover", the company's in-house software for handling CSEM data. Rocksource continued to focus on offshore activities and made significant additions to its exploration portfolio*. The Company continues to adhere to its business model of leveraging its technology expertise to gain access to high-impact prospectivity. A number of partnerships with large international companies, including India's ONGC and Australia's Ophir Energy, demonstrate the positive perception of Rocksource's technical abilities in the international market. This has also allowed the Company to access significant resources. The Company has also added to its portfolio following successful license round applications in Norway and the United Kingdom, where the Company increased its number of licenses to fifteen, five of which are operated licenses. The successful awards and farm-ins contributed in taking the net risked resources from 20 up to 65 M Sm*^{3} *o.e. Several of the Company's operated licenses already have positive CSEM anomalies that indicate high probability of the presence of hydrocarbons. Testing of the remaining areas is ongoing and rig access has been secured for two drilling slots, which will be used to further develop the Company's assets* (Annual report 2008).

By the end of 2009 Rocksource evaluated its own portfolio to more than 160 *M Sm*^{3} *o.e.* net risked resources and the CEO wrote: *Rocksource's exploration potential is unique compared to our size and market capitalization. However, there is no gold medal for land grabbing – what matters is transforming our resources into reserves, by making commercial discoveries that make a difference. Therefore we are eager to move on to testing our prospects and hopefully demonstrate that our strictly disciplined exploration strategy will pay off.* Rocksource continued to add exploration potential to the portfolio in 2009 by successful award of new licenses in the NCS 20th Concession Round and through a farm-in agreement with Focus Exploration LLC. The new licenses on the NCS *contain prospects with a significant probability for commercial discoveries. The awards marked another milestone in the Company's development and added multiple, high value drillable prospects to the Rocksource portfolio. In August 2009, Rocksource announced a strategic step to extend its CSEM-led exploration strategy into the offshore Gulf of Mexico (GoM). Rocksource gained access to a portfolio of eight leases of which several had CSEM positive prospects. With the GoM entry Rocksource aims to accelerate its drill queue of CSEM positive prospects and create opportunities for short to medium term production growth and value creation. Following successful license awards and the rapid buildup of a significant GoM portfolio, Rocksource grew its net risked resources from close to 65 M Sm*^{3} *o.e. at year-end 2008 to more than 160 M Sm*^{3} *o.e. in 2009* (Annual report 2009).

2010 was a year for preparation in Rocksource, and the CEO used the annual report to look forward: *I am pleased to report on good progress for Rocksource in 2010. Although we had hoped to drill exploration wells last year, we most certainly will drill wells this year. Five high potential wells have been sanctioned and we are now virtually on the doorstep to a quite unique exploration campaign. Hence, 2011 will most definitely mark a step change in the history of Rocksource. We will move from acreage capturing to actual drilling – with the goal of transforming resources into reserves. Our upcoming wells are all characterized by a high chance of success and significant volume potential. The current 2011 program will expose Rocksource to net risked resources of approximately 32 M Sm*^{3} *o.e. Our goal is to firm up similar high potential drilling campaigns in the years to come. With a portfolio of more than 160 M Sm*^{3} *o.e. net risked resources, Rocksource has an exploration portfolio with exciting potential which means we are confident in our ability to follow-up this year's drilling program.* Rocksource described the future as bright, based on robust long term outlook for hydrocarbons, and a strong demand for effective oil and gas exploration. *Rocksource has created a potential game changing exploration strategy, based on the application of new technologies in combination with conventional exploration tools.* The future look so bright that the annual report had to explain why prospect size only was based on only 8 M Sm^3 o.e. in the calculations: *The Groups exploration strategy targeting high impact prospects means that this reflects a very conservative approach, where the average prospect size tested in the 2011 campaign is 38 M Sm^3 o.e. This means that the average prospect size used in calculations might be higher than industry average in the core areas where the Group operates, but reflects considerable reduction compared to the Group's prospect inventory and focus on relinquishing non-commercial prospects. The value of a discovery is closely linked to the assumed prospect size.* The technology driven exploration can in short be summarized by a statement in the annual report: *Rocksource focused on prospect quality rather than being geographically restricted. Our vision is to deliver among the highest exploration success rates in the industry. We have built a portfolio of high quality prospects, i.e. prospects with a high chance of discovery and high chance of commercial volumes. 2011 marks the start of our drilling campaign and our goal is clear; transforming as many prospective resources as possible into reserves.* In India ONGC drilled the third commitment well on the block which was subsequently found to be dry.

By year end 2011 Rocksource had drilled 5 high exploration wells and the CEO comment: *2011 marked a step change in the development of Rocksource with our long awaited exploration drilling campaign. We participated in five wells during the year, one of which we operated. Overall, the results for 2011 did not meet our expectations. Three out of the four NCS wells were dry, as was the frontier well in the AGC Profond PSC off the coast of Senegal and Guinea Bissau. The disappointing outcome of the drilling campaign left Rocksource in a financially challenging situation. Therefore, the short term focus during the autumn of 2011 and winter of 2012 was to reduce cost and strengthen the Company's balance sheet. However, looking ahead, we expect to re-commence drilling in 2013 and our aim is to participate in at least 3 to 4 wells each year from then onwards.* By the year end Rocksource manage to formally close a farm-down deal for the planned AGC well in Africa and to sell the onshore production in the US (Annual report 2011).

In 2012 the focus for Rocksource was the financial challengers and to create a future with no firm wells, 130 million Norwegian krone (NOK) in outstanding bond debt and high G&A costs. Key to the financial achievements in 2012 was an asset transaction with Valiant Petroleum. Through the transaction Rocksource enabled to repay the remaining bond debt, and a "carry fund" cover the cost of the planned wells and the CEO comment on the future: *Now, some 15 months later, Rocksource has built a drilling programme with five wells approved over the next two years, the bond has been repaid, G&A markedly reduced, and the Company is funded into 2014.* Also the exploration model have changed - *Rocksource's exploration model is to apply in depth geological knowledge, complemented by advanced seismic and CSEM analysis* (Annual report 2012).

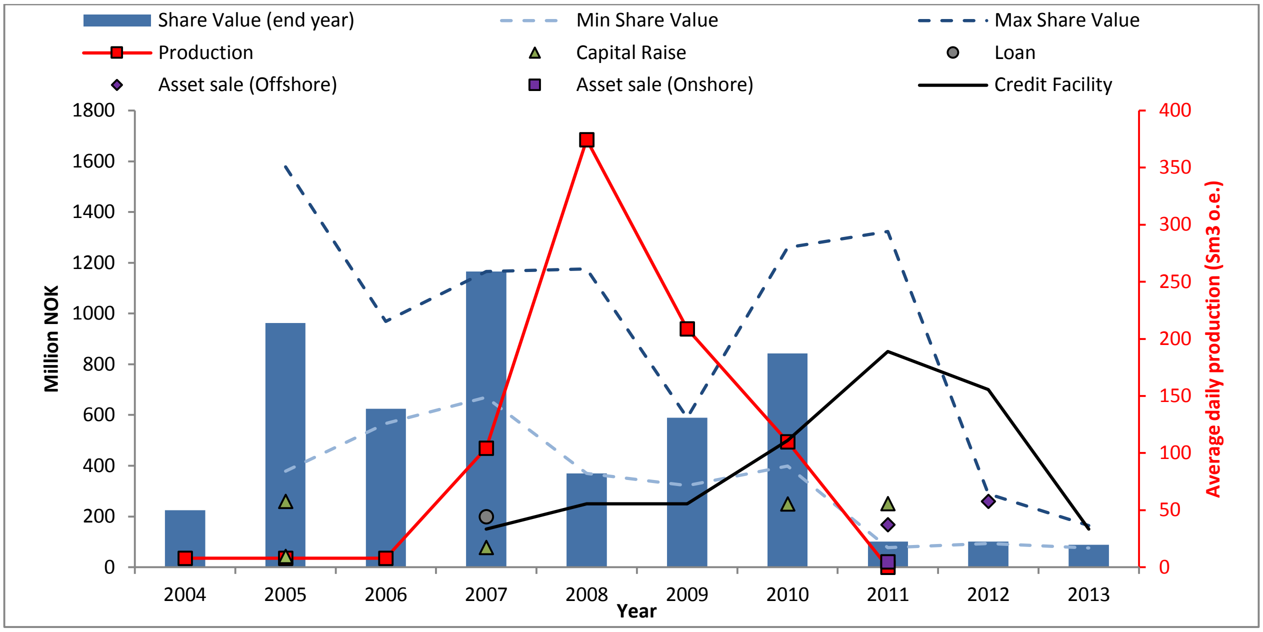


Figure 2 Overview of Rocksource history. Market value at Oslo Børs (blue column – year end share value (blue dashed lines indicate yearly maximum and minimum company value), credit facility (black line) daily production in US (red line – secondary axis), capital raise (green triangles), asset sale post tax (purple) and loan (grey). Source: Rocksource annual reports 2004-2013.

From 2005 Rocksource raised capital and sold asset for approximately 1.4 billion NOK, invested in new technology to de-risk prospects, and drilled wells to test a 38 M Sm^3 o.e. net Rocksource portfolio. Only the Norvarg well in the Barents Sea encountered hydrocarbons (41.58 B Sm^3 gas). Seven years of promoting a portfolio, internally evaluated large prospect with a high Chance Of Success (COS), and a new technology ended with disappointing drilling results (8.32 M Sm^3 o.e. net Rocksource – only 21 % of the expected) and falling share prices (Figure 2).

Oil companies operating on the NCS are subject to the Norwegian oil taxation regime. Under this regime, oil companies who are not in a taxable position can claim a 78 % refund of exploration costs, limited to the taxable loss for the current year. The deferred tax can only be netted off within each tax regime. Since 2005 Rocksource have almost used two billion NOK on the NCS, and received almost 1.7 billion NOK in tax refund from the Oil Taxation Office ("OTO") (Figure 3). Only direct exploration costs on the NCS will be refunded, not indirect cost as financial cost (credit and interest rents) and expenditures used outside Norway. The system implies a net Rocksource investment of around 450 million on the NCS, in addition to non-refundable investments on NCS.

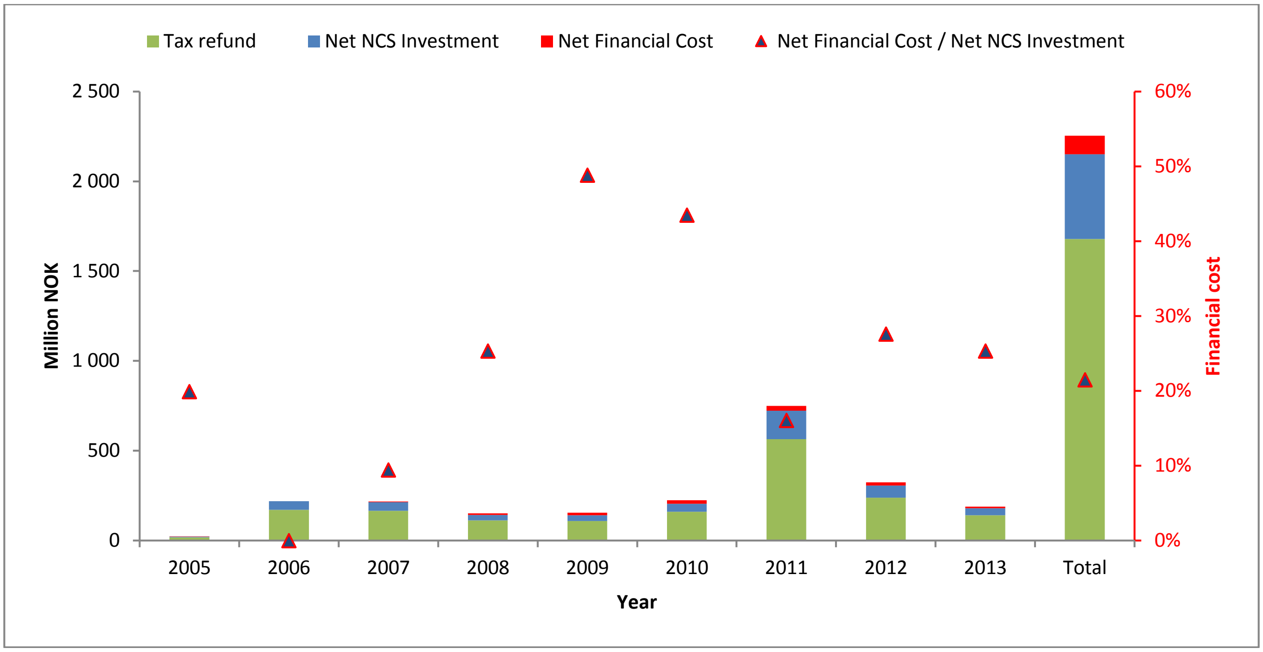


Figure 3 Rocksource annual expenditure on the NCS with associated tax refund (2013 numbers is based on approximation). The OTO change of Rocksource tax assessments for 2007, 2008 and 2009 is not included in the graph. The OTO questioned the pricing of CSEM interpretation services provided from Rocksource's wholly owned subsidiary, Rocksource Geotech AS, and decided that tax refunds of NOK 48.3 million would have to be repaid. For 2012 the refund consist of two parts, the ordinary exploration tax refund of NOK 139.5 million, as well as the pay-out of the tax value of uncovered losses related to its restructuring of NCS activities in 2012 (NOK 98.8 million). Annual financial costs for the Rocksource Group, not deductible for tax refund is shown in red. Red triangles represent Rocksource financial cost as per cent of net Rocksource investments in the NCS. Source: Rocksource annual reports 2005-2013.

The Rocksource business model is to apply appropriate technology to reduce risk and enhance success. The exploration model is based heavily on the application of the company's expertise in the use of Electromagnetic (CSEM or CSEM) surveying techniques, tied closely with excellence in other geology, geophysics and business areas. A fully integrated exploration workflow based on the pre-drill analysis and subsequent ranking of prospects with CSEM has been developed. Two, broadly parallel paths for Farm-ins and Concession Rounds have been developed within this workflow. The Concession Rounds model is most relevant to the current study, hence the farm-in model was illustrated when Rocksource in early 2008 established a technology agreement with the Indian state company, ONGC, to apply CSEM in India and internationally. As a result of this co-operation in July 2008 the company was able to farm-in to a large exploration block in India, in partnership with ONGC, Oil India and Petrobras.

2.1 Summary

Rocksource is a relatively new oil company on the NCS. Access to the new CSEM technology the business model was based on the better ability to de-risk hydrocarbon prospects compared to the rest of the industry. Based on regional mapping Rocksource launched large CSEM campaigns to find resistive hydrocarbon accumulations on the NCS. To develop proprietary technology enabling to handle electromagnetic data for exploration purposes Rocksource established an internal subsidiary, Rocksource Geotech. The new technology was tool for Rocksource to develop a game changing exploration strategy, based on the application of new technologies in combination with conventional exploration tools to develop en successful and effective oil and gas exploration. Based on the business model, Rocksource raised large amounts of money to continue the prospect evaluation. After years of evaluation, CSEM campaigns, development of possessing tools. Five high potential wells was sanctioned believed to be a unique exploration campaign, with a high chance of success and significant volume potential. The drilling campaign proved disappointing hydrocarbon volumes, and the value of the company fall dramatically, and many questions was raised. This thesis focus on how Rocksource evaluated uncertainty and risk related to hydrocarbon prospects and the new CSEM technology.

3 Rocksource on the Norwegian Continental Shelf

Section 3 give a short overview of the challenges and opportunities for oil companies on the NCS, and how this have changed over time. A deeper understanding is important to understand the uncertainty and risk associated to hydrocarbon exploration. At the same time the chapter describes the evolution of Rocksource and give perspectives to how uncertainty and risk was evaluated in context to the industry.

According to resources estimations made by Norwegian Petroleum Directorate (NPD) (Appendix 1: NPD classification of resources and Appendix 2: NPD's method for evaluation of petroleum resources), substantial resources remain to be found on the Norwegian Continental Shelf (NCS). Combination of resources from discoveries and improved recovery from producing fields, forms the basis for the oil industry in the next decades (Figure 4). How long exploration and production can be maintained depends on several factors, including resources, technological advances, cost developments, the player picture, political operating parameters and the price of oil and gas in relation to other energy carriers.

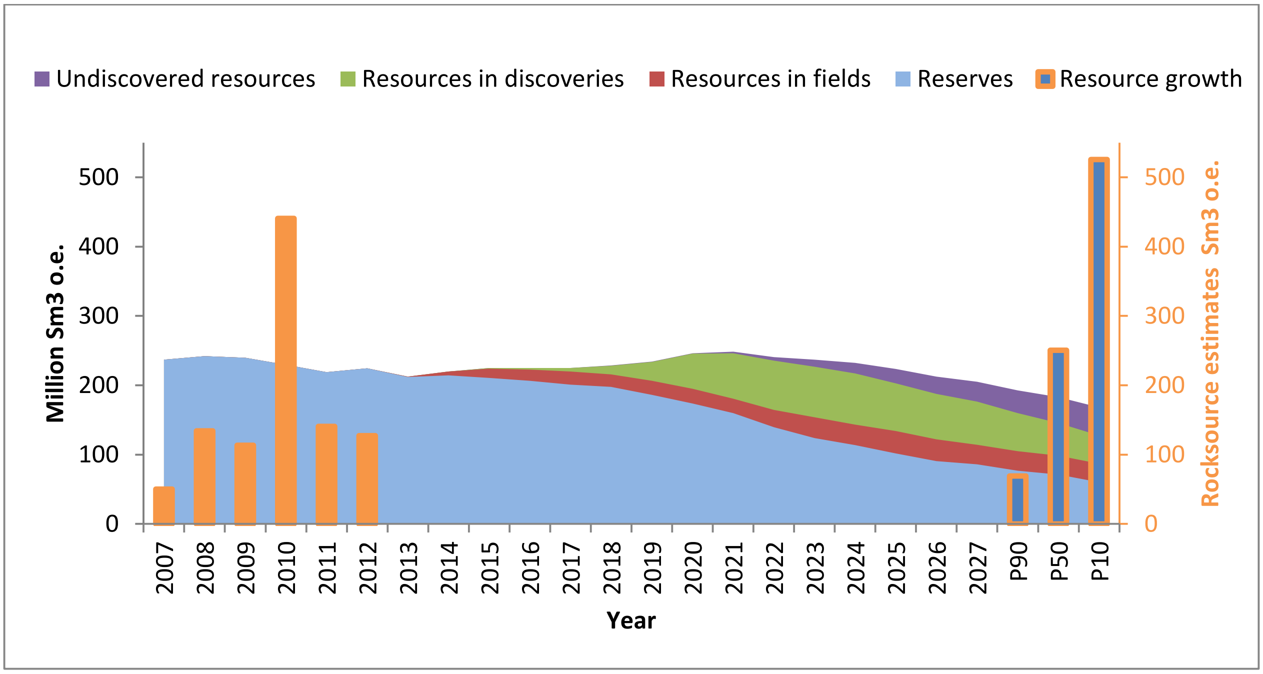


Figure 4 NCS resource growth, historical and expected, 2007-27. Orange columns: annual growth from 2007-12. Secondary axis: Rocksource estimated P_{90}, P_{50} and P_{10} volumes of the portfolio. Source: NPD and Rocksource data.

Active exploration is essential if undiscovered resources are to contribute to production and create value both for the industry and for society. Through the exploration policy, the government has provided the companies with a great deal of exploration acreage in both mature and frontier areas, given good results so far. The exploration activity on the NCS has been high, particularly over the past five years, and several major discoveries have been made.

The last decades increased activity on the NCS has given an extensive acquisition of seismic data and during the past five years more than 40 exploration wells is spudded per annum. The increased exploration activity primarily reflects high oil prices, optimism generated by new discoveries and changes in the

Norwegian exploration policy at the start of the year 2000. Considerable knowledge of mature areas, technology, combined with diversity and new solutions plus a willingness to accept risk, have yielded to a large number of wildcats with good results, especially in the North Sea and the Barents Sea. The increased exploration activity is not only related to Norway, but a trend also observed internationally as the oil price raised.

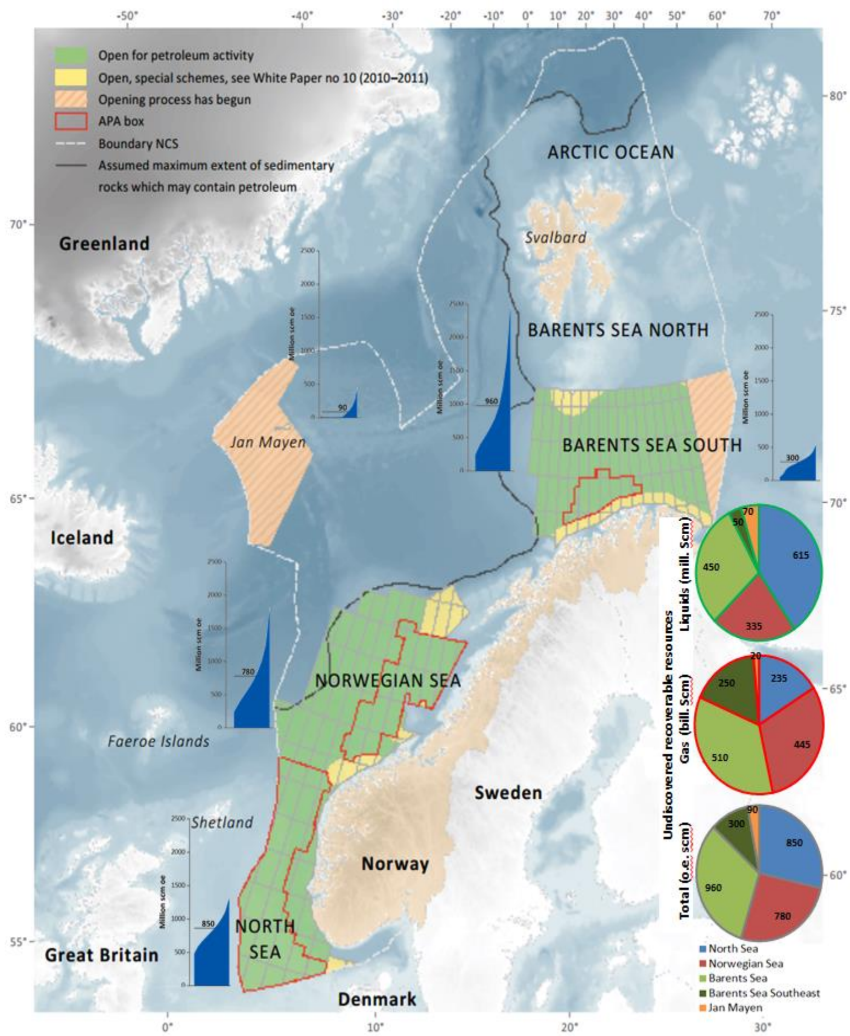


Figure 5 Area status for the NCS and estimate for undiscovered recoverable resources with uncertainty range, broken down by the various parts of the NCS. Source: NPD and Rocksource data.

3.1 Acreage

Norway's overall offshore area covers 2 million km^2, approximately 6.5 times greater than the mainland size. About half the area comprises sedimentary rocks with petroleum potential (Figure 5). On the NCS companies primarily gain access to acreage by applying for production licenses in the awards in predefined areas (APA) scheme and numbered licensing rounds, in addition to buy and swap interests in production licenses.

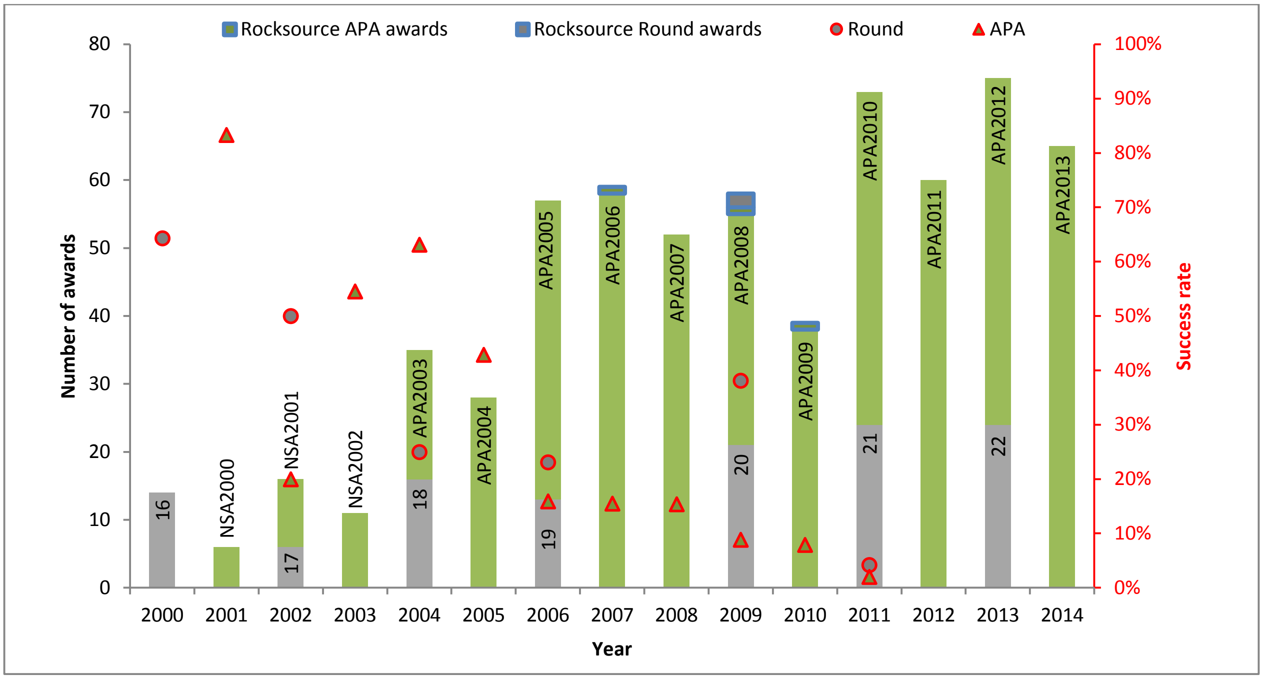


Figure 6 Number of license awards over the past years by licensing round (Green: APA awards & Grey: Numbered round awards) and average success rate (secondary axis) in actual round (low number from 2011 is a consequence few wells). Only Rocksource awards tested by exploration wells are relevant for this study and marked in the figure. The PL 416 was awarded in the APA 2006, while PL 506 and PL 559 were awarded in APA 2008 and APA 2009 respectively. The PL 530 and PL 535 were awarded in the 20th concession round. Source: NPD and Rocksource data.

The whole North Sea was put on offer in the very first licensing round on the NCS, in 1965. The second largest numbered round was the 13th in 1991. The past 15 years, the amount of acreage put on offer has steadily increased. In the period 2004-12 the number of product license (PL) awards and acreage awarded were at record levels, with an annual average of some 50 new license awards (Figure 6). To create a sustainable model the government applied changes to the area fee and introduced work programs which put the oil companies under greater pressure than before to work actively with awarded acreage. As a consequence the relinquished acreage increases and more area becomes available for evaluation and application. Most of the acreage licensed under the APA scheme has been awarded and relinquished earlier. When new companies get the chance to explore relinquished acreage, new technology and exploration models can be used to mature substantial petroleum resources (e.g. Utsira High where the recent Johan Sverdrup discovery is located). The Norwegian exploration model and high success rate have generated a great interest for new and international companies to apply for pre-qualification on the NCS (Figure 7).

3.2 Players on the Norwegian Continental Shelf

Diversity of participants is important to achieve the highest possible value creation from petroleum operations on the NCS. Ideally the player picture reflects challenges the industry are facing both mature and frontier areas and the companies must play an active role to find new solutions to the challenges. When the oil prices were around United States dollar ($) 10 per barrel in the late 1990's the industry faced a substantial consolidation, which directly influenced the player picture, where the international companies become fewer and larger. At the same time the NCS moved into a more mature petroleum province (declining size of discoveries). Therefore existing and potentially new players evaluated the opportunities on the NCS to be of limited interest (Figure 9, Figure 13 and Figure 14). To make the NCS more attractive the Norwegian government implemented several measures to boost the value creation from both mature and new areas. A key change was to permit more companies to become licensees and to introduce a new prequalification scheme. As a result small and medium-sized oil and gas companies and foreign energy and downstream enterprises became established on the NCS in addition to a number of new independent Norwegian companies (Figure 7). The policy was changed at a time of low exploration activity at the NCS (Figure 13), resulting in almost doubled the number of participants from 2002-07 (Figure 8). A more diversified player picture was established and yielded good results, with greater exploration activity and more discoveries, where medium-sized companies appear to take over the position held by the major oil companies on the NCS since activities began almost 50 years ago (Figure 9).

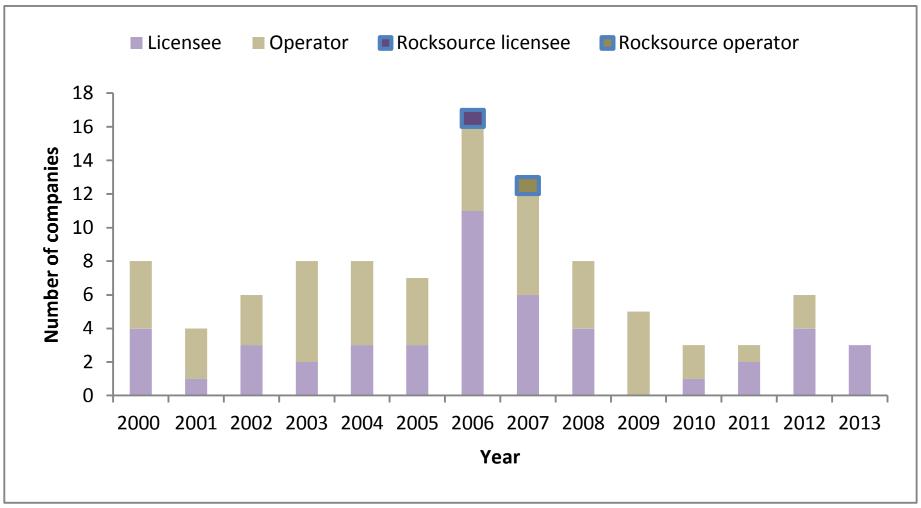


Figure 7 Number of pre- and requalification's at the NCS. Rocksource was qualified as licensee holder in 2006 and license operator in 2007. Source: NPD and Rocksource data.

In 2006 Rocksource become qualified as license holder at NCS started to apply for licenses (Figure 6), and have in total been part of 20 licenses on the NCS (not counting overlaying stratigraphic licenses and license extensions). A year later (2007) Rocksource's experience and expertise convinced the Norwegian authorities to qualify the Company as an operator on the NCS. As operator Rocksource have been awarded five licenses and drilled two wells on the NCS.

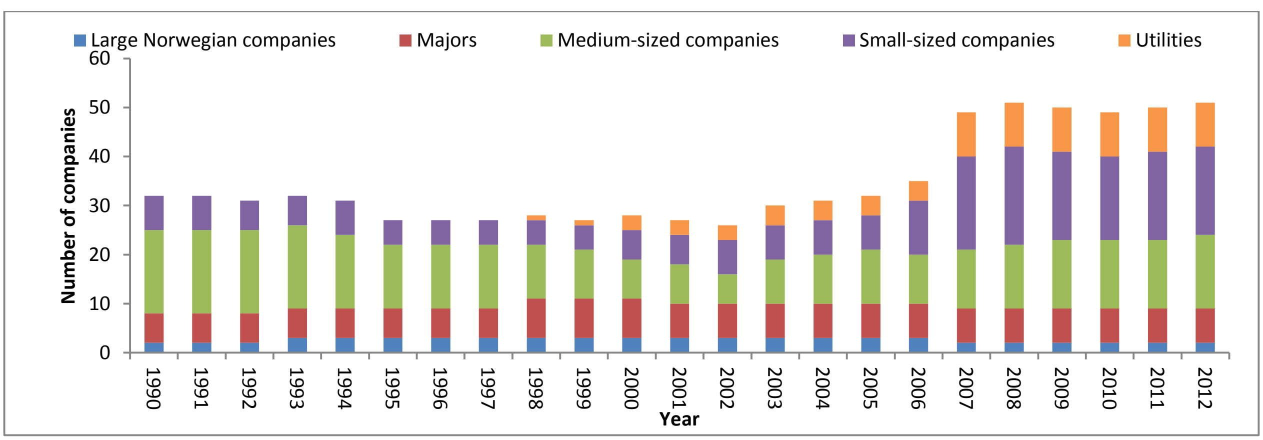


Figure 8 Change in number of players on the Norwegian Continental Shelf from 1990 to 2012. Rocksource is defined as a Small-sized company, and have been present on the NCS from 2006. Source: NPD and Rocksource data.

3.3 Awards on the Norwegian Continental Shelf

Number of awarded production licenses in licensing rounds depend both on numbers of applications submitted and the extent to meet government criteria. Number of licensing rounds and awards per round has increased over the past 15 years (Figure 9). In the early days (1965-97) larger Norwegian companies secured the biggest share of the license awards, while the last 15 years medium-sized companies have secured the largest proportion of awards, both in APA and numbered rounds (Figure 9, Figure 10 and Figure 11)

As total numbers of licenses have increased, small companies have got many awards, almost same amount as large Norwegian companies, to further develop the business on the NCS. Numbers of awards to large Norwegian and majors have been fairly stable, although their relative share of awards has declined (Figure 10 and Figure 11). On the other hand medium-sized and small companies have secured almost half the licenses awarded in the APA and North Sea Awards (NSA) in mature areas in the period from 1999 to 2013, while large Norwegian and majors oil companies obtained the largest proportion of awards in frontier areas from the numbered rounds in the same period.

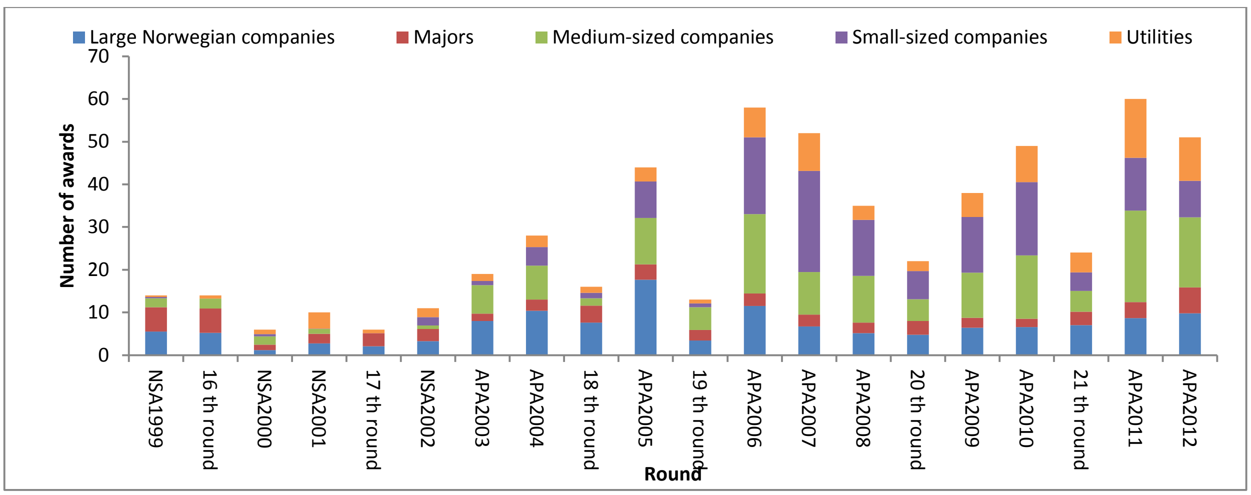


Figure 9 Number of awarded licenses since NSA 1999 until the 22[nd] Round in 2012. Rocksource have got awarded licenses in all APA and numbered rounds since 2006. Source: NPD and Rocksource data.

Rocksource have participated in all rounds, both APA and numbered rounds, from the company was qualified as license holder in 2006. Rocksource licenses tested by exploration wells are awarded through the APA (3 licenses) and numbered rounds (2 licenses) (Figure 6). Traditionally awards within the APA represent more mature areas, while frontier areas are awarded in the numbered rounds. For the Rocksource portfolio license awards in APA and numbered rounds was frontier areas, as access to the new CSEM technology gave a possibility to de-risk the large hydrocarbon prospects, independent of geological maturity.

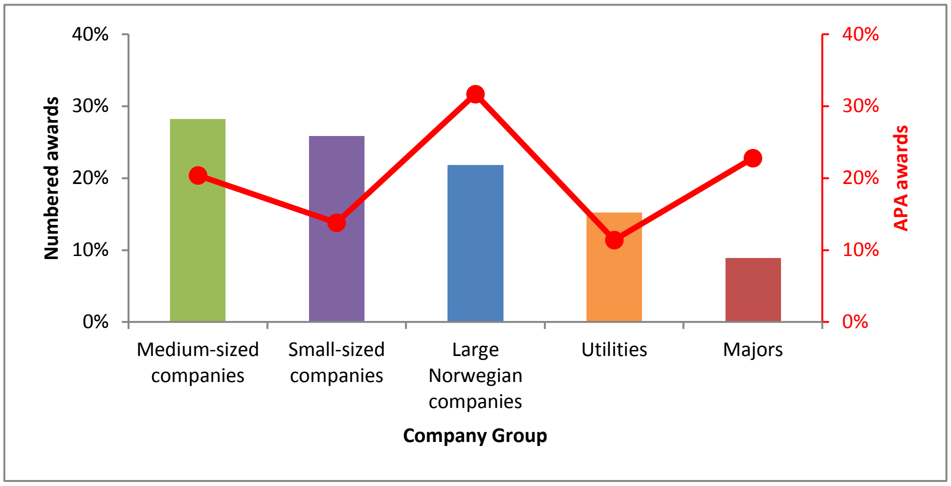


Figure 10 Group of companies' share of awarded licenses in ordinary numbered rounds (red line) and NSA/APA from 1999-2012.
Source: NPD and Rocksource data.

3.4 Production licenses

Holdings of production licenses by companies are the result of applications in licensing rounds, farm-ins/outs and swap of interests or company acquisitions. The production license governs the oil company's rights and obligations vis-à-vis the Norwegian State, regulated through The Petroleum Act and a set of detailed terms and conditions for each individual license. The production license give companies within the licenses exclusive rights to carry out surveys, exploration drilling and production of oil and gas within the defined geographical area. As a general rule, the production license is valid for an initial period (exploration period) of one to six years. The licensees can apply to extend this period to up to ten years. During this time, a specific work commitment must be completed e.g. seismic data acquisition and/or exploration drilling. When the initial period is over and the work commitment is completed, the licensees can apply for license extension (generally 30 years). If exploration drilling does not prove hydrocarbons, the main rule is relinquishment of the area at the end of the initial period. The timeframe and work commitment secure an active exploration and recycling of awarded acreage. As a result the proportion of licenses possessed by large Norwegian companies and international oil companies has declined from around 70 % in 1998 to less than 45 % in 2013. In contrast European gas/power companies, small and medium-sized companies have increased their share of production licenses on the NCS (Figure 11).

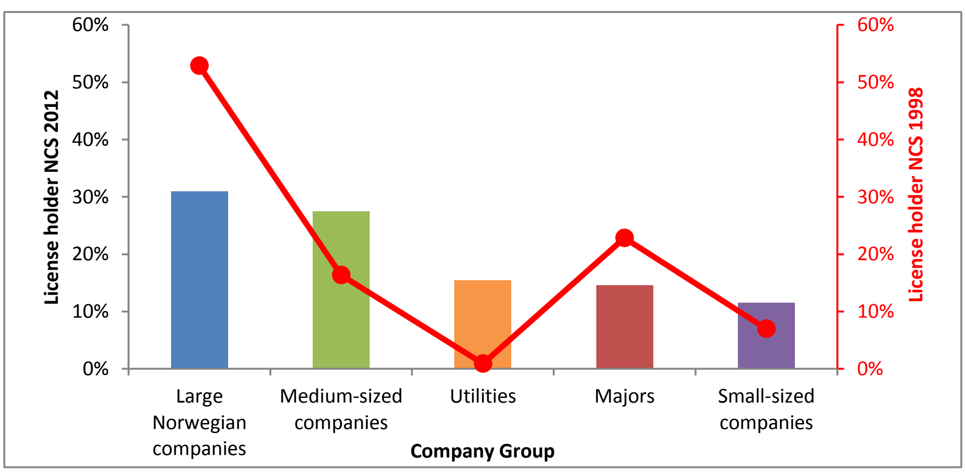


Figure 11 Share of production licenses by company type on the NCS in 1998 (red line) and 2012. Source: NPD and Rocksource data.

As active small-sized player on the NCS from 2006, Rocksource have only taken part in the initial period, exploration part, of the license stages. If a discovery is made, the strategy is to capitalize and sell the discovery before development.

3.5 Secondary market

The secondary license market has expanded substantially over the past 15 years on the NCS, in line with an increasing number of companies, number of awarded production licenses and changes in the oil prices. Large Norwegian and major oil companies were active in the farm out market up to 2007, the buyers where mainly small oil and medium sized companies. In addition European gas/power companies, increased their license portfolio actively through the secondary marked from 2000 to 2012 (Figure 12). Small companies often use the secondary market farm in/out, to optimize the portfolio align with the overall strategy and to reduce the economical exposure before drilling.

Before the drilling campaign Rocksource had not used the NCS secondary license market. The internal evaluation indicated a portfolio consisting of large volume prospect with high chance of success (COS) for finding hydrocarbons. The high COS estimations was a consequence of access to the new and unique CSEM technology used to de-risk the prospects. Evaluation of other license and prospect on the NCS came all out with lower volumes and lower COS, therefor the options was not explored further. After Rocksource sold half the NCS portfolio to Valiant Petroleum in 2012 (Section 7).

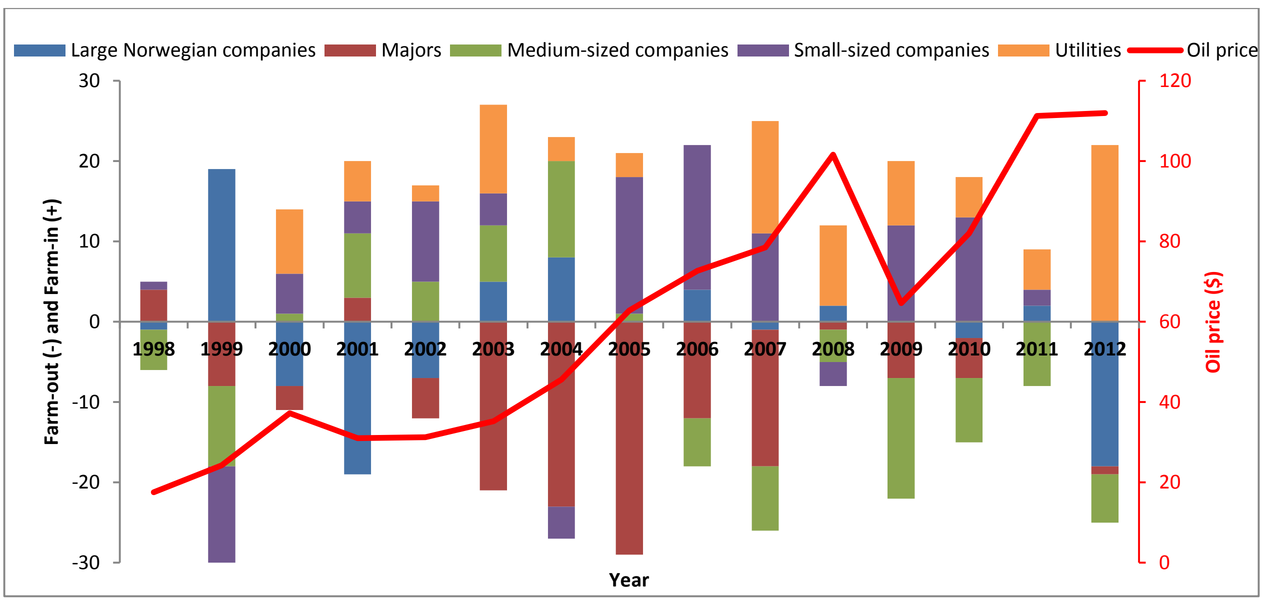


Figure 12 Net (in – out) farm-ins (positive number)/outs (negative number) and swops to interests in production licenses over the past 15 years by company type and oil price (red line, secondary axis). Before selling licenses to Valiant (2012), Rocksource had not taken part of the secondary NCS marked. Source: NPD and Rocksource data.

3.6 Exploration wells on the Norwegian Continental Shelf

From the first well in 1966 until August 2013, almost 1 430 exploration wells have been drilled on the NCS ("Exploration well" is a collective term for wildcats and appraisal wells. "Wildcat" is the first well drilled in a geological structure (prospect) and “appraisal well” is drilled to determine the extent and size of a discovery (NPD definitions)). Number of exploration wells increased until the 1980’s, when almost 50 exploration wells were drilled per annum. During the 1990s, the annual count varied from 20 to nearly 50 before the numbers of exploration well started to decline from the late 1990s, until 2005 where only 12 exploration wells was drilled (Figure 13).

Since 2005 the number of exploration wells has risen sharply. Although the North Sea is regarded as a mature area, it remains the part of the NCS where most wells are drilled. From 1982 numbers of wells drilled in the Norwegian Sea have been relatively constant, while the exploration activity in the more frontier Barents Sea have varied, hence the success rate in the Barents Sea have been among the highest recent years (Figure 14).

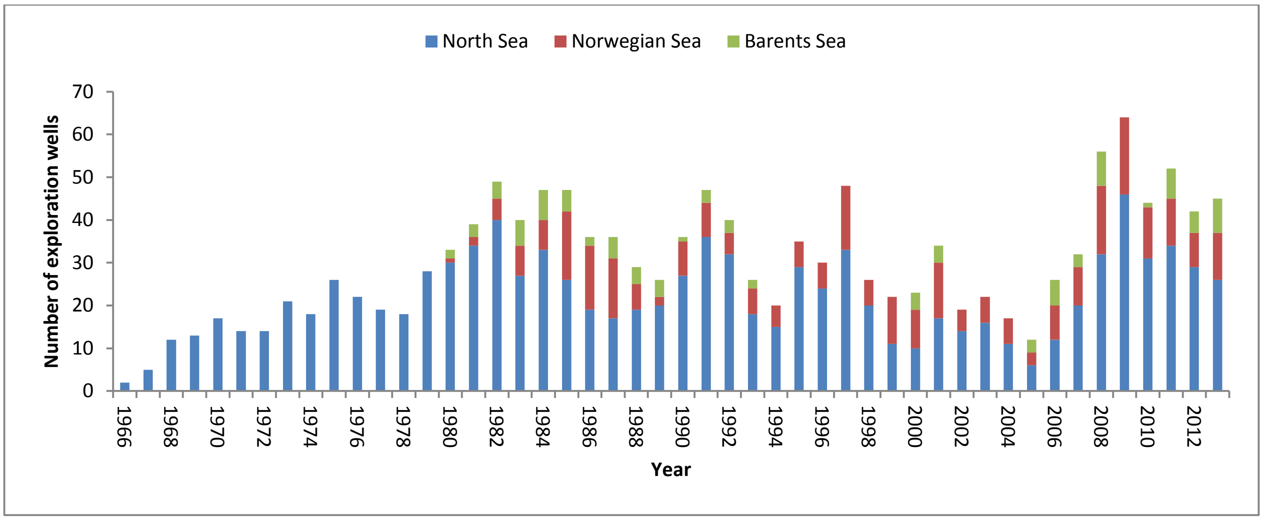


Figure 13 Number of exploration wells spudded on NCS. Source: NPD and Rocksource data.

Rocksource have totally drilled five wells on the NCS, two in the North Sea, one in the Norwegian Sea and two in the Barents Sea. All the wells have to be defined as “explorations wells.” New technology and lack of historical presence in the North Sea gave Rocksource an opportunity to prioritize areas outside core areas to the industry. Rocksource plan was to hire competent people to reduce prospects uncertainty and risk for hydrocarbon prospects in combination with new the CSEM technology. Drilling results on the NCS have so far been disappointing, resulted in in one gas discovery in the Barents Sea (Norvarg) and four dry wells.

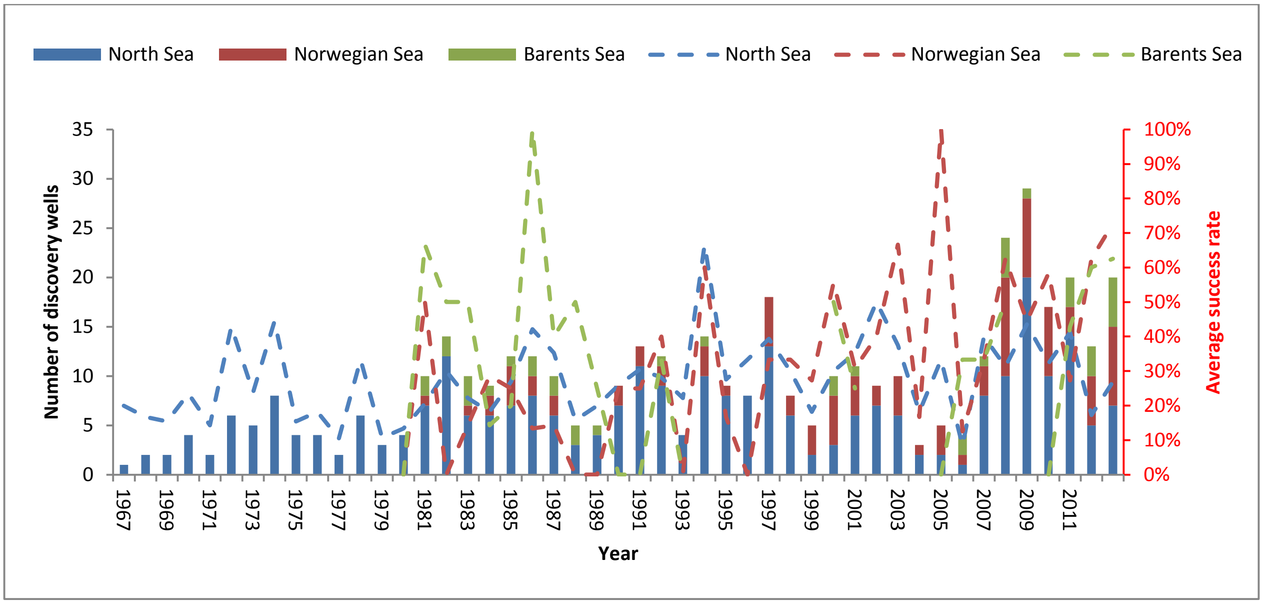


Figure 14 Discovery wells per offshore area per annum on NCS and relative yearly success rate per area (dotted lines on secondary axis). Rocksource is part of one discovery in the Barents Sea (Norvarg, 2011), in addition to four dry wells (two in the North Sea, one in the Norwegian Sea and one the Barents Sea). Source: NPD and Rocksource data.

3.7 Discoveries

The high level of exploration activity on the NCS in recent years has also resulted in a series of discoveries (Appendix 1: NPD classification of resources). Three of the past five years accounted for the largest ever number of finds on the NCS (Figure 18). A large proportion of these discoveries have been made in acreage awarded in the four first licensing rounds and recycled in the APA rounds (Figure 6). The average NCS finding rate has been rising in line with growing knowledge of geology and technological advances. Technical and commercial finding rates are on averaged about 55 % and 40 % respectively during the past 15 years (Figure 15). Even if the finding rate is high and many discoveries are made, the overall resource growth during last years is substantially smaller than before 2000, but the past five years have been positive with several large discoveries (Figure 18).

Rocksource has drilled five exploration wells on the NCS, in addition to one appraisal well on the Norvarg discovery in the Barents Sea. Only the Norvarg well is classified as a discovery. Outside Norway Rocksource participated in two dry exploration wells (India and Guinea Bissau). Rocksource NCS success rate is 20 %, reduced to 14 % if the two international exploration wells is included (Figure 15). Rocksource's game changing exploration strategy based on the application of new technologies in combination with conventional exploration tools resulted in a lower average finding rate compared to companies taking decisions on conventional exploration tools on the NCS.

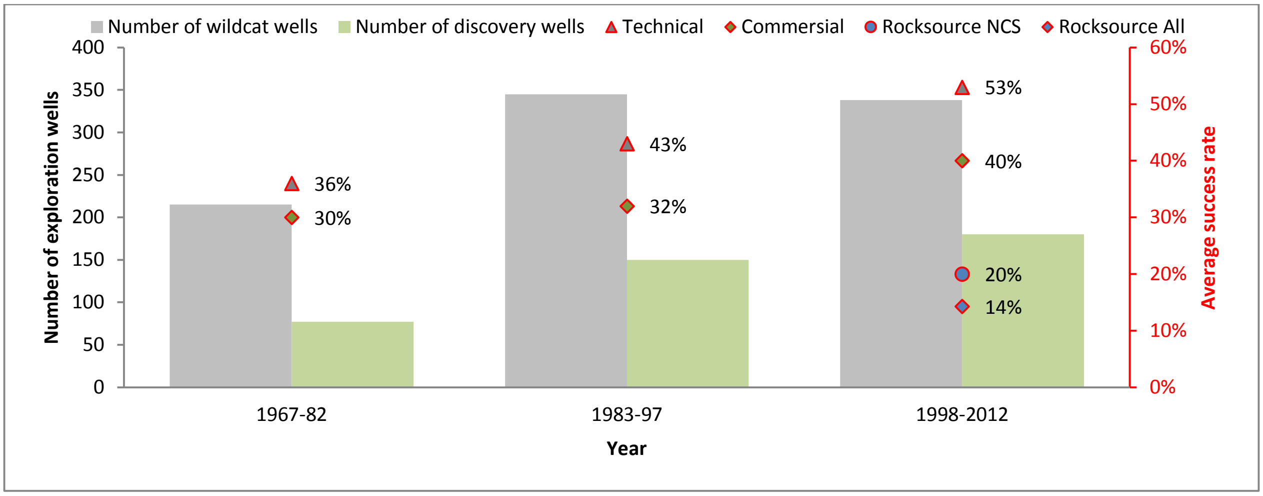


Figure 15 Completed wildcats, discovery wells and average finding rate, excluding and including resource category 6 (Appendix 1: NPD classification of resources) on the NCS, 1967-2012. Rocksource finding rate is 20 % on the NCS and 14.3 % totally. Calculation of technical finding success includes all discovery wells, while commercial finding success excludes discoveries in resource category 6. Source: NPD and Rocksource data.

3.8 Exploration costs

Total exploration costs comprise the cost of seismic data acquisition, exploration wells, field evaluation and administration. The total exploration costs generally develop in line number of wells drilled, indicating that drilling represents the biggest single factor in total exploration costs (Figure 16). A sharp increase in daily rig rates has occurred worldwide in recent years, helping to explain the increased drilling costs. However, rig rates remain higher in Norway than in other petroleum provinces such as the US and UK continental shelf. According to the Reiten commission, the most important reason for this is higher Norwegian operating costs. From 2010 the average total exploration cost per license have been around 650 million NOK (Figure 16). After fulfilling the work obligations, typically seismic data acquisition and/or other geological studies, most licenses decide not to proceed to drill an exploration well. The actual "average" cost per exploration well is therefore on the low side of the presented numbers in Figure 16.

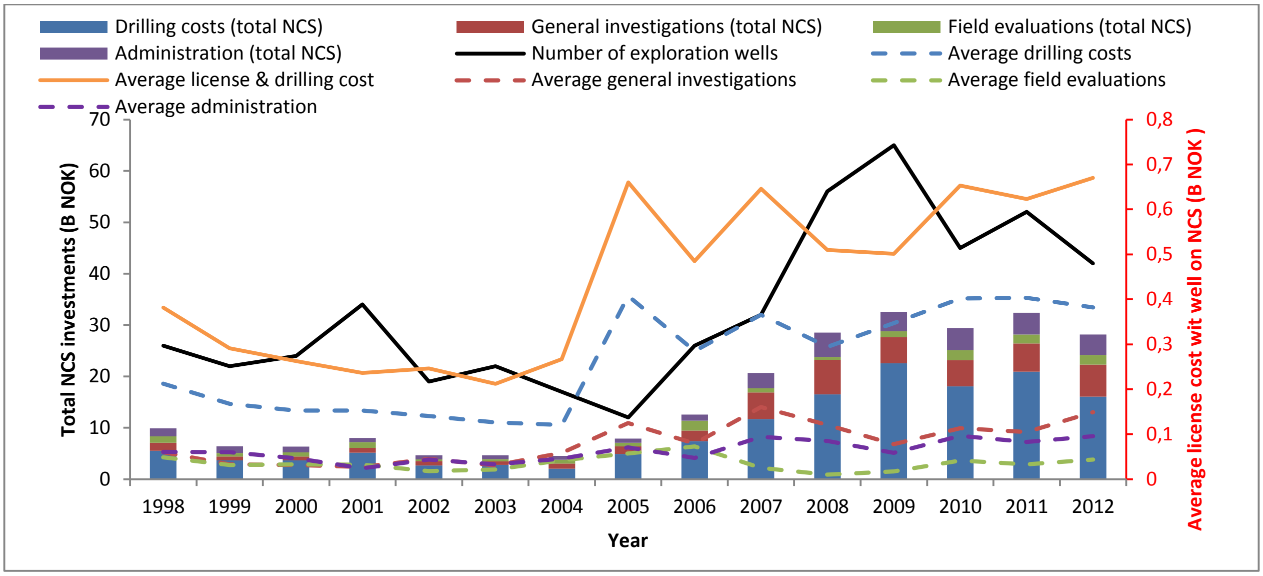
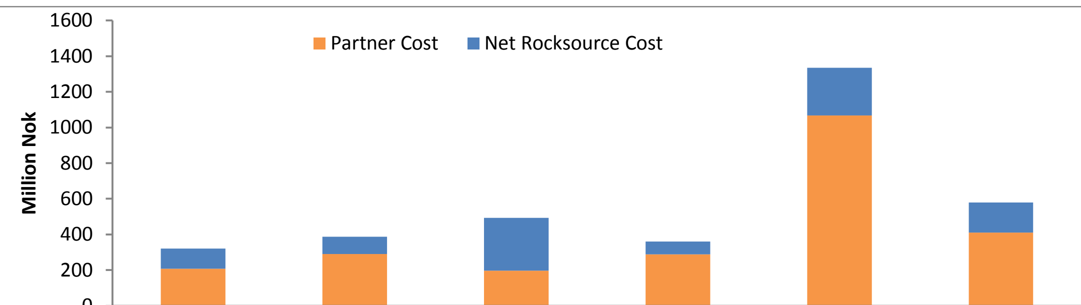


Figure 16 Developments in total exploration costs (billion NOK – primary axis) on the NCS and number of drilled exploration wells (black line). Average total exploration costs (billion NOK – secondary axis) per drilled is presented in orange line, while dotted lines represents the average costs break down. Source: NPD and Rocksource data.

The total license costs for the five drilled wells in the Rocksource portfolio on the NCS is on average 579 million NOK (Figure 17), approximately 70 million NOK below the average cost on the NCS (Figure 16). The cheapest license is the PL 416 in the North Sea (320 million NOK), while the PL535 in the Barents Sea is most expensive (a large portions of the cost is related to drilling operation problems). The highest net investment was in the PL559 in the Norwegian Sea, where the Rocksource was operator and drilled with 65 % equity interest. The data shows that the main contributor to the license cost is the rig cost, while the location is less important.



	PL416	PL506	PL559	PL530	PL535	Average
Net Rocksource Cost	112	97	296	72	267	169
Partner Cost	208	291	197	288	1068	410

Licences

Figure 17 Total license cost for Rocksource five drilled licenses. Source: Rocksource data.

3.9 Investment for resource growth

Traditionally large Norwegian and majors companies invested the highest sums in exploration, and was responsible for finding the most resources (Figure 18). After the new tax regime, where exploration companies can claim a 78 % refund of exploration costs, small and medium-sized companies have been more interesting to take on-board more uncertainty and risk in the portfolio, hence proved more hydrocarbons on the NCS.

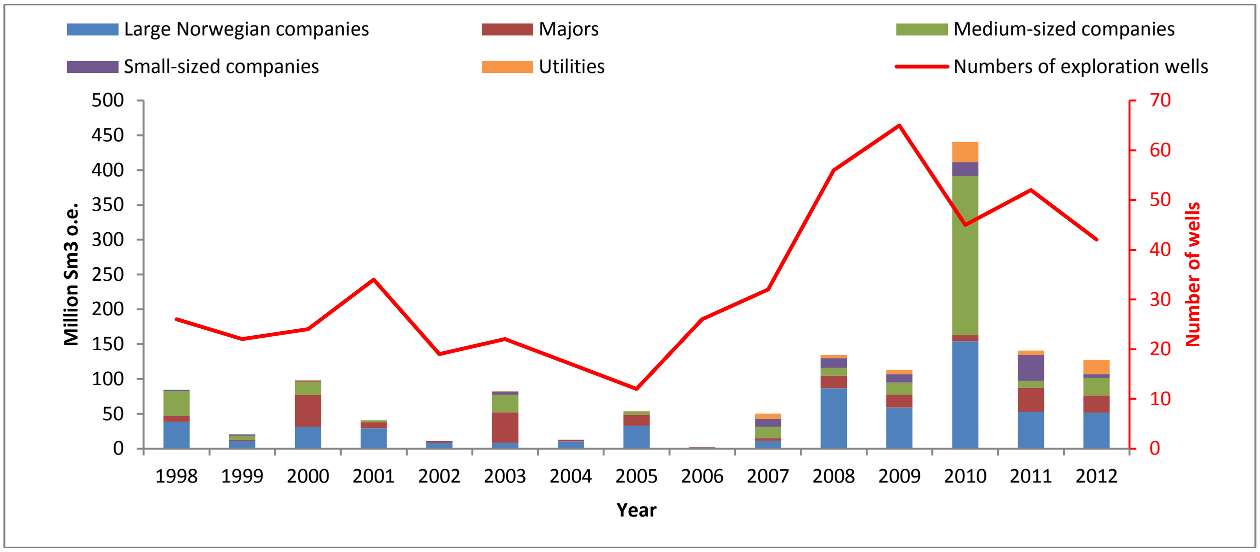


Figure 18 Resources in discoveries by company type over the past 15 years, by equity interests. Black line represents number of drilled exploration wells/year (secondary axis). Source: NPD and Rocksource data.

The discoveries are a direct consequence of investments, no discoveries without wells. On the other hand no drilling decision is taken before all the data is technical evaluated, and the uncertainty and risk for each prospect is presented. Estimates of the resource growth per NOK 1000 spent on exploration during the past five years shows that large Norwegian and medium- sized companies achieved the best return on their spending. Resource growth per exploration krone for European gas/power and small companies was also positive, but lower than medium and large-sized companies (Figure 19).

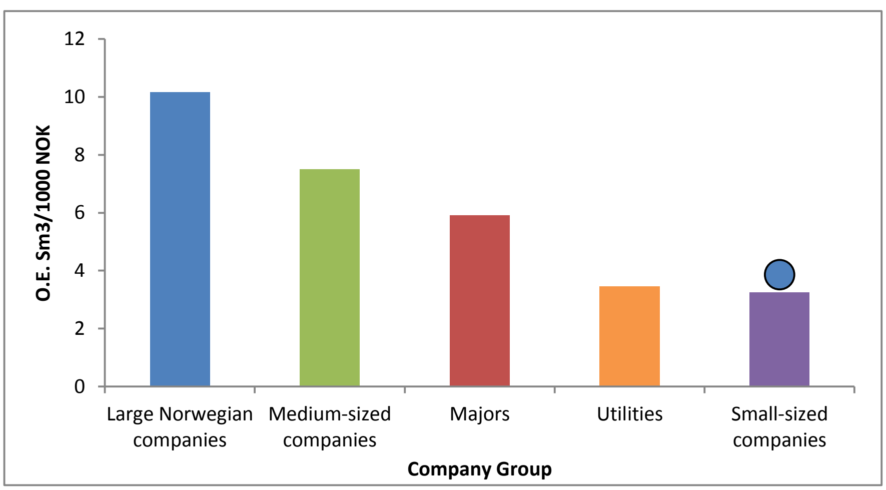


Figure 19
Resource growth (Sm^3) per NOK 1 000 spent on exploration by equity interest 2008-12, by company type.
Rocksource proved 4.26 Sm^3 o.e. per 1000 NOK spent on NCS, above the average for small-sized companies. Source: NPD and Rocksource data.

The conclusions drawn from such an analysis must not be exaggerated, since the analysis may undervalue the benefits which a diversified player picture can confer, e.g. underestimate the value of the contribution made by small companies because these are often taken over, with resource growth being attributed to the new owner. It is also important to understand the enormous yearly variations; a large discovery in a year with low drilling activity will have high impact, while a small discovery in a year with many wells will most likely have a limited implications on the data, but can have enormous effect for a company (Figure 20).

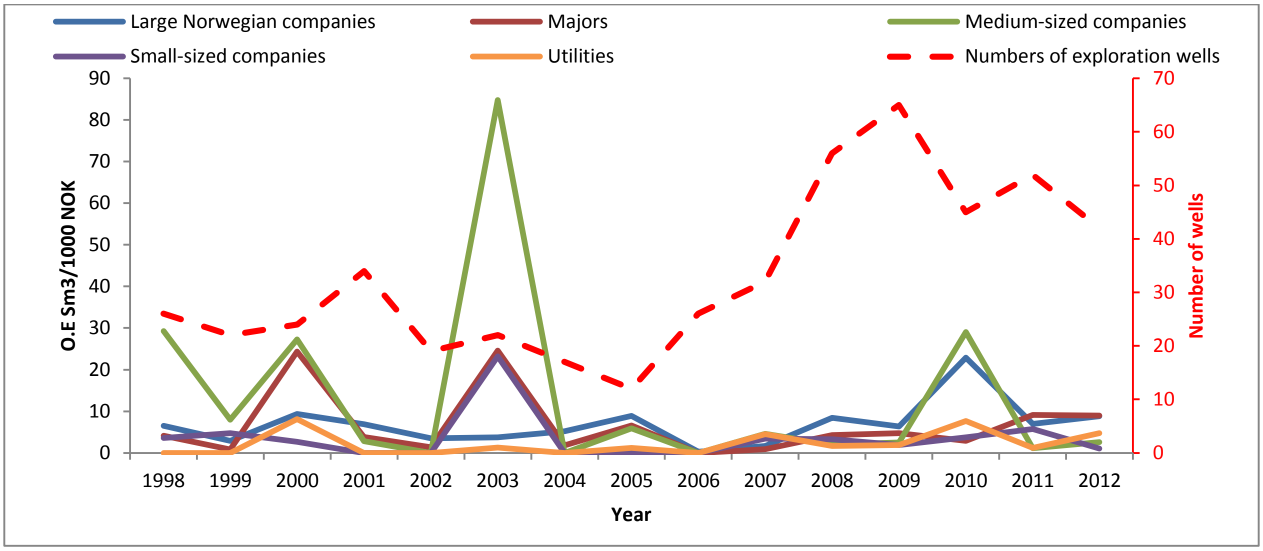


Figure 20 Yearly resource growth (Sm^3) per NOK 1 000 spent on exploration by equity interest 1998-12, by company type. Source: NPD and Rocksource data.

In 2011 Rocksource was part of the Norvarg discovery in PL535 in the Barents Sea. The discovery is estimated to contain 41.58 billion Sm^3 gas, with a Rocksource interest of 20 %. Numbers form the Norwegian Oil Taxation Office shows that Rocksource has used approximately 2 billion on the NCS qualifying for tax refund (Figure 3) (Annual reports 2005-2012). Rocksource has proved net 8.3 billion Sm^3, which give 4.26 Sm^3 o.e. per used 1000 NOK on the NCS, above the average for small companies and European gas/power companies on the NCS (Figure 19). On the other hand Rocksource faces commerciality problems with the Norvarg discovery, as the discovery is located remote in the Barents Sea and consists of gas.

3.10 The future exploration on the Norwegian Continental Shelf

Future exploration activity on the NCS depends on available acreage, increased geological understanding and new technology. To become a successful oil company on the NCS it will be essential to adapt and develop new technology and at the same time improve the understanding of the overall uncertainties and risk associated with hydrocarbon exploration.

3.10.1 NPD estimates of undiscovered petroleum resources

Over the last 60 years, many estimates have been made of the total petroleum reserves potential of the Earth ranging between 1 and 4 trillion barrels of conventional oil (most of the estimates is centered around 2 trillion barrels). Estimates of supply security ranges from imminent shortage to several decades of supply at present consumption levels (Maugeri, 2012).

Producing estimates of undiscovered resources on the NCS is a key part of the NPD's work. These calculations are important for the choices made by government with regard to offshore exploration and are used by exploration companies to evaluate new acreages. NPD's estimates of undiscovered resources are based on knowledge and information from all of the industry's exploration of the NCS (wells, discoveries, fields, prospects and plays). Still large areas exist with limited geological data and the exploration history shows that areas regarded as mature can surprise with large discoveries. Therefore the uncertainty about the size of undiscovered petroleum resources on the NCS accordingly remains high (Figure 5).

3.10.2 Estimated undiscovered recoverable resources

NPD's preliminary aggregation and uncertainty calculation for the undiscovered resources, including Jan Mayen and Barents Sea South-East, provides an uncertainty range of 935 to 5 420 M Sm^3 o.e. with an expected value of 2980 M Sm^3 o.e. on the whole NCS (except Barents Sea North-East) (Figure 5). The liquid potential is expected to be greatest in the North Sea, while the gas potential is highest in the Barents Sea. In new areas gas is most likely to be found in Barents Sea South-East and oil around Jan Mayen.

Companies on the NCS will face many challenges in the future, but the governmental stepwise exploration philosophy secure a future with many opportunities. The next decade's industry moves into more challenging and remote locations. To secure a sustainable future new technology have to be developed and implemented, both in production and exploration. Estimation from NPD clearly indicates a large potential to discover more hydrocarbons on the NCS. For companies with a good understanding of the overall uncertainty and risk in the industry will face endless opportunities on the NCS over the next decades.

3.11 Probability of discovery

To define uncertainty and risk in prospect evaluation explorationists simplify the geology into "sophisticated" models (however the model it is always a gross simplification) for three reasons:

- Not possible to be present at subsurface
- Impossible to handle all data, and even if it was possible
- A good model can actually represent the reality excellent.

Prospect evaluation consists of studying data sets to define subsurface models related to the potential of entrapment of petroleum. Risk and uncertainty are examined pertaining to:

- **Charge**: Source rock, kitchen, expulsion efficiency and migration efficiency.
- **Reservoir**: Gross section, net section (N/G), porosity, hydrocarbon saturation and recovery efficiency.
- **Trap**: Structural or stratigraphic closure, quality of map and depth conversion.
- **Retention (Sealing)**: Vertical, lithology, thickness. Lateral in fault assisted closures and stratigraphic traps.

Calculations of hydrocarbon volumes are computed from assessments of individual components representing the size of the deposition (uncertainty). Correlation between components can only be ignored if the assumption of component independency is absolutely convincing. When the assumption of independence is not warranted, it is better to use the covariance structure of a good geologic analogy, rather than ignore the covariance of individual components (Kaufman, 1996).

To reduce the geological uncertainty and risk tools are used to increase resolving power of detection technology, do smarter interpretation with intensive and extensive data analysis, increase calibration, accuracy and precision of expert judgment, diversify intelligently and employ up to data decisions aids finning the company style. The state of the art within geological technology range widely: Burrow-Newton and colleagues focus on a modern approach to processing and presenting subsurface spatial uncertainty, and in the same spirit, Grant, Milton & Thompson (1996) develop the concept of play uncertainty maps and play risk maps. Dahl & Meisingset (1996) show how state of the art menu driven basin modelling software can yield quick basinal assessments and projections of accumulations histories. Spatially distributed petroleum inclusions (Bhullar et al., 2003), predicted reservoir quality on a regional scale using log data (Bergan & Knarud, 1993; Bjørlykke & Gran (1994); Bjørlykke (2014)), and uncertainties in source rock yields and trapped hydrocarbons (Krokstad & Sylta, 1996) show method to assessing geological data.

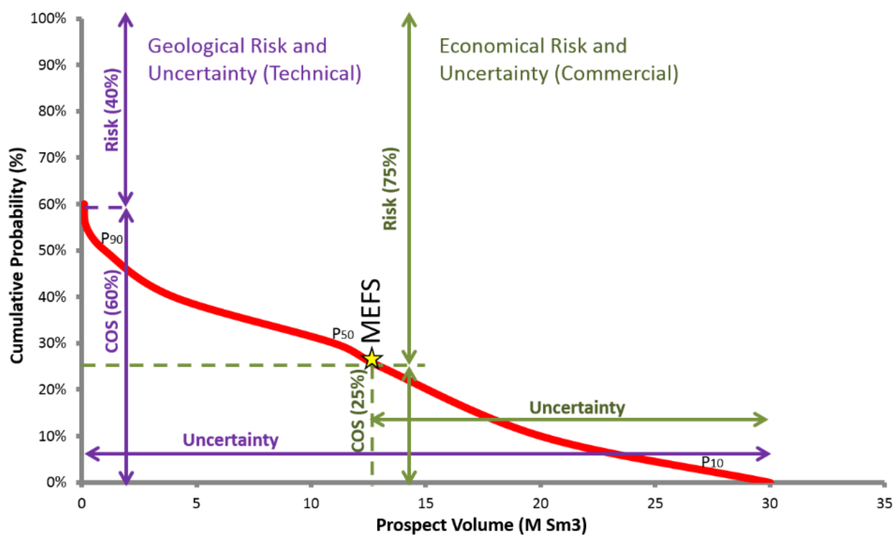


Figure 21 Expectation curve (red) developed from geological input parameters and associated probability. Purple color indicates risk and uncertainty for the whole cure, from a few Sm^3 of hydrocarbons to 30 Sm^3. The green color describes risk and uncertainty for the expectation curve above minimum economical field size (MEFS), 13 Sm^3.

A common convention in exploration today is to use expectation curve of volume (P_{90}, P_{50}, P_{mean} and P_{10}) and associated probability. The expectation curve can be translated into geological risk and uncertainty. In the figure the risk of failure are 40 % and the COS is 60 %. The uncertainty is represented by the range of potential discovery from a very small volume to 30 Sm^3 of hydrocarbons. However, a few barrels are generally not economic in any area. Therefore there is a threshold volume at which it becomes economic to develop and produce (MEFS). The threshold volume may change with area and time. Factoring in the cut off volume of 13 Sm^3 there is a 75 % risk of failure or not finding an economic deposit. The uncertainty range from 13 to 30 Sm^3 hydrocarbons with an associated chance of 25 % to find 13 Sm^3 or greater (Figure 21).

After the calculations of hydrocarbon volumes, defined by the expectation curve, the associated individual and independent risk elements are multiplied together to define the Probability of Geology (P_g). Additional information, described as Direct Hydrocarbon Indicator (DHI), is added to the P_g in order to define the COS (COS= P_g+DHIUplift). In a portfolio the prospects is aggregated according to various classifications to create expectations of exploration finding success for a budget program, an exploration strategy over several years, specific play, basin or region areas. From the shape of the expectation curve different types of expected risk and uncertainty can be deduced (Figure 22).

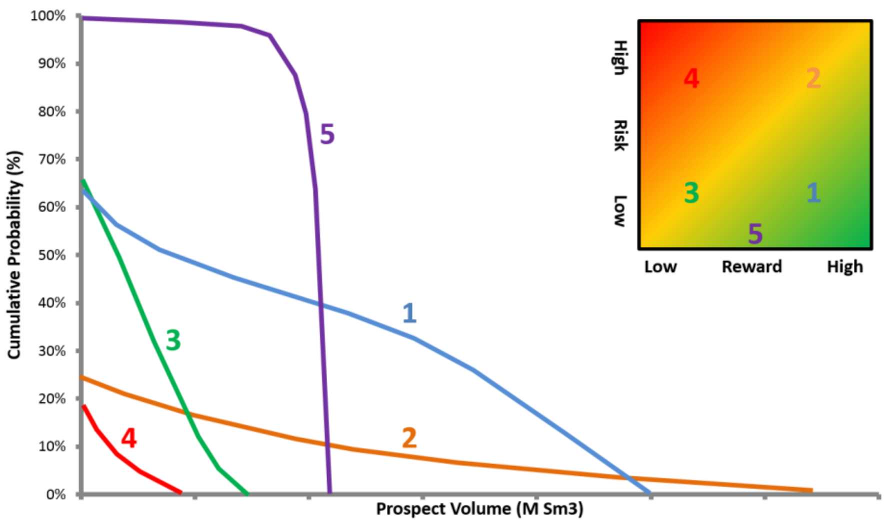


Figure 22 Expectation curve related to uncertainty risk, and reward: 1 high reward and low risk. Practically unknown in frontier plays, but can be present in new open areas with proven plays. 2 high reward and high risk. Well known prospects within the oil industry. 3 low reward and low risk. Mature hydrocarbon producing basin, near field prospect. 4 low reward and high risk, a prospect not likely to be tested. 5 medium reward and low risk.

3.12 The new CSEM technology

The concept of remote resistivity surveys is based on propagation of a CSEM field induced in a conductive subsurface mainly is affected by spatial distribution of resistivity (Hesthammer & Boulaenko, 2005). In marine environments, salt-water filled sediments represent good conductors, whereas hydrocarbon-filled sediments represent examples of resistive inclusions that scatter the CSEM field. The CSEM field scattered by sub-surface in homogeneities propagates back to the seafloor where it is recorded by the receivers. The information obtained can be used to resolve the subsurface resistivity distribution by applying inversion techniques. An important aspect of marine CSEM is that the recordings of CSEM fields on the seafloor are contaminated with noise. This, along with acquisition uncertainties and sparse source/receiver spacing, makes interpretation of the data challenging (Figure 23).

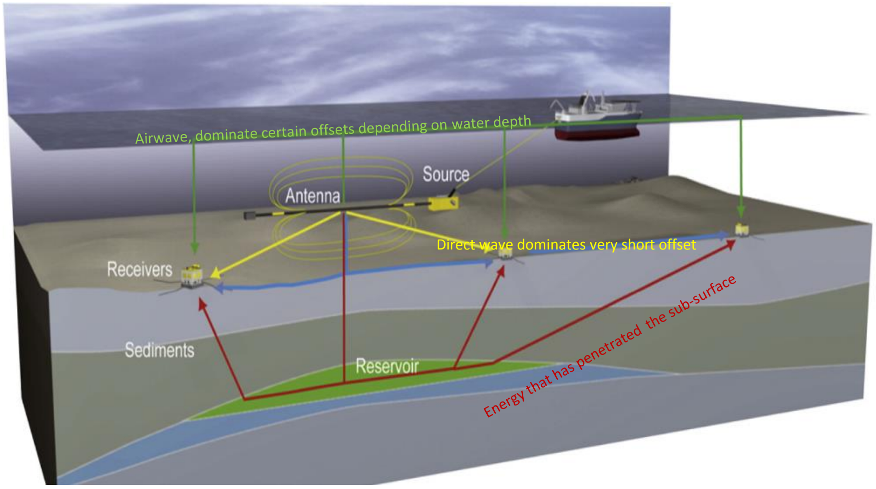


Figure 23 Schematic view of a CSEM survey. A horizontal electric dipole (Source - HED) is towed above receivers that are deployed on the seafloor. The source emits a continuous signals which is recorded by the receivers. The energy is sensitive to resistivity contrasts, causes energy to diffuse back to the seabed where it can be recorded by the receivers. Source: www.emgs.com

In the early stages of handling marine CSEM data for hydrocarbon detection, simplified approaches were used to process and display the data. Such processing certainly have its merit as it tend to preserve the raw results better than more advanced processing technology, including inversion. However, the approach suffer from a number of limitations, including lack of frequency content, multiple offset processing and dealing with data from multiple receivers simultaneously, resulting in lack of depth control. As a result, companies handling CSEM data have turned to inversion to provide resistivity images of the sub-surface, hence the algorithms used to invert CSEM data are highly important. An unconstrained inversion of the acquired CSEM data can be affected by a more complex geology. A solution to the problem is to also use seismic information when handling CSEM data, by constrained inversion. In order to avoid over simplistic interpretations in more complex geological settings, false positives and false negatives CSEM anomalies have been addressed. A *false positive* CSEM anomaly represent a hydrocarbon filled reservoir whereas in fact it is caused by something else, while a *false negative* is described as not identifying hydrocarbons even though presence of a hydrocarbon-filled reservoir. Understanding false positive and false negative scenarios are crucial for the detection aspect by allowing the chance of geological success (P_g) to be revised on the basis of interpretation of CSEM data. Handling uncertainties and decisions quickly become crucial in order to solve these challenges and to unlock the full potential of the CSEM technology (Hesthammer et al. 2010).

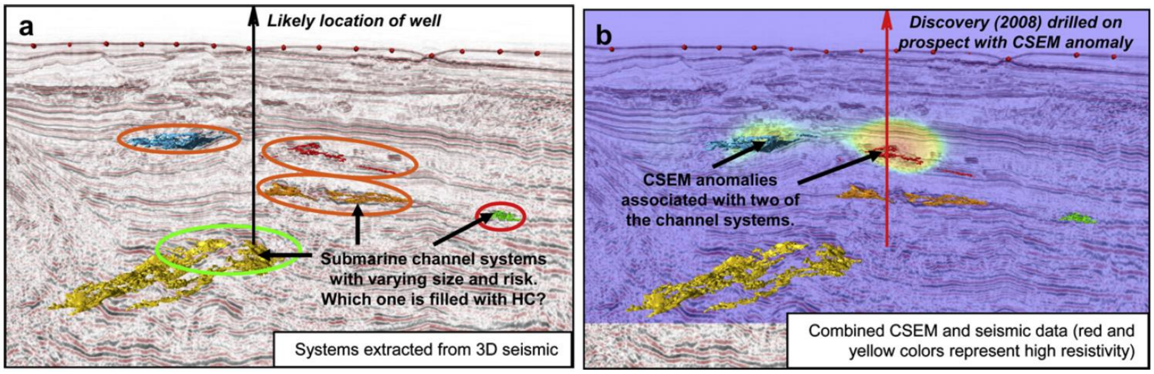


Figure 24 (a) A 2D seismic line extracted from a 3D seismic volume. Several channel systems can be extracted from the seismic data and represent potential hydrocarbon filled structures. The prospect marked with a green circle is the largest and a well targeting this prospect has a chance of geologic success of approximately 25 %. **(b)** Adding resistivity information to the seismic data using CSEM technology, shows that only the two shallower targets are likely to be filled with hydrocarbons. In this specific case, the seismic and CSEM data were processed independently. Source: Modified from Hesthammer et al. 2010.

3.13 Summary

Rocksource's visions was to use the new CSEM technology to de-risk offshore hydrocarbon prospects, more efficiently and cheaper than the rest of the industry. The immature CSEM technology was used together with internal developed software's with the believed capability to handle the new data, integrate them and finally de-risk the hydrocarbon prospects, a model believed to give Rocksource a competitive advantage above the rest of the industry. To achieve the goals, drilling of CSEM positive hydrocarbon prospects, Rocksource was qualified as license holder and operator on the NCS. Internally a work processes was establish to deal with all aspects of CSEM technology from initial screening to fully integrated analyses. After a global screening of offshore sedimentary basins, business development activities was focused in prolific areas where the technology was applied to de-risk high potential prospects to low risk drillable prospects. This study explore how Rocksource evaluated uncertainty and risk in different dimensions, in order to improve the framework for future decisions. To explore the fully potential on the NCS oil companies must implement new technology. The companies must develop a greater understanding of the uncertainties and risk related to a new technology, handle technically by mitigations, witch finally lead to the desired outcome (hopefully). In the next section the theoretical framework is presented.

4 Theoretical context

Section 1 is build up by four subsections, each consisting of several building blocks (Figure 25). The first section define uncertainty and risk. The second section, Rationality and decision, builds on the understanding of uncertainty and risk established in in the first section. The third section illuminate how uncertainties and risks are related to disruptive innovations. The last section, Escalation of commitment, describes possible consequences of not taking rational decisions, misinterpreted project uncertainty and risk or lace of risk management.

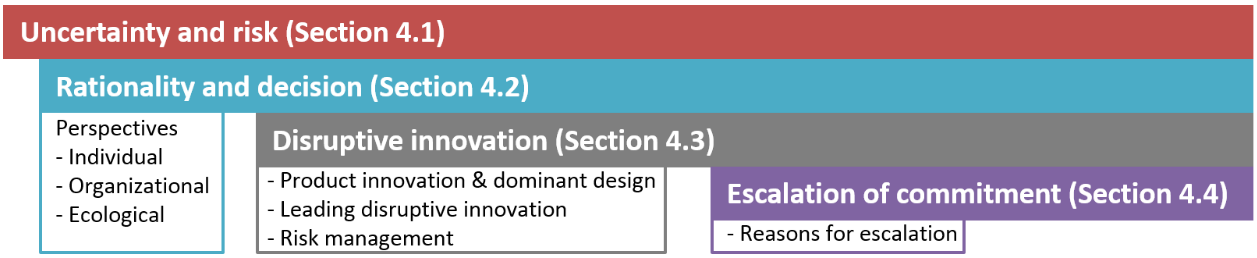


Figure 25 Section 1 is build up by four subsections, each consisting of several building blocks (Figure 25). The first section (Section 4.1) define uncertainty and risk. The second section, Section 4.2 Rationality and decision, focus on decisions taken in situations containing uncertainty and risk. The third section illuminate how uncertainties and risks are related to disruptive innovations (Section 4.3). The last section, Escalation of commitment (Section 4.4), describes possible consequences of not taking rational decisions, misinterpreted project uncertainty and risk or lace of risk management.

Remarks and definitions to the terms uncertainty and risk is presented in Section 4.1 and followed by the theoretical context of decision making in Section 4.2. In the start of the chapter some initial remarks are given on the concepts “rationality" and “decision" before a traditional, normative approach to decision making under uncertainty and risk is presented. Subsequently challenges to normative approach is discussed form three perspectives (4.2.1 The individual perspective, 4.2.2 The organization perspective and 4.2.3 The ecology perspective). In Section 4.3 Disruptive innovation is discussed in the context of uncertainties and risks related to an immature and untested product from three different perspectives. First the product development from an early stage to the emergence of a dominant design related to the Utterback-Abernathy model is presented (Section 4.3.1 Product innovation & dominant design). Secondly (Section 4.3.2 Leading disruptive innovations), capability to leading disruptive innovation requires a different mindsets and behaviors, both for leaders themselves and for the organizations in order to understand and reduce the uncertainties, hence reduce the risks. Finally, Section 4.3.3 Risk management – project success and technological uncertainty, describes the theoretical context for how organizations must be prepared for project risks and be ready to do something about them. In the last part, Section 4.4 Escalation of commitment, the theoretical context for escalation situations is presented. Situations where the decision makers are faced with negative feedback concerning a previously chosen course of action and must decide whether to persist with or withdraw from the previously chosen course of action. Previously studies have proved that escalation is a complex phenomenon and mechanism of escalation of commitment remains relatively unknown and under researched influenced by many factors.

4.1 Uncertainty and risk

Risk is the potential of losing something of value, weighed against the potential to gain something of value. Values can be gained or lost when taking risk resulting from a given action, activity and/or inaction, foreseen or unforeseen. Cohen & Hansel (1956) define risk as "*to do something you are not sure you are able to do*" and risk-taking as "*doing something whilst tacitly or explicitly estimating, on incomplete data, ones capacity to do it.*" The uncertainty is looking forward, encompasses the range of possible outcomes, some of which involve success/gain and others involve failure/loss. Frank Knight (1921) established an important distinction between risk and uncertainty: "*Uncertainty must be taken in a sense radically distinct from the familiar notion of risk, from which it has never been properly separated.... The essential fact is that 'risk' means in some cases a quantity susceptible of measurement, while at other times it is something distinctly not of this character; and there are far-reaching and crucial differences in the bearings of the phenomena depending on which of the two is really present and operating.... It will appear that a measurable uncertainty, or 'risk' proper, as we shall use the term, is so far different from an unmeasurable one that it is not in effect an uncertainty at all.*"

4.2 Rationality and decision

A detailed discussion of rationality (Elster, 1983) is outside the scope of this work, but Gigerenzer (2001) viewed rationality as an optimization strategy. In the thesis a rational choice is defined as one where the costs and risks of all alternatives have been weighed against each other, and the alternative that gives the optimal expected outcome is selected. A decision can be described as conscious choice between at least two alternatives (Brunsson, 1982) or "*important, in terms of the actions taken, the resources committed, or the precedents set*" (Mintzberg et al., 1976). This thesis is more aligned with the last definition and focus on the decisions taken to fulfil the strategy, rather than all decisions.

Historically the study of decision making is not a new discipline, even antiquity scholars was interested in how decisions was made. Aristotle described the process of the "*deliberate choice*" in the Nicomachean Ethics (Bartlett & Collins, 2011). A more mathematical approach, often cited as the first example of a math-based approach to decision making (Siegfried, 2006), is exemplified of Blaise Pascal's famous "wager", where the existence of God is framed as a mathematical wager, using the idea of expected value. The St. Petersburg Paradox was solved by Daniel Bernoulli when a concept case of expected utility, encompassed objective gains and probabilities in addition to subjective circumstances (Bernstein, 1996). Bernoulli proved that two individuals can judge the same outcome differently, based on individual preferences and circumstances, or in modern economic terms, their individual utility functions (Rothbard, 2006). A way of quantifying an individual's utility function in the form of a logarithmic function, taking into account diminishing marginal utility of money as the wealth of an individual increases (Bernoulli, 1954). Expected utility theory (Neumann & Morgenstern, 1953) in game theory expanded the concepts to derive mathematically a number of axioms defining the behavior of a rational decision maker under risk (Hunt, 2006), to prove that it is "*possible to describe mathematically human actions in which the main emphasis lies on the psychological side.*" Yet other, economists and statisticians have followed the same tradition, expanding further on the mathematical modelling of individual`s utility functions (Friedman & Savage, 1948).

Much of the research and the theoretical models for decision making today is shaped from the historical mathematical view of decision making under risk or uncertainty, above (Fishburn, 1988). Bazerman & Moore (2009) presented six steps (1: perfectly define the problem, 2: identify all criteria, 3: accurately weigh all the criteria according to their preferences, 4: know all relevant alternatives, 5: accurately assess each alternative based on each criterion and 6: accurately calculate and choose the alternative with the highest perceived value) the decision maker should strive describe when applying a rational decision making process. Many variations of processes describing the optimal decision making process in an ideal world (a world of "mathematical economics"). To facilitate a complex decisions process, sophisticated tools is developed for decision analysis. Even if decision makers often have been disappointed by the contribution of decision support systems, the enthusiasm seems to be increasing (Power, 2002).

4.2.1 The individual perspective

Previous sections have described a mathematical approach to decision making, implying individuals have a complete understanding of the choices and act rationally to maximize the benefits. However, evaluation of geological uncertainties and risk is strongly dependent on interpretation of available data and information. The theory describes that the individuals, organization and ecological perspectives affect the rationality and the normative model in a decision.

The normative model assuming that the decision maker is exposed to all necessary information before making a rationally decision, which is it is unlikely in the real world. Many decisions are related to complex problems, where the problem itself is undefined, it is unclear when a problem is solved and each problem is unique (Rittel & Webber, 1973). Therefore an extensive information search can be necessary. The underlying assumptions in the normative rational choice theory divagated from the real world in at least three ways (Simon, 1997):

- Requires complete knowledge of the consequences of considered alternatives, but this knowledge is always fragmentary.
- Requires assigned values to all future consequences, consequences cannot be experienced up front, therefore only imagine and approximate values can be assigned to the consequences.
- Requires possible alternatives to be evaluated, this is never the case.

To optimize the decision itself, a rational decision maker must decide the optimal (cost effective) information search, if not the decision maker moves into the realm of hyper rationality (Elster, 2009). However, to identify the point where the costs of continued search outweigh the benefits is also a complex task (Gigerenzer & Selten, 2001). The costs limits deviate from the rational decision, but in addition bounded rationality include complex nature of decisions and limited cognitive abilities. In the striving for rationality, humans have developed some working procedures to partially overcome difficulties related to the psychological characteristics of humans to reinforce bounded rationality, such as the learning processes, limited memory and habits (Simon, 1997). On the other hand the behavioral and cognitive limitations are not limited to individual decision makers.

Another challenge to the idea of the "economic man" is the heuristics people use to evaluate uncertainties and risks when making decisions and the biases they are prone to – the human beings factor in the total wealth when making decisions (Kahneman, 2003). Allais paradox (Allais, 1953), indicates that people on average do not behave according to the normative independence axiom expected utility theory (Neumann & Morgenstern, 1953) exposed to two separate choice scenarios (Lehrer, 2010). Experiments performed by Kahneman (2003) proved that people regularly behaved completely contradictory to the normative axioms of rationality. The Prospect Theory (Kahneman & Tversky, 1979) showed how Bernoulli and the mathematical economics tradition was on the right track in terms of focusing on utility instead of value, but had failed to recognize the "carriers" of utility are changes of wealth rather, than states of wealth. Behavioural Economics has been established as a consequence of a large number of experiments designed, conducted and replicated around the world, showing clearly that the basic assumptions of human rationality underlying the idea of economic man are not universally valid.

The conceptual model for "System 1" and "System 2" thinking describes two different mechanisms of how the human minds relate to the world and make decisions (Stanovich & West, 2000; Kahneman, 2011). System 1 builds on intuition, comes up with a story fitting the available information, are fast and operates with little effort or sense of control like reactions, recognize of sensory impact, evaluation of distance and time in addition to answers of easy questions. The System 1 is mainly controlling routine behaviors in daily life, but it relies on heuristics and the biases to which they lead, e.g. representativeness, availability and anchoring (Tversky & Kahneman, 1974), and can therefore sometimes come up with wrong decisions or interpretation of the situation. The problem arises when the heuristics of System 1 can lead to systematic biases, by reducing the amount of data needed to make decisions and recognizing familiar situations and finally lead to irrational conclusions. In contrast the System 2 requires mental effort, deliberate, work slow and monitoring the decision and perceptions. System 2 has an opportunity to intervene when System 1 are making an error, but the slow and lazy System 2 does not necessary intervene in poor decisions even when the knowledge needed to come up with a better decision is present.

Langley (1995) describes decision making as a balancing act between "paralysis by analysis" and "extinction by instinct." Structural and cultural issues work as determinants to the extent of formal analysis in decision making in addition to underuse and overuse of formal analysis to the cognitive style of the decision maker, but emphasizes the need to find an efficient balance. Studies have proved that managers who collect information and us analytical techniques make decisions more effective than others (Dean & Sharfman, 1996), but in an unstable industry, comprehensive decision processes can be negatively related to performance (Fredrickson & Mitchell, 1984). The term "satisficing" (Simon 1979) describes to find the right balance of analysis to put into a decision. The concept include the individual dimension (cognitive style), as well as the organizational dimension (rules, culture, politics).

4.2.2 The organizational perspective

Non-economic motives and processes are fundamental to understand the organizational behavior, and the "economic man" can be replaced by the "administrative man" instead (Barnard, 1971). An organization divides work among persons, establishes standard procedures, and transmits decisions through the authority systems. The organization also influence and indoctrinates the members, provides channels of communication and "members trains" (Simon, 1997). The "administrative man" finds options that are good enough, rather than optimal ("satisfices") and simplifies the world by leaving out aspects of reality seeming irrelevant in the moment.

4.2.3 The ecological perspective

The "decision" concept sometimes is an artificial construction serving to confusing. The "decisions" are difficult to track down, can be a result of an iterative and often undocumented process, be inadvertent, or even unconscious. Strategy can be viewed as patterns of behavior whereas decisions can be seen as commitments for single behavior, but patterns of behavior do not need to be intended and single behaviors does not need to be decided (Mintzberg & Waters, 1990). Miller (2010) concedes that there are problems related to delimiting "decisions" exactly, and concluded that studying the processes during which managers believe they are making decisions is a useful source for understanding organizational behavior, regardless of whether their view of decisions was awed or not.

4.3 Disruptive innovation

Petroleum geoscientists worldwide are well aware of the significance of seismic data for hydrocarbon exploration and few will dispute the significant leap in moving from 2D to 3D seismic. Such a technological breakthrough happens rarely, but the impact can be enormous for both oil companies and the service industry. Over the past few years there has been much talk about the potential of the new CSEM (Young & Cox, 1981; Chave & Cox, 1982; Webb et al., 1985; Sinha et al., 1990; Chave et al., 1991; Evans et al., 1994; Constable & Cox, 1996; MacGregor et al., 1998; 2001; Eidesmo et al., 2002; Ellingsrud et al., 2002) for hydrocarbon detection in marine environments. The technology has been argued to be as significant as the transition from 2D to 3D seismic. If this is correct, the impact will be tremendous and require a fundamental change in the way hydrocarbon exploration is viewed by oil companies worldwide.

The term disruptive technologies was introduced in the article Disruptive Technologies: Catching the Wave (Bower & Christensen, 1995). The article is aimed at managing executives who make the funding/purchasing decisions in companies rather than the research community. Clayton M. Christensen's bestselling Innovator's Dilemma (1997) is classic literature on disruptive innovation. Disruptive technologies bring to a market a very different value proposition than previously available. Generally, disruptive technologies underperform established products in mainstream markets, but have other features that a few fringe (and generally new) customers value. Products based on disruptive technologies are typically cheaper, simpler, smaller, and, frequently, more convenient to use (Christensen, 1997). For companies the dilemma is that innovations is necessary to satisfy the needed growth, but on the other hand require the companies to take aboard unwanted uncertainties and risks. Innovation, at least disruptive innovation requires vision, nerve and patience. Driven by quarterly results, most companies will eschew long-term growth for short-term profitability. Larger companies typically needs push from owners or customers before committing to an innovation, involving more uncertainties and higher risk to the existing portfolio. As a results new entrants, start-ups and entrepreneurs are more likely to grow through innovation. Christensen's dilemma solution is to identify a new technology with potential to disrupt, and build a product based on that technology, instead of starting by identifying a need in the market and then build a product meeting the needs. The future opportunity space for companies is likely to be found in new technology and new niches rather than new interpretations of the existing marked situation. To distinguish between different technologies and to take good decisions it is helpful to identify the critical success factors for deploying new disruptive technology and to understand the "technology dynamics" of a segment, specifically why a new technology is adopted or rejected.

4.3.1 Product innovation & dominant design

As a new started oil company Rocksource business plan was mainly to identify and explore large prospects and opportunities based on the potential from the new CSEM technology. The company goals could only be reached if the immature technology was supported with large investment in combination with a multidiscipline, geological and geophysical, integrated approach. To process and interpret the CSEM data Rocksource needed to develop an internal software to process the data.

Early participants in new industries experiment freely with new processes, data, forms and materials, because they are not limited by universal technical standards or by uniform product expectations in the marketplace. This fury of radical product innovation eventually ends with the emergence of a dominant design (Utterback & Abernathy, 1975). With the marketplace forming its expectations for a product in terms of features, form, and capabilities, the bases on which product innovation can take place become fewer. Users develop loyalties and preferences, and the practicalities of marketing, distribution, maintenance, and so forth, demand greater standardization. This causes the focus of research and development to narrow to incremental innovations on existing features (Utterback, 1994). Looking at process innovations, the Utterback-Abernathy model (1975) describes a different pattern regarding the rate of innovation over time (Figure 26). During the formative period of a new product, "*the processes used to produce it are usually crude, inefficient, and based on a mixture of skilled labor and general-purpose machinery and tools*" (Utterback, 1994). The product itself matter to innovators, but product and process innovations are interdependent. As the rate of product innovations decreases, the rate of process innovations increases (Figure 26). Utterback & Abernathy (1975) identified three distinct phases, each of them impacting differently on single companies, on the market and on the capabilities and resources required to develop the innovation. When a new technology emerges a number of alternative designs and updated designs will be released incorporating incremental improvements. At some point, an architecture that becomes accepted as the industry standard may emerge (Anderson & Tushman, 1990).

Dominant design is a technology management concept introduced by Utterback and Abernathy in 1975, identifying key technological features that become a de facto standard (Suarez, 2004). A dominant design is the one that wins the allegiance of the marketplace, the one that competitors and innovators must adhere to if they hope to command significant market following (Utterback & Suarez, 1993 and Figure 26). Most of the previous models were static in nature, meaning they considered the factors affecting innovation under a fixed perspective, without transitions or dynamicity. Abernathy & Utterback (1978) broke the standard by creating a model where product innovation, process innovation, competitive environment and organizational structure were all interacting and closely linked together. Utterback & Suarez (1993) argue that the competitive effects of economies of scale only become important after the emergence of a dominant design, when competition begins to take place on the basis of cost and scale in addition to product features and performance. Dominant designs may not be better than other designs; they simply incorporate a set of key features that sometimes emerge due to technological pathdependence and not necessarily strict customer preferences. Dominant designs end up capturing the allegiance of the marketplace and this can be due to network effects, technological superiority, or strategic maneuvering by the sponsoring firms. Dominant designs are often identified after they emerge. Some authors consider the dominant design as emerging when a design acquires more than 50 % of the market share (Anderson & Tushman, 1990) while more promising approach is to study the specific product innovations introduced by different firms over time to determine which ones are retained (Christensen et al., 1998).

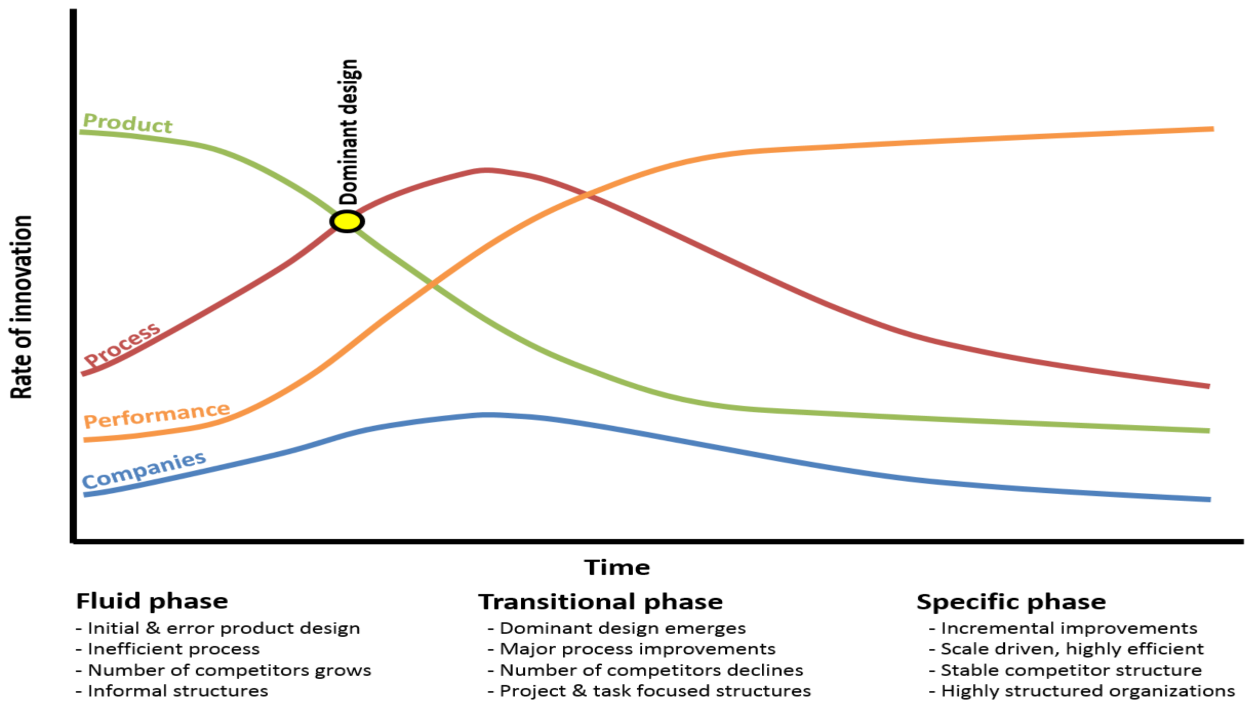


Figure 26 The Utterback-Abernathy model illustrating the innovation intensity, and how the product, process, performance and number of companies develop over time. Source: modified from Utterback, 1994.

4.3.2 Leading disruptive innovation

In today's complex, dynamic world, having a disruptive innovation capability is mandatory, both for growing a business and protecting existing markets. But leading disruptive innovation requires new mindsets and behaviors, for leaders themselves and for the organizations that develop them. Disruptive innovation that transforms or creates new markets has become the Holy Grail for many companies.

Leaders face challenges when it comes to disruptive innovation and few leaders are formally prepared to deal with the realities of leading or responding to disruption. Many executives rise through the ranks of management, where predictability and control are valued and rewarded. Unlike operations management, disruptive innovation involves extreme uncertainty. Unexpected events, inevitable failures, and a fundamental lack of control are inherent to the process. The most defining characteristic of disruptive innovation is the great uncertainty for leaders, organizations, and entire industries (Christensen, 1997). The organizations possess a general awareness of the importance and necessity of disruptive innovation and change in general, but there is a gap when it comes to understanding the deeper leadership qualities necessary for driving them. When going after disruptive innovations or focusing on “blue oceans”, representing a white-space of opportunities to create entirely new markets, the leadership issues are similar. Many leaders rely on research and data for decision-making to manage daily operations, for example, but during times of disruption, waiting for hard data to make decisions can quickly result in failure. Leaders must embrace ambiguity, live with uncertainty for long periods of time, and confront the critiques of naysayers both inside and outside of their organizations. More and more leaders and companies recognize that they must proactively disrupt, or risk being disrupted. Leading disruptive innovation involves adopting principles that fall outside the traditional training of managers and leaders (Christensen, 1997).

Leaders must be comfortable using whatever information they have on hand, integrating inputs from diverse sources around them, and then using their intuition to round out the decision-making process. The challenge for any business is that the competencies necessary for leading disruptive innovation are not formulaic or quantifiable. Cooper (1999) argue that new product project teams and leaders seem to fail into the same traps that their predecessors did back in the 1970s; moreover, there is little evidence that success rates or research and development productivity have increased very much. Kaplan (2012) highlights the key dynamics involved in leading disruptive innovation, and outline the core leadership experiences and practices involved in the process. A five-phase model “LEAPS” is presented and provides a structure for understanding the ways leaders create clarity during times of great uncertainty. Research has uncovered two types or classes of success factors. The first deals with doing the right projects, control, include characteristics of the new product’s market, technologies, and competitive situation, along with the ability to leverage internal competencies; the second with doing projects right, focus on process factors or action items-«things the project team does (or too often does not do) (Montoya-Weiss & Calantone, 1994).

4.3.3 Risk management – project success and technological uncertainty

Everyone exposed to projects knows “there is no risk free projects” and especially at the early stages of any new technology, the uncertainties are high and many questions develop. Currently, the hydrocarbon exploration industry is evaluating the significance of CSEM technology. There are some published success-cases (e.g. Johansen et al. 2005; Choo et al. 2006; Smit et al. 2006) but also skepticism within the industry. One likely reason for the skepticism is that CSEM technology is new to most petroleum geoscientists and thus requires them to acquire an understanding of the fundamental concepts and how to handle the data from basic to advanced analyses. To develop projects successes the uncertainties and risk must be managed.

All projects are different, and involves some degree of uncertainty, yet many organizations still tend to assume that all their projects will succeed, and often fail to consider and analyze the project risk, and prepare in case something goes wrong (Raz et al., 2002). This attitude frequently leads to project failure and disappointing results, and as many studies have shown, project success rates are less than satisfactory (Morris & Hough, 1987; Pinto & Mantel, 1990; Tishler et al., 1996). Today's rapid dynamic change and increased competition, it is not enough to have a good project plan, or even a proper monitoring and controlling system. Organizations need to be prepared for project risks and be ready to do something about them. Project risks may come from the task itself, which can be characterized by uncertainty, complexity, and urgency, or from lack of resources or other constraints such as skills, or policy. No one can avoid project risks, but certainly prepare by adding risk management activities to project plans, and putting in place mechanisms, backups, and extra resources, that will protect the organization when something goes wrong, defined as project risk management, characterized by additional planning, identification, and preparation for project risks. The awareness to project risks and the need to manage them has become in recent years one of the main topics of interest for researchers and practitioners (e.g. Williams, 1995; Raz et al., 2002). Within the current view of project management as a life-cycle process, project risk management (PRM) is seen as an encompassing process, starting at project definition, continuing through planning, execution, and control phases, up to completion and closure. Several forms of PRM processes have been proposed (Boehm, 1991; Fairley, 1994; Dorofee et al., 1996; Kliem & Ludin, 1997; Chapman, 1997). PRM processes are typically supported by tools and techniques such as, checklists, brainstorming, prototyping, simulation, and contingency planning (Raz & Michael, 1999). Yet, projects differ in many ways, such as size, duration, uncertainty, complexity, pace, objectives, constraints, and other dimensions the described processes, tools and techniques are generic in nature.

4.4 Escalation of commitment

Escalation of commitment involves a decision-making situation in which an individuals must choose whether or not to continue with a previously chosen course of action. It is reasonable to investigate the role of selective perception when Rocksource received negative information. There are different modes of why companies fail to implement new technology. One of the most difficult management issues that can arise is deciding whether to abandon or continue a troublesome project. In escalation situations, decision makers are faced with negative feedback concerning a previously chosen course of action and must decide "*whether to persist with or withdraw from the previously chosen course of action*" (Brockner, 1992). Escalation is a complex phenomenon and "*the mechanism of escalation of commitment remains relatively unknown and under researched*" (Schmidt & Calantone, 2002) influenced by many factors. Escalation occurs in many different contexts, all escalation situations involve, by definition, "*decision making in the face of negative feedback about prior resource allocations, uncertainty surrounding the likelihood of goal attainment, and choice about whether to continue*" (Brockner, 1992). There is a lack of conceptual clarity regarding how much negative feedback is required and indeed whether the decision maker must even be aware of the negative feedback (Keil et al., 2000). Prior researching suggests that when unambiguously negative feedback is presented, escalation is no longer sustainable and de-escalation ensues (Garland et al., 1990), and are managers are able to process the information and detect the problem. The literature suggest that escalation most likely occur when negative feedback is ambiguous, and the direction forward is unclear (Keil, 2007; McCain, 1986). Under these circumstances, the decision makers may be unduly influenced by cognitive biases that cause them to interpret the situation in a manner that impedes problem recognition and promotes escalation behavior. Research on escalation in the new product development context suggests that "biased belief updating" may be an important factor in promoting escalation behavior. Specifically, it appears that the reasons for escalating is that people distort or improperly weight new information to conform an initial belief structure (Biyalogorsky et al., 2006). It is possibility that cognitive biases impede problem recognition and thereby promote escalation behavior. Keil et al. (2000) suggest that in some cases managers are "*aware of negative information but choose to ignore it (or discount it heavily) due to certain cognitive biases, thereby promoting escalation*."

4.4.1 Factors promoting escalation

Previous research suggests that escalation is a complex phenomenon that may be influenced by many different factors. Staw & Ross (1987) groups these factors into four categories: project, psychological, social, and organizational (Figure 27). The four factors are also linked the theory presented in Section 4.2 Rationality and decision.

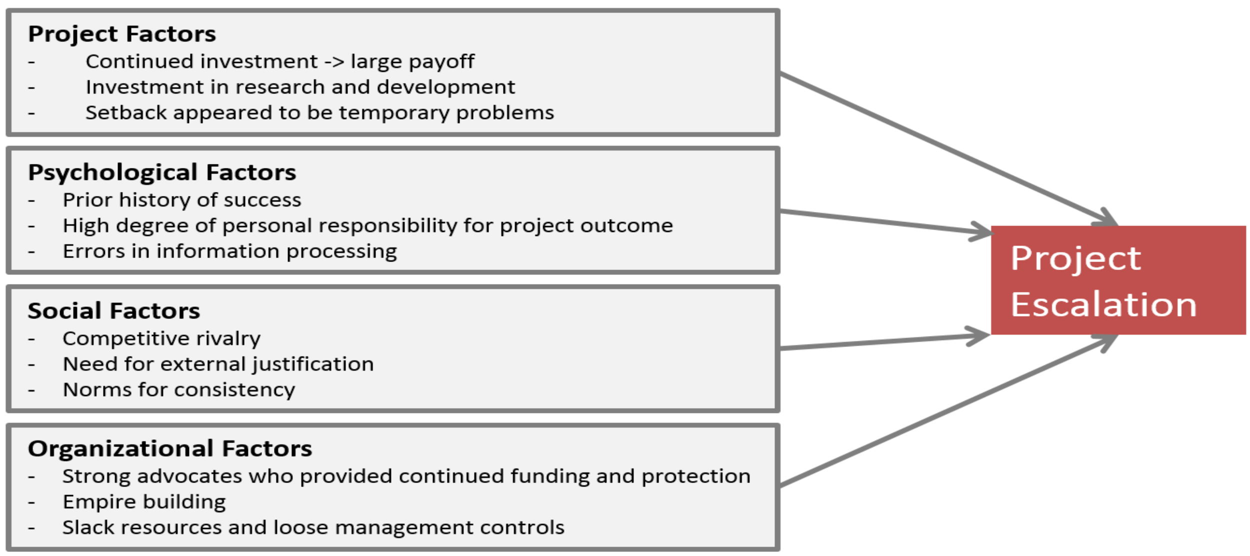


Figure 27 Summary model of factors promoting escalation. Modified from Staw & Ross (1987).

Project factors are the objective features of the project itself and how it is perceived by management (Ross & Staw, 1993). These factors include the costs and benefits associated with the project as well as the expected difficulty and duration of the project. Other things being equal, projects are more prone to escalation when they involve a large potential payoff, when they are viewed as requiring a long-term investment in order to receive any substantial gain, and when setbacks are perceived as temporary problems that can be overcome.

Psychological factors are those that cause managers to convince themselves that things do not look so bad and that continuation will eventually lead to success (Brockner, 1992). These factors include the manager's previous experience with similar projects, the degree to which the manager feels personally responsible for the outcome of the project, as well as psychological and cognitive biases that can affect the way in which information concerning the project is perceived or processed. Projects are more prone to escalation when there is a previous history of success and when there is a high level of personal responsibility. Escalation is also more likely to occur when managers make errors in processing information. Previous research shows, for example, that human decision making is subject to numerous biases, many of which operate at a subconscious level (Kahneman & Tversky, 1982). One such bias can lead to "*throwing good money after bad*" in an effort to turn around a failing project (Garland et al., 1990). Prior research also suggests that managers may engage in a type of self-justification behavior in which they commit additional resources in order to turn a project around rather than terminating the project and admitting that their earlier decisions were incorrect. Self-justification can lead managers to "*bias facts in the direction of previously accepted beliefs and preferences*," resulting in project escalation (Ross & Staw, 1993).

Social factors can also promote escalation. These factors include competitive rivalry with other social groups, the need for external justification, and norms for consistency (Ross & Staw, 1993). Projects are more prone to escalation when competitive rivalry exists between the decision making group and another social group, when external stakeholders have been led to believe that the project is (or will be) successful, and when norms of behavior favor "staying the course."

Organizational factors involve the structural and political environment surrounding a project. These factors include political support for the project and the degree to which the project becomes institutionalized with the goals and values of the organization. Projects are more prone to escalation when there is strong political support at the senior management level and when the project has become institutionalized.

4.5 Summary

In the oil industry a key to success is the ability to understand, manage, handle and mitigate uncertainty and risk in the different phases form exploration to production (Figure 1). For exploration companies, it is crucial to mitigate uncertainties and risks before capital intensive drill decisions (Figure 16), as the average historical drilling success on the NCS below 40 % (Figure 14 and Figure 15). Rocksource business plan was to mitigate the prospect uncertainties and risks by implementing the new CSEM technology in the evaluation process. The collected data (Section 1) show how Rocksource evaluated risk and uncertainty before the decision to drill five large prospects on the NCS (Figure 4, Figure 21 and Figure 48).

The modern day implementations of techniques that attempt to mathematically model decisions, has been to set the stage for a series of attacks on the normative rational choice paradigm of decision making. Companies exploring for hydrocarbons are using normative mathematical models to optimize decisions, but the outcome of the models will always be influenced by the methodology used to evaluate, handle and experience uncertainty and risk. Individuals, as well as the organization and the ecological environmental, can influence the bout decisions and the basis for the decision. The presented data (Section 1) describe the Rocksource internal decision process (Section 6.1), how RRT evaluated uncertainty and risk was evaluated (Section6.6) and how pre well evaluations is compared to the actual results (Section 6.8).

Disruptive technologies bring to a market a very different value proposition than had been available previously. The new CSEM technology was believed to disruptive the hydrocarbon exploration process, characterized by reduced costs, and a possibility to identify and de-risk prospects. The rapid development of new technologies in the fluid phase, is associated with uncertainties and risks for the early adapters. For companies using new technology it is important to possess a general awareness of the importance and necessity of disruptive innovation and change in general. In the data and findings the organization (Section 6.2) and the decision making process (Section 6.1) to illuminate Rocksource knowledge and ability to understand projects uncertainties and risks when develop disruptive technology. In the study all pre drilling CSEM evaluations are compared to CSEM evaluation after drilling (Section 6.8). The results are related to the Abernathy and Utterback model to evaluate the evolution of the CSEM technology.

One of the most difficult management issues that can arise is deciding whether to abandon or continue a troublesome project. When companies build a business model on disruptive innovation there will often be decision points where the company must choose whether or not to continue with a previously chosen course of action. The organization must use whatever information they have, integrating inputs from diverse sources around, and then using intuition to round out the decision-making process. The leaders must be prepared for negative feedback about uncertainty surrounding the likelihood of goal attainment, and choice about whether to continue. There is a lack of conceptual clarity regarding how much negative feedback is required and indeed whether the decision maker must even be aware of the negative feedback. The escalation literature provides a promising theoretical base for explaining failure of developing disruptive technology. Using the model of escalation based on the literature, the findings in Section 1 is discussed and analyzed.

5 Method

5.1 Introduction

The aim of the study is to understand how Rocksource evaluated uncertainty and risk, and how new technology was implemented in the evaluations. Finally the study hope to conclude on some recommendations to improve future prospect evaluations and how uncertainties and risk related to implementation of new technology can be mitigated. To achieve the goals, a set of related events and results with high validity and reliability is collected and define the frame work for the case study.

5.2 Single case studies and unit of analysis

A case represents somehow the interesting topic of the study empirically, while the unit of analysis is the actual source of information. Single cases is used to confirm or challenge a theory, or to represent a unique or extreme case (Yin, 1994) and for cases where the observer have access to a phenomenon previously inaccessible. The flexibility of case study design is in selecting cases different from those initially identified, not in changing the purpose or objectives of the study to suit the cases. For this case study each of the prospect evaluations represents the source of information, and the unit of analysis. All units are collected from Rocksource, implying an embedded single case study. The case has a holistic design searching for consistent patterns of evidence across the five independent units. Data and information required to undertake the study must be regarded as sensitive and inaccessible to external researchers, even within the company the data is not previously collected, systemized and analyzed.

Case study is an ideal methodology for a holistic, in-depth investigation (Feagin et al., 1991) and the investigator has little or no possibility to control the events. Case studies are designed to bring out details by using multiple sources of data for a contemporary phenomenon within its real-life context. The boundaries between the explored phenomenon and its context are not clearly evident, with many variables of interest, multiple sources of evidence, the theoretical propositions guide the data collection and data analysis are present. In order to document how Rocksource implemented the new CSEM technology to de-risk uncertainty and risk before drilling wells, the study is designed as an explanatory case, but with elements of exploratory and descriptive elements (Yin, 1993). The design of case studies depends of three conditions (Yin, 1984); type of research question posed, extent of control an investigator has over actual behavioral events and degree of focus on contemporary events. The research questions for this study consist of “how” and “what” questions. The researcher had no control over the behavioral events, the new technology was implemented, the uncertainties and risks was assigned to the projects, hence the preferred methodology, and the decision to drill was taken before the researcher was part of the organization.

5.3 Developing the research question

Before developing research questions it is important to map out limitations and available data to secure the validity and reliability the study.

5.3.1 Limitations and data selection

To maximize the learning in the time available for the study.

All the five prospects evaluated have multiple reservoir targets, and different scenarios have been mapped out in the company's evaluation process. To maximize the learning in the available time, some limitations is considered as important:

- *NCS*: Rocksource have also been part of two drilling operations internationally (India and Guinea Bissau) and production in the USA. International operations are excluded from the study because additional and uncontrolled drivers may influence the company's decisions, in addition the prospect evaluation and accessible data do not have the same quality as from the NCS, but it is important to underline that conclusions from the study also will be valid for the international operations.
- *Drilled prospects (5)*: Rocksource have been and are part of many licenses on the NCS, in addition are CSEM data acquired in many areas, but as this prospects remain untested it is impossible to make conclusions. All the wells de-risked with the new CSEM technology (Figure 28).
- *Final prospect evaluation (uncertainty and risk)*: During a long evaluation process the prospect uncertainty and risk change, in the study only the final expectation curve and risks, used for economic and final drill decisions, presented.
- *Main targets*: only targets tested by the exploration well is evaluated, but deeper can be part of the roll-up volumes (PL416 – Breiflabb).
- *Related uncertainty and risk*: only selected uncertainty parameters used to create the expectation curve (Section 3.11 and Section 6.8) and the associated risk is presented:
    - Reservoir (P1 (%)): reservoir thickness (m), net/gross (0-1) and porosity (0-1)
    - Trap (P2 (%)): depth to top of prospect (m)
    - Charge (P3 (%)): hydrocarbon column (m)
- *Economic*: difference between hydrocarbon types (gas vs. oil) is neglected in the study.
- The study will not discuss the Rocksource strategy and economics decisions as this is considered to be outside the project's theme, but comment how a different understanding of uncertainty and risk could have influenced decisions.

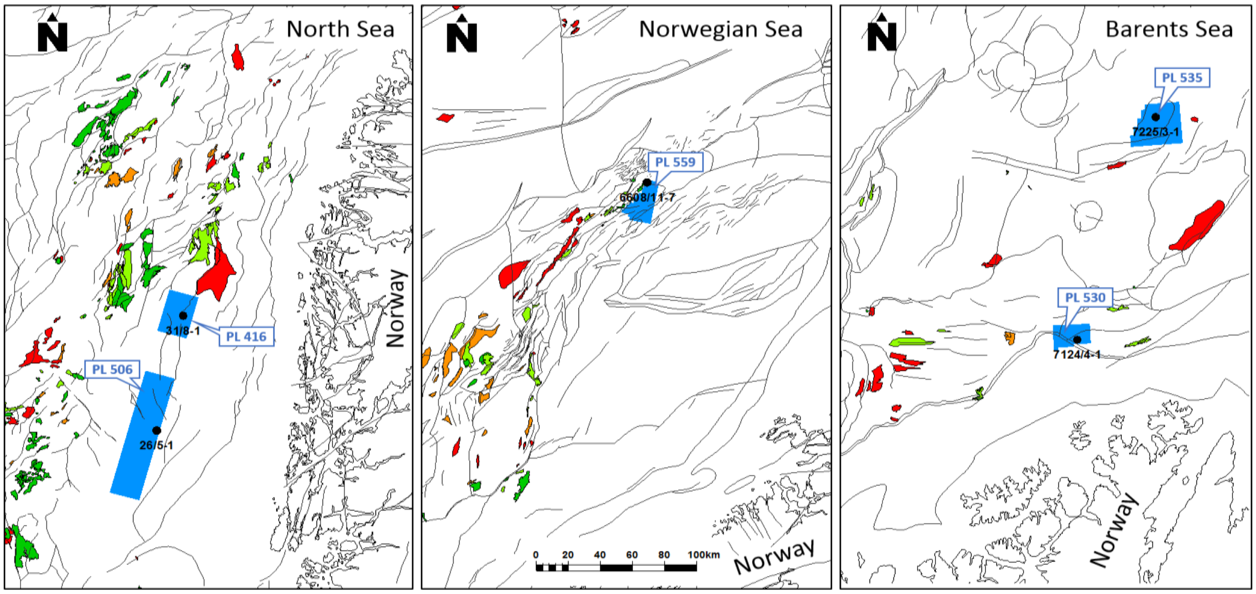


Figure 28 Selected data to be evaluated in the study. Rocksource have tested totally 5 CSEM driven prospects on the NCS, two in the North Sea, one in the Norwegian Sea and two in the Barents Sea.

Based on mentioned limitations pre well estimations is revisited and compared with actual drilling results (Section 6.8). To develop a deeper understanding of how Rocksource evaluated uncertainty and risk it was necessary map the work and decision process (Section 6.1), the organization (Section 6.2) and the used methodology (Section 6.6). It was also important to collect information of how the new CSEM technology (Section 3.12) was implemented in the workflow (Section 6.5) by developing internal software (Section 6.4). The results from the study are of course most relevant for internal use in Rocksource, but widely applicable in for companies implementing new technology when exploring for oil.

5.3.2 Qualitative and quantitative data

Quantitative data is collected to answer the research questions and are predominantly concerned with the actual organizational understanding of uncertainty and risk before drilling compared to the actual results. The quantitative data give also a better understanding of the expectations to the new CSEM technology (Section 6.8).

Qualitative data used to enlighten additional information, give wider perspectives for more open reflections and answers. Qualitative data is collected to improve the understanding of the cultural and contextual assumptions affecting the outcomes of the prospect evaluations. The collected qualitative data describe the organization, methodology and the decision systems within Rocksource (Section 6.1 - 6.7).

The source for both the quantitative and qualitative data is all Rocksource internal data. The data are reports, spreadsheets databases and internal procedures. All collected data is company sensitive internal information and it is difficult to find comparable data and reports. Therefore quantitative data from the NPD in the public domain is used as an additional data source to give additional and wider perspectives (Section 1).

5.3.3 Validity and reliability

In all research, consideration must be given to construct validity, both internal and external, and reliability. In a single case study, external validity can be difficult to attain, but generalizations can be made from theoretical relationships. Yin (1994) suggested use of multiple evidence sources to ensure constructed validity. To secure a high degree of internal validity all relevant data in Rocksource is collected from multiple sources of evidence like historical documents, guidelines and interpreted data. In the case study protocol all data are collected and provides reliability required for the research, therefore the reliability of the collected data is evaluated to be to be high. The validity of the study can be discussed as only five drilled prospects are evaluated, and it can be difficult to draw general conclusions valid for other companies. On the other hand, Rocksource are the only company on the NCS with an integrated CSEM approach to de-risk hydrocarbon prospect and the data must be considered as unique. Almost all companies on the NCS are investing large amounts of money new technology to de-risk hydrocarbons prospect before drilling, therefore some of the findings in the study can used for generalization. The external validity and generalization can be achieved by linking the findings to theoretical relationships and to lightening challenges related to integration of new technologies well known in the industry.

5.3.4 Research question

Uncertainties and risks appears in all project, therefore the company's ability and knowledge to identify, monitor and mitigate risks is critical. In a business with a success rate around 40 % (Figure 15) the understanding of uncertainties and risks are crucial. A new de-risking technology requires knowledge and ability to evaluate the initial prospect risks, in addition to count for uncertainties and risks of technology failure and other possible hazards when implementing a new technology. Rocksource post drilling results, indicates a failure due to high expectations of the new CSEM technology, an inability to realize the risk of a new technology (Section 3.7). Pre drilling the Rocksource communicated high volume expectations of the portfolio (Figure 4 and Section 1). Based on the disappointing drilling results is not clear whether the outcome was a consequence of misinterpretation of a new technology or a generally inability to understand and evaluate uncertainty and risk within the industry:

- How is pre drilling evaluations compared to actual drilling results?
    - How to explain the difference?
- How did Rocksource evaluate geological prospect uncertainty and risk?
    - What methodology was used?
    - What could influence the evaluations?
- What expectations did Rocksource have to the new CSEM technology?
    - How are new technology developing?
    - How are the industry using the new technology?
    - How was the uncertainty and risk for the CSEM evaluated pre drilling?
    - What could influence the evaluations?
- How can other drivers have been important for the decisions?
- How implemented Rocksource new information the projects?
- How can Rocksource improve uncertainty and risk evaluation in the future?

Answers to the questions above can help Rocksource, and other companies, to develop a more realistic best practice for uncertainty and risk analysis. By using available research and performing the planned research, the hope is to increase the awareness for uncertainty and risk processes, in addition to the limits of rationality in the decision-making process. Answers to the research questions can also give an indication of the reliability of a new technology, improved understanding of how a new technology develop over time and finally how the technology can be implemented in the risking process. Based on the findings in the study adjustments and changes can be proposed to improve the decision process for Rocksource.

5.4 Conducting the case study

This case study is based on the methodology devised by Yin (1984) and Levy (1988), each stage of the methodology consist of a discussion of procedures recommended in the literature, followed by a discussion of the application the procedures in the study.

5.4.1 Determine the Required Skills

During my professional career I have experienced the practice of uncertainty and risk evaluations from the perspective of an exploration team member in large and small oil companies. I have also been exposed to different levels of exploration management and being in a group dedicated to providing and developing methods/applications to assess uncertainty and risk in exploration. The background as a working explorer, risk team experience and knowledge has given me a useful understanding of the importance of uncertainty and risk in hydrocarbon exploration and developed a preferred way to understand and evaluate risk and uncertainty. The foreknowledge is important in order to understand the oil industry and the challenges faced in the day to day work, but the foreknowledge can also influence the thesis. Therefore the investigator must be able to function as a "senior" investigator (Feagin et al., 1991).

In the data section it has been important to be objective and only use the raw data from the company without any interpretation, but my background and knowledge is used to secure a good understanding of the data. In situations where the data have been unclear project owners or other relevant experts have been contacted to clarify. To compare forecasted values to real well data, it has been necessary to interpret and evaluate the final well results. The interpretation is performed by using standard well log evaluation methodology, and quality checked by internal experts (without any disagreements).

Based on the understanding of uncertainty and risk in hydrocarbon exploration, the project working hypothesis has been:

- Rocksource struggle to evaluate the uncertainties and risks within:
    - Prospect evaluations
    - Implementing a new technology

5.4.2 Develop and Review the Protocol

The study protocol is important to the overall progress and reliability of the study, in addition to keep the focus on the main tasks and goals. Yin (1994) proposed that the case report to be planned at the start of the project. Case studies do not have a widely accepted reporting format, hence the experience of the investigator is a key factor, but some use a journal format (Feagin, et al., 1991), but not necessarily for other studies. A fixed reporting format is not to recommend as each case study is unique, where the data collection, research questions and unit of analysis cannot be placed into a fixed standard as in experimental research. The protocol for this study report consist of project objectives, case study issues, and presentations about the topics under study. In the report the field procedures presented, credentials for access to data sources and location of the sources, everything presented in a guide for the case study report. All the reports, spreadsheets and documents for this study is collected in a database. The data is reviewed, analyzed and systematized in a spreadsheets (Appendix 3: Datasheets for evaluated prospects) before presented in the thesis.

5.4.3 Collecting the evidence

A successful case study is characterized by three phases; preparation for data collection, collect historical data and analyzes. The case study should use as many sources as relevant to the study, where use of each source requires different skills from the researcher. Not all sources are essential in every case study, but multiple sources of data create a case study database and maintain a chain of evidence, hence increase the reliability of the study (Stake, 1995; Yin, 1994). No single source has a complete advantage over others; rather they might be complementary and could be used in tandem. *Documents* can be letters, memoranda, agendas, study reports, evaluation reports and other items added to the database (Yin, 1994). To increase the validity, the documents in the study are carefully reviewed to avoid incorrect data being included in the data base. The documents are mainly used to corroborate and better understand the evidence gathered from other sources, possible over-reliance on evidence in the documents are evaluated as low. For this study the internal documents are mainly used to support and increase the researcher's understanding of collected data and to avoid problems of miss interpretation. When ambiguous and unclear documents were discovered internal experts was contacted to explain and clarify. *Archival records* have been useful in the study since they include prospect description, records, maps, charts, uncertainty and risk data. In the research much time is used and meticulous work is performed to determine the origin of the records and to secure correct, accurate and high quality of the collected data. *Direct observation* occurs when the investigator visit the site to gather data. The observations could be formal or casual activities, but the reliability of the observation is the main concern. For this study no direct observations has been carried out, but as the researcher is part of the organization a good understanding of the evaluation and decision processes in Rocksource is present. Direct observation is mainly used as additional qualitative data to describe the organization. *Participant observation, physical artifacts* and *interviews* are sources not used in the study. Direct *participant observation* was not possible as the prospect uncertainty and risk, was evaluated before the researcher joined the company. This is important as the potential bias of the researcher as an active participant is avoided. *Physical artifacts* do not have any relevance for the study and *interviews* is opted out of several reasons. Members of the RRT are changed, and some have even left the company. Before collecting all data and good understanding of the historical RRT evaluations is performed direct interviews would most likely have provided answer bias and rationalizations to defend own reputation and professional integrity. Strong personalities of the team members make it also difficult to define good questions before the historical performance to the RRT is evaluated. Results from this study can be used for further studies where interviews are an actual approach and add valuable information to the study. This thesis is limited to evaluate predictions from the RRT over time compared to actual results in order to evaluate if the organization is able to learn. Most likely it is impossible to remove all biases in prospect evaluations, but the biases must be recognized in order to understand where and how biases arise and to minimize them.

Case study is as a triangulated research strategy, searching for converging findings from different data sources increases the reliability of the data and the process of gathering it. In this study triangulation between data, theories (Snow & Anderson (cited in Feagin et al., 1991)) and protocols (Stake, 1995) are used from an investigator triangulation perspective where several projects are investigated to examine the same phenomena (Denzin & Lincoln, 2000). Before deciding on information sources the cost of each source was evaluated and measured against the ability to carry out the task. The data presented in this study is collected from multiple sources and organized in databases, as well as tabular materials, narratives, and other notes, and presented in this thesis. The data is well organized in order for other researchers to use the material based on the descriptions contained in the documentation. The chain of evidence in the study is maintained, to increase the reliability, by involving internal and external observers to follow the derivation of evidence from initial research questions to ultimate case study conclusions. This thesis has citations to the case study database where the actual evidence is to be found.

5.5 Analyses of the case study evidence

Data analysis consists of examining, categorizing, tabulating, or otherwise recombining the evidence to address the initial propositions of a study (Yin, 1994). The analysis methodology of data is one of the least developed aspects in the case study. The researcher use experience and literature to interpret and present the collected evidence in various ways, as statistical analysis is not valid in all case studies. On the other hand an attempt to make the study conducive to statistical analysis could inhibit the development of other aspects of the study.

To avoid bias a general analytic strategy is crucial, to guide the decision regarding what to be analyzed and for what reason. In general, the analysis relies on the theoretical propositions and independent on analysis method the researcher must ensure use of all relevant evidence and rival explanations reflecting the significant aspects of the case study. The researcher's knowledge and experience must be used to maximum advantage in the study to secure the highest possible quality of the analysis.

Pattern-matching as one of the most desirable strategies for analysis (Trochim, 1989). Empirically based pattern are compared to a predicted one, given pattern match, the internal reliability of the study is enhanced. Patten matching is used to understand the relationship between the collected data and the theory. Some discretion from the researcher have been necessary in the interpretation of data. The most common analytic outcomes of compared empirically based patterns with predictions are: *expected outcomes*, predicted results are observed in the data and alternative patterns are absent. *Rival explanations*, searching if theoretically salient are explaining conditions articulated in the empirical findings, where presence of certain explanation exclude the presence of others and *simpler patterns*, derived patterns are predicted to have enough clear differences only with a few variables. Analysis by building an *explanation* of the case and identifying a set of causal links, is frequently used in explanatory case studies. In the discussion part the explanation-building method have been used as an iterative process beginning with a theoretical statement, compare findings in the case, revising statement, revises the proposition and repeating this process from the beginning. In part of the discussion it have been challenging to keep the track of the subject and not drafting away.

The aim for the study have been too rely on all the relevant evidence where all the major rival interpretations are dealt with and the most significant issue of the study is addressed. At the end, expert knowledge is brought to the study.

6 Data and findings

The data and findings chapter present the collected data from the study. The chapter start with a short overview of the decision process (Section 6.1), the organization (Section 6.2) and the responsibility of the RRT (Section 6.3) in Rocksource. Previously Section 3.12 gave a short introduction to the CSEM technology, followed by the development of internal software to handle the acquired CSEM data (Section 6.4) and the strategy in the selection of CSEM feasible prospects (Section 6.5). In Section 6.6 the methodology used in Rocksource to estimate prospect uncertainty and risk is presented. Section 6.7 present a summary of the applied Rocksource workflow, before the last section (Section 6.8) presents pre- and post-well evaluations of the drilled wells together with the associated CSEM evaluation (pre and post well).

6.1 Rocksource decision process

In order to understand the importance of the uncertainty and risk evaluations performed by RRT, the internal workflow and decisions within Rocksource must be understood. Requirements and processes related to the New Ventures and Exploration (NVE) in Rocksource is not described in details, but an overview of the processes and decisions relying on RRT evaluations is presented.

Rocksource's management system is underpinned by decision quality principles, to ensure quality work and thinking to enable good decisions. In the context of NVE this means thinking upfront all the way from accessing opportunities, through drill decision and possible well outcomes. Many stages in the NPV process require RRT decisions, the RRT members need to know and think through the flow of decisions: What will need to be decided and when? A well driven RRT ensure an internal decision discipline, clarity on how an NVE opportunity fit the rest of the business and what resources are necessary to manage each opportunity and can adequately be supported. At each phase of the NVE process Rocksource take a decision on whether and how to proceed. The workflow between each phase should be directed at enabling these decisions to be taken confidently, whilst effectively using the company's resources.

Generally the internal work-flow in Rocksource can be divided into four types of NVE project requiring a RRT evaluation to proceed the process (Figure 29). In some cases the processes are triggered automatically by external processes (License Rounds) or company commitments (License milestones), while other processes are results of one-off decision to initiate the framing phase by the exploration manager (Farm-in/out & Direct Negotiation). The NVE process overlaps with the well construction process (between the Drill or Drop phase and the Post Well Phase), and are also linked to the Strategic Planning and Annual Budget process. At the end of the NVE process (after the Post Well phase) opportunities go into the Appraisal process upon success or are recycled.

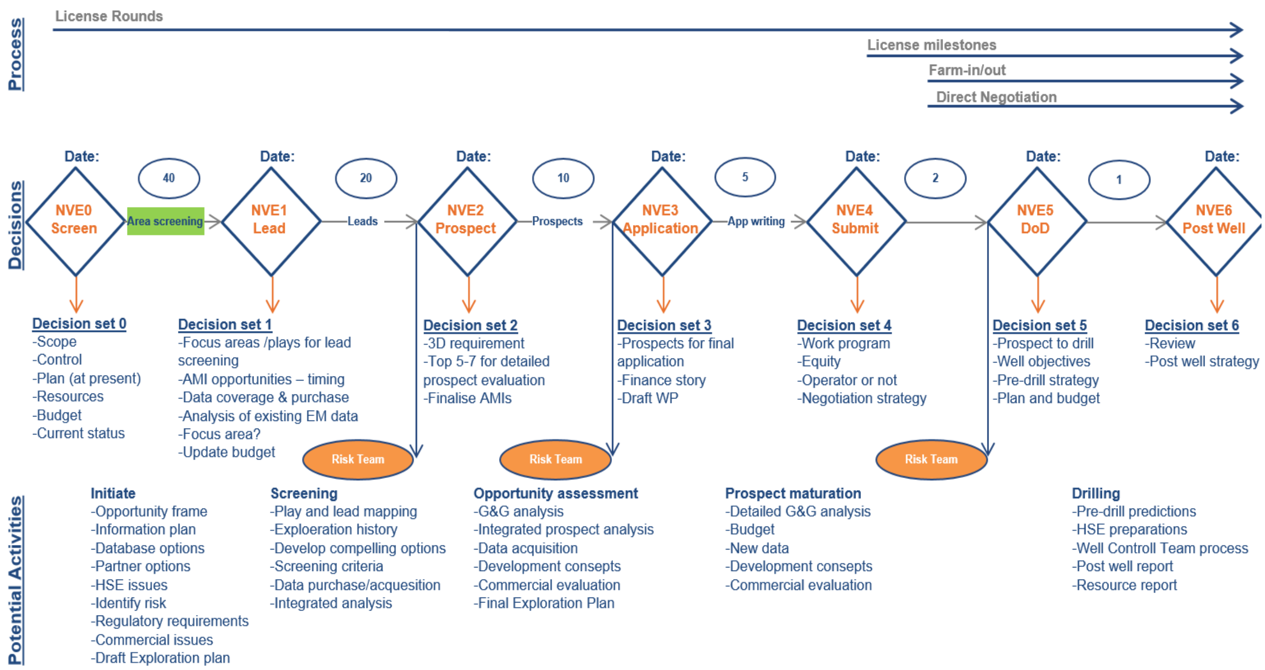


Figure 29 Rocksource RRT evaluations related to working process and decision gates. Source: Rocksource.

6.2 Rocksource organization

In Rocksource the exploration manager is responsible to ensure that the proper decision process are followed throughout the company and shall review the New Ventures and Exploration (NVE) business processes at regular intervals to see that the procedure function as intended (Figure 29 and Figure 30). The VP HSSE&Q is responsible for controlling the implementation of the procedure, and prepare information for the management review to ensure that the requirements set forth in this procedure is followed. Rocksource Line Managers are responsible for projects to follow the requirements described in this procedure in their day to day work. The RRT work as an independent unit, but reports direct to the exploration manager.

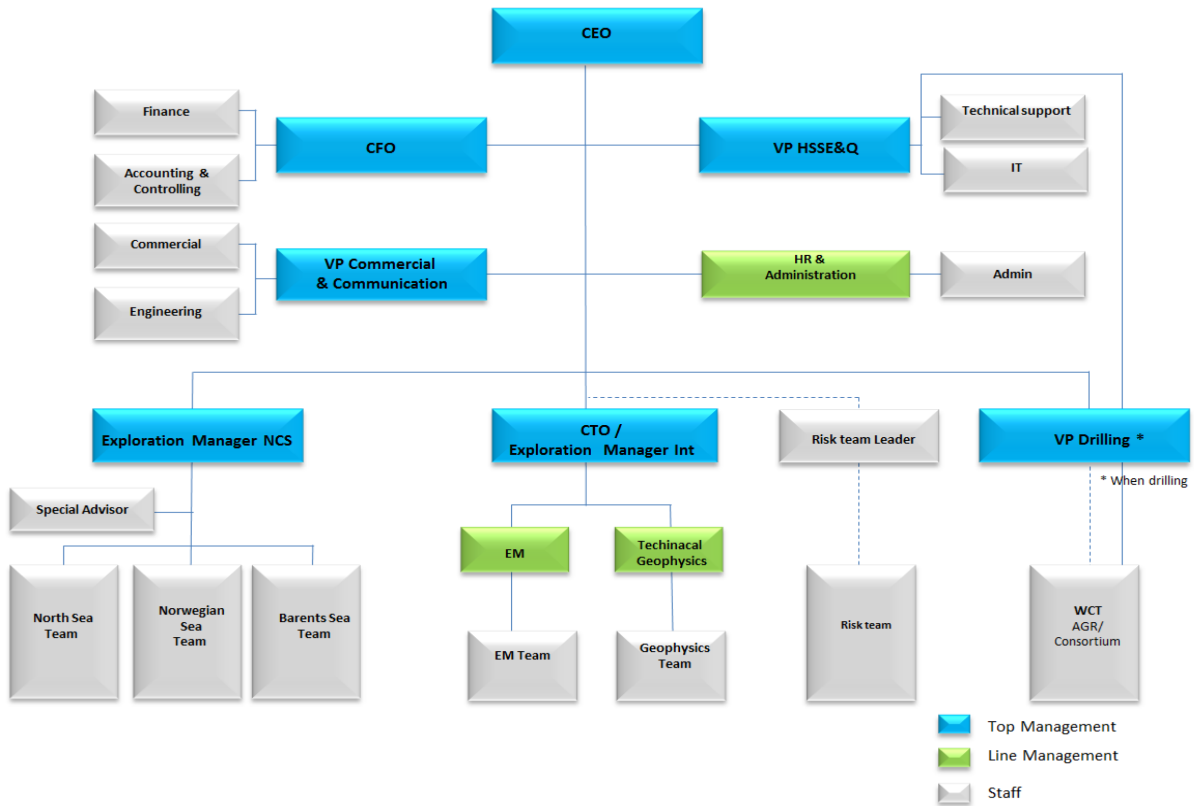


Figure 30 Rocksource organizations chart. Source: Rocksource.

As projects are evolving, the recommendation from risk team is evaluated by the management team, before final decisions are made in management team and board of directors (Figure 31)**.**

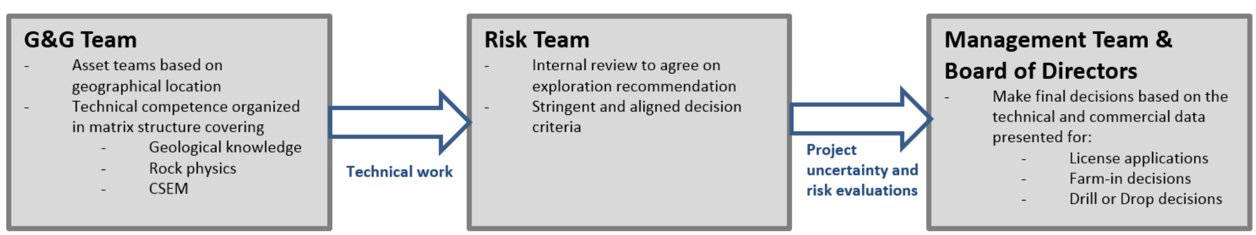


Figure 31 Rocksource Risk Team evaluations influence direct the decisions to the management team and board of directors. Source: Rocksource.

6.3 Rocksource risk team

The RRT assigns the final volume (expectation curve) and COS (Section 3.11) for all prospects. The objective to the RRT is to improve the predictive uncertainties of volumes and risk, achieve consistent evaluation across exploration opportunities, and provide feedback on the technical prospect evaluations. RRT has traditionally consisted of four to five, highly experienced members. The RRT is also responsible for quality check of technical evaluations and integration of geology and geophysics (Figure 30). The final risks are assigned after the meeting, using the input from the technical teams. Assigned risk and volumes are further used in technological and economical project evaluation.

6.4 Rocksource internal developed CSEM tools

In order to understand and use the new CSEM technology, Rocksource developed internal software to handle uncertainties and risks associated with the technology (e.g. geological uncertainties, noise models, survey designs, forward modelling parameters, inversion/migration parameters and reprocessing of real data), and implement it into the company strategy and decisions. Rocksource believed that a good understanding of the CSEM uncertainties and risks could help to define and constrain the COS and geologic-success-case net present value for prospects prior to drilling wells. As such, the CSEM technology has a significant potential to increase exploration efficiency, if applied correctly. To maximize use of CSEM Rocksource developed an internal CSEM processing tool, Rocksource Discover, and Value of Information (VOI) tool, by Decision Strategies, Inc (a company based in Houston).

6.4.1 Rocksource Value of Information (VOI)

The VOI tool was used to take decisions in where the data yields information about multiple uncertainties and requires some thought. As a result, complex decisions trees was used justify CSEM acquisition. Increased confidence of success, manifested as a higher COS, is a combination of the geologically established P_g and the confidence in the interpretation of the CSEM response. The increase in COS and the associated value-of-information from CSEM data are thus strongly affected by the reliability of both the CSEM data and the interpretation of that data. This will again be dependent on: whether or not other resistive bodies are present near the target, signal-to-noise ratio, survey design, quality of processing tools, the experience of the data processor, the interpreter, and more. Pre-CSEM chance of geologic success and detailed CSEM modelling studies was used to decide if a CSEM data set should be acquired by carrying out proper VOI analyses.

Positive reliability: 1 - (probability of a false negative). Hydrocarbons exist at a given location, what is the probability for running a CSEM survey will allow Rocksource to correctly interpret that there are hydrocarbons present?

Negative reliability: 1 - (probability of a false positive). Hydrocarbons are not present at a given location, what is the probability for running a CSEM survey will allow Rocksource to correctly interpret that there are no hydrocarbons present?

After data processing in Rocksource Discover the VOI tool was used to estimate the prospect uplift by implementing a CSEM processed survey on an exploration prospect, given a number of inputs (including the minimum P_g the company considers drillable). The VOI tool estimates the value of interpreting the presence or absence of hydrocarbons following an CSEM survey and/or an seismic AVO analysis, thereby increasing the probability, based on a Bayes's Law, of making the correct decision to drill or not to drill an exploration well. However, either type of analysis is likely to provide additional value in at least two ways: 1) In the event of a positive interpretation, the analysis can give an idea of the size of the potential accumulation, thus helping to prioritize the exploration drilling program. 2) In the event of a successful well, the size indication from the analysis can help to optimize the development plan (Figure 32). The expected post-analysis values of P_g in the event of all possible combinations of a positive or a negative Seismic/CSEM interpretation was implemented by a standard Bayesian transform update the COS based on DHI results. The main criterion is the positive and negative reliability of DHI interpretation.

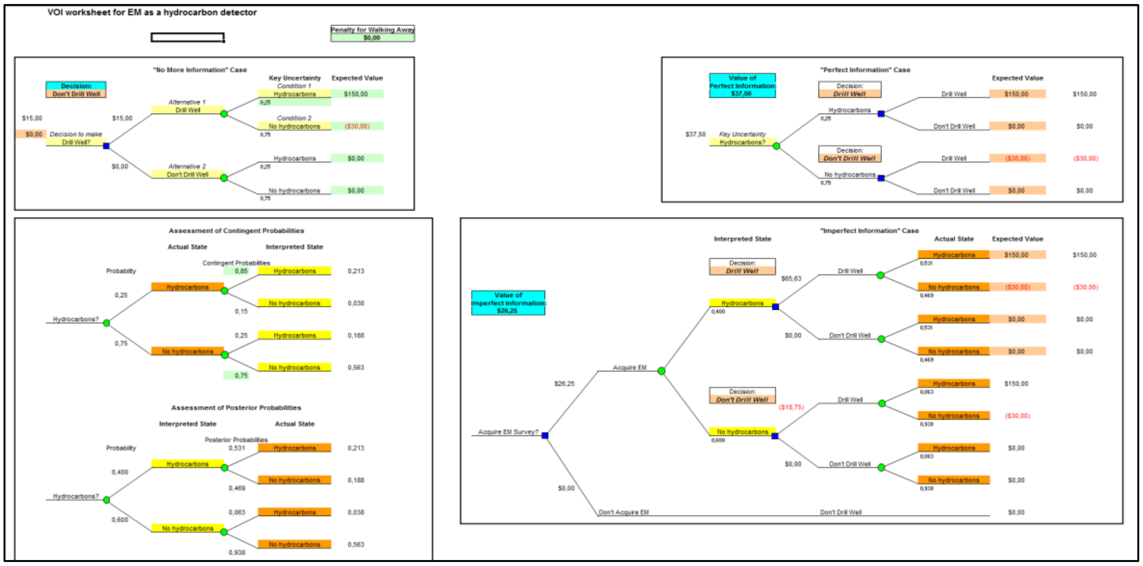


Figure 32 Example of the CSEM DHI VOI analysis tool.

6.4.2 Rocksource Discover

After CSEM acquisition Rocksource Discover was used to process and interpret the data, and to model the hydrocarbons effects on the prospects. Rocksource focused on the development of reliable resistivity inversion techniques that would allow CSEM data to be fully integrated with seismic data and we successfully tested this on a number of real data sets with well control. In addition the Rocksource Discover modelled the prospect in order to evaluate pre- and post-acquisition uncertainties and how to gain a high degree of confidence in the results.

6.5 Rocksource CSEM strategy and workflow

No remote sensing tools can yet, unequivocally detect the presence of hydrocarbons, but new technology can possible change the prospect COS before drilling. Rocksource invested significant money, work and time to identify the correct places to run CSEM. To ensure CSEM value, quality and reliability, the dataset was analyzed together with other available information. No new technology guarantees success, but the right technology, spread across a range of opportunities (portfolio) can significantly improve the chances of drilling the right prospects, accelerating development and reducing the environmental impact. To develop a CSEM friendly prospect portfolio Rocksource developed a work flow (Figure 34):

6.5.1 Initial Basin Screening

As the CSEM technology is not a universally applicable tool, the first stage was to determine where the technology was suitable on the NCS. Limitations include:

- Depth of investigation - as a general rule the effectiveness of the CSEM decreases with depth. Rocksource modeling suggested a 2000 m below seafloor as a cut-off.
- Water depth - CSEM works best in deep waters, as the water column shields the receivers from the background (magneto-telluric) noise and the airwave.

- CSEM detects resistivity in the subsurface, presence of other resistive bodies (e.g. basalt sills, evaporite bodies etc.) and high background resistivity make the tool ineffective to detect resistive hydrocarbons.

6.5.2 Play screening, leads and prospect generation

Once the key areas had been selected, an initial screening of plays (A *play* is characterized by geological factors which are simultaneously present in a clearly delineated area (basin), both stratigraphically and geographically, source rocks and a trap (Appendix 2: NPD's method for evaluation of petroleum resources)) was undertaken to identify suitable targets. Approximately 2/3 of the available NCS acreage was screened out, and focus put on the remaining acreage for prospect identification. Total of 170 prospects was identified, mapped and ranked according to volumetric, P_g, and commerciality. Top ranked prospects where run through the first stage of the internal CSEM process - "Rocksource feasibility assessment." During the feasibility assessment a synthetic model was generated to determine if the prospect was suitable for CSEM de-risking. Ultimately 39 high quality prospects were selected for the CSEM campaign. In addition to the CSEM suitability, prospects were chosen to test different plays to spread the new technology across different areas with different challenges, reducing the risk of single failure factor.

6.5.3 CSEM Campaign

Rocksource commissioned EMGS, CSEM data provider, to collect more than 30 surveys in a campaign. Each survey was individually designed with respect to optimizing orientation, receiver spacing, frequencies etc. for each prospect.

6.5.4 CSEM analyses Phase 1

All the acquired CSEM lines were subject to a "Phase 1 analysis" using Rocksource's proprietary software, Rocksource Discover, and associated work flow. Based on the analysis 1/3 were found to have a clear CSEM anomaly ("CSEM positive") and 1/3 had no CSEM anomaly ("CSEM negative"). The results from the remaining 1/3 were inconclusive and required further analyses to determine if the prospect was worth pursuing or not. The inconclusive interpretations were typically related to issues of data quality and complex geological settings.

6.5.5 CSEM analyses Phase 2

The Phase 2 analysis was undertaken the surveys which had yielded positive or inconclusive results in Phase 1. The Phase 2 work involves more detailed study to determine the reliability of the results and to delineate the extent of the anomaly and thus potentially the hydrocarbon accumulation. Parallel to the CSEM processing, G&G work continued to:

- Improve the understanding of the prospects and refine the P_g.
- Map other prospects and leads within the area in order to evaluate the full potential, beyond CSEM positive prospects.
- Improve the geology and geophysics (G&G) work to optimize the analysis of CSEM data. The geoscientist provided the CSEM geophysicist with geological background models showing how the resistivity is likely to vary both within the target section and also in the over- and underburden.

6.5.6 Commercial analysis and final ranking

Once the CSEM analysis was done, the prospect was presented to RRT to modify the initially P_g and to give an updated COS from the CSEM (and in some cases advanced seismic analysis). This final COS was then used to rank the prospects and to evaluate development opportunities for the chosen areas. Final ranking was based on a combination of COS, size and projects economics.

6.6 Rocksource uncertainty and risk evaluation

In Section 6.3 the responsibilities for RRT were presented. In the following sections tools and methodology used for prospect uncertainty and risk evaluations are presented.

6.6.1 Software to evaluate prospect volume uncertainties and risks

Rocksource, like many other small and large oil companies in the industry, use GeoX software (developed by Schlumberger) for prospect evaluation. GeoX is an "on-the shelf" exploration risk and resource assessment software is an easy-to-use and scalable decision support for risk, resource, and economic evaluation of exploration projects and portfolios. Rocksource used only GeoX to evaluate prospect volume uncertainty and risk, and not taken the full benefit of using the software for an economic evaluation of exploration projects and portfolios. The software enables the company to perform consistent, unbiased, and accurate assessment of exploration opportunities in all exploration environments and risk scenarios. The GeoX software assesses risk and resource opportunities in individual or multiple reservoir compartments, in addition scenarios are summarized in an overall assessment through probabilistic aggregation.

6.6.2 Evaluation of Geological probability (Pg), elements and definitions

Risk exists in the assessment of finding compliable hydrocarbons of any size in a prospect (Section 3.11 and Figure 33). Prior to risks assignment a complete prospect volume calculations, for each separate reservoir interval, is performed in GeoX. For multi-zone prospects a rollup of each zone is preformed and dependency assigned. A standard predefined Power Point template is used to give a brief geological summary, describing the regional geology and the prospect(s). The presentation give an overview of acquired data in the area, well control, seismic and CSEM (including data vintage, quality and density) in addition to a short discussion of the rationale for the uncertainty in the volume estimations for each prospect. The *Project Team* present the proposed risk and recommend further technical work to complete the evaluation and/or de-risk the prospect. Final volume estimations and risk, associated with minimum volumes (P_{99}), is assigned to each prospect by the RRT. Economic evaluations, using the mean value of the volume distribution, are based on the final volume and risk recommendations.

Rocksource risk parameters		
Fluids	**HYDROCARBON CHARGE: (Source, Migration, Timing & Quality)** What is the probability or confidence that hydrocarbons of the correct phase and quality are present, having been generated from an adequate volume and richness of source rocks, such that the trap has had access to them in reasonable quantity to provide producible hydrocarbons at the drill site?	P10 Filled Area P01 Reserves
Rate	**RESERVOIR: (Porosity, Permeability, Thickness & Continuity)** What is the probability or confidence that reservoir rock is present and of adequate permeability to produce at commercial rates at the proposed drill site and has sufficient porosity, thickness and lateral continuity to attempt a development completion?	P10 Porosity P Net Pay P10Filled
Shape	**STRUCTURAL INTEGRITY: (Quantity, Quality & Control)** What is the probability or confidence that the geometry of the trap at the closing contour and the geologic age of the horizon are essentially as represented on maps and cross sections; such that any subtle variation would not jeopardize the accumulation of hydrocarbons at the proposed well?	Closing Contour
Barriers	**SEAL: (Continuity, Proximity, Impermeable & Preservation)** What is the probability or confidence that all top and lateral seals at the median filled area exist with adequate differential permeability and proximity to the reservoir to retain a column of hydrocarbons of sufficient height to be tested by the proposed well?	Median Filled Area

Figure 33 Important elements to evaluate and understand in the risking process.

6.6.3 DHI prospect uplift (COS)

Rocksource methodology allow RRT to assign uplift to the P_g if a DHI is observed in the prospect, and a final COS is calculated (COS= P_g+DHI_{Uplift}, Section 3.11). Rocksource treated CSEM anomalies as a DHI on the basis of that hydrocarbon-filled reservoir typically are associated with higher resistivity than surrounding rocks. A advantage for shallow CSEM anomalies compared to seismic is that CSEM anomalies requires a high hydrocarbon saturation, while seismic DHI can be caused by low hydrocarbons saturation.

Standard geological risking, based on critical, independent parameters, also provides information on the likelihood that a CSEM survey will identify a resistivity anomaly associated with a hydrocarbon-filled structure. The interpretation of a positive CSEM response will result in a revised post-CSEM COS. The post-CSEM COS will be equal to the sum of the chance of a True Positive and the chance of a False Negative (Hesthammer et al., 2010). After data processing in Rocksource Discover the VOI tool was used to estimate the prospect uplift by implementing a CSEM processed survey on an exploration prospect, given a number of inputs (Section 6.4.1 and Figure 34).

The seismic COS update for the Norvarg prospect was based on Seismic Amplitude Anomaly Module (SAAM) program, developed by Rose and Associates. Since Rocksource had not access to the SAAM database the update was not calibrated, which reduces the certainty of COS upgrade.

6.7 Summary of Rocksource workflow

The first stage in the internal Rocksource workflow was regional interpretation. All available data, both seismic and wells, was undertaken to identify suitable plays and areas to evaluate. Prospects was identified, mapped and preliminary ranked according to volumetric, P_g, and commerciality in GeoX before the internal VOI evaluation. After the VOI process the top ranked prospects where run through a CSEM feasibility assessment in the Rocksource Discover software, before a final decision to acquire CSEM data. To optimize future data analyzes each prospect acquisition was individually designed with respect to optimizing orientation, receiver spacing, frequencies etc. After acquisition the acquired CSEM lines were subject to a "Phase 1 analysis" and possible a "Phase 2 analysis" using Rocksource's proprietary software, Rocksource Discover. In parallel, and in interaction, geological work continued to define geological uncertainties and risks (Red arrow in Figure 34). After finalizing all data interpretation, geological, seismic and CSEM, the prospect was presented to the RRT to define a final expectation cure with associated COS. The described process is present in Figure 34.

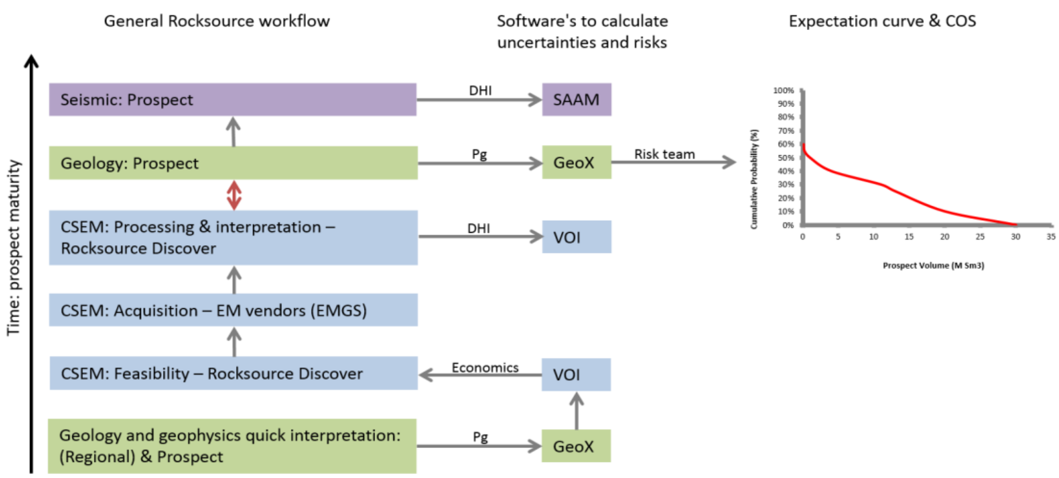


Figure 34 Rocksource workflow, from regional screening to company approved expectation curve and COS.

6.8 Drilled Rocksource prospects

To evaluate the how Rocksource evaluated uncertainty (expressed by the uncertainty curve (Section 3.11)) and risk, the pre well evaluation is compared with actual drilling results for each prospect. All prospects and reservoir levels are tied to wells, interpreted on 2D and 3D seismic data and depth converted using a velocity model. CSEM data is actively used to evaluate uncertainties and risks elements for each prospect. Input parameters used to evaluate hydrocarbon volume in the prospects are based on all available data, including seismic, CSEM, studies, core measurements and petrophysical evaluation of offset wells. The volume uncertainty and risks for all prospects are collected presented in Appendix 3: Datasheets for evaluated prospects.

The used method and tools for calculating the expectation curve, P_g and COS are presented in Section 6.6. In the following sections all drilled prospect are presented, with volume uncertainty and risk. For each prospect the uncertainty used for the volume calculations and the associated risk is presented, both in numbers and a short version of the subjective evaluation from the RRT. The DHI evaluation and final chance of success is also presented. At the end a summary of the post well interpretation is presented together with a post CSEM evaluation.

6.8.1 PL535 Norvarg – well 7225/3-1

The Norvarg prospect is located in blocks 7225/3 and 7226/1 in the Barents Sea and was awarded in the 20th concession round on the NCS. The Norvarg prospect is a multi-zone opportunity in Stø, Snadd, Intra Snadd, Kobbe and Havert formations (fm's) (Figure 35, Figure 36, Figure 37, Figure 38 and Figure 39).

6.8.1.1 Reservoir

Based on relevant wells the Snadd formation (Fm) is anticipated to contain laterally extensive sheet sands with the best excellent reservoir properties. The Triassic Snadd and Kobbe fm's are reservoir both in the Goliat and in the Tornerose discovery, deposited in a fluvial setting (features interpreted as channels are observed), making the reservoir distribution less predictable. The Triassic sands are generally of lower quality and multiple reservoir units separated by shale are commonly observed. The Kobbe reservoirs tend to be mineralogically immature and burial related alteration of feldspar to clay can result in poor reservoir quality. The Havert Fm is considered to have very poor reservoir potential, based upon the deep burial and mineralogically immature sands. No erosion or thinning was observed in the prospect.

Within the ranges used in the evaluation the chance of not having reservoir present, especially for Stø Fm is relatively low. Snadd and Kobbe fm's are common reservoirs in the region, but relatively unpredictable with respect to exact position and properties as wells have failed due to poor reservoir in the Triassic, despite apparent seismic evidence. Reservoir presence for Snadd and Kobbe are relatively low risk whereas reservoir quality, based on the seismic response is regarded as a low to moderate risk (P1 in Figure 35, Figure 36, Figure 37, Figure 38 and Figure 39).

6.8.1.2 Trap

The Norvarg prospect is a four way closure which is compartmentalized by numerous faults in a near radial pattern. The structure clearly observed at all levels and is not sensitive to depth conversion. The spill point is well defined. The risk for not having a structure is extremely low.

The prospect is heavily partitioned by numerous small faults limited throw and mainly juxtapose reservoir against the cap rock or against itself. Even with reservoir-reservoir contact there is a high probability of compartmentalization, especially for the Triassic. Such compartmentalization could give rise to different hydrocarbon contacts, and eventually different fluid types in the different compartments. The overall succession is shale rich with multiple, laterally extensive seal intervals. These include the transgressive packages within the Triassic and the thick Hekkingen shale that overlies the Realgrunnen. Cretaceous shales further overlie the Hekkingen and offset the risk that the crestal faults will breach the top seal of the structure. However the top seal breach and vertical leakage remains a risk, especially for the shallower levels (P2 in Figure 35, Figure 36, Figure 37, Figure 38 and Figure 39).

6.8.1.3 Charge

The basin modelling study showed that the Norvarg structure is most likely charged by a source rock from within the Kobbe Fm. The structure may have received hydrocarbons from a large drainage area and also as a result of spill from nearby structures. The modelling predicts mainly oil in the Kobbe and Intra-Snadd targets, and gas in the upper Snadd and Realgrunnen. However, there is an uncertainty in the migration modelling related to the timing of the uplift episode and the exact amount of erosion. This can affect migration routes and also the timing of migration. There are several discoveries with both oil and gas in the nearby area and these discoveries are most likely sourced from one of the kitchens that drain into the Norvarg area. A good quality source rock has been proven in the Svalis Dome to the west. The source rock risk is considered low for both the oil and gas cases (P3 in Figure 35, Figure 36, Figure 37, Figure 38 and Figure 39).

6.8.1.4 Retention

Although the current depth of the Stø and Snadd fm's reservoirs is only 300- 450 m below seabed, a high degree of biodegradation is not anticipated as it has been buried approximately 1500m deeper prior to uplift experienced high enough temperatures to prevent severe bio-degradation. Changes in the stress system as a result of uplift and erosion may lead to opening of faults and fractures. Several faults are mapped to extend from the prospect and into the overburden, however no faults are mapped to seabed. The late timing of the uplift limits the time available for subsequent recharging.

6.8.1.5 DHI

Detailed analyses forming the basis for estimating CSEM reliabilities are concluded as follows:

- The positive reliability of the interpretation is estimated to 80 %.
- The negative reliability of the interpretation is estimated to 75 %.

It should be noted that the CSEM data suggest hydrocarbons in more than one target and that there are uncertainties associated with which targets are hydrocarbon-filled. Seismic and rock physics study undertaken suggests a weak discrimination between the different fluid saturations, although a positive DHI indications can be observed from the seismic data, the existence of alternative interpretations mean that the reliability of this evidence is not enough to uplift the COS (Prospect summary in Figure 35, Figure 36, Figure 37, Figure 38 and Figure 39).

6.8.1.6 Norvarg prospect summary

To define the overall value to the project multi-layer roll-up was performed in GeoX. Internally Rocksource evaluated the Norvarg prospect as oil mature prospect, containing 44 M Sm^3 o.e. (P_{mean}) with an associated COS of 53 % (Figure 48).

6.8.1.7 7225/3-1 (Norvarg) drilling results

Wildcat well 7225/3-1 was spudded with the semi-submersible installation West Phoenix on 30 April 2011 and drilled to TD at 4150 m in the Permian Isbjørn Fm. No major drilling problems were encountered, but P&A in the upper part was subject to extensive delays associated with trying to retrieve casing, failed cement plugs or leak in 20" casing and extra time spent trying to locate the source of a gas leak. Gas was proven both in intervals from the Jurassic and the Triassic. The Stø Fm was gas bearing from top at 726 m to 766.5 m. In the upper part of the Snadd Fm with top at 804 m was supposed to be gas bearing, but this was not proven by sampling. The best Snadd sands, below 1040 m, was sampled, but turned out to be water bearing. An intra-Snadd section was penetrated from 1146 m to 1521 m, and contained gas in two zones with water contact at 1218 m and ca 1250 m, respectively, and in a third thin sandstone from 1347 m to 1357 m (MDT sampling). The Kobbe Fm was 634 m thick with a 27.5 % net/gross based on petrophysical evaluations. Gas was tested in numerous thin sandstone beds from 1557 m to 1779 m by MDT sampling and by a DST. The Havert Fm with top at 2554 m had only poorly developed reservoir rocks. MDT testing failed, but is assumed to be gas bearing. Rig site analyses of fluorescence (oil shows) and by gas analyses of up to C7 components in mud gas ("FLAIR analysis") suggested that the Stø and upper Snadd gas zones were oil-associated. The deeper gas zones were practically devoid of liquid components based on these analyses.

Four conventional cores were cut in intra-Snadd, (1204-1258 m), Kobbe (1675 to 1695 m), Havert (2610 to 2637) and Isbjørn (4013 to 4016) fm's. During two successful MDT wire line runs a total of 9 sampling stations were performed in Snadd, intra-Snadd and Kobbe fm's. The well was tested in Kobbe Fm, by perforating from 1557-1570 m, 1580-1621 m and 1631-1685 m in the Kobbe interval. The test produced 180000 Sm^3 gas/day through a 44/64" choke. The gas gravity was 0.618 (air = 1). The well was permanently abandoned on 25 September 2011 as a gas discovery (P1, P2, P3 and Prospect summary in Figure 35, Figure 36, Figure 37, Figure 38 and Figure 39).

6.8.1.8 Post well CSEM Norvarg evaluation

In general, the pre-well assessment and previous studies were correct in identifying the potential for hydrocarbon saturation. The pre-well study determined that either two or three level targets were possible, with considerable ambiguity between the deeper prospects at the Snadd and Kobbe levels. The uppermost prospect level, the shallow Stø Fm, was associated with a significant resistivity anomaly at the well, with saturations of 95 % and associated resistivity of 500+ ohm-m). This was evident from both post-well unconstrained and constrained inversions, which proved the requirement for a saturated Stø Fm reservoir to fit the data. For both the Snadd and Kobbe fm's prospects, it is clear that the relatively high background resistivity of the Triassic fm's, in this case the Snadd Fm, and the low resistivity associated with the in-situ saturations of 40-60 %, result in minimal contrast in resistivity between the saturated reservoirs and the background resistivity of the shales above and below. The low resistivity associated with the saturations are a result of the relatively conductive pore fluids (due to high salinity, 60000 ppm = 0.063 ohm-m pore fluid resistivity). The high background resistivity are most likely associated with depth of burial and diagenetic processes that occur to shales at deep depths of burial. Given that the in-situ saturations produced no significant resistivity anomalies above the general background, it is believed that the reliabilities given to an intra-Snadd prospect in the Pre-Well study was too high. The CSEM dataset is currently not adequate for delineation of the Kobbe sand channels. A spacing of 3 km between receivers was also believed to potentially reduce the sensitivity to the channel sands.

Figure 35 Norvarg Stø Gas evaluation (pre drilling uncertainty and risk evaluated by RRT and evaluation of the post well results (primary (black) axis in meters, secondary (red) axis in fraction (0-1) – Data: Appendix 3: Datasheets for evaluated prospects).

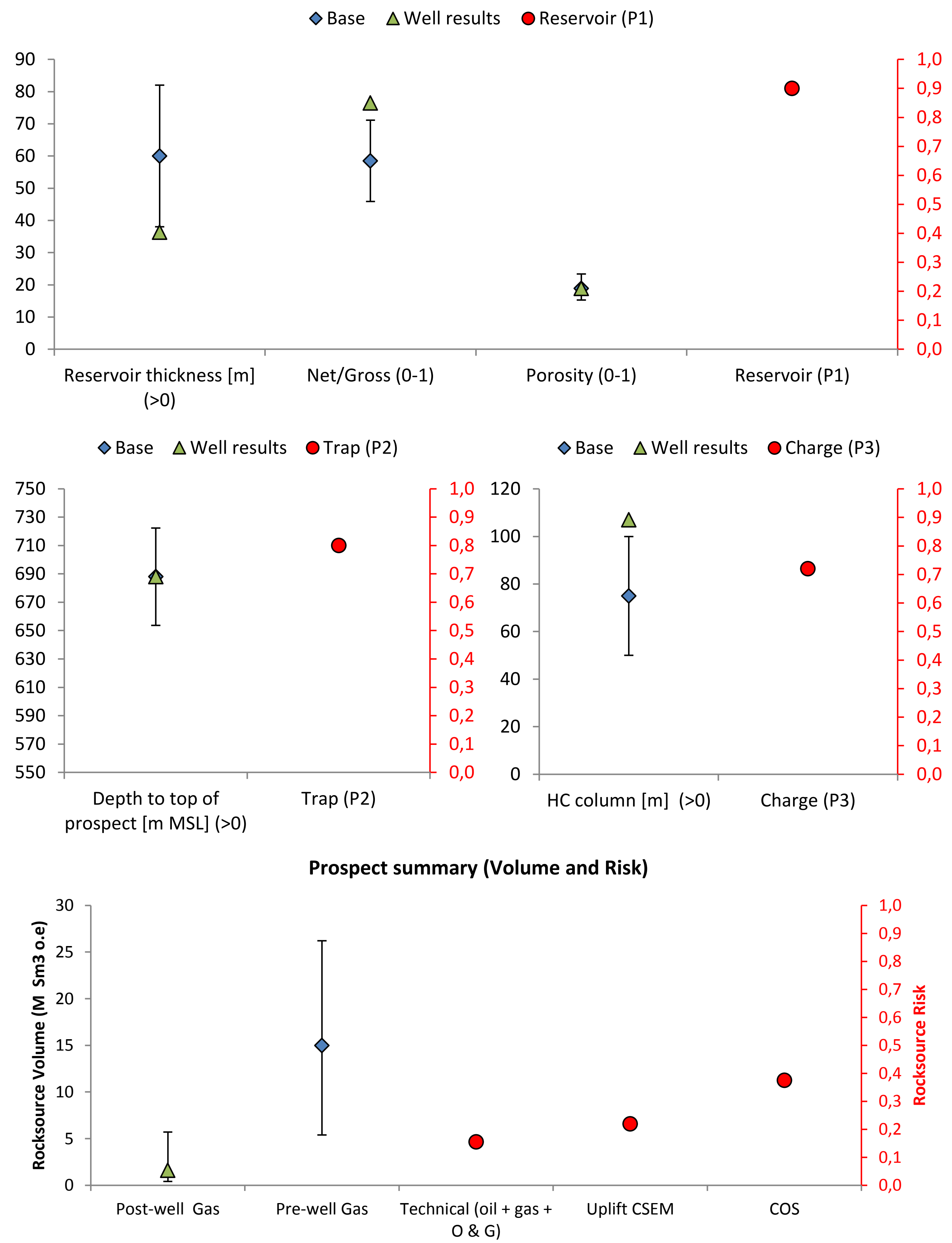


Figure 36 Norvarg Snadd Gas evaluation (pre drilling uncertainty and risk evaluated by RRT and evaluation of the post well results (primary (black) axis in meters, secondary (red) axis in fraction (0-1) – Data: Appendix 3: Datasheets for evaluated prospects).

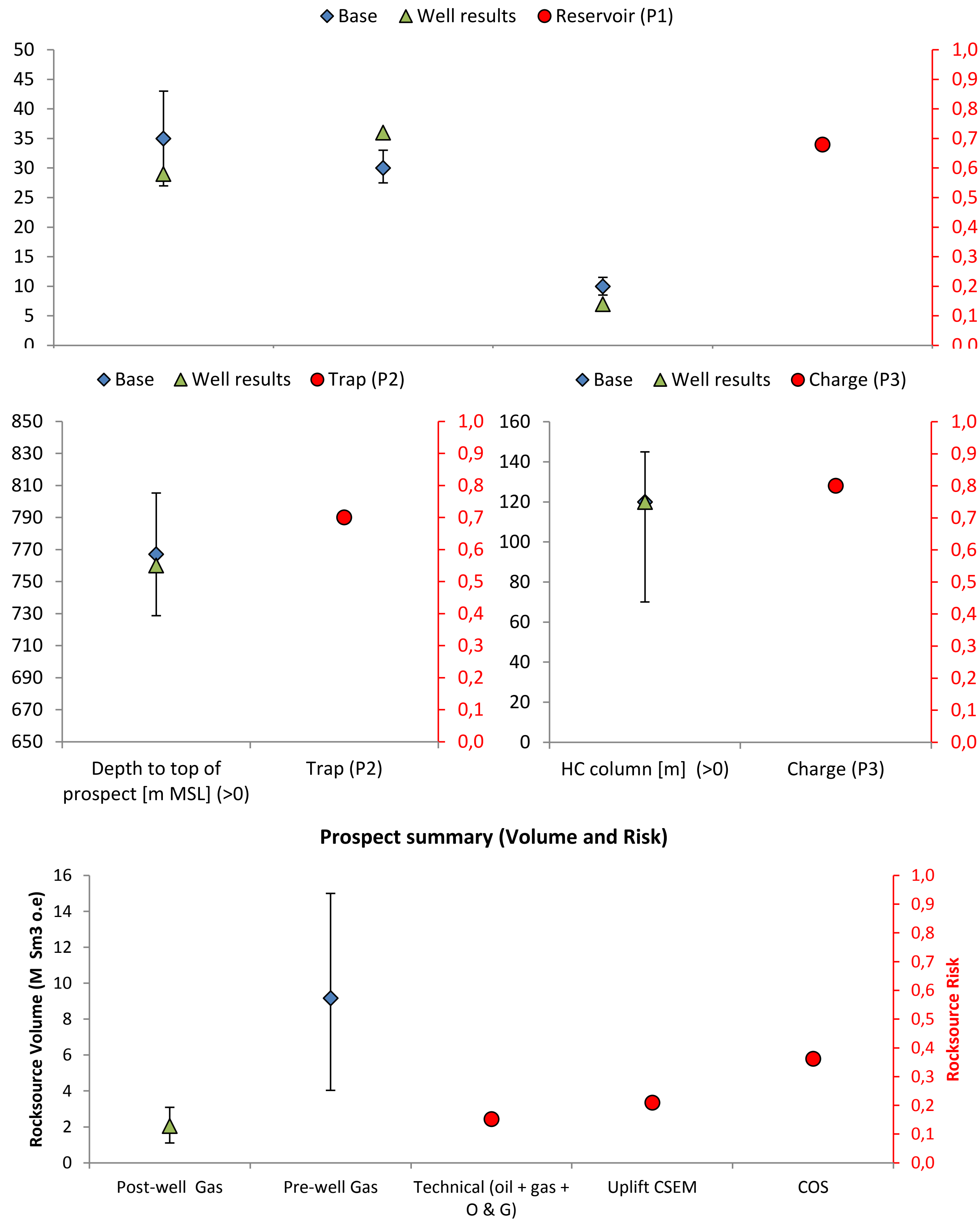


Figure 37 Norvarg Intra Snadd Oil evaluation (pre drilling uncertainty and risk evaluated by RRT and evaluation of the post well results (primary (black) axis in meters, secondary (red) axis in fraction (0-1) – Data: Appendix 3: Datasheets for evaluated prospects).

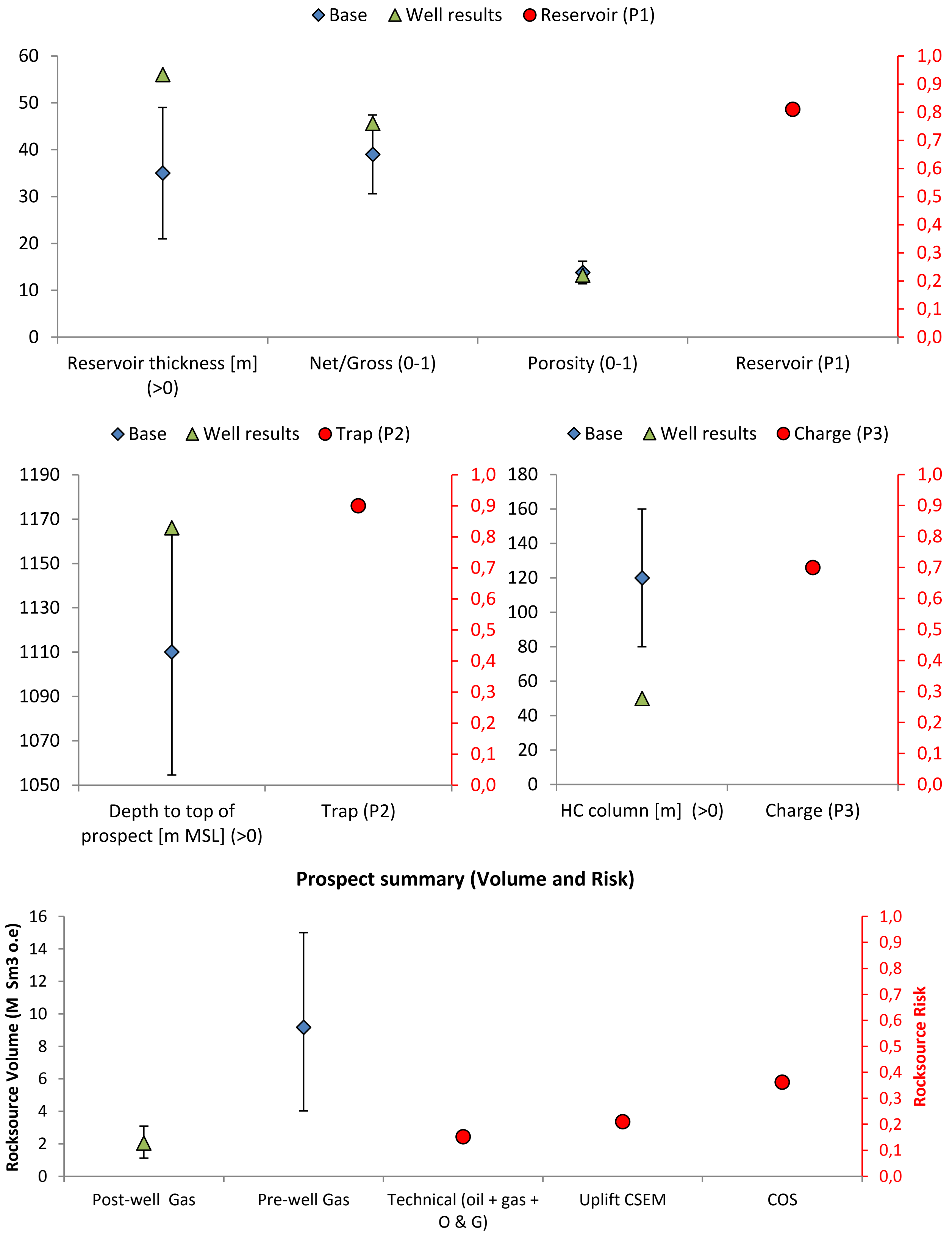


Figure 38 Norvarg Kobbe Oil evaluation (pre drilling uncertainty and risk evaluated by RRT and evaluation of the post well results (primary (black) axis in meters, secondary (red) axis in fraction (0-1) – Data: Appendix 3: Datasheets for evaluated prospects).

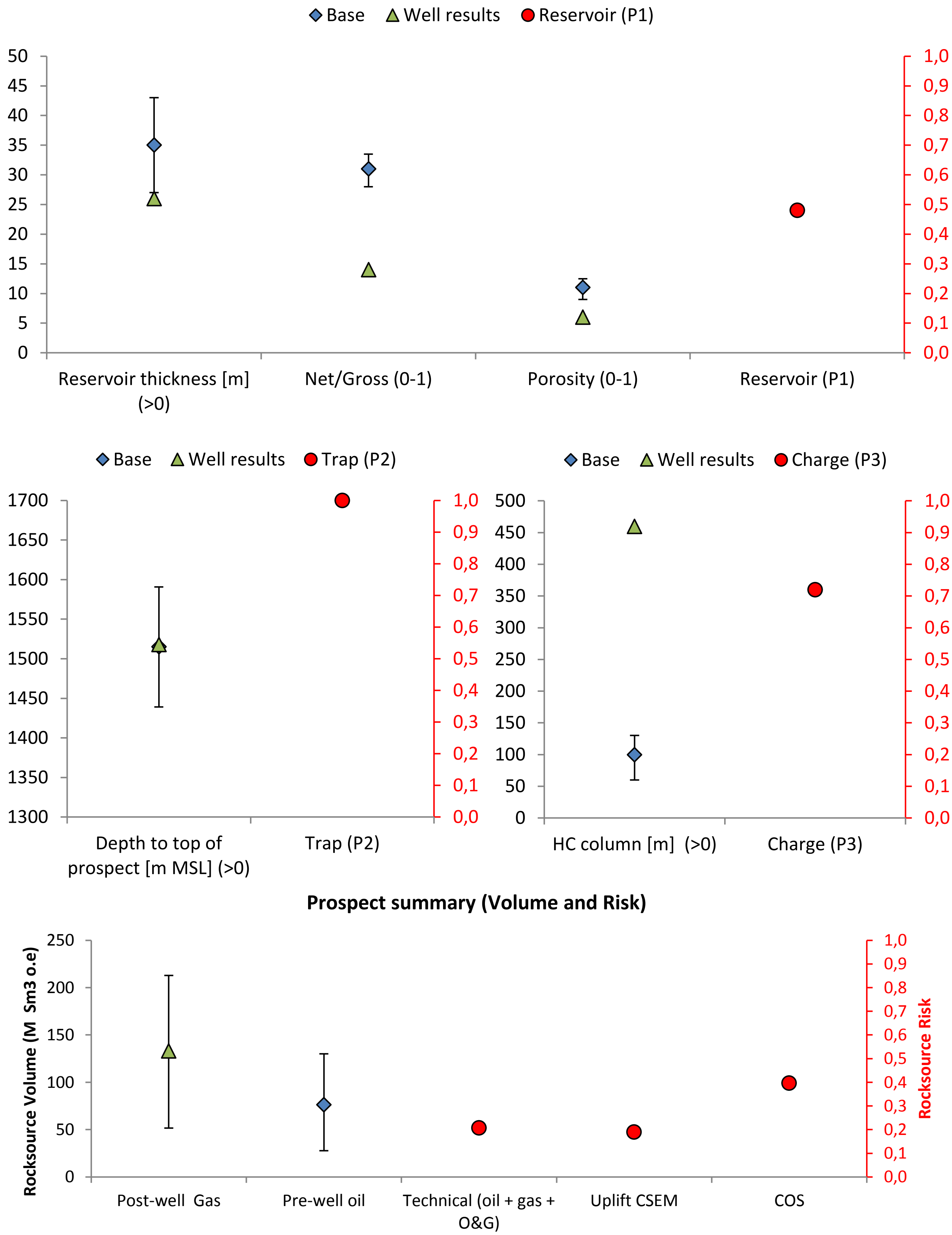
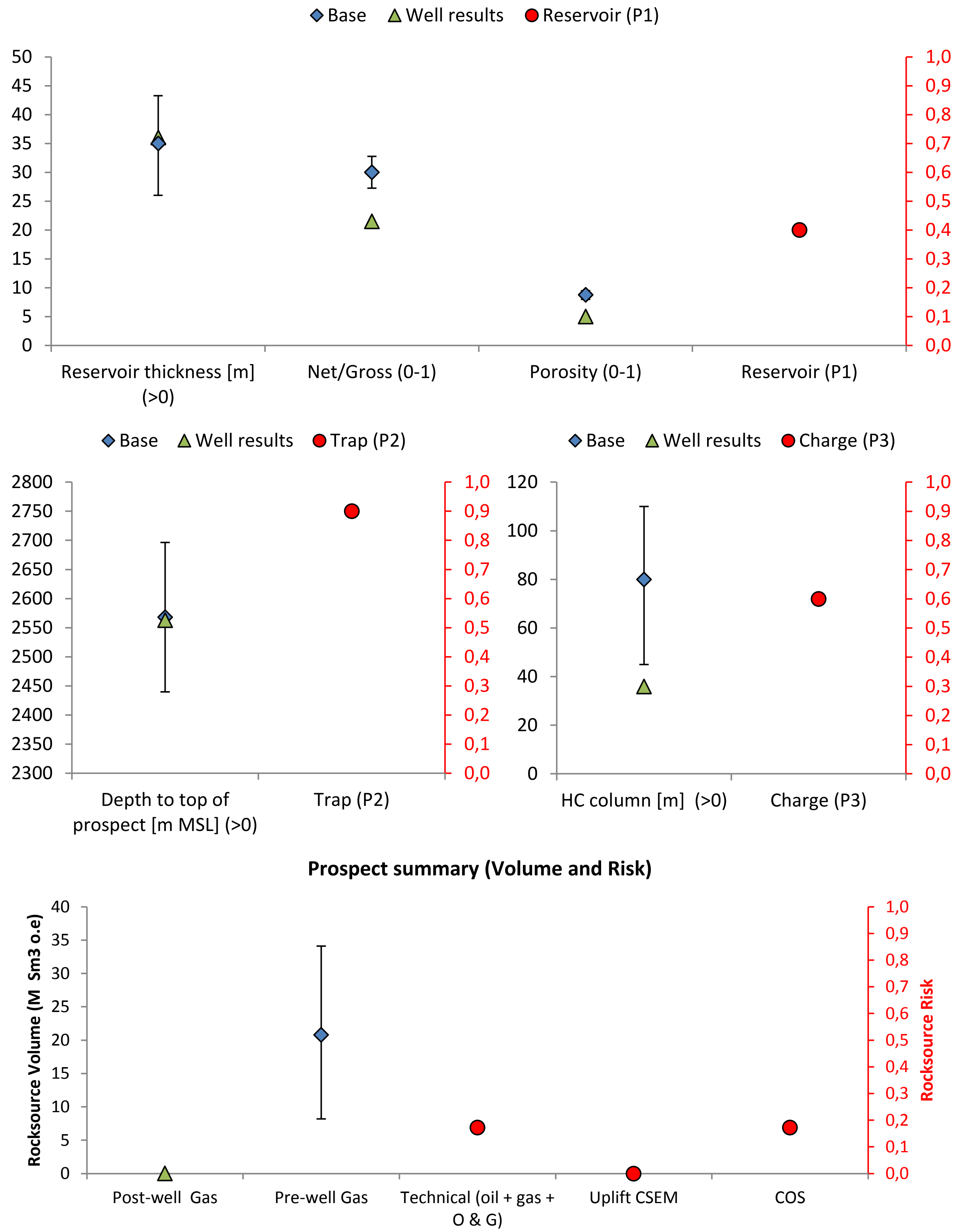


Figure 39 Norvarg Havert Gas evaluation (pre drilling uncertainty and risk evaluated by RRT and evaluation of the post well results (primary (black) axis in meters, secondary (red) axis in fraction (0-1) – Data: Appendix 3: Datasheets for evaluated prospects).



6.8.2 PL530 Heilo – well 7124/4-1S

The Heilo prospect is located in blocks 7123/6 and 7124/4 in the Barents Sea and was awarded in the 20th concession round on the NCS. The Heilo prospect is a multi-zone opportunity in Stø, Snadd, and Kobbe fm's (Figure 40, Figure 41 and Figure 42). The blocs was considered as the "golden blocks" in the concession round as they was located between several discoveries.

6.8.2.1 Reservoir

The Stø Fm is predicted to contain the best reservoir potential, deposited from fluvial to shallow marine setting and are typically mineralogical mature which results in very good reservoir quality in the absence of quartz cementation (shallow burial). Seismic inversion data also indicate high porosity in the Stø Fm, comparable to the upper range of what is observed in Goliat field. The Triassic Snadd and Kobbe fm's are generally of lower quality and were deposited in a less predictable fluvial setting. The Snadd is proven reservoir in both the Goliat field and in the Tornerose discovery. The Kobbe reservoirs tend to be mineralogical immature and burial related alteration of feldspar to clay can result in poor reservoir quality. Channels are observed on various seismic attributes and the inversion cubes show discontinuous zones of low Acoustic Impedance (AI), suggesting channelization with various fill. The RGB blend attribute have a clear high frequency anomaly above the Snadd spill point. The Kobbe Fm is a hydrocarbon filled reservoir both in the Nucula and Goliat discoveries. The Kobbe reservoirs tend to be mineralogical immature and burial related alteration of feldspar to clay can result reduced the poro-perm properties and the reservoir quality. Based on geological setting and seismic inversion the reservoir properties are proposed to be comparable with the Kobbe Fm in the Goliat Field. No erosion or thinning observed in prospects.

Within the ranges used in the assessments there is low risk for not having the Stø reservoir present. The reservoir presence for Snadd and Kobbe is evaluated to have low risk, while reservoir quality is evaluated as moderate risk (P1 in Figure 40, Figure 41 and Figure 42).

6.8.2.2 Trap

Lepus is a faulted 4 -way closure, divided into three main compartments at Stø and Snadd levels, of which the two easternmost are the largest and situated on the main hanging wall of the Troms- Finnmark Fault Complex. At the Kobbe level and (deeper) a closure is defined in the Heilo compartment. The structure is clearly observed at all levels and although the closure is less than 100m high it is not very sensitive to depth conversion, and the spill point is well defined. The area range is wide for Heilo and the risk for not having a structure is very low.

Overall there is a low risk of the prospects failing due to seal. The most important seal for the Stø Fm is typically the Hekkingen Fm which thins over the prospects and may have poor seal properties. However, the structure are overlain by a thick, Cretaceous clay unit and while thief sands may be present this unit should provide a good cap rock. The both Kobbe and Snadd multiple seal units are expected to exist above the reservoirs sands, deposited by transgressive events defining internal pressure barriers and are thought to have high sealing capacity. The presence of seal risk is therefore considered low for all segments. The faults within the prospect have relatively limited throw and either juxtapose the reservoir against the cap rock or against itself. Despite their limited throw these faults may be barriers to fluid flow and compartmentalize the prospect. Compartmentalization is recognized as a risk (P2 in Figure 40, Figure 41 and Figure 42).

6.8.2.3 Charge

The basin modelling and migration modelling studies indicated that the south eastern part of the Hammerfest Basin is likely to be the main hydrocarbon source kitchen for the Heilo area. An oil (and gas) prone source rock is likely to be present within the Hammerfest basin within the Kobbe Fm which has been in the oil window throughout the Tertiary, until the last 2 Ma possible explain the accumulation found in Goliat and Nucula. A two-phase hydrocarbon system with a free gas cap above an oil leg is considered most likely. It is also a possibility that a deeper paleo-column exist in the prospect that is deeper than the present day column. The source rock risk is considered as low both for the oil and gas case. Migration modelling shows several possible migration routes from the Hammerfest Basin into the prospect. In addition the Kobbe source rock is in the oil window within the Heilo area giving possibility for a local kitchen. The migration risk is considered to be low both for the oil and gas case for both prospects for all segments (P3 in Figure 40, Figure 41 and Figure 42).

6.8.2.4 Retention

Changes in the stress system as a result of uplift and erosion may lead to opening of faults and fractures. Especially the shallowest segment has a risk associated with this, and gas is more likely to leak. For Stø Fm it is a high risk for gas as it will receive any gas leaked out from the deeper reservoirs. Kobbe has a low closure and oil will easily be forced below spill point if gas is coming in or expands. Since Kobbe has the lowest closure of all that is also the segment that most easily can lose hydrocarbons as a result of tilting the spill point although it is also a risk for the other segments. Biodegradation is not considered a risk despite the present day shallow burial depths because of high paleo-temperatures and also because the analogous Goliat field is at a comparable depth and its oil is only slightly biodegraded. There is a high risk that the hydrocarbon contact has changed through time as a result of tilting of the traps or as a result of leakage. A paleo-column may therefore exist where the hydrocarbon saturation is low. This may cause a false positive response when interpreting DHI from seismic data.

6.8.2.5 DHI

Overall the CSEM reliabilities are considered as good since the presence of anomalies is supported both by inversion results and normalized difference plots for the 2D line and the scanning data. Synthetic tests indicating that variations in the stratigraphy are not sufficient to produce CSEM resistivity anomalies in the order of the anomalies resolved over Heilo. The Heilo CSEM anomaly suggests a fill level between P_{50} and P_{10} at Stø and/or Snadd level. The negative reliability is relatively low as residual hydrocarbons may be present thus giving rise to the observed hydrocarbon response in the inverted seismic data:

- Positive reliability is estimated to 70 %.
- Negative reliability is estimated to 60 %.

Based on the CSEM evaluation COS in Stø and Snadd fm's was upgraded (Prospect summary in Figure 40, Figure 41 and Figure 42).

6.8.2.6 Heilo prospect summary

The Stø, Snadd and Kobbe prospects intervals are rolled-up in GeoX. Internally Rocksource evaluated the Heilo prospect as oil mature prospect, containing 30 M Sm^3 o.e. (P_{mean}) with an associated COS of 65 % (Figure 48).

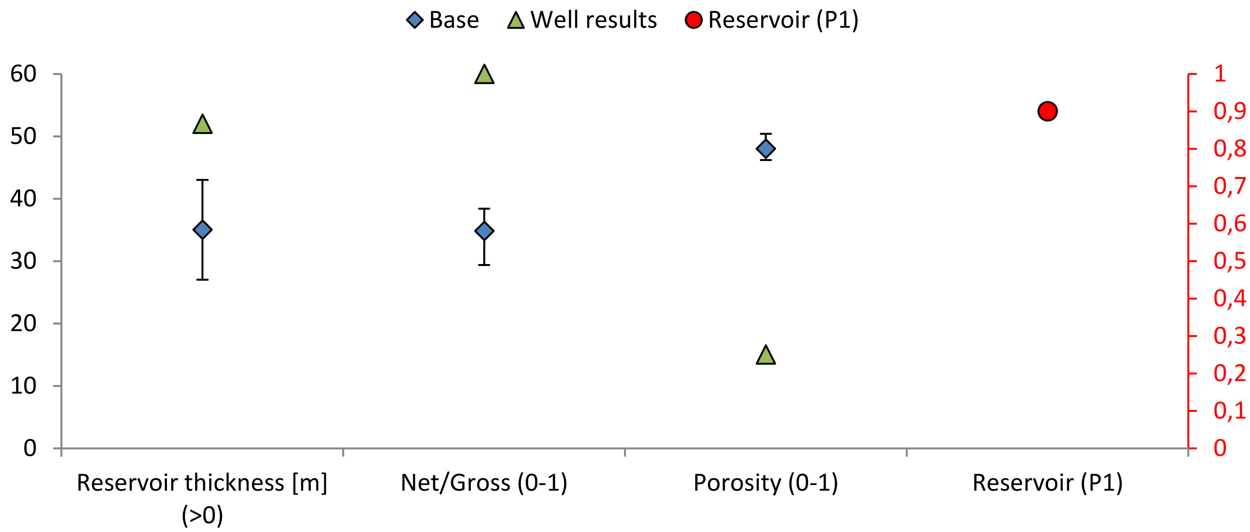
6.8.2.7 7124/4-1S (Heilo) drilling results

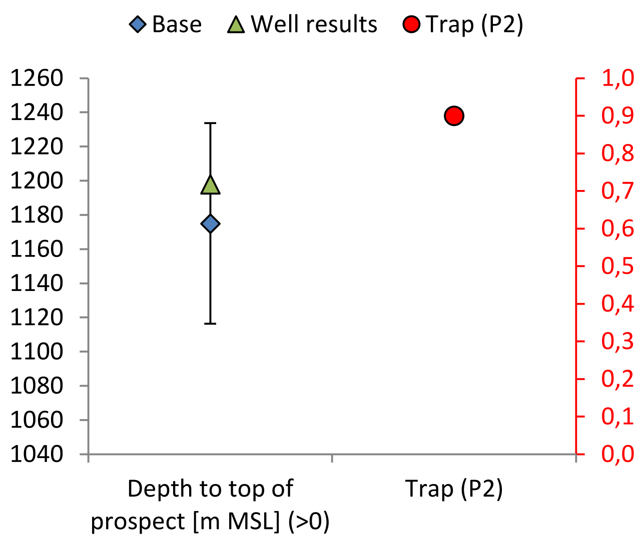
Wildcat well 7124/4-1 S was spudded with the semi-submersible installation Aker Barents on 16 September 2011 and drilled to TD at 2814 m in the in the Early Triassic Havert Fm. The well encountered the Stø Fm at 1259 m. The Stø Fm was 50.5 m thick, with good reservoir quality. The Triassic Snadd Fm at 1330 m also proved good reservoir properties. The deeper Kobbe, Klappmyss and Havert fm's all contained sand layers at the top, but with reduced reservoir quality downwards. No shows were recorded in the well. No cores were cut and no wire line fluid samples were taken. No drill stem test was performed and the well was permanently abandoned on 12 October 2011 as a dry well. Based on the results it is unlikely that hydrocarbons have migrated through the area (P1, P2, P3 and Prospect summary in Figure 40, Figure 41 and Figure 42).

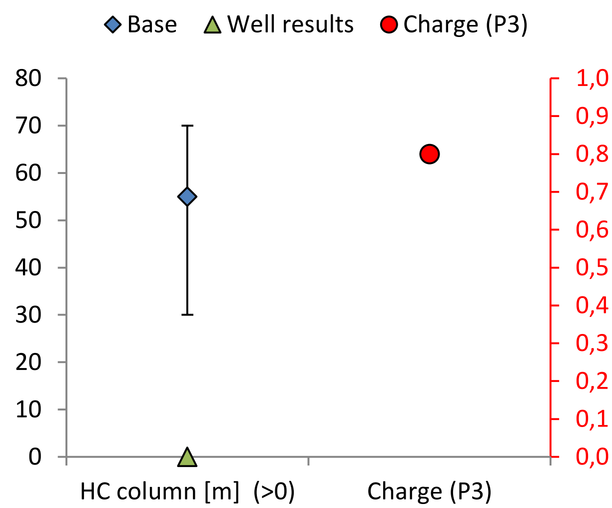
6.8.2.8 Post well CSEM Heilo evaluation

The CSEM data would not have supported a scenario of 50m of good quality sand being filled with HC, but as the pre-drill reservoir predictions were much less favorable, the CSEM data were not able to rule out a positive outcome prior to drill. With the expected reservoir quality at the time, there was a similar fit to the CSEM data whether the target was HC filled or not, and based on lateral variations in CSEM data fit, the pre-drill prediction was leaning towards a HC scenario, but low CSEM reliabilities were given. Comparison of the deep and shallow resistivity logs indicated micro-scale anisotropy for the MWD logs, the same observation was not made for the CPI log. When the combined post-drill resistivity distribution is compared to the pre-drill prediction, most layers are coincide but a better fit was achieved for the pre-drill scenario; although the difference between the pre and post-drill resistivity distribution was limited for most layers. The most important difference is the difference found for the layer just below the seabed.

Figure 40 Heilo Stø Oil evaluation (pre drilling uncertainty and risk evaluated by RRT and evaluation of the post well results (primary (black) axis in meters, secondary (red) axis in fraction (0-1) – Data: Appendix 3: Datasheets for evaluated prospects).







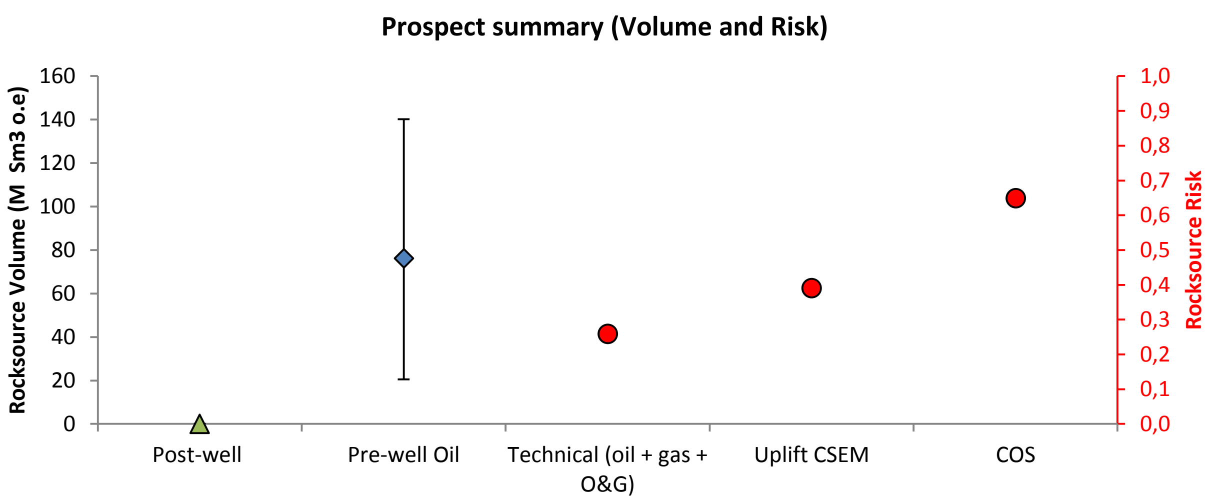


Figure 41 Heilo Snadd Oil evaluation (pre drilling uncertainty and risk evaluated by RRT and evaluation of the post well results (primary (black) axis in meters, secondary (red) axis in fraction (0-1) – Data: Appendix 3: Datasheets for evaluated prospects).

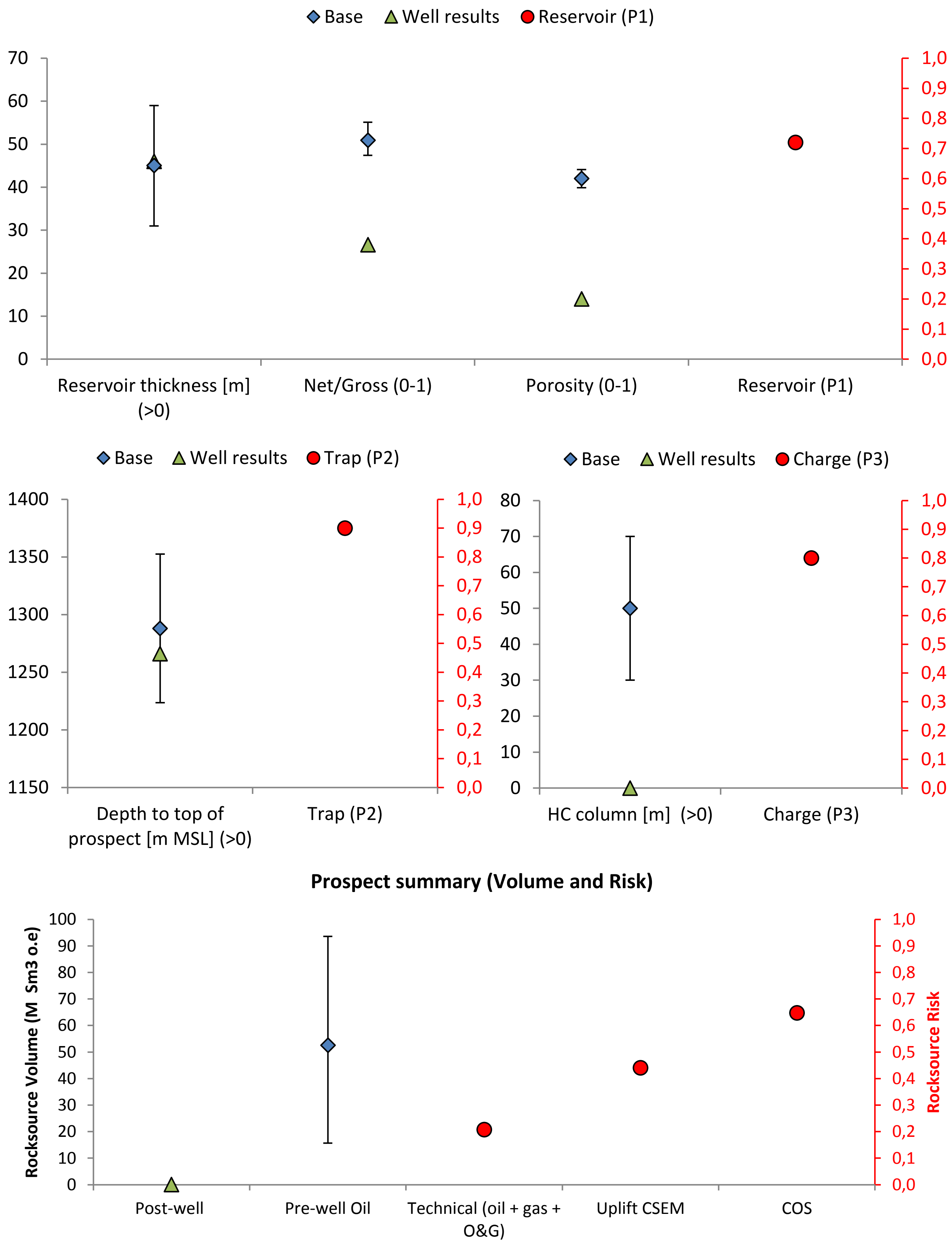
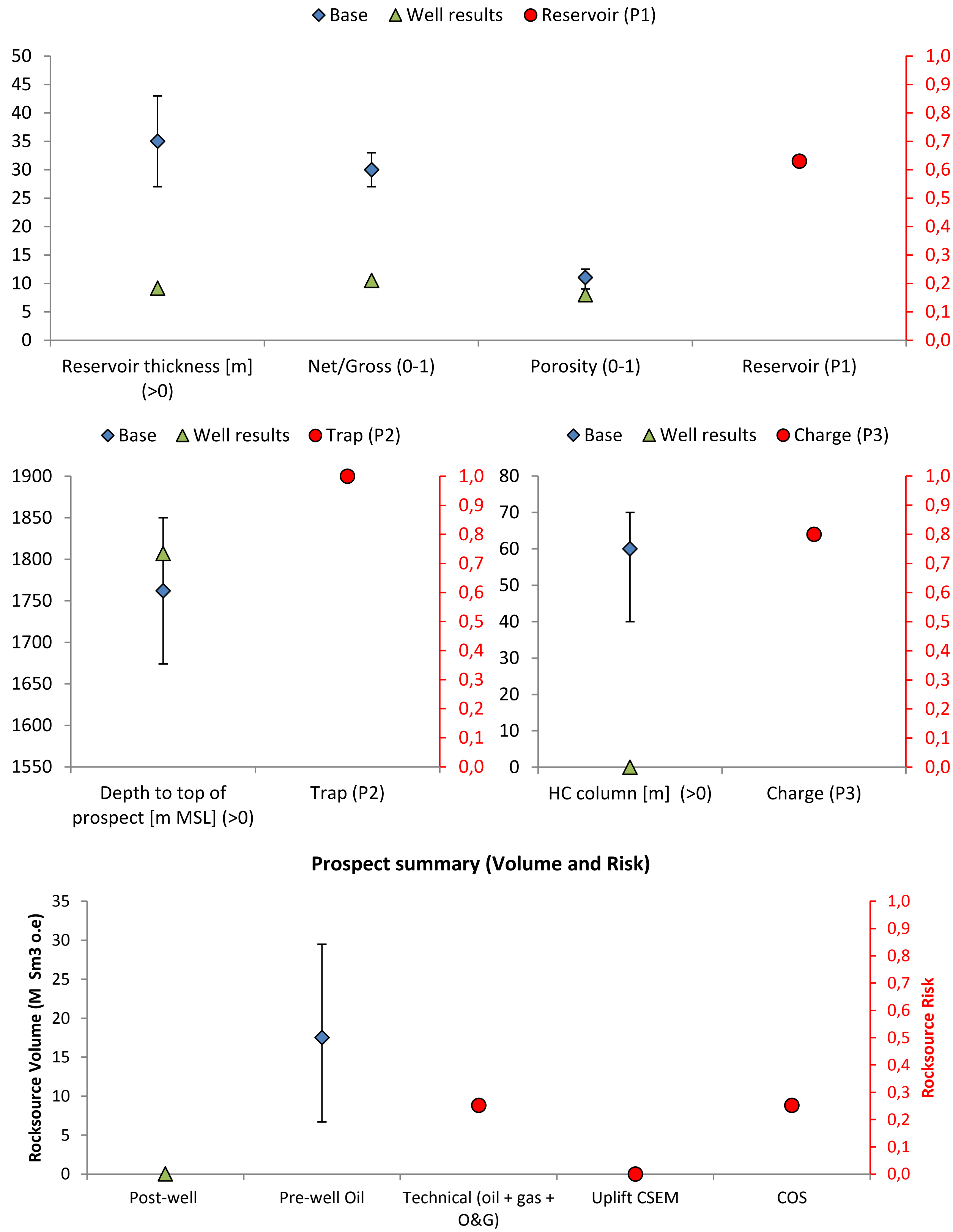


Figure 42 Heilo Kobbe Oil evaluation (pre drilling uncertainty and risk evaluated by RRT and evaluation of the post well results (primary (black) axis in meters, secondary (red) axis in fraction (0-1) – Data: Appendix 3: Datasheets for evaluated prospects).



6.8.3 PL416 Breiflabb – well 31/8-1

PL416 in block 31/8 lies within the Stord Basin, approximately 30 km south-southwest of the Troll Field in the North Sea. The block was awarded in the APA 2006 on the NCS. The primary prospectivity within the block was the Breiflabb prospect, which is a fault controlled structural trap with potential for multiple vertically-stacked reservoir intervals at Sognefjord, Brent and Johansen fm's.

6.8.3.1 Reservoir

The primary reservoir target for the Breiflabb prospect is provided by shallow marine and deltaic sandstones of the Sognefjord Fm, which is also the main reservoir unit in the neighboring Troll Field. The deposits feature a series of coarsening-upward cycles corresponding to periods of rapid progradation, interrupted by fining-upward cycles deposited during transgressive pulses. The reservoir potential in relatively thin Etive Fm consisting of shore face and distributary channel deposits. Johansen Fm forms a clastic wedge that has been interpreted as a large west and northward prograding delta, interfingering with shales and heterolithic deposits of the Amundsen Fm further to the west.

The overall risk associated with the presence and quality of reservoir within the primary target is considered to be low on the basis of the well constrained regional distribution of the Sognefjord Fm and the uniform thickness and seismic character of the reservoir interval from well 31/6-3 to the prospect area. The sand distribution is well understood, and provides good quality reservoir for the majority of the fields on the Horda platform. The reservoir risk for the Etive Fm is considered to be moderate. The reservoir risk for the Johansen Fm is considered to be relatively low, as thick sand sections with high net to gross values were encountered in wells to the north of the Brieflabb prospect (P1 in Figure 43).

6.8.3.2 Trap

Structurally, the prospect is related to, and to some extent defined by the Troll East Main Boundary Fault (MBF). The area appears to be defined by a relay structure with a continuation of the Troll East MBF structure to the southeast and are clearly defined on seismic data and can be well constrained. The prospect bounding faults is mapped with a fair degree of confidence, but does not completely constrain the relationship in the northern part of the prospect.

Based on this seismic data, the Upper Jurassic section contain up to 140m of laterally extensive Heather and Draupne Fm shales and have proven sealing capacity on the Horda platform area. The overall seal risk for the Sognefjord Fm is consequently considered to be low. The seal risk for the Etive Fm is considered to be moderate, as the overlying shales are poorly developed in the southern Troll Øst area and have not been tested in the area around the prospect. The seal risk for the Johansen Fm target is considerably lower, as this interval is overlain by approximately 70 m of Drake Fm shales, which has proven sealing capacity and are expected to have a good sealing capacity (P2 in Figure 43).

6.8.3.3 Charge

The prospect is located directly to the south west of the giant Troll Øst gas field, which has a 65m Upper Jurassic gas column and a 5m oil column, filled by long distance migration from Heather and Draupne Fm shales in the deeper, more mature parts of the basin further to the south and west. Brieflabb prospect lies between the Troll Øst field and the kitchen, and is most likely charged from the same source as no obvious migration barriers as observed. The overall source and migration risk is considered to be moderate, primarily due to the fact that long distance migration is required and no wells have been drilled south of the Troll field. Furthermore, if the prospect does lie on the migration pathway to the Troll field, it is unlikely to be under-filled due to the huge volumes of gas and oil migrating though this area (P3 in Figure 43).

6.8.3.4 Retention

For the Breiflabb prospect the retention is direct linked to the sealing capacity. If hydrocarbons have migrated into the prospect, the retention sealing risk is considered as low. However the retention must be evaluated in the light of uncertainty in the fault interpretation. Fault leakage and potential thief sands have to be encountered as risks.

6.8.3.5 DHI

Seismic sections through the Brieflabb prospect do not have any well-defined flat-spots like those observed on the neighboring Troll field. However, given that Troll is a super-giant field and the majority of the smaller discoveries on the Horda platform do not have any obvious flat-spots either, this does not constitute significant negative evidence. It should also be noted that a possible gas chimney is observed above the prospect. Based on internal evaluation of the CSEM data the prospect was believed to contain oil, and the observed anomaly was related to trapped hydrocarbons. An uplift of 29 % was given for Sognefjord Fm, while the deeper targets remained unchanged (Project summary in Figure 43).

6.8.3.6 Breiflabb prospect summary

The Songnefjord, Etive and Johansen fm's prospects intervals are rolled-up in GeoX. Internally Rocksource evaluated the Breiflabb prospect as oil mature prospect, containing 26 M Sm^3 (P_{mean}) with an associated COS of 44 % (Figure 48).

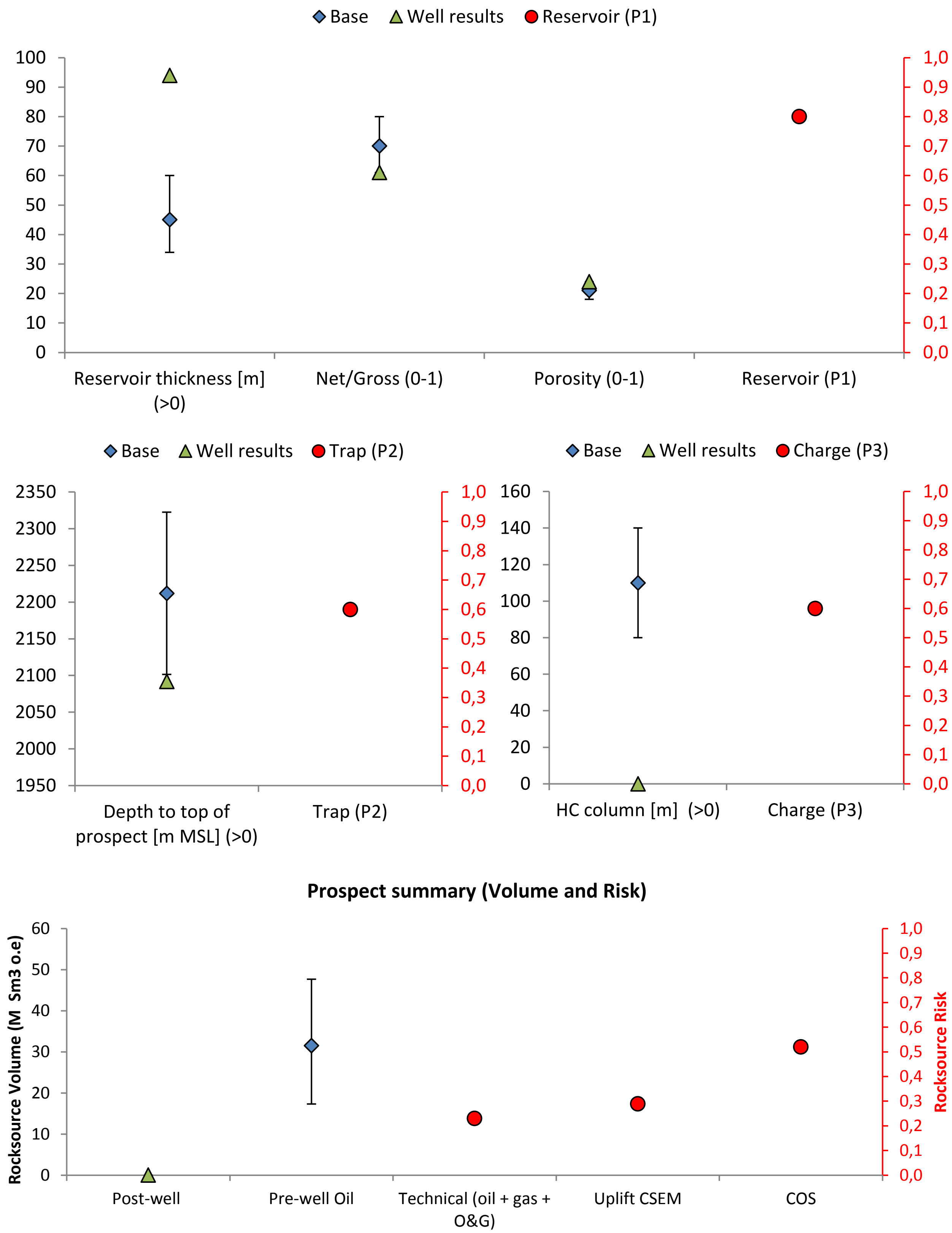
6.8.3.7 31/8-1 (Breiflabb) drilling results

The wildcat well was spudded with the semi-submersible installation Borgland Dolphin on 27 June 2011 and drilled to TD at 2629 m in the Middle Jurassic Krossfjord Fm. No significant problem was encountered in the operations. Top Draupne came in 110 m thick at 1999 m, while Sognefjord, Fensfjord and Krossfjord fm's came in at 2123 m, 2366.5 m, and 2498 m, respectively. All formations were water bearing and no oil shows were recorded in the well. Lower Krossfjord was first believed to be the Brent Group, but biostratigraphy studies concluded that the well did not penetrate top Brent. No cores were cut and no wire line fluid samples were taken. No drill stem test was performed and the well was permanently abandoned on 24 July 2011 as a dry well. Based on the results it is unlikely that hydrocarbons have migrated through the area (P1, P2 P3 and Project summary in Figure 43).

6.8.3.8 Post well CSEM Breiflabb evaluation

New forward modelling, based on resistivity data from the 31/8-1 well, confirmed that the expected response from a hydrocarbon filled target at the depth of the Breiflabb prospect would be weak to moderate. Some anisotropy was required in order to gain a good fit between the real and modelled data. Guided inversion of the real data using a background layer model based on values from the 31/8-1 well showed the presence of a localized resistive anomaly at the target depth, similar to that observed in the pre-drill inversions. However, analysis of different inversion steps showed that the lateral position of the anomaly to be highly inconsistent. On this basis, it is concluded that the anomaly is most likely related to inversion parameterization, rather than a subsurface resistor, and does not justify the uplift to the chance of success that was applied prior to the drilling of the 31/8-1 well.

Figure 43 Breiflabb Oil evaluation (pre drilling uncertainty and risk evaluated by RRT and evaluation of the post well results (primary (black) axis in meters, secondary (red) axis in fraction (0-1) – Data: Appendix 3: Datasheets for evaluated prospects).



6.8.4 PL 506 Storbarden – well 26/5-1

The blocks 26/5 and 26/8 are located East of the Balder and Grane fields in the Stord Basin. The area was awarded in the APA 2008 on the NCS. The primary exploration target is to prove petroleum in the Balder Fm (Storbarden) and Utsira Fm (Langenuen).

6.8.4.1 Reservoir

Balder Fm interval is identified within the despite less widespread clastic sedimentation. In response to a major transgression, extension of the current sand fairway is proposed. The presence of Balder age sandstones are based on observations within the Utsira High area and well-tied reflector correlation. Offset wells with thick Utsira Fm units have proved well-developed coastal-deltaic systems, mainly supported sediment storage within shelfal environments with only minor activity of sediment gravity flows, but the Langenuen position is very different as this is a pinch out trap. A shallow reservoir will encounter good porosity, as cementation is unlikely. However, fairly fine grained sand with high bioclastic content and glauconite can affect the porosity negatively. Poorer porosity must be expected in the more distal pinch out area. Limited understanding of the reservoir unit's development and low sand presence in nearby within the Stord Basin give a high risk for presence and quality of reservoir within the Storbarden and Langenuen prospects (P1 in Figure 44 and Figure 45).

6.8.4.2 Trap

The prospects contains two stratigraphic pinchout elements within the Balder and Utsira fm's. The influence of sediment remobilization is recorded, most commonly expressed as injectite structures. Minor faulting is locally observed within eastern (pinchout) margins of the constituent prospect traps and is also attributed to sediment remobilization. Limited risk is associated with trap definition of the prospects. Up-dip distal pinchout is well defined to the east and has been mapped with a good degree of confidence. The trapping stratigraphic mechanism for both Storbarden and Langenuen fm'sprospects requires top and bottom sealing. Constituent mudstone and claystone facies characterize background sedimentation within basinal environments of this area and provide excellent intra and internal seal potential and are confirmed by petrophysical well evaluations. Balder Fm tuffs provide an additional sealing lithology which gives excellent top seal competence to the Balder Fm. The continuous character of the Balder intervals is interrupted by sub-vertical reflectors interpret as water escape structures and sand injections. The sand injected into overlying series, from the Hermod or Ty fm's, can facilitate communication between reservoir intervals. The presence of competent sealing lithology within the Balder and Utsira fm's is not defined as high risk (P2 in Figure 44 and Figure 45).

6.8.4.3 Charge

Geochemical analyses indicate three possible source rocks in the Jurassic; the Draupne (oil prone), Sleipner (gas prone) and Statfjord (oil and gas prone) fm's. The potential for a gas prone Carboniferous source interval within the Stord Basin is also acknowledged. Due to the unconfirmed status of mature source rock in the Stord Basin, charge and migration represent the main risks within this province. Secondary and long distance hydrocarbon migration is also evaluated, but complexity associated with migration pathways and unproven source intervals within the Stord Basin represent the greatest risk. Dry basin flank wells (26/4-1 and 26/4-2) confirm questionable charge potential (P3 in Figure 44 and Figure 45).

6.8.4.4 Retention

Limited risk is associated with hydrocarbon retention, by the proven sealing potential of the Balder shale within neighboring Palaeocene fields of the east South Viking Graben. The Balder Fm within nearby wells 26/4-1 and 26/4-2 records a dominant shale prone character, however these do not lie within the basin proper - which remains untested. Limited risk is associated with seal competence and capacity. Risk is introduced in response to the acknowledged potential stratigraphic pinch out have leakage through sand prone feeders or other weak zones.

6.8.4.5 DHI

Based on seismic studies a Class IV AVO in the Storbarden prospect. The seismic reliability was considered as low, as there is high chance for the seismic data is interpreted to be no-unique. A potential flat spot, defining the hydrocarbon water contact, was observed in the southern part of the Storbarden prospect. The seismic uplift was evaluated to be 5 % for the Storbarden prospect. The CSEM evaluation have a weak CSEM anomaly up dip of best/thickest seismic anomaly (Positive reliability = 58 % and Negative reliability = 65 %). Based on the CSEM data the Storbarden prospect was given a 9 % uplift (Prospect summary in Figure 44 and Figure 45)

6.8.4.6 Storbarden prospect summary

GeoX rolled-up volumes of the Langenuen and Storbarden prospects give 124 M Sm^3 o.e. (P_{mean}) of oil with an associated COS of 26 % (Figure 48).

6.8.4.7 26/5-1 (Storbarden) drilling results

Wildcat well 26/5-1 was spudded with the semi-submersible installation Borgland Dolphin on 10 April 2013 and drilled to TD at 1910 m in the Tor Fm in the Late Cretaceous Balder Fm. The primary objective, Balder Fm, was entered at 1490 m, but did not encountered sand stones. The well encountered also Miocene deposition, Utsira Fm, at 816 m. The Utsira Fm did not encounter sandstone reservoir, but aquiferous shale. No cores were cut and no wire line fluid samples were taken. No drill stem test was performed and the well was permanently abandoned on 12 October 2011 as a dry well (P1, P2, P3 and Prospect summary in Figure 44 and Figure 45).

6.8.4.8 Post well CSEM Storbarden evaluation

The 2.5D inversion results (both pre- and post-drill) show a good correlation to the up-scaled resistivity distribution logged in the well. The inversion results also make good sense when the vertical resistivity from the log is considered. Except for the 3D inversion results from EMGS, elevated resistivity related to the northern part of the Storbarden outline, both all the internal and external inversion and modelling work were negative. Although the CSEM results over the 26/5-1 well was not a clear-cut case: In hindsight, the 2.5D work (which formed the basis for the reliability estimates) should therefore have downgraded the prospect with a quantifiable amount, whereas the impact of the constrained 3D results remains unknown.

Figure 44 Langenuen Oil evaluation (pre drilling uncertainty and risk evaluated by RRT and evaluation of the post well results (primary (black) axis in meters, secondary (red) axis in fraction (0-1) – Data: Appendix 3: Datasheets for evaluated prospects).

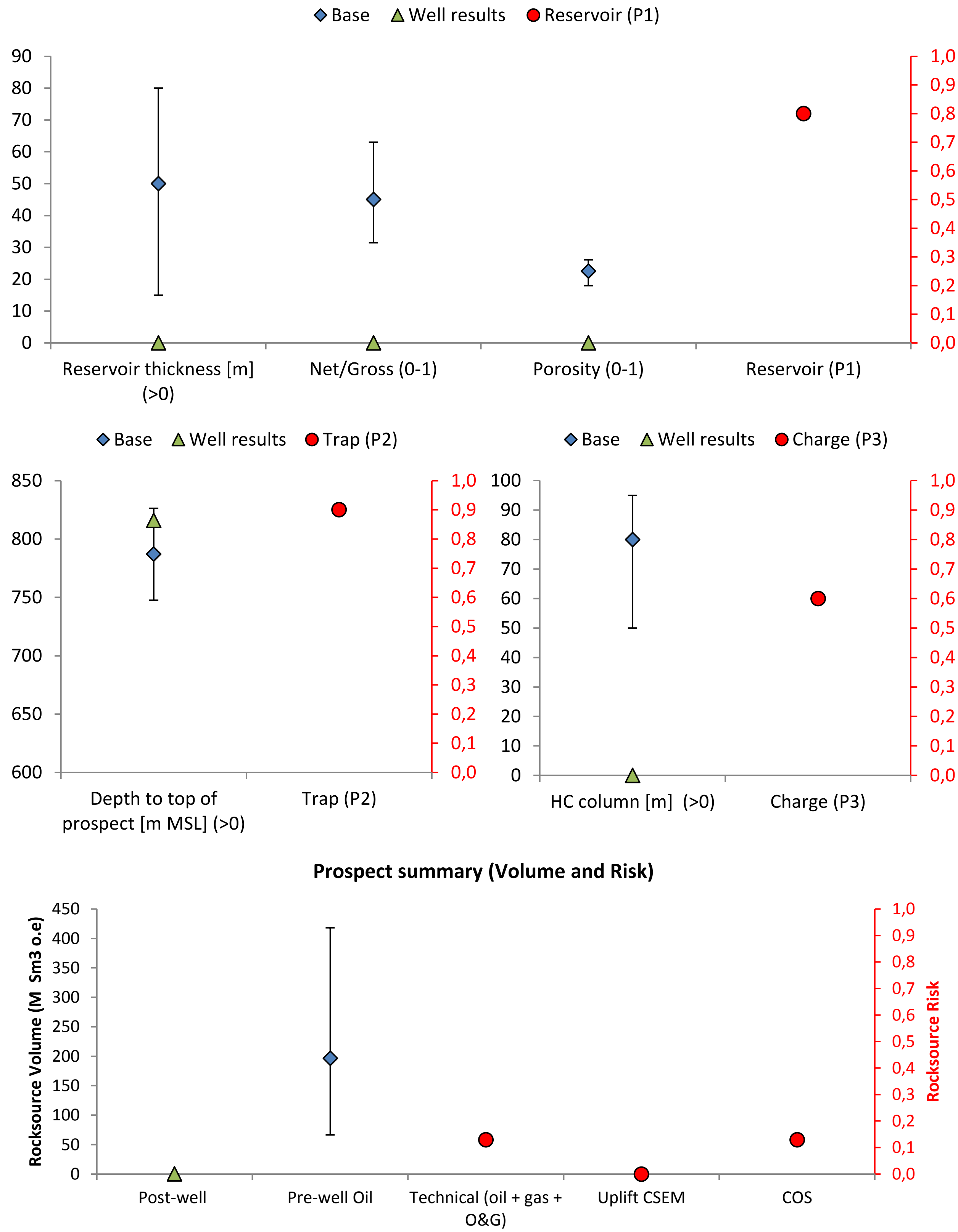
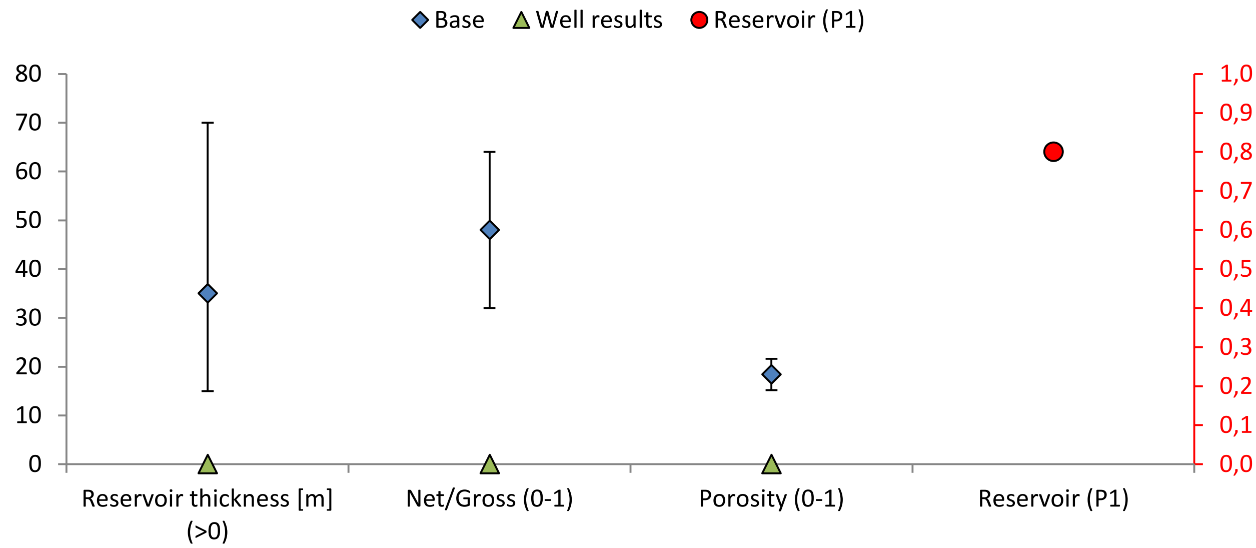
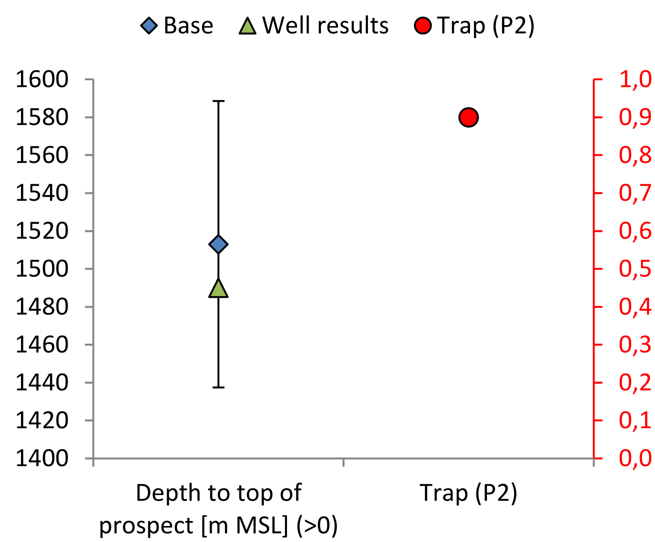
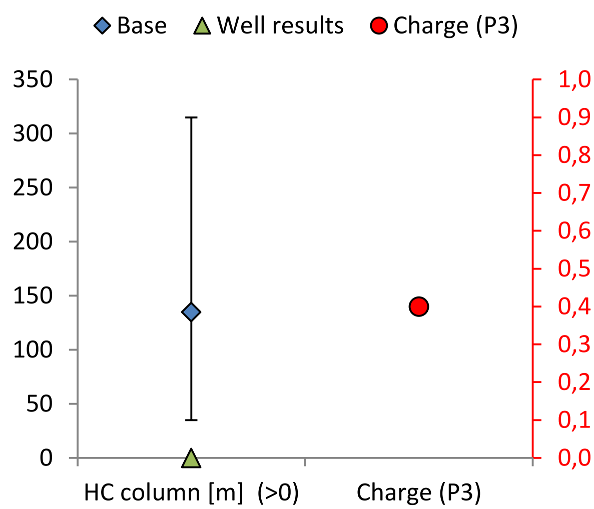
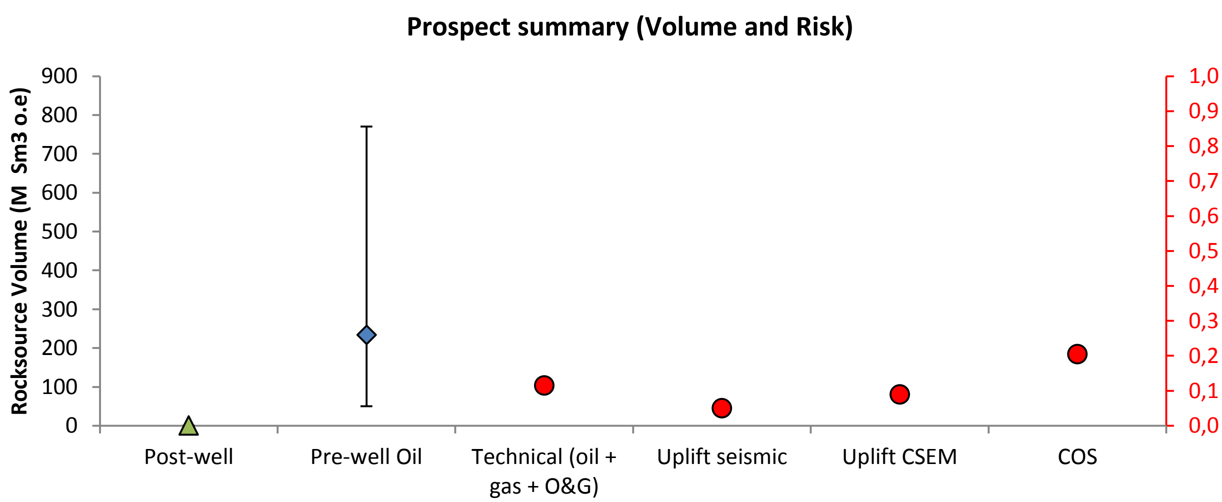


Figure 45 Storbarden Oil evaluation (pre drilling uncertainty and risk evaluated by RRT and evaluation of the post well results (primary (black) axis in meters, secondary (red) axis in fraction (0-1) – Data: Appendix 3: Datasheets for evaluated prospects).









6.8.5 PL559 Phoenix – well 6608/11-7S

The PL 559 license consists of blocks 6608/10 and 6608/11and was awarded in the APA2009. The license is located close to the Linerle Discovery on the Rødøy High in the Norwegian Sea. The primary target in the license was to prove petroleum in Early Jurassic to Late Triassic Åre Fm. The secondary target was to prove petroleum in the Late Triassic Grey Beds and Red Beds.

6.8.5.1 Reservoir

The Early Jurassic Åre Fm sandstones are deposited in a westward prograding coastal- and floodplain setting. Well correlations indicate a prograding delta sourced from an uplifted eastern hinterland. Time equivalent conglomerates are documented by shallow drilling near the present coast to the east. The Åre Fm is well proven and reservoir in the Norne and Urd fields. The formations sand content alternate between mud-prone and coal-bearing inter distributary bay, to swamp units and sand-prone units dominated by fluvial and distributary channels which yield significant, moderate-good quality reservoir sands, over the prospect area. Wells have proven the Grey Beds reservoirs, consisting of a sequence of inter-bedded sands, shales and thin coal layers in which the individual sands can be isolated from each other. The Phoenix prospect are located east of wells 6608/11-4 and 6608/11-5 where the Åre and the Triassic Grey Beds are present with good reservoir characteristics. Reservoir presence at both levels is therefore assigned a high degree of confidence. There is a small risk that the uppermost parts of the reservoir, the better parts are eroded by the BCU. Given the ranges used in for the prospect it is considered to be no risk associated with presence of reservoirs in Phoenix (P1 in Figure 46 and Figure 47).

6.8.5.2 Trap

The Phoenix prospect is a sub-crop trap separated from other wells by a significant north-south fault complex where an extensional faulting has resulted in significant rotation of the hanging wall dip slope. Uplift of the Nordland Ridge led to graben erosion and reservoir is trapped within the sub-crop below a package of Upper Cretaceous shales. The geometry is difficult to map, but the minimum and most likely cases are based on individual closures which seem fairly robust although small. No fault seal is required in the minimum area case, and the caprock is interpreted to exist (P2 in Figure 46 and Figure 47).

6.8.5.3 Charge

The prospect is in a prolific hydrocarbon province with several discoveries, proving a working hydrocarbon system. Basin modelling indicate a possible generation and expulsion migration from the Spekk and Melke fm's source rocks and migration along a series of carrier beds or major fault zones. The Phoenix prospect could also be filled through a complex migration route and spill from the proved Linerle discovery. Both the closest wells, 6608/11-4 and 6608/11-5 proved hydrocarbons, although not very large columns. No risk is associated with the maturation of the source rock for the oil case (P3 in Figure 46 and Figure 47).

6.8.5.4 Retention

Due to relatively shallow burial and low temperatures there is clearly a potential that the oil is heavy and biodegraded as seen for example in the nearby Linerle discovery. However this has been accounted for in the ranges and is therefore not considered as a risk. Given the high density oil which it is expected the fault is only required to hold approximately 2 bars for a HC column between 125 and 200 m, and the retention risk is considered as low.

6.8.5.5 DHI

AVO analysis has not been performed, as AVO feasibility studies have indicated that the Jurassic and Triassic sands (6508/5-1 and 6608/10-6) will not give an AVO response to fluid content. Although flat events have been observed in the Phoenix Fire prospects no uplift has been given. A "positive anomaly" was interpreted from CSEM data that was acquired over the Linerle prospect prior to drilling the discovery well 6608/11-4. For the Phoenix prospect special studies were carried out, to assess whether the observed CSEM anomaly over Valkyrie can be explained by electrical anisotropy, or whether the well actually did not test the CSEM anomaly. It is very improbable that even an extreme case of anisotropy could cause the observed anomaly, whereas a synthetic model with a resistive hydrocarbon filled target located just north east of the well (Phoenix) give a good match to the real data. The observed anomaly observed in the real data cannot be explained by anisotropy, but can be explained by a hydrocarbon filled Phoenix. Rocksource hypothesis is that Statoil drilled the 6608/11-5 well without testing the observed anomaly and the failure of the well was erroneously related to electrical anisotropy. The CSEM technology de-risk the prospects in the area (Prospect summary in Figure 46 and Figure 47).

6.8.5.6 Phoenix prospect summary

The different levels, Åre and Grey beds, in the Phoenix prospect are rolled-up in GeoX. Rocksource evaluated oil to be the most likely phase. Totally the prospect contained 26 M Sm^3 o.e. (P_{mean}) of hydrocarbons with an associated COS of 50 % (Figure 48).

6.8.5.7 6608/11-7S (Phoenix) drilling results

Well 6608/11-7 S was spudded with the semi-submersible installation Borgland Dolphin on 7 September 2011 and drilled to TD at 2435 m in the Triassic Red Beds 75 m below top Carnian. Drilling the hole went quick and efficient, without significant problems. Due to hole-problems the wire line program was less than planned. Stuck logging tool and fishing caused 102.5 hours down time. The primary objective Åre Fm was entered at 1657 and had reservoir properties of lower quality than expected. There were traces of fluorescence in the top of the Åre Fm. The Grey Beds had better reservoir properties than expected, but was dry. Post-well geochemical analyses did not confirm these to be migrated hydrocarbons. Otherwise there were no indications of hydrocarbons in the well. No cores were cut and no wire line fluid samples were taken. No drill stem test was performed and the well was permanently abandoned on 12 October 2011 as a dry well (P1, P2, P3 and Prospect summary in Figure 46 and Figure 47).

6.8.5.8 Post well CSEM Phoenix evaluation

Calibration of well data to inversion results give a new CSEM inversions maps give a horizontal resistivity within what is acceptable, but a 2.5D inversion is less reliable in areas with thin resistivity. All the EMGS 3D inversion anomalies are confirmed through the new Rocksource updated workflow. Petromarker, CSEM data provider, data seems to be able to map out Falk discovery, better than EMGS data. More integrated interpretation and geological understanding (seismic data/inversions) is necessary for improved understanding of the strong CSEM anomalies.

Figure 46 Phoenix Åre Oil evaluation (pre drilling uncertainty and risk evaluated by Rocksource risk team and evaluation of the post well results (primary (black) axis in meters, secondary (red) axis in fraction (0-1) – Data: Appendix 3: Datasheets for evaluated prospects).

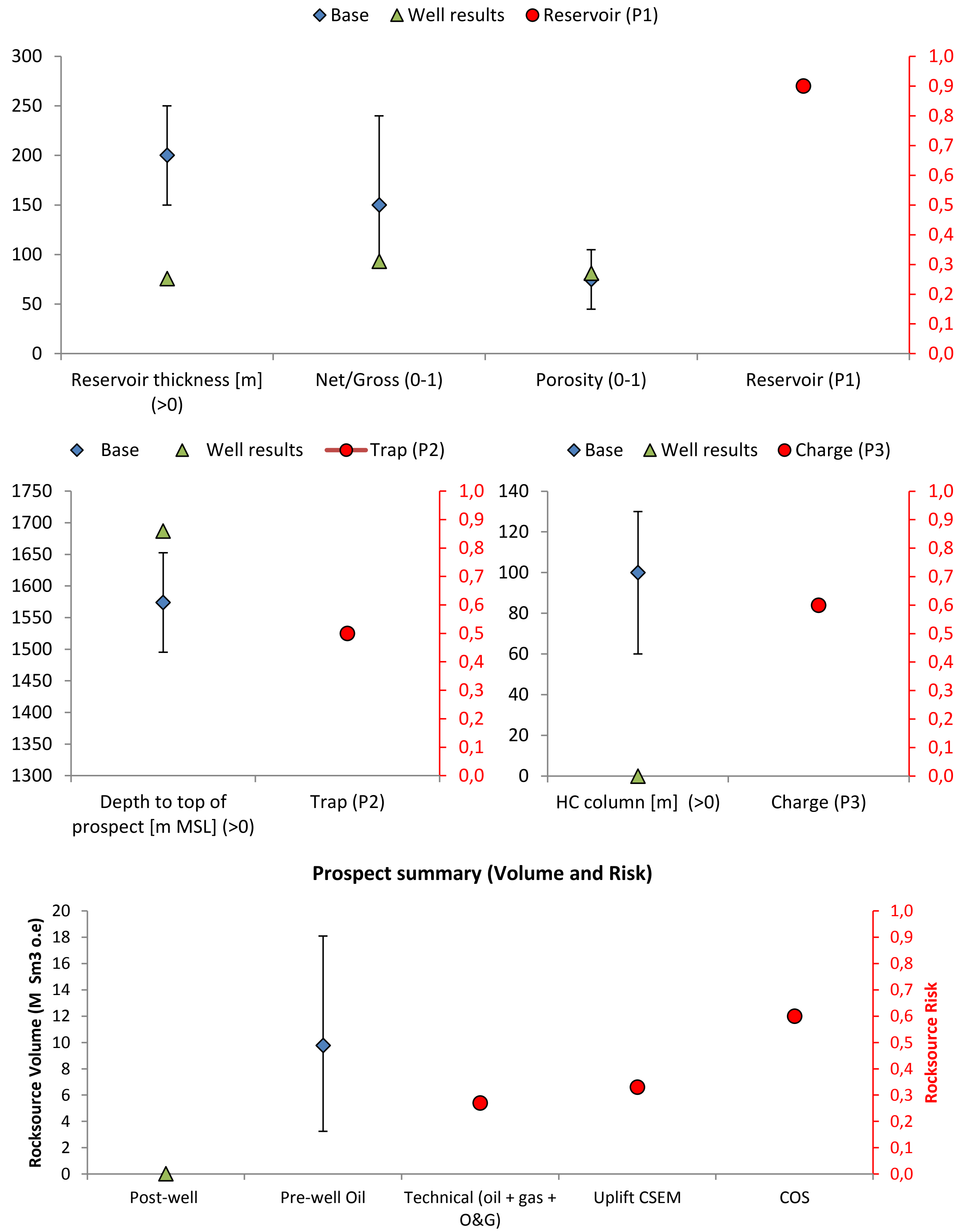
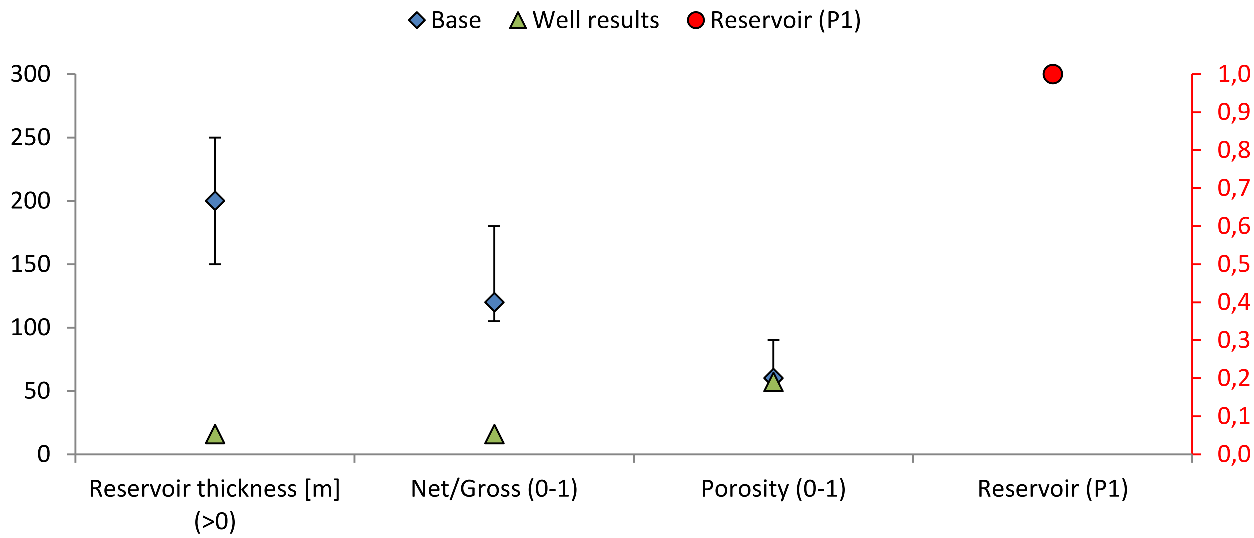
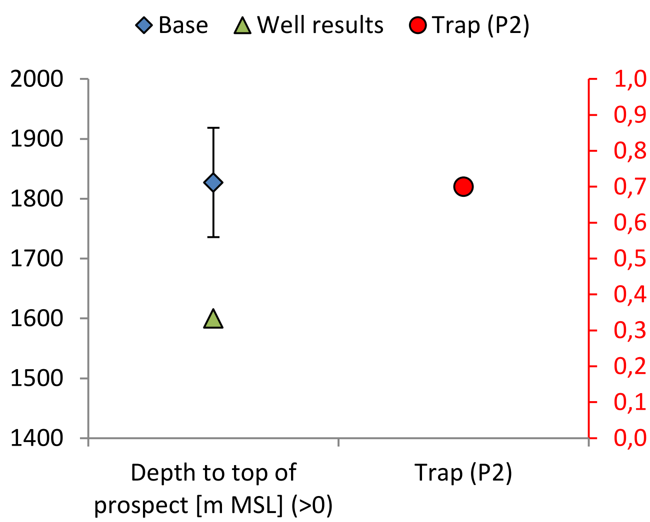
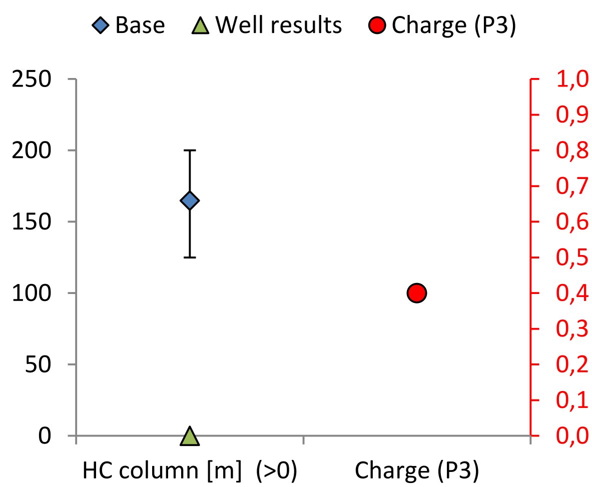
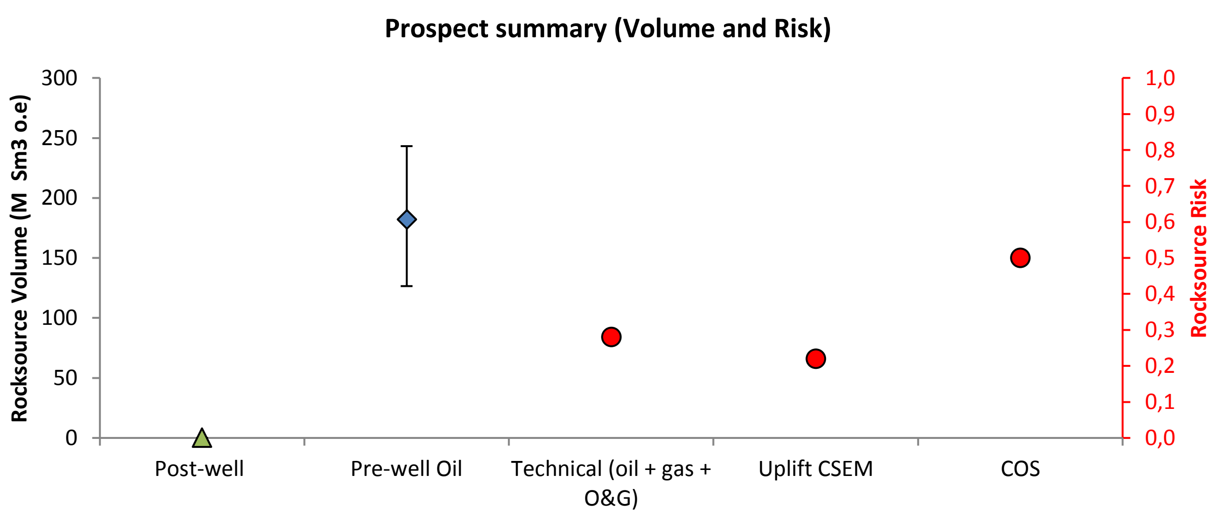


Figure 47 Phoenix Grey Beds Oil evaluation (pre drilling uncertainty and risk evaluated by RRT and evaluation of the post well results (primary (black) axis in meters, secondary (red) axis in fraction (0-1) – Data: Appendix 3: Datasheets for evaluated prospects).









6.8.6 Summary and Rocksource portfolio

Based on the new CSEM tool, Rocksource, developed internal software to process and handle the new technology. At the same time an organization and a decision system was developed. In order to prioritize resources and take high quality decisions RRT was developed. Based on the uncertainty and risk evaluations form RRT, prospects and opportunities was evaluated. After multiple CSEM campaigns the drilling campaign in started in 2011. Five large oil prospects, all associated with a high COS, was identified and matured for drilling through Rocksource's decisions system (Figure 48). The prospects was all located in unproven areas on the NCS. The larges tested prospect was the PL506 (Storbarden) while PL530 (Heilo) had the highest COS (65 %). Summarizing all roll-up prospects give a P_{mean} estimate of 250 M Sm^3 o.e. (ranging from 69 (P_{10}) to 526 (P_{90}) M Sm^3 o.e.), with an average COS of 40 % (Figure 48). In the PL559 (Phoenix) Rocksource drilled with 60 % interest.

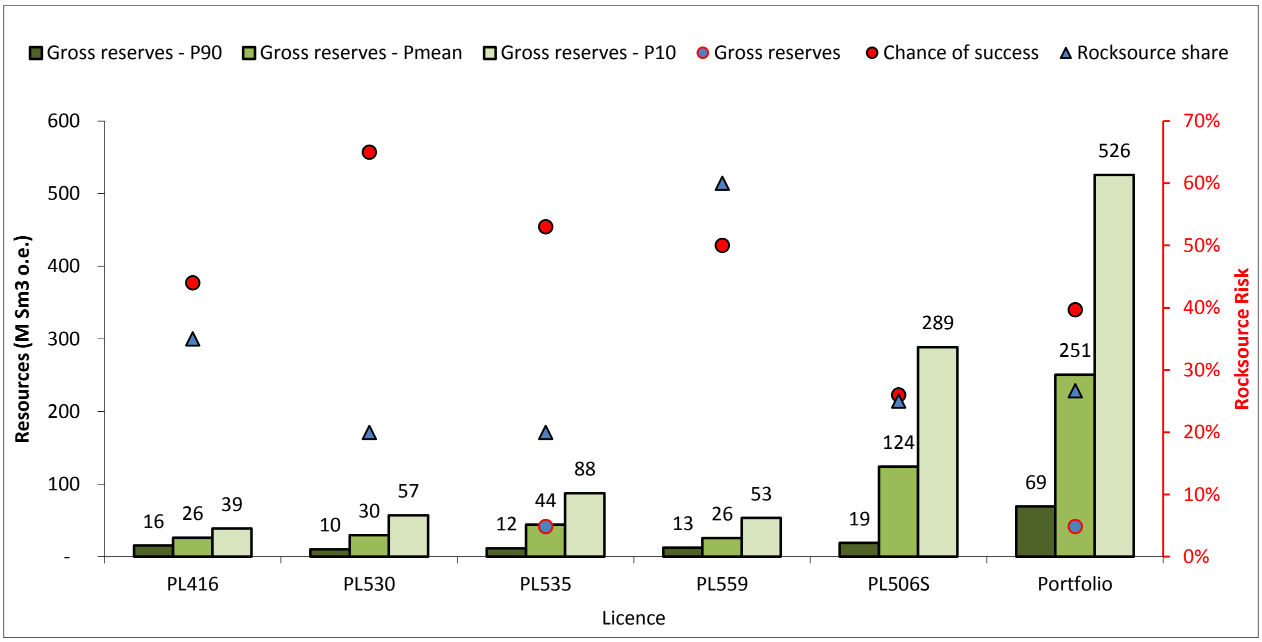


Figure 48 Rocksource pre drill estimated prospect reserves (P_{90}, P_{mean} and P_{10}). Secondary axis represent estimated COS and Rocksource share of license. PL535 (Norvarg) proved 41.8 G Sm^3 gross reserves of gas, a result around the pre-calculated mean volumes. Portfolio volume numbers are estimated cumulative resources in the license, while COS and Rocksource share in the license are average numbers. Source: Rocksource data.

7 Discussion and conclusions

7.1 The decision process and organization

The main purposes of the study has been to gain an insight into the extent to which Rocksource have defined processes for making rational strategic decisions. The study show how Rocksource developed an organization (Section 6.2) and implemented a decision system (Section 6.1) to ensure high quality decisions (Section 4.2). The Rocksource decision system is less complex compared to decision systems of larger companies. This is in line with the findings of Fredrickson and Iaquinto (1989) who found that the comprehensiveness of decision processes is correlated to the size of the companies.

In lager companies the board is collectively responsible for risk management, while the business unit organizations are responsible for managing day-to-day operations and a safe delivery of the group's business plan. Corporate functions are responsible for managing designated group-wide corporate risks and providing oversight, together with regional business management, of business unit activities and operational and financial performance. Risk identification and progress in implementing risk mitigation are reported regularly to the board. In this way, it is clear whether risk mitigation has been achieved, is in progress, or whether risk has escalated and requires immediate attention. Overall this approach ensures to managing risk in a transparent and accountable way. The implemented decision process in Rocksource have the same intention, but is less complex, as larger companies, and builds on the same processes (Figure 29 and Figure 31).

To achieve the desirable effects from the decision system, requires a common understanding and an agreed methodology to evaluate uncertainty and risk, and a common way to mitigate the risks. Especially within hydrocarbon exploration, where it is more likely to fail than succeed (Figure 15) and the investments are large (Figure 18), it is critical for companies to understand uncertainties and risks before taking onboard large drilling commitments (Figure 16 and Figure 17). In Rocksource the drilling decisions have to be approved in the management team and finally the board (Figure 29 and Figure 31). To take rational decisions (Section 4.2) the Rocksource management team and the board must have an exceeded understanding of the project uncertainties and risks. To ensure independent (Figure 30), uniform and high quality evaluation of project uncertainties and risks the RRT (Section 6.3) was formed. Based on Rocksource decision system (Figure 29) the RRT evaluations influence many decision levels and is, probably the most weighted factor, when the management team and the board take decisions (Figure 31).

The collected data show five pre-drill prospect evaluations from RRT, presented to the management team and the board, all containing large hydrocarbon volumes and an associated high COS (Figure 48). Based on the numbers a NCS drilling campaign was planned for more than five years (Section 1). The wells proved only 41.8 M Sm^3 o.e. of uneconomical gas in the Barents Sea, less than the predicted P_{10} reserves (Figure 48). The drilling results was a huge disappointment for the whole organization and the investors (Figure 2). To improve the future decisions process in Rocksource it is important to gain a better understanding of how the existing process effected the uncertainty and risk evaluations, and how this can be improved.

In the following the data is used to compare pre drill estimations with the actual results from the drilling campaign. The methodology used for uncertainty and risk evaluation is discussed, in contexts of biases and implementation of the new technology. Finally a brief summary of the findings is presented together with the consequences of the uncertainty and risk evaluation for the company. The section is ended by future recommendations.

7.2 Improvements of judgments

Post drilling analysis of the quality of subjective probabilistic assessments made by explorationists are an increasingly attractive way to improve the quality of risk assessment. Many companies are riding this bandwagon. Without a vigorous effort to encode and analyze the historical performance, expert judgment is not likely to improve. In a 1987 AAPG paper, Rose describes how to improve the precision and accuracy of probability judgments: *"most technical people have almost no idea as to their degree of uncertainty-they cannot differentiate between 98 % confidence and 30 % confidence! Moreover, the prevailing pattern is one of overconfidence-when asked to make estimates at, say, 90 % confidence, they characteristically set predictive ranges that actually reflect about 35-40 % accuracy."*

Based on the experience from the industry and the theoretical context (Section 4.2) biases is nearly universal and expresses itself specifically in forecasts that are exceeded by subsequent events. That is, in their quantitative predictions, experts usually set their predictive ranges far too narrow. In qualitative forecasts, this bias is expressed by a strong tendency to rely on only one or two hypotheses-rather than on many-in carrying out a scientific investigation. The observation is also described by Rose (1987); *"I have tested more than 100 technical audiences, totaling well over 5.000 professional scientists and engineers. The results are always the same - they are significantly overconfident, actually estimating at about 40% confidence while believing they are estimating at 80% confidence."*

The experience from multiple risk meetings have provided insights into different methods to mitigate biases in-line with observations from Rose (1987); *"We have found that, with training and practice, scientists and engineers can improve significantly, but even after considerable effort, they have a hard time consistently setting ranges that really do correspond to demonstrable uncertainty."* Humans are influenced by biases when evaluating uncertainty and risk, but training and practice can improve the evaluations. The influenced biases can vary from human to human and from organization to organization (sections 4.2.1, 4.2.2 and 4.2.3). The theory describes post drilling analysis as one way to improve future decisions. Based on the post well analysis the used methodology to evaluate uncertainty and risk can be evaluated and biases understood, hence improve future decisions.

7.3 Post drilling analysis

To evaluate used methodology and if biases have influenced Rocksource's evaluations, pre well uncertainty and risk predictions are compared to the actual findings in the well for prospect levels (Section 6.8). According to Rose (1987) the three most influential values in a decision process are; target size, discovery probability and finding cost. The further discussions in this thesis is limited to target size (uncertainty) and discovery probability (risk) performed by RRT. Finding cost are excluded as limitations omits economic evaluations (Section 5.3.1). All the five drilled prospect are associated with large volumes ranges (uncertainty) and high COS (risk) (Figure 48), but if the target size and discovery probability was influenced by methodological errors and biases in the organization, poor decisions were taken (Section 4.2) and the expected outcome from the drilling was unrealistic.

Uncertainly is broadly used in science and technology, but it is difficult to find a proper definition (Section 4.1). Zimmermann (2000) presents a more detailed definition of the term: "*Uncertainty implies that in a certain situation a person does not dispose about information which quantitatively is appropriate to describe, prescribe and predict deterministically and numerically a system.*" The variability in hydrocarbon volume in prospects represent the geological uncertainties.

Risk is a common term in science, economy and industry (Section 4.1). Being a complex and difficult concept, there is still no agreement how risk should be defined. According to the definition of the Society of Risk Analysis, "*Risk is the potential for the realization of unwanted consequences of a decision or an action. Risk analysis is the process of quantification of the probabilities and, expected consequences of risks.*"

The collected data in the study show that in order to follow the decision process uncertainty and risk must be assigned to prospects before the drilling decision (Section 6.1). The study show that the process is followed and, the data is used in the study. The portfolio average COS was 40 % and except for the PL506 all prospects had a COS above the average finding rate on the NCS. After the drilling campaign Rocksource finding rate was below the NCS average (Figure 15 and Figure 48). In the data it is observed a mismatch between parameters used in the pre well uncertainty estimates compared to the actual well results.

The decision analysis is a joint application of procedures for choosing optimal decisions in the face of uncertainty, and is a subject very close to the risk analysis, only more general than the latter one. The rich experiences of decision analysis can also be applied to the analysis of risks in geology. The main goal of risk analysis is to predict as accurately as possible the likelihood of the unwanted or accidental events and to clarify the uncertainties that impede the producing of reliable predictions. The correct distinction of the sources of uncertainty should be the starting step of any risk analysis in geology.

7.3.1 Uncertainty evaluations

To define uncertainty explorationists simplify the complex geology into “sophisticated” models (Section 3.11), a methodology also applied in Rocksource (Section 6.6.2). The collected data show that Rocksource used a large and wide ranges in the geological models (Figure 35, Figure 36, Figure 37, Figure 38, Figure 39, Figure 40, Figure 41, Figure 42, Figure 43, Figure 44, Figure 45, Figure 46, Figure 47 and Appendix 3: Datasheets for evaluated prospects), adding a high degree of uncertainty to the models. Compared to the well results the used parameters are overrepresented on the high side. As a consequence of the high uncertainty, all the prospects contained large hydrocarbon volumes before drilling (Figure 48) compared to the discovery size on the NCS last 15 years (Figure 4 and Figure 49). The estimates for PL416 are same range as the hydrocarbon volume 72 exploration wells proved from 1998 to 2002 in the North Sea. The P_{50} estimates in PL506 (124 M Sm^3 o.e.) is larger than all other discoveries on the NCS last 15 years, except the Johan Sverdrup discovery (300 M Sm^3 o.e., and only NCS discovery greater than 100 M Sm^3 o.e. last 15 years). In the Norwegian Sea (PL559) the volume range indicated one of the largest discoveries in the areas for decades. PL530 and PL535, in the Barents Sea, was assumed to contain larger hydrocarbon volumes together than the rest of the industry had proved through 41 exploration wells during the last 15 years (Figure 49).

Within mathematics it is common to distinguish between three types of uncertainties (Dubois & Prade, 2000). *Imprecision* or *inaccuracy*, expressing the deviation (error) of measurements from a true value. The term bias is also frequently used in the case of consistent under- or- over estimation of the true value. *Vagueness* or ambiguity expresses the uncertainty of non-statistical or non-measurable properties or objects. The measurements are replaced by observations and linguistic descriptions. *Incompleteness*, occur when the amount of information or knowledge is insufficient to perform an adequate evaluation of the given population. Often the term approximation is used for the results of the evaluation of such situations. In addition Zimmermann (2000) distinguishes further two sources of uncertainties. *Conflicting evidence*, when considerable information is available pointing to a certain evidence, but there might be contradiction information pointing to another evidence and *belief*. There are situations in which all available information is subjective, as a kind of belief or an expert's option.

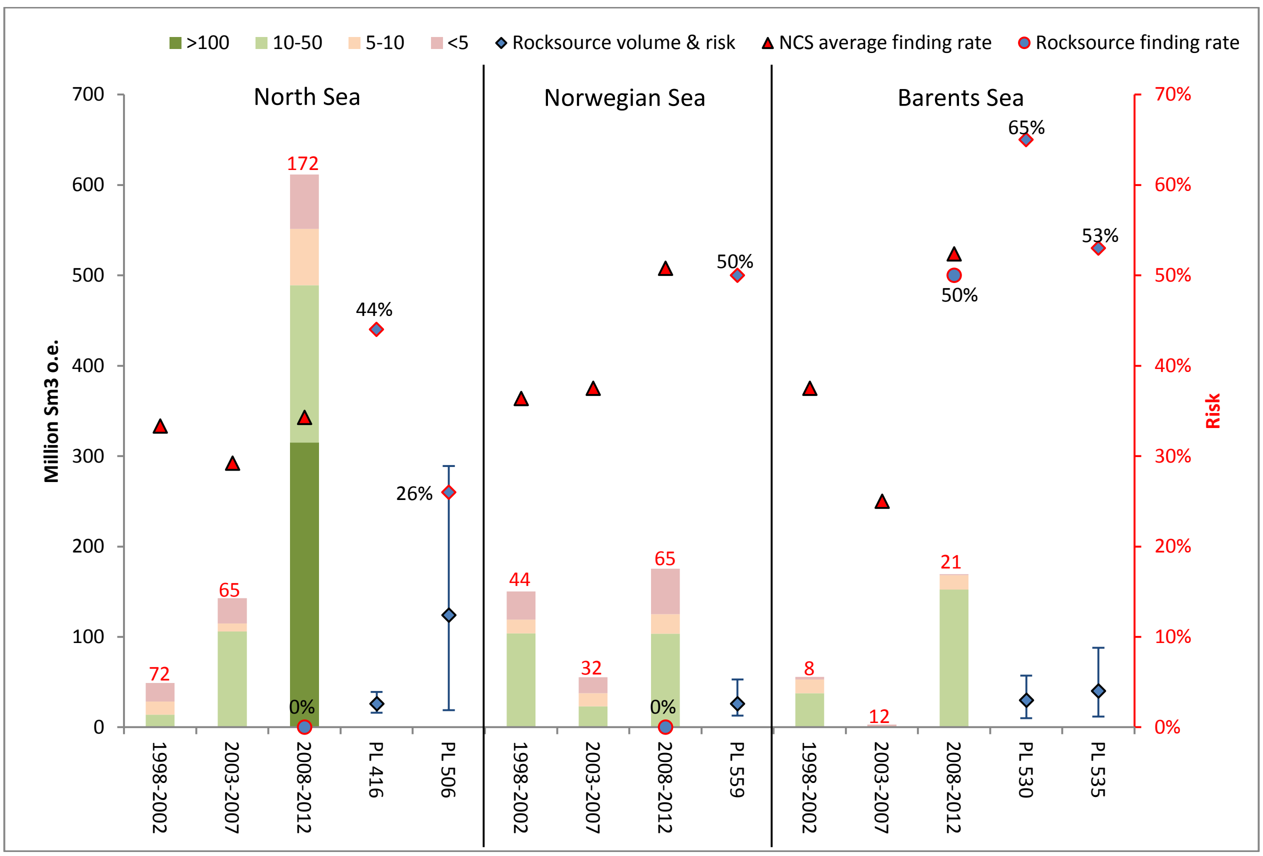


Figure 49 Resources by discovery size (>100, 10-50, 5-10 & <5 M Sm3 o.e.) during last 15 years on the NCS, separated into 5 years intervals for the North Sea, the Norwegian Sea and the Barents Sea. Number of drilled wells (red number), average 5 years finding rate (red triangle) and Rocksource average finding rate (blue and red circle) for the different areas and time period. Diamonds represent pre drill volume (P_{90}, P_{50} (black and blue) and P_{10}) and risk (red and blue) evaluated by Rocksource. Source: NPD and Rocksource data.

When developing geological models it is important to distinguish objective information from subjective observations, based on the expert's opinion. However the sources of uncertainties are undoubtedly valid for the geological problems as well, but based on experience two additional sources of uncertainties must be distinguished in geology. Uncertainty due to *natural variability* and uncertainties due to *human imperfections and incompetency*. Variability is an inherent natural property of all geological features, objects and features. The degree of variability of a geological feature, expressed by mathematical terms, may be quite varied depending on the geological feature, object, process or environment. Generally, higher variability give a higher uncertainty, require more investigation and it is necessary to collect more input data. A significant particularity of geological objects is that features can be *structured* (trends – more or less regular spatial and temporal changes that can be described by known methods) and *unstructured* (geological object and their spatial position and/or magnitude cannot be exactly predicted). The higher the proportion of the unstructured locations, the higher is the overall uncertainty of the given object. The uncertainties due to human shortcomings, incompetency or inadequate conditions may occur in all stages of geological investigations and they are extremely varied. Their main sources are incomplete knowledge of the given geological object or process, shortcomings in modeling, the inaccurate application of mathematical methods and finally financial, economic, temporal or other natural limitations of the investigations.

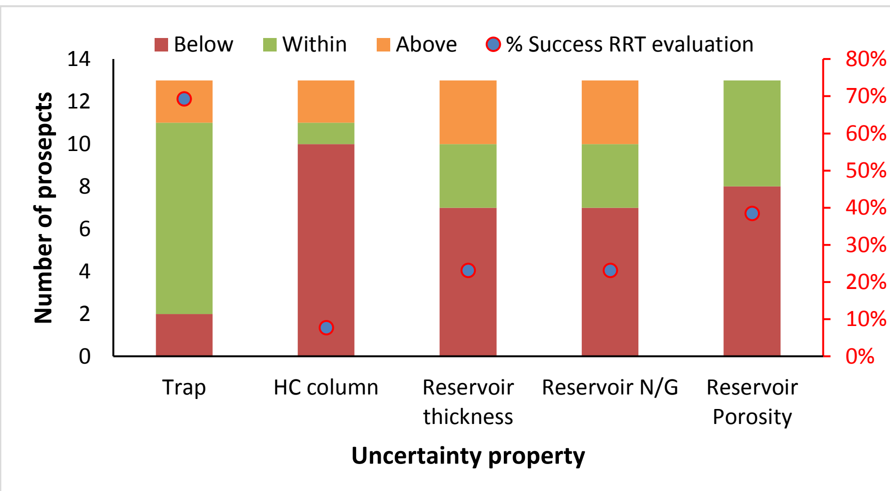


Figure 50 Well results compared to RRT pre well uncertainty evaluations used in the geological model. The collected data is presented in Figure 35, Figure 36, Figure 37, Figure 38, Figure 39, Figure 40, Figure 41, Figure 42, Figure 43, Figure 44, Figure 45, Figure 46 and Figure 47. Source: Appendix 3: Datasheets for evaluated prospects.

The Rocksource prospects are all located in immature and frontier areas with no or few valid data points (Figure 28). The data used in the evaluation are not inaccuracy, but are vague in the contexts of relevance, as the data points are few and often far away from the prospects, leading to incompleteness as the amount of information is insufficient to perform an adequate evaluation of the given population. As a consequence observations and approximation is used in the uncertainty evaluation, and the ranges become wide. Several researches have concluded that this type of uncertainty cannot be properly handled by stochastic methods, but must be treated by the possibility theory (Smithson, 1989) or other uncertainty theories. Generally the sampling results are most biased when sampling points are irregularly clustered. According to the "theory of regionalized variables" (Matheron, 1971) sampling points should be closer to each other than the range of influence of the studied variable. From industry experience a common way to handle limited and scattered geological information is to use play analysis (Appendix 2: NPD's method for evaluation of petroleum resources). Play analyses secure a filtering and weighting of data, to ensure only relevant data to be included in evaluation by excluding irrelevant data. RRT evaluated prospect uncertainty without using play analyses to control and quality check used input parameters (Section 6.6.2).

Instead of play analysis, the processed CSEM data influenced the RRT uncertainty evaluations. Information from the observed CSEM anomalies processed in Rocksource in-house programs and the VOI tool was used to predict the uncertainty range of hydrocarbons volumes and reservoir quality (Section 6.7). This was done to ensure consistence between the modelled CSEM response, the CSEM response from the acquired data and the prospect size.

Few data points generally generate low variability in the geological features, leading to low data uncertainty and require less investigation. The only outcome is to collect more data, hence drill a well. However, the data show that Rocksource used the few and scattered data information to develop approximation, trend observations and additional information (e.g. CSEM) to justify the large uncertainty range in the geological models (Section 6.8 and Appendix 3: Datasheets for evaluated prospects). In the collected data set there is not observed a correlation between the wide uncertainties ranges used in the pre well models compared to the actual well results. For the parameters in the study, except trap (seismic, data driven), the results from the wells matched the pre uncertainty range in less than 40 % of the cases (Figure 50). The data also show that the pre well uncertainty range are generally too optimistic, as most of the well results came in on the low side. The collected data can indicate problems for RRT to distinguish objective information from subjective observations, based on the expert's option and belief.

7.3.2 Risk evaluations

After deciding the prospect uncertainties, the RRT assigned an associated COS to each prospect. The purpose of risk assessment in petroleum exploration is to estimate the COS prior to drilling of a mapped prospect, hence make the best decision for the company based on all the available information. Probability theory provides four fundamental rules, which must be considered when dealing with prospect and/or play risk assessments:

- The probability of a given occurrence or event is equal to 1 minus the risk for this event not occurring ($P_g = 1\text{-}P_{risk}$).
- The probability of the simultaneous occurrence of several independent events is equal to the product of their individual probabilities ($P_g = P_{Charge} \times P_{Reservoir} \times P_{Structure} \times P_{Seal}$).
- Given the occurrence of several mutually exclusive events, the probability of occurrence of at least one event is equal to the sum of the probabilities of each individual event ($P_{g\ total} = P_{g(a)} + P_{g(b)}$).
- The probability of either one or both of two independent events can be estimated by calculating the risk that neither of the events will occur $(1\text{-}P_g) = (1 - P_{g(a)}) \times (1 - P_{g(b)})$.

To define the geological probability of success (P_g), RRT risked the prospect presence, minimum volumes (P_{99}), of four independent events (charge, reservoir, structure and seal) (Section 6.6.2). In addition the prospects was given an uplift (seismic or CSEM) to the initial P_g if a DHI was observed, before the final COS was calculated (COS= P_g+DHI_{Uplift}, Section 3.11 and 6.6.3). The collected data shows that all drilled wells had an assigned CSEM DHI uplift, while only one well (Norvarg-1) had assigned seismic DHI uplift (for Stø and Snadd fm's targets) (Section 6.8 and Appendix 3: Datasheets for evaluated prospects).

To evaluate the P_g for the prospect many techniques is used within the industry. *Analogue comparison* is very common approach in geology to evaluate risk for prospects. The main challenge for the method is to define an appropriate and relevant analogue to the study area. Small differences during the geological history can be critical for the petroleum system and makes the analogue model irrelevant. Therefore great care has to be taken when using this technique, especially when using analogues from "foreign" basins and in frontier exploration, but there is undoubtedly a considerable scope for comparing basins or areas of similar tectono-stratigraphic style. *Historical performance* methods can be utilized in areas with large numbers of exploration wells and a significant numbers of discovered fields. The outcome can be used to calibrate systematic prospect and play studies where play/prospect attributes and their risk are examined and statistically manipulated to define expectation curves.

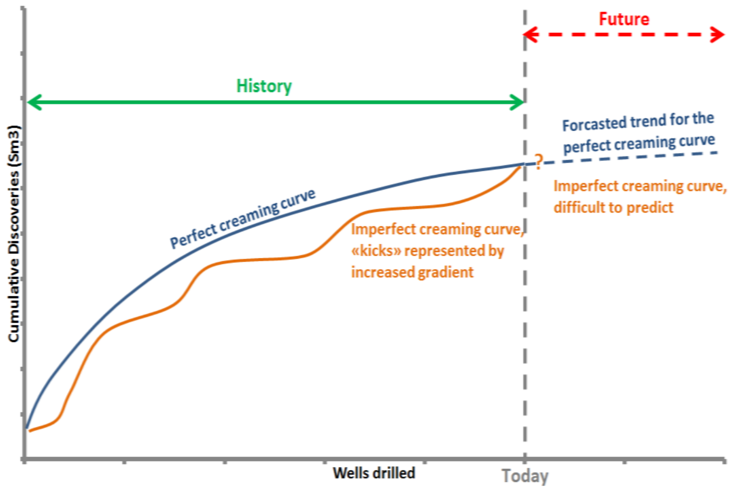


Figure 51 Perfect (blue) and imperfect creaming (oranges) curves is a function of cumulative discovery volumes over time - the largest hydrocarbon discoveries are made first and with time the discovery volumes reduces and the curve flattens. Note that that the curve start at first discovery, not including wells before a play/area discovery.

Decline and creaming curves project future discovery based on the premises that the largest volumes are discovered first and over time the discovery volumes become smaller and smaller. In principle the build-up of a creaming curve assumes that the largest hydrocarbon discoveries are made first and with time the discovery volumes reduce and the curve flattens. By projecting the curve into the future, the curve flattens towards the asymptote with an indication of the likelihood of maximum volume to be discovered within the geological play and the associated number of exploration wells needed to achieve the volume. Creaming curves plotted against number of drilled exploration wells give an idea of the effort involved and also the success rate if all wells are included. Imperfect creaming curves exhibit gradient changes, reflecting variation in rate and amount of accrual discovered hydrocarbon volumes. Innovation of geological concepts and/or technology can be reflected in the creaming curves by increased gradient, followed by a lowering gradient as the particular innovation creams the prospect volumes. An increased gradient reflects often a new successful idea or application of technology. An almost perfect creaming curve may lead to overconfidence in understanding of the geology and failure to realize new or hidden potential within the area, while a more imperfect the creaming curve represent challengers in elucidating the underlying geology (Figure 51).

The P_g is a value partly based on objective knowledge and historical data, partly on extrapolations and partly on our subjective judgments of local geological parameters (Section 6.8). The value (P_g) cannot be directly measured after drilling, since the result of the drilling always is either a discovery or a dry prospect. Compare to the average finding rate on the NCS, the Rocksource P_g values cannot be regarded as high. On the other hand, the risk is associated to very large prospects in frontier areas (unproven play). RRT performed analogue comparison at prospect level, to discoveries in the area. But without being an appropriate and relevant analogue, small differences during the geological history is critical for the petroleum system and the used analogue become irrelevant. The data show a generally a positive (high values) and low spread in use of risking parameters (Figure 52). For the 13 evaluated prospect the average chance to find presence of reservoir (P_{99}) was 0.76 and hydrocarbon charge was 0.66. The overall highest risk was evaluated to retention (seal) (0.57), while presence of structure had the lowest risk (0.82). The generally high (positive) values in frontier areas can be the consequences of risking the minimum value (P_{99}) together with a wide uncertainty range (Section 6.6.2 and Figure 49). Another common misunderstanding in risking is to use the creaming curve to justify high P_g in frontier areas, assuming that the largest hydrocarbon discoveries are made first in frontier areas. The first discoveries are generally large in frontier areas are always large, but before starting to accumulated volumes on the curve many dry wells are drilled (Figure 51). From experience a common way to prevent or reduce the errors in the risking process in frontier areas is to include play risk in the evaluations.

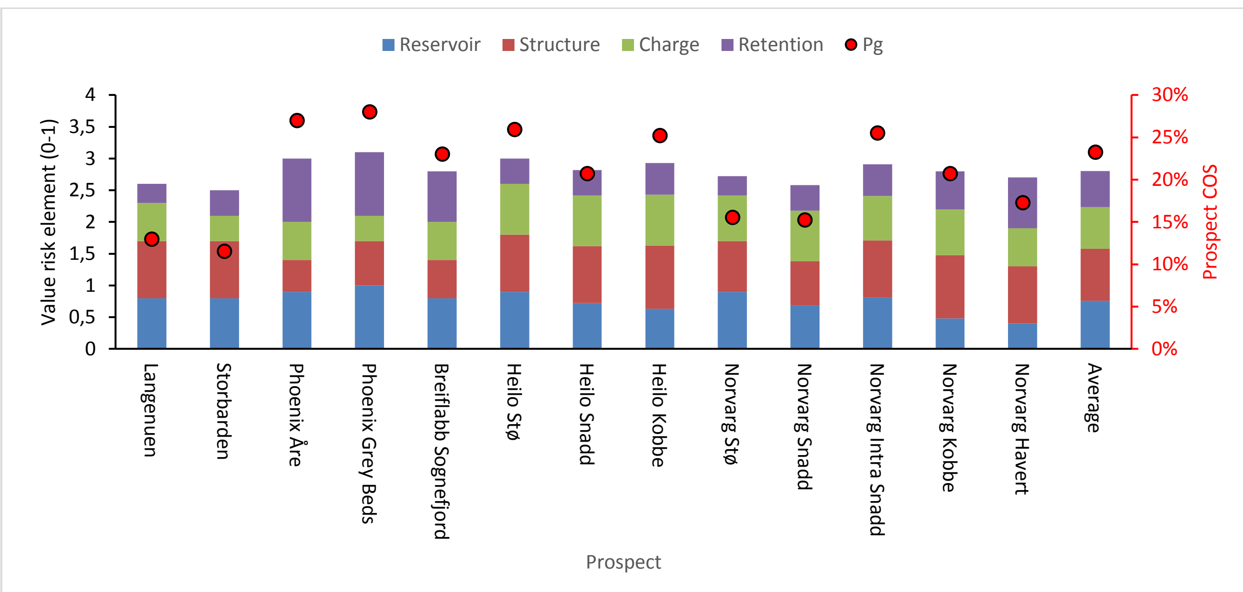


Figure 52 Rocksource evaluation (0-1) for each risk element (reservoir, structure, charge and seal) and total P_g for all prospect levels. Source: Appendix 3: Datasheets for evaluated prospects.

The collected risk data also give valuable information to understand how Rocksource weighted the different sources of information (Figure 37, Figure 40, Figure 43, Figure 45 and Figure 46). Based on information from acquired, processed and interpreted CSEM data (Section 6.4.1 and 6.4.2) the RRT assigned a DHI_{uplift} (Section 6.6.3 and 6.7) to the initial prospect P_g. The data show that Rocksource put more weight on CSEM data than seismic DHI's and traditional geological work and knowledge. The studied data show that the new CSEM technology, processed internally, was the most important source to de-risk prospects (Figure 53).

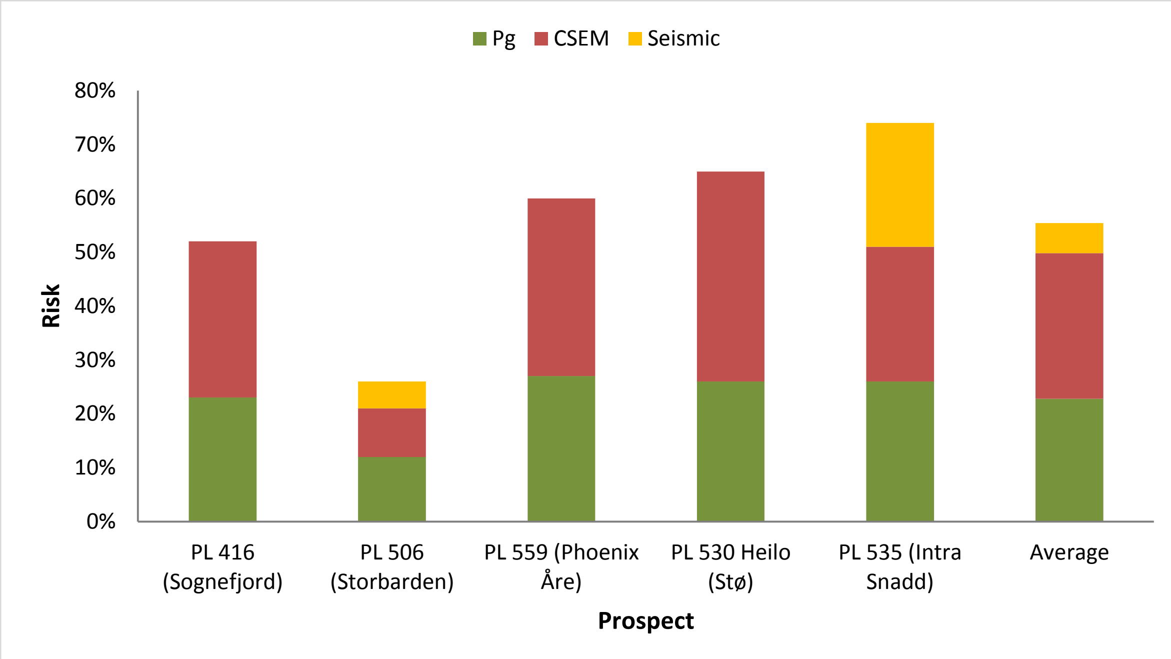


Figure 53 The collected data show how Rocksource weighted geological (P_g), CSEM, and seismic DHI in the risking process. Note that the uplift is used for defined levels, and not represent the rollup risk for the whole prospect. Source: Appendix 3: Datasheets for evaluated prospects.

7.4 Managing the new CSEM technology

As shown in Section 1, 7.3.1 and 7.3.2 Rocksource weighted the new CSEM technology heavily to estimate and understand the prospect uncertainty and risk. The collected data show how Rocksource developed an exploration portfolio consisting of only CSEM suitable prospects (Section 6.5). After identifying large prospects on 2D seismic data, Rocksource acquired CSEM data over the prospects. The most promising CSEM data was processed with the internal developed Rocksource Discover and Value of Information (VOI) tools (Section 6.4 and 6.7) to evaluate the uncertainty and risk. The collected data the main challenge is to correctly handle the acquired CSEM data and was the main reason to develop internal software to handle the data (Section 1, 3.12 and 6.4).

The recorded electromagnetic response must be decomposed into components, and the appropriate energy levels must be attributed to each contributing factor. This process is well known in the seismic industry. However, higher level of complexity governs the propagation of the electromagnetic field through the subsurface forces creatively thinking. As the product not was available in the market Rocksource established an internal subsidiary, Rocksource Geotech, to develop proprietary technology enabling to handle electromagnetic data for exploration purposes (Section 1 and 6.4). Large amounts of money was used to develop new algorithms, ensure proper processing, rapid modelling, and software development. The Rocksource Discover was Rocksource's proprietary system for handling CSEM data at all stages of the exploration work flow (Section 6.4.2 and 6.7). To allow fast processing of data up to the level of full 3-D inversion and migration, an integrated approach was incorporated where geological a priori information was used as an iterative interpretation process. Through a structured and iterative interpretation process, appropriate values for each individual contributing factor was obtained, and as a result, the complexity of the problem is reduced (Hesthammer & Boulaenko 2005). The CSEM knowledge, expertise and proprietary data software was Rocksource's competitive advantage to a give information about geological uncertainties and the overall prospect risks. The CSEM technology was believed disruptive hydrocarbon exploration by bringing to market a cheaper and simpler way of de-risking prospects, and finally give huge profitability (Section 1). When implementing a new technology there are many pitfalls, and the leaders must be aware of uncertainties and risks within the technology itself.

There are "no risk free projects", especially at the early stages the uncertainties are high and many questions develop to the new technology. Projects are all different, but projects involving new technology generally involves higher uncertainty and risk. However organizations still tend to assume that projects will succeed, and therefore often fail to consider and analyze the project risk, and prepare in case something goes wrong (Raz et al., 2002). The study have shown how Rocksource weighed the new CSEM technology (Section 1, 1, 7.3.1 and 7.3.2). The theoretical context in Section 4.3 give a framework to understand uncertainties and risk related to a new technology, and how these can be managed.

Disruptive innovations (Section 4.3), don't attempt to bring better products to established customers in existing markets; rather, they disrupt and redefine that trajectory by introducing new products. The disruptive technologies offer other benefits to the user, typically, they are simpler, more convenient and less expensive products (Christensen, 1997). The CSEM technology is much cheaper than conventional seismic, approximately 1/10 of the cost. For a new oil company on the NCS, the upfront seismic investments are large (Figure 7) and a lot of geological work have to be done before prospects are mature enough for drilling. In order to develop a competitive advantage, save upfront investments and without taking the time to develop geological models Rocksource used the CSEM (Section 3.12) as a risk reduction tool for hydrocarbon exploration. The CSEM reliability, methodology and results are widely debated in the oil industry. This is related to the ability to map resistivity contrasts in the sub-surface and thus aid the detection of hydrocarbons which are typically more resistive than surrounding rocks. Seismic energy is used for sub-surface structural mapping and to evaluate fluids within the structure, while CSEM energy only describes the fluids contained within the mapped structures. Based on the findings and the expectations to the new CSEM technology fit the criteria's presented by Christensen (1997) to be regarded as a disruptive innovations.

To understand how new technology are developing the Utterback-Abernathy model (1975, Section 4.3.1) can be used. The complete model is solid and carried on very broad analyses, ranging from technological impact upon products and processes to market dynamics and competition to organizational structure and strategic decisions within companies. As Figure 26 indicates, the rate of product innovation in an industry is highest during its formative years. During the "fluid phase" considerable experimentation with product design and operational characteristics takes place and the phase is characterized by high product innovation. The strategy for Rocksource, as a new entrants in the player picture (Figure 7 and Figure 8) on the NCS, was to use the radical and competence-destroying CSEM innovation. By implementing the new CSEM technology Rocksource could apply for acreage regarded as "high risk" (P_g below 20 %) in conventional oil companies (Section 1 and 6.5 and Figure 54), by give the prospects a large DHI_{uplift}. At the same time Rocksource developed internal software to outmaneuver competitors and establish a "dominant design" product (Figure 26 and Section 6.4). According to the Utterback-Abernathy model the rate of product innovation is highest during in the "fluid phase", hence representing a source for additional uncertainty and risk, but can be handled by risk management. In the early days of the CSEM technology it was reported challenges to the processing data (Section 3.12 and 6.4). To see if the data processing develop as predicted in the Utterback-Abernathy model, the CSEM data was re-evaluated as part of the study (Section 6.8.1.8, 6.8.2.8, 6.8.3.8, 6.8.4.8 and 6.8.5.8). The data used in the re-evaluation is exactly the same as the used for the pre well evaluations in Rocksource (Figure 53), only processing software is changed. The new processing results differs significantly form the processing results pre well. In the new evaluations almost all the previously observed CSEM anomalies associated with hydrocarbon prospects have disappeared. Based on the new results would have been unlikely to give DHI_{uplift} to any of the drilled prospects. The new CSEM processing confirm the fast development in the start phase of a new technology predicted by the Utterback-Abernathy model. The new results underline the uncertainty and risk related to implementation of a new technology, why it is challenging to lead disruptive innovation and to be successfully it is crucial with risk management.

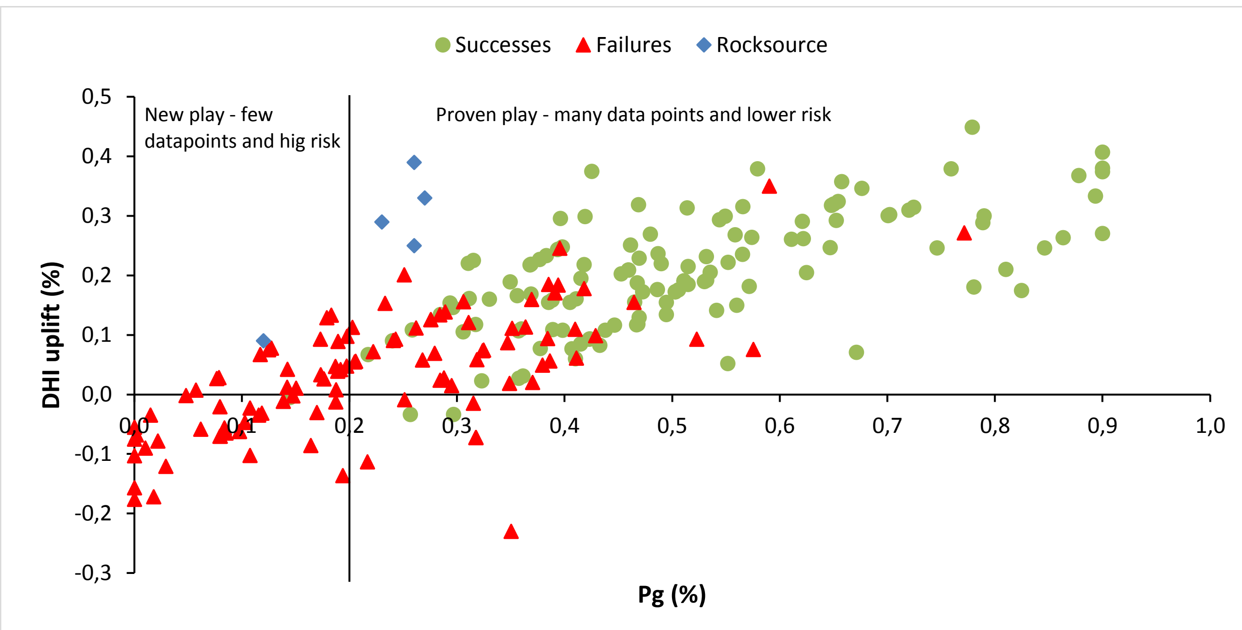


Figure 54 Approximately 250 drilled hydrocarbon prospects drilled worldwide, and how oil companies have evaluated P_g and seismic DHI_{uplift} before drilling. Negative value indicate a negative DHI_{uplift}, based on observations in the data. The color distinguish between post well successes (green) and failure (red). Blue diamond represent Rocksource prospect P_g and CSEM DHI_{Uplift}. Based on the data, Rocksource give an anomaly high uplift to the prospects based the new CSEM data, compared to the well-known seismic DHI_{uplift}. There is not observed a direct correlation between DHI_{uplift} and drilling success before P_g exceed 0.2. The observed positive correlation between drilling success and seismic DHI_{uplift} when Pg>0.3, is a results of increased number of data points, hence a better understanding of the play. Source: Rocksource data and Appendix 3: Datasheets for evaluated prospects.

The observations from the re-evaluated data is aligned with the perceptions in the industry. More than 14 year after the first acquired CSEM data, the industry struggle with the same challenges. Meju (2012) from

PETRONAS recently published the article “The Robust quantitative interpretation of CSEM surveys - How far have we come?” The article describes today’s technical challenges with CSEM and can be summarized by; geological complexity and non-linearity, uncertainties in forward modelling of physical reality, multiple sources and computational limitations, fusing physical and non-physical data to reduce uncertainty (including reliability of a priori information or background model), and consistency of CSEM models with geo-exploration models.

Disruptive innovation in the fluid phase need leaders prepared to deal with the realities and knowledge to responding to changes and disruption (Section 4.3.2). Unlike operations management, disruptive innovation involves extreme uncertainty. Unexpected events, inevitable failures, and a fundamental lack of control are inherent to the process. The most defining characteristic of disruptive innovation is the great uncertainty for leaders, organizations, and entire industries (Christensen, 1997). The awareness to project uncertainty and risks is crucial in order to mitigate and manage them (Williams, 1995; Raz et al., 2002). It is not possible to avoid project risks, but is possible, through risk management, to put in place mechanisms, backups, and extra resources, to protect the organization if something goes wrong. For Rocksource the risk management become very critical, as all drilling decisions in the portfolio was dependent on the new CSEM technology. From the first drilled CSEM positive prospect on the NCS (three years if international operations is included) to the last well started it was almost two years. Within the time period it was possible to mitigate the impact on the organization, but it is not possible to observe any behavioral change in the data. The unchanged behavior is confirmed by studies implying that organizations tend to assume that all their projects will succeed (Raz et al., 2002). When implementing a new technology, independent of the outcome from the first test, in this case drilling a dry well, the theory find it natural to re-evaluate the portfolio in order to increase future win and reduce potential loss (Section 4.3).

Rocksource developed many projects, but when positive CSEM anomaly was detected in the project, the projects was unlikely to be killed. Having tough go/kill decision gates is correlated strongly with the profitability of new product efforts (Cooper and Kleinschmidt, 1995), but tough go/kill decision points are the often the weakest ingredient of all process factors (Cooper, 1999). For Rocksource the drill decision can be regarded as a go/kill decision, even if it possible to farm-out or sell the license after. Rocksource’s first well CSEM positive well (PL416 – 31/8-1) on the NCS was finished almost two years before the last well in the study was started (PL506 – 26/5-1). Before the first NCS well, Rocksource also drilled two dry CSEM positive wells internationally (Section 1). The data show that Rocksource continued in the same direction in almost 3 years, without re-evaluating the CSEM technology, changing the internal prospect evaluation processes, hence reduce exposure and de-risk trough a wider portfolio in order to increase future win and reduce the potential loss. In order to be able to handle the leaders must understand the company’s overall uncertainty and risk, and have the ability face negative feedback. The lack of risk management and predefined go/kill decision gates, made Rocksource continued in the same direction without proper re-evaluation of the CSEM supported prospect uncertainty, hence actively take part of the secondary marked (Figure 12).

7.5 Escalation of commitment

Empirical evidence shows that concerning investment projects, escalation of commitment leads to inefficient allocation of funds, higher costs and more severe organizational disruption by project failures (Meredith, 1988). Research suggests that escalation of commitment is a phenomenon which leads to systematic delay of exit decisions. In other words, far more projects are terminated too late, rather than to early (Lange, 1993). Since Staw introduced escalation of commitment as an explanation for escalating projects (Staw, 1976) a large body of literature has emerged, and the key issues are presented Section 4.4. It is also commonly recognized that escalation of commitment involves a decision-making situation in which an individuals must choose whether or not to continue with a previously chosen course of action, but is debated how much negative feedback is required and indeed whether the decision maker must even be aware of the negative feedback (Keil et al., 2000).

The collected data give some indications of when and how strong negative information Rocksource must have been aware of. There is a systematic mismatch between Rocksource pre drill uncertainty and risk evaluations compared to the industry. Rocksource P_{50} volume estimate for five prospects is 251 M Sm^3 o.e, with an average COS of 40% (Figure 48). The portfolio P_{50} volume are almost equal to the hydrocarbon volume approximately 150 NCS explorations wells (Figure 13) proved of hydrocarbons all together in 2007, 2008 and 2009 (Figure 4). The CSEM technology have always been debated within the industry, and many was skeptical how much Rocksource weighted CSEM in the evaluations. Even today, around 14 years after the method was first used on the NCS, many remain skeptical to CSEM as a high profile tool for petroleum exploration. The sceptics is mainly based on experience from large companies. The last eight years Shell has acquired or reviewed over 50 CSEM surveys and drilled 17 wells post-CSEM. Shell have used time to build up learning and confidence to an appropriate application of the technology, so CSEM can be applied to projects where the technology provides the required additional value. The confidence has increased through extensive reviews of the data, improved inversion capabilities, and better interaction between the technical and asset teams – to the point that CSEM is now used in projects decisions (Rosenquist, 2012). The data also show that the methods used to estimate the CSEM DHI_{uplift} generated anomalous high values compared to the methodology used in the industry for seismic DHI_{uplift}. In addition the high DHI_{uplift} was associated with a low P_g, normally not support a large uplift value (Figure 54). Undoubtedly the dry wells must be regarded as negative feedback. If the negative feedback had been recognized and used the portfolio could have been used to mitigate the uncertainty and risk. When developing an exploration portfolio fully dependent on a new technology, the limit for negative information regarding the CSEM technology must be low, but as the data show all the information was neglected and not used for future decisions, and the previously chosen course of action was continued for several years.

Previous research suggests that escalation is a complex phenomenon influenced by different factors. Staw & Ross (1987) defined a model where the project, psychological, social, and organizational all are possible factors contributing to escalation (Figure 27). The collected data cannot be used directly to explain the escalation, but based on the history of the company and the annual reports (Section 1) some comments can be made. Psychological factors influencing the decision to continue the previously chosen course, can be that the manager feels personally responsible for the outcome of the project, as well as psychological and cognitive biases affecting the way project information is perceived or processed. Escalation is more likely to occur when managers make errors in processing information, and that the decision making is subject to numerous biases (Kahneman & Tversky, 1982). Rocksource promoted the new CSEM technology as the future key to a successful exploration, large volumes and high COS, and it became competitive rivalry with other companies. To achieve external justification, described as a factor leading to the escalation (Ross & Staw, 1993), the volume and economical numbers in the annual reports become larger and larger (Section 1). At the same time Rocksource always presented the key to success on all academic conferences in Norway and abroad. For more than six years Rocksource communicated to the internal and external stakeholders the project become more and more successful, leading to a norm of behavior favor "staying the course." Generally projects are more prone to escalation when there is strong political support at the senior management level and when the project has become institutionalized. The data show a very strong support for the CSEM technology (Figure 53), and only CSEM positive prospects could rank high enough to be drilled (Figure 54), the CSEM positive projects became institutionalized.

7.6 Risk team

While the evidence-based approach of science is lauded for introducing objectivity to processes of investigation, the role of subjectivity in science is less often highlighted in scientific literature. Nevertheless, the scientific method comprises at least two components; forming hypotheses (in this study a geological model (Section 3.11), and collecting data to substantiate or refute each hypothesis (Olscamp, 1965). Allowing subjectivity is a positive aspect of the scientific method as it allows for leaps of faith, which occasionally lead to spellbinding proposals proved to be valid. Some scientific studies have analyzed how subjectivity contributes to the progression of ideas, and some of those studies are in the geological sciences (Aspinall, 2010). Studies have proved that when a geologist develop a geological model the geologists' background and experience correlated significantly with the likelihood of having invoked the correct concepts. Variations in prior experience are shown to bias (Section 4.2) the formation of evidence-based geological hypotheses (Bond et al., 2012). Biases include over-confidence, anchoring and adjustment, availability, and motivational bias are well documented (Kahneman et al., 1982; O'Hagan et al., 2006). All such biases occur in situations of uncertainty (such as when forming hypotheses), when various heuristics (rules of thumb) are employed subconsciously.

Based on the data and findings in the study it is likely that biases have influenced the evaluation of uncertainty and risk at different levels in Rocksource (Section 6.8, 7.3.1 and 7.3.2, in addition to Figure 49, Figure 52, Figure 53 and Figure 54). One of the growing areas of focus in risk management is the field of human factors where behavioral and organizational psychology underpin the understanding of risk based decision making (Section 4.2). Framing (Tversky and Kahneman, 1981) is a fundamental problem with all forms of risk assessment. In particular, because of bounded rationality the risk of extreme events is discounted and the probability is too low to evaluate intuitively. By identifying biases in the uncertainty and risk evaluating, training and practice can improve future prospect evaluations (Rose, 1987). This is also viable in the data, where the large companies with large organizations and well established systems to handle uncertainty and risk generally prove more hydrocarbons per investment (Figure 20), even if some of the differences in the diagram can be explained by accessibility to more attractive acreage.

While concepts are generalizations of many instances, the models are simplified representations of the natural reality, that is, of one particular geological object, feature or process, as it is impossible to depict and represent them in all details, from point to point. The model uncertainty expresses the deviation of the given model from the natural reality. The two main human sources of model uncertainties are, according to Nilsen and Aven (2003), the limitations of the researcher's knowledge (experience) and deliberate simplifications introduced by the researcher (models become more complex when increasing the level of detail and the model uncertainty increases as well, Section 7.3.1). Both are frequent sources of uncertainty in the geological investigations.

Observations used in the geological models may be biased by lack of experience of the experts, or by specific interests. The collection of CSEM data must be evaluated as a sampling campaign. Often it occurs that a sampling campaign finally collected more exceptional samples than the typical ones. Averaging the features of these samples, without adequate selection or correction, inevitably leads to biased results. Uncertainties resulting from such samplings may be significant and they can distort the results of an entire research campaign.

The RRT had mainly experience from universities and production phase, where the subsurface-related uncertainties and risk are different, and generally lower (Figure 1). The collected data show that the project teams presented large piles of information to the RRT in a relatively short period of time in the risk team meetings. It is possible that the presented information was linked to the members' previous experience, and "System 1" (Tversky & Kahneman, 1974 and Section 4.2.1) reduced the amount data needed to make the decisions by recognizing familiar situations from the past, but then related to production, not exploration. Members of the RRT was also in decision positions with the organization, and even leading the CSEM subsidiary (Rocksource Geotech). The tight connection did not make the RRT evaluation independent form the company strategy, technology development, the organization and the ecological environment. It is possible that this tight connections influenced the RRT's weighting of the new CSEM technology. The most important factor in Rocksource uncertainty and risk evaluation, weighted more than more than 30 year experience from seismic, both internally and externally (Figure 53 and Figure 54).

The organizational perspective can be beyond the main subject for the study, but gives broader perspectives to understand the RRT evaluations (Section 4.2.2). March (2002) pointed out that much of the behavior in organizations is based on following rules, operating procedures, professional standards, cultural norms etc. The decision is then a function which is based on appropriateness, obligation and duty, rather than on the value of the consequences of decisions. The founders of Rocksource, and some of the largest shareholders, were actively part of the organization. They had an enthusiastic personality influencing strongly the "Rocksource culture", promoted the new CSEM technology strongly and were members of the RRT. Strong personalities representing the "Rocksource culture" in the RRT can have created biases, hence the uncertainty and risk evaluations.

Brunsson (1982) argued that decisions are not end products, but rather steps towards some desirable action. The processes should therefore be designed with the aim of ensuring successful action, rather than the philosophy of identifying the rational choice from the available alternatives, as assumed in the normative model. The data in Section 1 and 1, can indicate that geological evaluations was not the most important, and the real desire was to drill CSEM positive wells. Tingling and Brydon (2010) introduce the term “decision-based evidence making" to describe situations where facts are marshalled ex-post to support decisions that have already been made, the collected evidence is symbolic and used ex-post to legitimize the decision, and signal that the decision makers have followed a rational process.

A study from Polson and Curtis (2010) show evolution of expert opinion during the structured group elicitation process (Figure 55). The expert opinion changed significantly during the process, even in the absence of new information. However, subjectivity is also shown to be important: the consensus position for “Fault” in Figure 55 was not adopted by any geologist before the meeting, without group dynamics it might not have been considered. Consensus-driven results may only represent the group opinion at one instant in time, and may not represent the true range of uncertainty about the issue at hand. This is disturbing because consensus is often used in the geosciences. Group interactions might reduce individual biases, such as anchoring and over-confidence (Oppenheimer et al., 2007). However, the group consensus approach may also introduce dynamic biases (Mastrandrea et al., 2011), which are more difficult to detect without tracking the dynamics of opinion. The collected data show how the RRT reservoir consensus generally are on the high side, representing a harmony or conformity in the group (Figure 52 and Figure 55). But it is interesting to observe the low values for assigned for “retention” (Figure 55). The effect is most likely not reflecting a wider range of probabilities from expert’s opinions in RRT, but can be explained by three factors; a) some of the prospect have a stratigraphic trap (within the industry is regarded as a very high risk ($P_g < 0.3$), b) the expected hydrocarbon column in all prospects are high and need very high sealing capacity and finally c) the observed CSEM anomaly (false positive) could represent resistivity anomalies created by recent hydrocarbons (blown seal). When RRT act as s conformal and homogeny group the process of decision making may decrease the members' ability to think independently and critically.

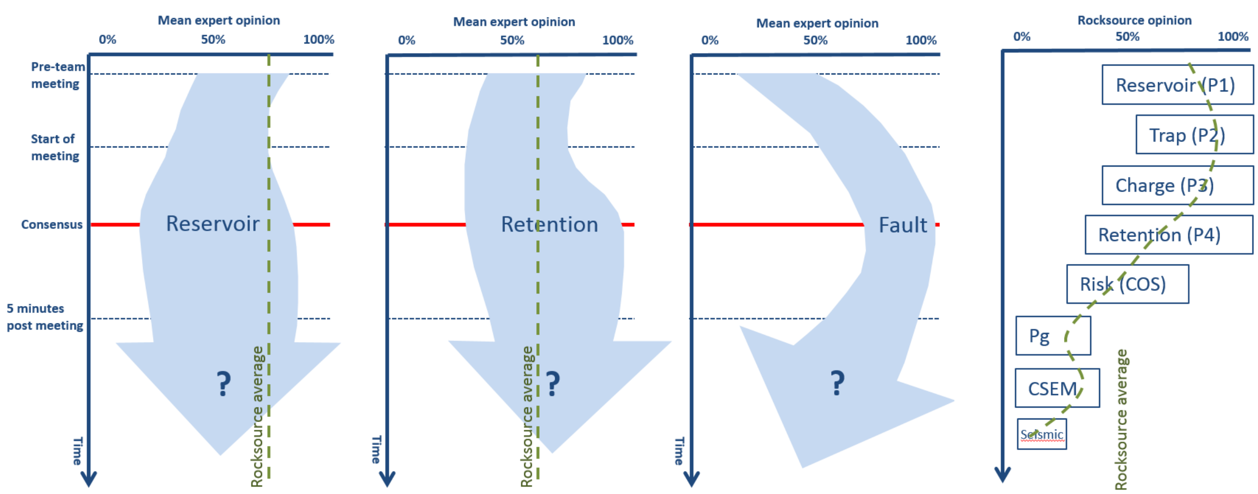


Figure 55 Evolution of expert opinion during the structured group elicitation process of Polson and Curtis (2010). Horizontal axes: estimated probability of the existence of a specific reservoir, seal, and fault. Vertical axes show expert opinion at four points in time. The width of the arrow reflect the range probabilities of experts’ opinions. Red lines show the group consensus at the decision point in a usual committee of experts. Green dotted line show average RRT evaluation of reservoir and retention. Rocksource options show the spread in RRT evaluation of reservoir (P1),

trap (P2), Charge (P3), total prospect risk (COS) for the different prospects. The green dotted line indicate RRT consensus for reservoir and retention from the evaluated prospects. Source: Appendix 3: Datasheets for evaluated prospects.

7.7 Summary and consequences

The theory describes post drilling analysis as one way to improve future decisions for exploration companies. Based on the collected data a post drill evaluation of the pre drill uncertainty and risk evaluations for five drilled wells is performed. The post well analysis of the CSEM data give an impression of how fast a new technology develop. Analyses performed on the same data set two years later, but with a new processing software, had most likely not give any CSEM DHI_{uplift} to the prospects. The data show a substantial gap between pre and post well uncertainty and risk estimations. Even if large and wide ranges was used in the pre well evaluations, the post well results was overrepresented on the negative side (Figure 50 and Figure 52). To develop a competitive advantage Rocksource used the new CSEM technology in the uncertainty and risk evaluations. In the RRT's evaluations CSEM was the single most important factor (Figure 53). The new CSEM technology was weighted higher in Rocksource, even if the prospects was associated with a low Pg, than companies within the industry are weighing seismic DHI's (Figure 54). Even if CSEM was a new technology and all uncertainties and risks evaluations in Rocksource were dependent on the immature technology the data do not show any mitigating actions to reduce the portfolio risk when negative information is received.

In order to take rational decisions (Section 4.2), it is necessary to understand the portfolio uncertainties and risks. The collected data and discussion (Section 1 and 1), show that Rocksource's uncertainty and risk evaluation was influenced by with high expectations to the new CSEM technology. Lack of experience with in the RRT influenced the pre well evaluations, hence the prospect uncertainty and risk was influenced of belief and biases. Most likely the missing understanding of uncertainty and risk, within exploration and implementing a new technology, was represented by the whole organization, from the board to the employee. The consequences for not understanding the risk of implementing a new technology without well-defined risk management, hence the portfolio uncertainty and risk, gave limited the options for Rocksource to develop a more balanced portfolio. The data show a systematic optimistic use of parameters used for calculations hydrocarbon volumes and a heavily weighted technology to de-risk (Figure 56). The portfolio was evaluated to be as *low risk-high reward*, but as the most of the prospect was located within new plays (high uncertainty and risk) the portfolio consisted more likely of high risk-low reward prospects, or something in-between (Figure 56).

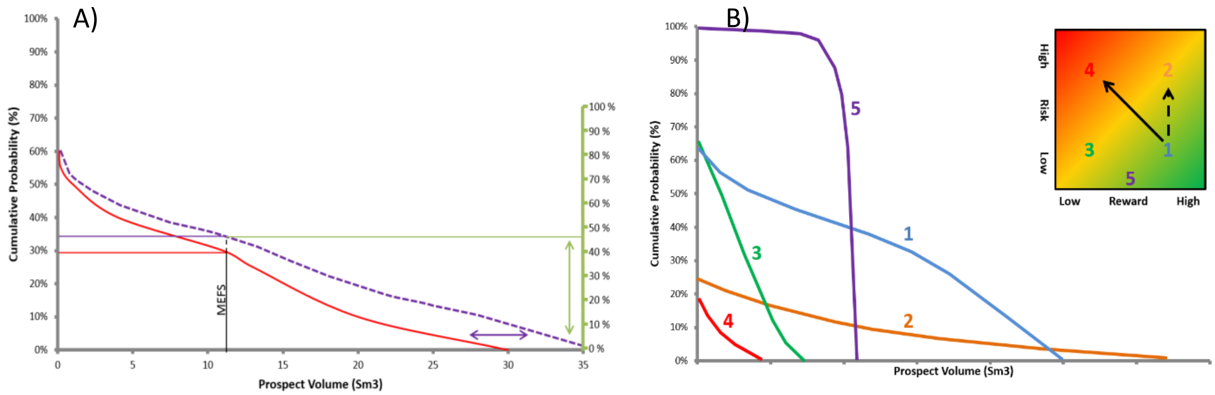


Figure 56 A) Conceptual sketch of the consequences when optimistic parameters are used to estimate the prospect uncertainty (purple line, compared to the red line). At the same time new technology is used to reduce the risk (green line). Initially the MEFS volumes (12 Sm3) had an associated COS of 30 %. When to positive parameters lift the curve to purple, and the associated COS is 35 %. The new CSEM technology was used to de-risk the prospect further, and final COS is 45 %. See Figure 21 for details.

B) Conceptual sketch of the consequences for how expectation curve related to uncertainty risk is related to reward. Optimistic uncertainty and COS change the expectation of the prospect, and in some cases the hole portfolio. A *low risk high-reward* portfolio (1) can easily turn into a *high risk-low reward* portfolio (4), or something in-between (2) if the evaluations are wrong. See Figure 22 for details

7.8 Future work

The current study is carried out in order to get an overview and a better understand for the uncertainty and risk evaluations performed in Rocksource to improve future decisions. As a result many several topics have been included in the study (decision processes, uncertainty, risk and new technology) without doing an in-depth investigation of each subject. For further studies in-depth analysis of each topic can be performed, together with their role in a greater context. Interviews and/or questionnaires can add valuable information and give new perspectives to future studies.

The results of the study can be implanted in Rocksource to improve the decision process and improve the overall understanding of uncertainty and risk. However the results can be used by other companies within the industry and companies implementing a new technology to limit the uncertainty and risk.

7.9 Recommendations

The study and my professional experience has given me a useful understanding of the importance of uncertainty and risk in hydrocarbon exploration. In short oil company can have to be developed by a great understanding of how uncertainty and risk is handled, and can be summarized in a few themes:

- Accounting correctly for covariance of uncertain quantities at all levels of aggregation prospect, play, basin, and exploration portfolio, as dependencies among uncertain quantities can lead to seriously distorted estimates.
- Decisions to prioritize exploration effort among technologies, basins, plays and prospects should account for covariability of returns to exploration effort introduced by technological, price and cost uncertainties and, in particular, should distinguish between systematic and unsystematic risk. According to Kaufman (1993) unsystematic risks are those that can be reduced by geographic and geological diversification of exploration and development activities, whereas systematic risks axe those risks that cannot be so reduced (e.g. technology, oil and gas price).

- Exploratory risk analysis is based on personal assessments of uncertainties by technical experts, post drilling evaluations are aiming to measuring the quality of the assessments. Post well evaluations are much talked about, but unfortunately little is done (Kaufman, 1993). Direct education of judgments about dependencies among uncertain quantities is almost always difficult and often infeasible. Ignoring even modest correlations can distort both the accuracy and precision of assessments of risk and uncertainty.
- Valuing project flexibility. The most frequently used method of project valuation is based on probability distribution of project net present value (NPV) computed at a pre-assigned discount rate, an appropriate method when the project is under way and management cannot alter the future direction. If management can expand, contract, or abandon the project as the future unfolds then the NPV-method does not correctly account for project value. When companies get license awards, with a work commitment to explore and then further development if oil or gas is found in commercial quantities, the license is in fact an option to explore or not before expiration. Modern finance theory offers option valuation methods that correctly account for flexibility in the timing of exploration and development.

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Appendix

Appendix 1: NPD classification of resources

NPD use a resource classification to estimate petroleum resources both discovered and undiscovered (Figure 57). Petroleum volumes are classified by their maturity. Resources are divided into the principal classes of historical production, reserves, contingent resources and undiscovered resources. Reserves relate to remaining recoverable petroleum resources in deposits which the licensees have decided to develop. Contingent resources are discovered petroleum volumes still not covered by a development decision. Undiscovered resources are volumes considered to be recoverable but not yet proven by drilling. Whether the estimated resources actually exist is uncertain. The various main classes are divided into sub-categories depending on the maturity of the various projects.

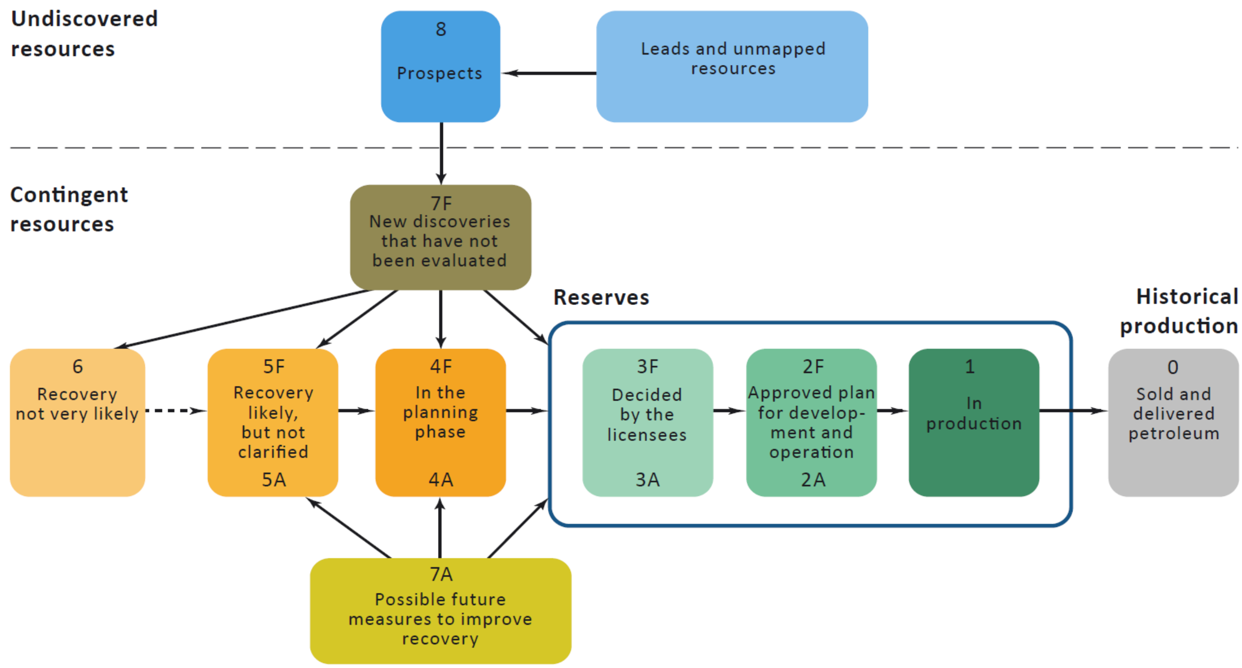


Figure 57 NPD resource classification covers all estimated petroleum resources, both discovered and undiscovered. Petroleum volumes are classified by maturity.

Historical production

Sold and delivered petroleum (Category 0) - Petroleum resources in hydrocarbon deposits that have been produced and have passed the reserves reference point. Including hydrocarbons produced from fields in production as well as from permanently closed fields.

Reserves

Reserves in production (Category 1) - Remaining, recoverable, marketable and deliverable quantities of petroleum decided to recover, and included in authorities approved plans for development and operation

(PDO). The reserves in this category are shown by subtracting the sold and delivered petroleum quantities from the originally recoverable reserves.

Reserves with an authorities approved plan for development and operation (Category 2)

- Recoverable quantities of petroleum (Category 2 F), but which have not been put into production.

Reserves which the licensees have decided to recover (Category 3).

- Recoverable, marketable and deliverable quantities of petroleum which the licensees have decided to recover, but for which the authorities have not yet approved a PDO or granted exemption from (Category 3 F). Including supplementary reserves from new deposits and quantities of petroleum (mainly gas) that have been held back, but which can be sold without significant investments at a later date.

Contingent resources

Resources in the planning phase (Category 4)

- Discovered, recoverable, petroleum resources which are expected to be covered by a PDO or granted exemption therefrom, and where specific activity is taking place with a view to clarifying whether development will be implemented (Category 4 F). Development is expected to be decided by the licensees within about 4 years.

Resources where recovery is likely, but not clarified (Category 5).

- Discovered, recoverable petroleum resources whose recovery is likely, but not clarified (Category 5 F). This category contains discovered, recoverable petroleum resources which are not being considered for development at the moment, but which can be developed in due course. It also contains supplementary resources from new deposits which can be tied in to fields and discoveries with resources in categories 1, 2, 3 and 4, but where matters regarding recovery still not have been clarified.

Resources whose recovery is not very likely (Category 6).

Discovered, recoverable petroleum resources which are not expected to be profitably even in the long term, and resources in small, untested discoveries whose recovery seems unlikely. Category 6 contains petroleum resources that require substantial changes in technology, prices, or other option values, to be recovered profitably, and where it is not very likely that the changes required will take place.

Resources that have not been evaluated (Category 7).

- New discoveries without finalized discovery evaluation report and only a provisional resource estimate exists (Category 7 F).
- Recoverable petroleum resources in fields and discoveries which have resources in categories 1, 2, 3, 4 or 5 and which may be recoverable by employing new technologies beyond those that are considered to be conventional (Category 7 A). For the individual field or discovery, this estimate of the resource will typically be based on rough valuations and great uncertainty.

«First oil/gas» and «Additional oil/gas» in categories 2, 3, 4, 5 and 7.

- «First oil/gas» (F) : The petroleum resource is given the designation First (F) if it is linked to the initial recovery project for the relevant petroleum-in-place. Supplementary resources (additional to petroleum initially in place) are also given the designation F.
- «Additional oil/gas» (A) : Petroleum resources are given the designation Additional (A) if they are linked to measures intended to improve production relative to initial plans. The A resources are

normally positive, but may also be negative (e.g where oil recovery improvements require gas consumption).

Undiscovered resources

Resources in mapped prospects (Category 8).

Undiscovered, recoverable quantities of petroleum in mapped, but not tested prospects, and therefore there is an uncertain whether the estimated resources are present. Untested prospects are risk-weighted, and reflect estimated volumes multiplied by the probability of making a discovery.

Resources in leads, and unmapped resources (Category 9).

Undiscovered, recoverable petroleum resources attached to leads. It is uncertain whether the leads, and if so the estimated resources, are actually present. The resource estimates reflect estimated volumes multiplied by the probability of making a discovery. The unmapped, recoverable resources are calculated by play analyses. The total resources of the plays include both discovered and undiscovered resources. The unmapped resources are the difference between the aggregated resources of the plays and the discovered and mapped resources.

Appendix 2: NPD's method for evaluation of petroleum resources

Several calculation methods are available for estimating undiscovered petroleum resources deposited in an area. The choice of method depends on knowledge in the area, but builds on a good understanding of the regional geology as well as an overview of prospects and how much petroleum each prospect might produce. In virgin areas, the uncertainty typically will prevail about

- total resources
- geographical distribution of the resources
- distribution of resources by size
- division between oil and gas in the resources.

Before discussing risk and uncertainty associated to resource estimates, NPD's preferred method for calculating undiscovered petroleum, play and prospect analysis, is shortly presented. This involves systematizing and describing the geological understanding of an area. Plays are then defined as the basis for calculating how much petroleum might be proven in and produced from each play.

A *play* is characterised by geological factors which are simultaneously present in a clearly delineated area (basin), both stratigraphically and geographically, source rocks and a trap. Several plays of differing geological age can be found in a single geographical area. Mapped and unmapped prospects, discoveries and fields can be found in a single play (Figure 58). A confirmed play is defined by a discovery with proven producible petroleum, but without evaluating the commerciality. Contradictory is an unconfirmed play is defined by not proved producible petroleum. Before a play is confirmed, the level of uncertainty must be taken into account. The likelihood that a play be confirmed is calculated by assessing the geological factors and the probability that these will work. NPD estimated resources are specified by an uncertainty range, but estimates of undiscovered resources are very uncertain. The uncertainty is greatest in areas with the least information and the shortest exploration history. The uncertainty is therefore greatest in the Barents Sea, where fewest wells have been drilled and most plays remain unconfirmed, and lowest in the North Sea where much data have been acquired and more plays have been confirmed by discoveries. Resource estimates within a play rise when the play is confirmed. NPD have identified 73 plays on the NCS, of which 40 have been confirmed by discoveries.

Prospects provide the fundamental elements in play analysis, number of prospects and producible volume of hydrocarbon determines the estimated resources for the play. A prospect is defined as a mapped potential petroleum deposit and where the quantity of possible producible petroleum is calculated based both on the estimated size of each prospect and on an evaluation of the relationship between assumed and actual discovery sizes. Information from each prospect along with knowledge of the discovery success for the play is used to estimate a common probability of success to the prospects in a play. The likelihood that an exploration well might prove producible petroleum in the prospect is called the probability of success. New information from the seismic interpretation and drilling results are used by the NPD regularly to update and adjust its resource estimates for the relevant plays.

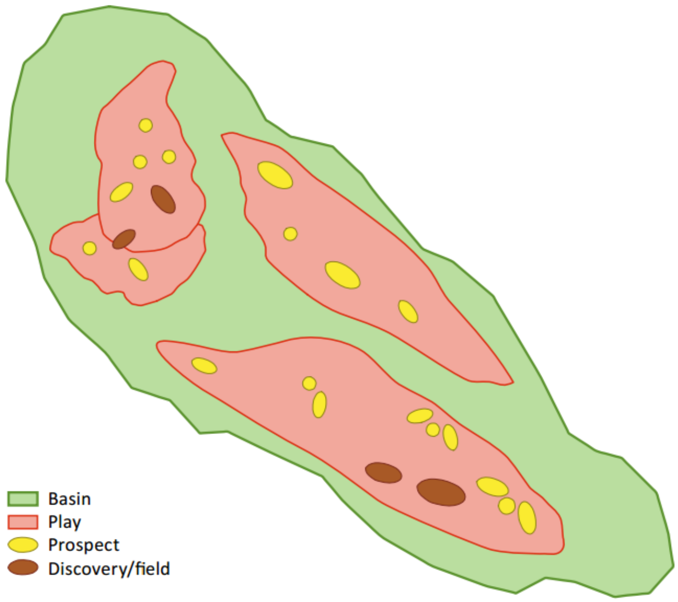


Figure 58 Relationship between basin, play, discovery and prospect.

Appendix 3: Datasheets for evaluated prospects

PL 506 – 26/5-1

- Langenuen
- Storbarden

PL559 – 6608/11-7S

- Phoenix Åre
- Phoenix Grey Beds

PL416 – well 31/8-1

- Breiflab

PL530 – well 7124/4-1S

- Heilo Stø
- Heilo Snadd
- Heilo Kobbe

PL535 – well 7225/3-1

- Norvarg Stø
- Norvarg Snadd
- Norvarg Intra Snadd
- Norvarg Kobbe
- Norvarg Havert

Prospect data									
Block	26/5 & 26/8	Prospect name	Langenuen Utsira	Discovery/Prospect/Lead	Prospect	Additional block potential (Y/N)	Yes		
Play name (NPD)		Proven Play (Y/N)	No	New Play (Y/N)	Y	Outside Play (Y/N)	Yes		
Oil, Gas or O&G case:	Oil	Company	Rocksource	Assessment year	2008	Numbered rounds/APA	APA	Seismic database (2D/3D)	2D & 3D
This case no.:		Structural element (NPD)	Stord Basin	Type of trap	Stratigraphic	Water depth [m MSL]	175	CSEM database	2D & 3D

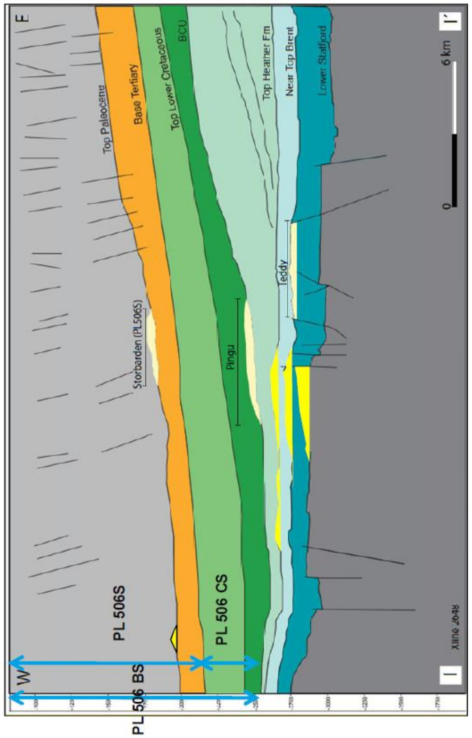
Reseources IN PLACE and RECOVERABLE Volumes, this case		Main phase Low (P90)	Main phase Base, Mode	Main phase Base, Mean	Main phase High (P10)	Associated phase Low (P90)	Associated phase Base, Mode	Associated phase Base, Mean	Associated phase High (P10)
In place resources	Oil [10^6 Sm^3]	66,6		196,4	417,9				
	Gas [10^9 Sm^3]			0,0		3,66		11,60	29,50
Recovarable resources	Oil [10^6 Sm^3]	8,1		27,6	83,1				
	Gas [10^9 Sm^3]					0,37		1,53	5,12

Timing									
Reservoir (from)	Eocene	Reservoir (from)	Utsira Fm	Source Rock (primary)	Eocene	Source Rock (primary)	Draupne Fm	Seal	Eocene Norland Fm
Reservoir (to)		Reservoir (to)		Source Rock (secondary)		Source Rock (secondary)		Seal	

Probability (0-1)									
Technical (oil + gas + O&G)	0,13	Oil case	0,3	Gas case	0,7	O&G case		Uplift seismic	
Reservoir (P1)	0,8	Trap (P2)	0,9	Charge (P3)	0,6	Retention (P4)	0,3	Uplift CSEM	0

Parameters	Application input Low (P90)	Application input Base	Application input High (P10)	Well results Low (P90)	Well results Base	Well results High (P10)
Depth to top of prospect [m MSL] (>0)		787			816	
Area of closure [km^2] (>0)	82,0	143,0	249,0			
Reservoir thickness [m] (>0)	15	50	80		0	
HC column [m] (>0)	50	80	95		0	
Gross rock volume [10^9 Sm^3] (>0)	0,1281	0,3494	0,6061		0	
Net/Gross (0-1)	0,35	0,5	0,7		0	
Porosity (0-1)	0,2	0,25	0,29		0	
Permability [mD] (>0)					0	
Water saturation (0-1)	0,35	0,45	0,6		0	
Bg [Rm^3/Sm^3] (<1)	82	96	110		0	
1/Bo [Sm^3/Sm^3] (<1)	0,94	0,89	0,8		0	
GOR, free gas [Sm^3/Sm^3] (>0)						
GOR, oil [Sm^3/Sm^3] (>0)	80	100	150		0	
Recovery factor, oil main phase (0-1)	0,05	0,15	0,25		0	
Recovery factor, gas ass. main (0-1)						
Recovery factor, gas main phase (0-1)	0,35	0,5	0,6		0	
Recovery factor, liquid ass. phase (0-1)						
Temperature, top reservoir [°C] (>0)						
Pressure, top reservoir [bar] (>0)						
Cut off criteria for N/G calculation						

Comments



Prospect data

Block	26/5 & 26/8	Prospect name	Storbarden Balder	Discovery/Prospect/Lead	Prospect	Additional block potential (Y/N)	Yes		
Play name (NPD)		Proven Play (Y/N)	Yes	New Play (Y/N)	yes	Outside Play (Y/N)	Yes		
Oil, Gas or O&G case:	Oil	Company	Rocksource	Assessment year	2008	Numbered rounds/APA	APA	Seismic database (2D/3D)	2D & 3D
This case no.:		Structural element (NPD)	Stord Basin	Type of trap	Stratigraphic	Water depth [m MSL]	175	CSEM database	2D & 3D

Reseources IN PLACE and RECOVERABLE Volumes, this case		Main phase				Associated phase			
		Low (P90)	Base, Mode	Base, Mean	High (P10)	Low (P90)	Base, Mode	Base, Mean	High (P10)
In place resources	Oil [10^6 Sm^3]	50,6		233,7	770,0				
	Gas [10^9 Sm^3]			0,0		8,60		42,10	146,70
Recovarable resources	Oil [10^6 Sm^3]	19,0		86,6	288,6				
	Gas [10^9 Sm^3]					1,19		2,11	4,04

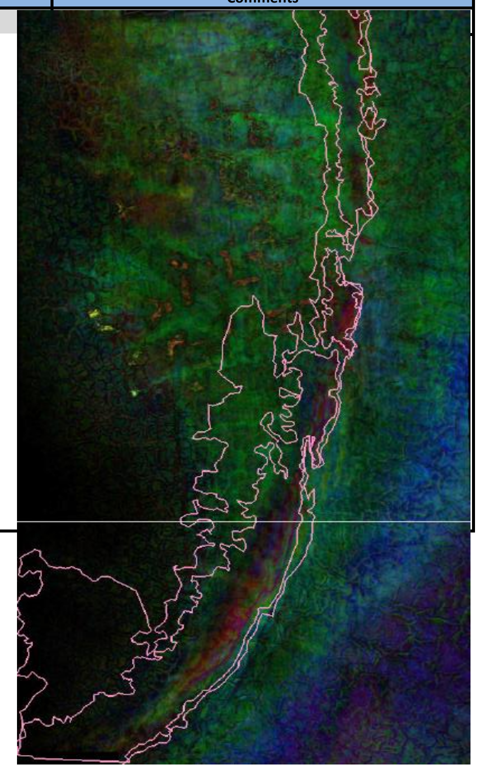
Timing

Reservoir (from)	Palaeocene	Reservoir (from)	Balder Fm	Source Rock (primary)	Eocene	Source Rock (primary)	Draupne Fm	Seal	Eocene Balder Fm
Reservoir (to)		Reservoir (to)		Source Rock (secondary)		Source Rock (secondary)		Seal	

Probability (0-1)

Technical (oil + gas + O&G)	0,12	Oil case	0,3	Gas case	0,7	O&G case		Uplift seismic	0,05
Reservoir (P1)	0,8	Trap (P2)	0,9	Charge (P3)	0,4	Retention (P4)	0,4	Uplift CSEM	0,09

Parameters	Application input			Well results			Comments
Parameter	Low (P90)	Base	High (P10)	Low (P90)	Base	High (P10)	
Depth to top of prospect [m MSL] (>0)		1513			1490		
Area of closure [km^2] (>0)	20,0	95,0	260,0				
Reservoir thickness [m] (>0)	15	35	70		0		
HC column [m] (>0)	35	135	315		0		
Gross rock volume [10^9 Sm^3] (>0)	0,371	0,557	0,746				
Net/Gross (0-1)	0,4	0,6	0,8		0		
Porosity (0-1)	0,19	0,23	0,27		0		
Permability (mD) (>0)					0		
Water saturation (0-1)	0,4	0,3	0,2		0		
Bg [Rm^3/Sm^3] (<1)							
1/Bo [Sm^3/Sm^3] (<1)	0,94	0,88	0,8				
GOR, free gas [Sm^3/Sm^3] (>0)							
GOR, oil [Sm^3/Sm^3] (>0)	15	18	20				
Recovery factor, oil main phase (0-1)	0,27	0,35	0,55				
Recovery factor, gas ass. main (0-1)	0,27	0,35	0,55				
Recovery factor, gas main phase (0-1)							
Recovery factor, liquid ass. phase (0-1)							
Temperature, top reservoir [°C] (>0)		58			49		
Pressure, top reservoir [bar] (>0)		184			unknown		
Cut off criteria for N/G calculation					n/a		



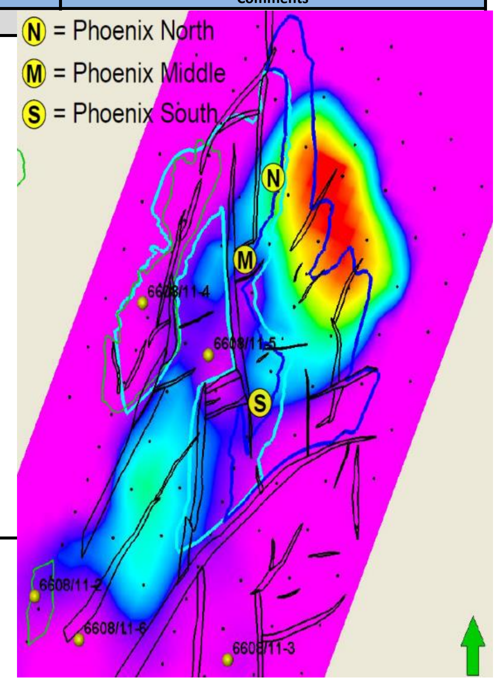
Prospect data									
Block	6608/10,11,12	Prospect name	Phoenix Åre	Discovery/Prospect/Lead	Prospect	Additional block potential (Y/N)	Yes		
Play name (NPD)		Proven Play (Y/N)		New Play (Y/N)		Outside Play (Y/N)			
Oil, Gas or O&G case:	Oil	Company	Rocksource	Assessment year	2009	Numbered rounds/APA	APA	Seismic database (2D/3D)	2D & 3D
This case no.:		Structural element (NPD)	Trøndelag Platform	Type of trap	Structural	Water depth [m MSL]	350	CSEM database	2D & 3D

Reseources IN PLACE and RECOVERABLE Volumes, this case		Main phase				Associated phase			
		Low (P90)	Base, Mode	Base, Mean	High (P10)	Low (P90)	Base, Mode	Base, Mean	High (P10)
In place resources	Oil [10^6 Sm^3]	3,3		9,8	18,1				
	Gas [10^9 Sm^3]			0,0		0,1		0,4	0,8
Recovarable resources	Oil [10^6 Sm^3]	0,9		2,9	5,6				
	Gas [10^9 Sm^3]					0,1		0,2	0,4

Timing									
Reservoir (from)	Sinemurian	Reservoir (from)	Åre Fm	Source Rock (primary)	Oxfordian-Kimmeridgian	Source Rock (primary)	Spekk Fm	Seal	Springar Fm
Reservoir (to)	Hettangian	Reservoir (to)	Åre Fm	Source Rock (secondary)		Source Rock (secondary)		Seal	Maastrichtian

Probability (0-1)									
Technical (oil + gas + O&G)	0,27	Oil case	1	Gas case		O&G case		Uplift seismic	0
Reservoir (P1)	0,9	Trap (P2)	0,5	Charge (P3)	0,6	Retention (P4)	1	Uplift CSEM	0,33

Parameters	Application input			Well results			Comments
Parameter	Low (P90)	Base	High (P10)	Low (P90)	Base	High (P10)	
Depth to top of prospect [m MSL] (>0)		1574			1687		
Area of closure [km^2] (>0)	0,6	1,3	8,8				
Reservoir thickness [m] (>0)	150	200	250		75,6		
HC column [m] (>0)	60	100	130		0		
Gross rock volume [10^9 Sm^3] (>0)							
Net/Gross (0-1)	0,3	0,5	0,8		0,31		
Porosity (0-1)	0,15	0,25	0,35		0,27		
Permability [mD] (>0)							
Water saturation (0-1)	0,4	0,3	0,2		1		
Bg [Rm^3/Sm^3] (<1)							
1/Bo [Sm^3/Sm^3] (<1)	0,833	0,909	0,952				
GOR, free gas [Sm^3/Sm^3] (>0)							
GOR, oil [Sm^3/Sm^3] (>0)	15	30	100				
Recovery factor, oil main phase (0-1)	0,1	0,3	0,45				
Recovery factor, gas ass. main (0-1)	0,4	0,5	0,6				
Recovery factor, gas main phase (0-1)							
Recovery factor, liquid ass. phase (0-1)							
Temperature, top reservoir [^oC] (>0)		54			59		
Pressure, top reservoir [bar] (>0)		160			No data		
Cut off criteria for N/G calculation					Vsh<0.40, Phie>0.10		



Prospect data									
Block	6608/10,11,12	Prospect name	Phoenix Grey Beds	Discovery/Prospect/Lead	Prospect	Additional block potential (Y/N)	Yes		
Play name (NPD)		Proven Play (Y/N)		New Play (Y/N)		Outside Play (Y/N)			
Oil, Gas or O&G case:	Oil	Company	Rocksource Trøndelag	Assessment year	2009	Numbered rounds/APA	APA	Seismic database (2D/3D)	2D & 3D
This case no.:		Structural element (NPD)	Platform	Type of trap	Structural	Water depth [m MSL]	350	CSEM database	2D & 3D

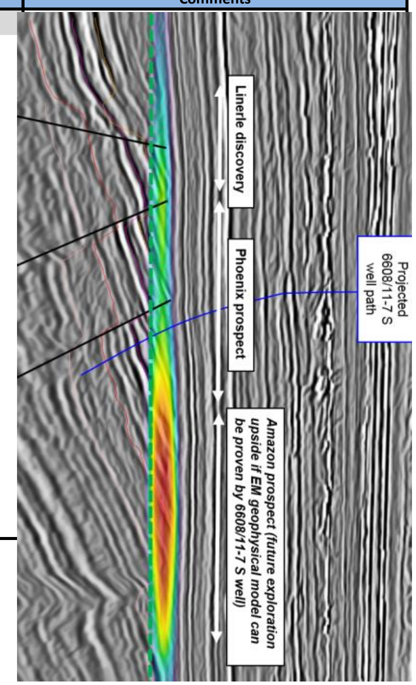
Reseources IN PLACE and RECOVERABLE Volumes, this case		Main phase Low (P90)	Main phase Base, Mode	Main phase Base, Mean	Main phase High (P10)	Associated phase Low (P90)	Associated phase Base, Mode	Associated phase Base, Mean	Associated phase High (P10)
In place resources	Oil [10^6 Sm^3]	126,6		182,0	243,2				
	Gas [10^9 Sm^3]			0,0		3,44		7,30	12,00
Recovarable resources	Oil [10^6 Sm^3]	30,4		53,1	78,1				
	Gas [10^9 Sm^3]					1,72		3,64	5,89

Timing									
Reservoir (from)	Norian	Reservoir (from)	Grey Beds	Source Rock (primary)	Oxfordian-Kimmeridgian	Source Rock (primary)	Spekk Fm	Seal	
Reservoir (to)	Rhaetian	Reservoir (to)		Source Rock (secondary)		Source Rock (secondary)		Seal	

Probability (0-1)									
Technical (oil + gas + O&G)	0,28	Oil case	1	Gas case		O&G case		Uplift seismic	
Reservoir (P1)	1	Trap (P2)	0,7	Charge (P3)	0,4	Retention (P4)	1	Uplift CSEM	0,22

Parameters	Application input			Well results		
Parameter	Low (P90)	Base	High (P10)	Low (P90)	Base	High (P10)
Depth to top of prospect [m MSL] (>0)		1827			1600	
Area of closure [km^2] (>0)	18,9	41,9	49,5		0	
Reservoir thickness [m] (>0)	150	200	250		5,3	
HC column [m] (>0)	125	165	200		0	
Gross rock volume [10^9 Sm^3] (>0)						
Net/Gross (0-1)	0,35	0,4	0,6		0,053	
Porosity (0-1)	0,18	0,2	0,3		0,19	
Permability [mD) (>0)						
Water saturation (0-1)	0,4	0,3	0,2		1	
Bg [Rm^3/Sm^3] (<1)						
1/Bo [Sm^3/Sm^3] (<1)	0,833	0,909	0,952			
GOR, free gas [Sm^3/Sm^3] (>0)						
GOR, oil [Sm^3/Sm^3] (>0)	15	30	100			
Recovery factor, oil main phase (0-1)	0,1	0,3	0,45			
Recovery factor, gas ass. main (0-1)	0,4	0,5	0,6			
Recovery factor, gas main phase (0-1)						
Recovery factor, liquid ass. phase (0-1)						
Temperature, top reservoir [°C] (>0)		54			74	
Pressure, top reservoir [bar] (>0)		160			No data	
Cut off criteria for N/G calculation					Vsh<0.40, Phie>0.10	

Comments



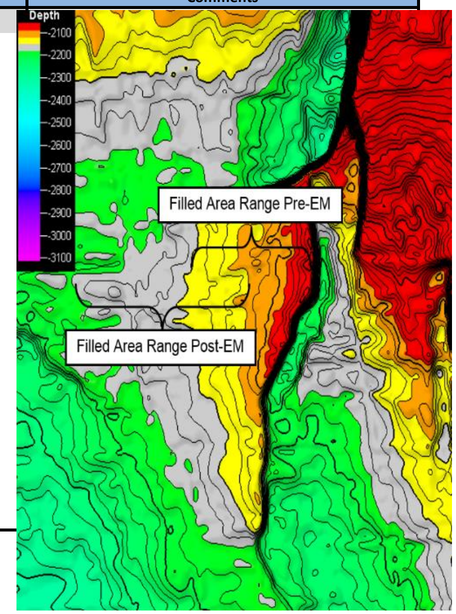
Prospect data									
Block	31/8	Prospect name	Beriflabb Sognefjord	Discovery/Prospect/Lead	Prospect	Additional block potential (Y/N)			
Play name (NPD)		Proven Play (Y/N)	No	New Play (Y/N)	Yes	Outside Play (Y/N)	No		
Oil, Gas or O&G case:	Oil [106 Sm3]	Company	Rocksource	Assessment year	2006	Numbered rounds/APA	APA	Seismic database (2D/3D)	2D & 3D
This case no.:		Structural element (NPD)	Bjarmeland Platform	Type of trap	Structural	Water depth [m MSL]		CSEM database	2D

Reseources IN PLACE and RECOVERABLE Volumes, this case		Main phase Low (P90)	Main phase Base, Mode	Main phase Base, Mean	Main phase High (P10)	Associated phase Low (P90)	Associated phase Base, Mode	Associated phase Base, Mean	Associated phase High (P10)
In place resources	Oil [10^6 Sm^3]	17,3		31,5	47,7	0,25		0,70	1,92
	Gas [10^9 Sm^3]			0,00					
Recovarable resources	Oil [10^6 Sm^3]					0,18		0,46	1,26
	Gas [10^9 Sm^3]	5,62		8,52	12,90				

Timing									
Reservoir (from)		Reservoir (from)	Sognefjord Fm	Source Rock (primary)		Source Rock (primary)	Draupne Fm	Seal	
Reservoir (to)		Reservoir (to)		Source Rock (secondary)	Oxfordian	Source Rock (secondary)	Heather Fm	Seal	

Probability (0-1)									
Technical (oil + gas + O&G)	0,23	Oil case		Gas case	1	O&G case		Uplift seismic	0
Reservoir (P1)	0,8	Trap (P2)	0,6	Charge (P3)	0,6	Retention (P4)	0,8	Uplift CSEM	0,29

Parameters	Application input Low (P90)	Application input Base	Application input High (P10)	Well results Low (P90)	Well results Base	Well results High (P10)	Comments
Depth to top of prospect [m MSL] (>0)		2212			2092		
Area of closure [km^2] (>0)	20,0	22,0	24,0				
Reservoir thickness [m] (>0)	34,0	45,0	60,0		94		
HC column [m] (>0)	80,0	110,0	140,0		0		
Gross rock volume [10^9 Sm^3] (>0)	0,46	0,63	0,85				
Net/Gross (0-1)	0,61	0,7	0,8		0,61		
Porosity (0-1)	0,18	0,21	0,24		0,24		
Permability (mD) (>0)					No data		
Water saturation (0-1)	0,44	0,35	0,25		1		
Bg [Rm^3/Sm^3] (<1)	0,00511	0,0048	0,00421				
1/Bo [Sm^3/Sm^3] (<1)							
GOR, free gas [Sm^3/Sm^3] (>0)	37,21	41,06	45,31				
GOR, oil [Sm^3/Sm^3] (>0)							
Recovery factor, oil main phase (0-1)							
Recovery factor, gas ass. main (0-1)							
Recovery factor, gas main phase (0-1)	0,65	0,7	0,75				
Recovery factor, liquid ass. phase (0-1)	0,6	0,65	0,7				
Temperature, top reservoir [°C] (>0)		88,0			No firm data (MWD)		
Pressure, top reservoir [bar] (>0)		216,8			No data		
Cut off criteria for N/G calculation					Vsh<0.40, Phie>0.10		



Prospect data

Block	7124/4	Prospect name	Heilo Stø	Discovery/Prospect/Lead	Prospect	Additional block potential (Y/N)	Yes		
Play name (NPD)	bjl,mj-7	Proven Play (Y/N)	Yes	New Play (Y/N)	No	Outside Play (Y/N)	No		
Oil, Gas or O&G case:	Oil	Company	Rocksource	Assessment year	2008	Numbered rounds/APA	20. Round	Seismic database (2D/3D)	2D & 3D
This case no.:		Structural element (NPD)	Nyslepp Fault Complex	Type of trap	4-way closure, faulted	Water depth [m MSL]	300	CSEM database	2D & 3D

Reseources IN PLACE and RECOVERABLE Volumes, this case		Main phase				Associated phase			
		Low (P90)	Base, Mode	Base, Mean	High (P10)	Low (P90)	Base, Mode	Base, Mean	High (P10)
In place resources	Oil [10^6 Sm^3]	20,5		76,1	140,2				
	Gas [10^9 Sm^3]			0,0		1,8		6,6	12,3
Recovarable resources	Oil [10^6 Sm^3]	8,1		30,3	58,0				
	Gas [10^9 Sm^3]					0,9		3,3	6,2

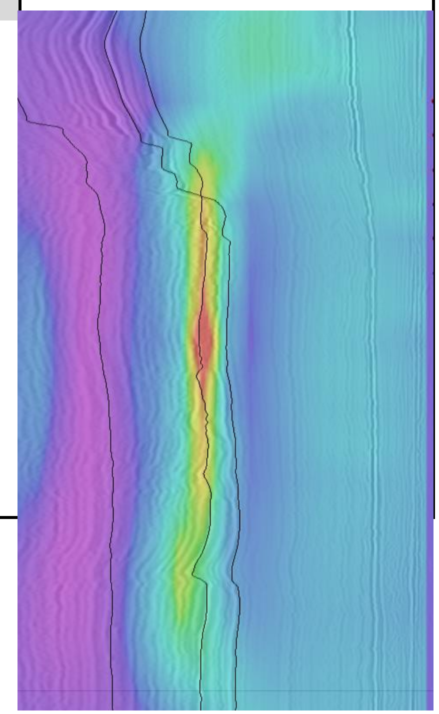
Timing

Reservoir (from)	Hattangian	Reservoir (from)	Tubåen Fm	Source Rock (primary)	Anisian-Ladinian	Source Rock (primary)	Kobbe Fm	Seal	Hekkingen Fm
Reservoir (to)	Bajocian	Reservoir (to)	Stø Fm	Source Rock (secondary)		Source Rock (secondary)		Seal	

Probability (0-1)

Technical (oil + gas + O&G)	0,26	Oil case	80	Gas case	20	O&G case		Uplift seismic	0
Reservoir (P1)	0,9	Trap (P2)	0,9	Charge (P3)	0,8	Retention (P4)	0,4	Uplift CSEM	0,39

Parameters	Application input			Well results			Comments
Parameter	Low (P90)	Base	High (P10)	Low (P90)	Base	High (P10)	
Depth to top of prospect [m MSL] (>0)		1175			1198		
Area of closure [km^2] (>0)	6,0	24,0	42,0				
Reservoir thickness [m] (>0)	27	35	43		52		
HC column [m] (>0)	30	55	70		n/a		
Gross rock volume [10^9 Sm^3] (>0)	0,18	0,58	0,98				
Net/Gross (0-1)	0,75	0,8	0,86		1		
Porosity (0-1)	0,18	0,23	0,27		0,25		
Permability (mD) (>0)					No data		
Water saturation (0-1)	0,17	0,25	0,33		1		
Bg [Rm^3/Sm^3] (<1)							
1/Bo [Sm^3/Sm^3] (<1)	0,82	0,83	0,84				
GOR, free gas [Sm^3/Sm^3] (>0)							
GOR, oil [Sm^3/Sm^3] (>0)	82	87	93				
Recovery factor, oil main phase (0-1)	0,35	0,4	0,45				
Recovery factor, gas ass. main (0-1)	0,45	0,5	0,6				
Recovery factor, gas main phase (0-1)							
Recovery factor, liquid ass. phase (0-1)							
Temperature, top reservoir [°C] (>0)		25			34		
Pressure, top reservoir [bar] (>0)		130			No data		
Cut off criteria for N/G calculation					Vsh<0.40, Phie>0.10		



Prospect data									
Block	7124/4	Prospect name	Heilo Snadd	Discovery/Prospect/Lead	Prospect	Additional block potential (Y/N)	Yes		
Play name (NPD)	bru-1	Proven Play (Y/N)	Yes	New Play (Y/N)	No	Outside Play (Y/N)	No		
Oil, Gas or O&G case:	Oil	Company	Rocksource	Assessment year	2008	Numbered rounds/APA	20. Round	Seismic database (2D/3D)	2D & 3D
This case no.:		Structural element (NPD)	Nyslepp Fault Complex	Type of trap	4-way closure, faulted	Water depth [m MSL]	300	CSEM database	2D & 3D

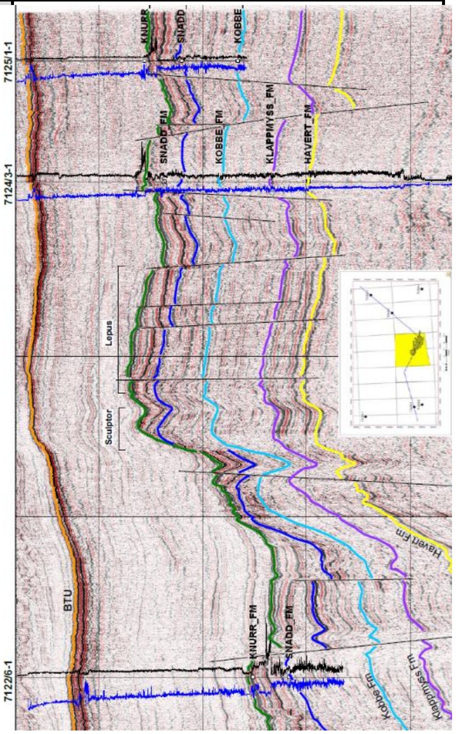
Reseources IN PLACE and RECOVERABLE Volumes, this case		Main phase				Associated phase			
		Low (P90)	Base, Mode	Base, Mean	High (P10)	Low (P90)	Base, Mode	Base, Mean	High (P10)
In place resources	Oil [10^6 Sm^3]	15,7		52,5	93,6				
	Gas [10^9 Sm^3]			0,0		1,5		4,8	8,5
Recovarable resources	Oil [10^6 Sm^3]	6,4		20,9	37,5				
	Gas [10^9 Sm^3]					0,8		2,4	4,3

Timing									
Reservoir (from)	Carnian	Reservoir (from)	Snadd Fm	Source Rock (primary)	Anisian-Ladinian	Source Rock (primary)	Kobbe Fm	Seal	Norian-Rhaetian
Reservoir (to)		Reservoir (to)		Source Rock (secondary)		Source Rock (secondary)		Seal	Fruholmen Fm

Probability (0-1)									
Technical (oil + gas + O&G)	0,21	Oil case	70	Gas case	30	O&G case		Uplift seismic	0
Reservoir (P1)	0,72	Trap (P2)	0,9	Charge (P3)	0,8	Retention (P4)	0,4	Uplift CSEM	0,44

Parameters	Application input			Well results		
Parameter	Low (P90)	Base	High (P10)	Low (P90)	Base	High (P10)
Depth to top of prospect [m MSL] (>0)		1288			1266	
Area of closure [km^2] (>0)	7	24,5	42			
Reservoir thickness [m] (>0)	31	45	59		46	
HC column [m] (>0)	30	50	70		0	
Gross rock volume [10^9 Sm^3] (>0)	0,226	0,727	1,33			
Net/Gross (0-1)	0,55	0,6	0,66		0,38	
Porosity (0-1)	0,17	0,2	0,23		0,2	
Permability (mD) (>0)						
Water saturation (0-1)	0,35	0,30	0,25		1	
Bg [Rm^3/Sm^3] (<1)						
1/Bo [Sm^3/Sm^3] (<1)	0,81	0,82	0,83			
GOR, free gas [Sm^3/Sm^3] (>0)						
GOR, oil [Sm^3/Sm^3] (>0)	86,5	92	97,5			
Recovery factor, oil main phase (0-1)	0,35	0,4	0,45			
Recovery factor, gas ass. main (0-1)	0,45	0,5	0,55			
Recovery factor, gas main phase (0-1)						
Recovery factor, liquid ass. phase (0-1)						
Temperature, top reservoir [^oC] (>0)		30			37	
Pressure, top reservoir [bar] (>0)		140			No data	
Cut off criteria for N/G calculation					Vsh<0.40, Phie>0.10	

Comments



Prospect data

Block	7124/4	Prospect name	Heilo Kobbe	Discovery/Prospect/Lead	Prospect	Additional block potential (Y/N)	Yes		
Play name (NPD)	brl,rm-4	Proven Play (Y/N)	Yes	New Play (Y/N)	No	Outside Play (Y/N)	No		
Oil, Gas or O&G case:	Oil	Company	Rocksource	Assessment year	2008	Numbered rounds/APA	20. Round	Seismic database (2D/3D)	2D & 3D
This case no.:		Structural element (NPD)	Nyslepp Fault Complex	Type of trap	4-way closure, faulted	Water depth [m MSL]	300	CSEM database	2D & 3D

Reseources IN PLACE and RECOVERABLE Volumes, this case		Main phase				Associated phase			
		Low (P90)	Base, Mode	Base, Mean	High (P10)	Low (P90)	Base, Mode	Base, Mean	High (P10)
In place resources	Oil [10^6 Sm^3]	6,70		17,50	29,50				
	Gas [10^9 Sm^3]			0,00		0,76		1,96	3,31
Recovarable resources	Oil [10^6 Sm^3]	2,65		6,94	11,78				
	Gas [10^9 Sm^3]					0,37		0,99	1,67

Timing

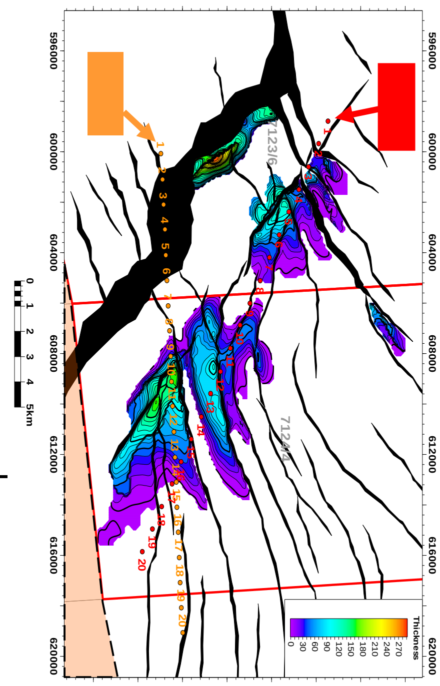
Reservoir (from)	Anisian	Reservoir (from)	Kobbe Fm	Source Rock (primary)	Anisian-Ladinian	Source Rock (primary)	Kobbe Fm	Seal	Anisian-Ladinian Kobbe-Snadd fms
Reservoir (to)		Reservoir (to)		Source Rock (secondary)		Source Rock (secondary)		Seal	

Probability (0-1)

Technical (oil + gas + O&G)	0,25	Oil case	0,4	Gas case	0,6	O&G case		Uplift seismic	0
Reservoir (P1)	0,63	Trap (P2)	1,0	Charge (P3)	0,8	Retention (P4)	0,5	Uplift CSEM	0

Parameters	Application input			Well results		
Parameter	Low (P90)	Base	High (P10)	Low (P90)	Base	High (P10)
Depth to top of prospect [m MSL] (>0)		1762			1807	
Area of closure [km^2] (>0)	4	9,5	15			
Reservoir thickness [m] (>0)	27	35	43		9,14	
HC column [m] (>0)	40	60	70		0	
Gross rock volume [10^9 Sm^3] (>0)	0,0905	0,23	0,371			
Net/Gross (0-1)	0,54	0,6	0,66		0,21	
Porosity (0-1)	0,18	0,22	0,25		0,16	
Permability [mD] (>0)						
Water saturation (0-1)	0,33	0,25	0,17		1	
Bg [Rm^3/Sm^3] (<1)						
1/Bo [Sm^3/Sm^3] (<1)	0,77	0,78	0,79			
GOR, free gas [Sm^3/Sm^3] (>0)						
GOR, oil [Sm^3/Sm^3] (>0)	106,5	112	117,5			
Recovery factor, oil main phase (0-1)	0,35	0,4	0,45			
Recovery factor, gas ass. main (0-1)	0,45	0,5	0,55			
Recovery factor, gas main phase (0-1)						
Recovery factor, liquid ass. phase (0-1)						
Temperature, top reservoir [°C] (>0)		40			55	
Pressure, top reservoir [bar] (>0)		175			No data	
Cut off criteria for N/G calculation					Vsh<0.40, Phie>0.10	

Comments



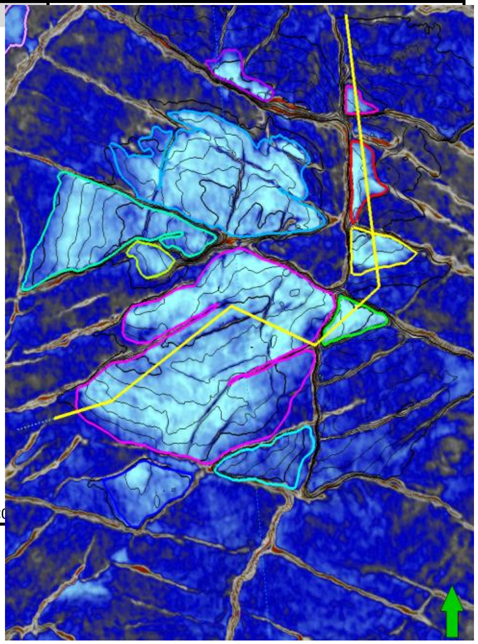
Prospect data									
Block	7225/3 & 7226/1	Prospect name	Norvarg Stø	Discovery/Prospect/Lead	Prospect	Additional block potential (Y/N)	Yes		
Play name (NPD)	bjl,mj-7	Proven Play (Y/N)	Yes	New Play (Y/N)	No	Outside Play (Y/N)	No		
Oil, Gas or O&G case:	Gas	Company	Rocksource	Assessment year	2008	Numbered rounds/APA	20. Round	Seismic database (2D/3D)	2D & 3D
This case no.:		Structural element (NPD)	Bjarmeland Platform	Type of trap	4-way closure	Water depth [m MSL]	390	CSEM database	2D & 3D

Reseources IN PLACE and RECOVERABLE Volumes, this case		Main phase				Associated phase			
		Low (P90)	Base, Mode	Base, Mean	High (P10)	Low (P90)	Base, Mode	Base, Mean	High (P10)
In place resources	Gas [10^9 Sm^3] (Post drill)	0,4		1,6	5,7	0,15		0,45	0,86
	Gas [10^9 Sm^3]	5,4		15,0	26,2				
Recovarable resources	Oil [10^6 Sm^3]					0,07		0,23	0,43
	Gas [10^9 Sm^3]	3,8		10,5	18,2				

Timing									
Reservoir (from)	Hattangian	Reservoir (from)	Tubåen Fm	Source Rock (primary)	Anisian-Ladinian	Source Rock (primary)	Kobbe Fm	Seal	Kimmeridgian Hekkingen Fm
Reservoir (to)	Bajocian	Reservoir (to)	Stø Fm	Source Rock (secondary)		Source Rock (secondary)		Seal	

Probability (0-1)									
Technical (oil + gas + O & G)	0,16	Oil case	0,20	Gas case	0,80	O&G case		Uplift seismic	
Reservoir (P1)	0,90	Trap (P2)	0,80	Charge (P3)	0,72	Retention (P4)	0,30	Uplift CSEM	0,22

Parameters	Application input			Well results		Comments
Parameter	Low (P90)	Base	High (P10)	Norvarg 1	Norvarg 2	
Depth to top of prospect [m MSL] (>0)		688		688	704	
Area of closure [km^2] (>0)	18,0	44,0	70,0	32		
Reservoir thickness [m] (>0)	38	60	82	36,4	38	
HC column [m] (>0)	50	75	100	107	107	
Gross rock volume [10^9 Sm^3] (>0)	0,633	1,79	3,18	0,72		
Net/Gross (0-1)	0,51	0,65	0,79	0,85	0,62	
Porosity (0-1)	0,17	0,21	0,26	0,21	0,21	
Permability [mD] (>0)						
Water saturation (0-1)	0,25	0,2	0,14	0,17	1	
Bg [Rm^3/Sm^3] (<1)	0,0155	0,0143	0,0132			
1/Bo [Sm^3/Sm^3] (<1)						
GOR, free gas [Sm^3/Sm^3] (>0)						
GOR, oil [Sm^3/Sm^3] (>0)	87,3	100	112,7			
Recovery factor, oil main phase (0-1)						
Recovery factor, gas ass. main (0-1)						
Recovery factor, gas main phase (0-1)	0,65	0,7	0,75			
Recovery factor, liquid ass. phase (0-1)	0,45	0,5	0,55			
Temperature, top reservoir [°C] (>0)		5		20	17	
Pressure, top reservoir [bar] (>0)		60		79		
Cut off criteria for N/G calculation				Vsh<0.40, Phie>0.08, Swe<0.4	Vsh<0.40, Phie>0.08, Swe<	



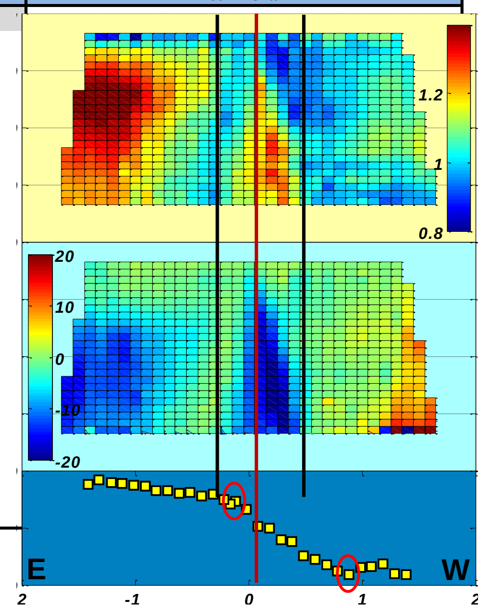
Prospect data									
Block	7225/3 & 7226/1	Prospect name	Norvarg Snadd	Discovery/Prospect/Lead	Prospect	Additional block potential (Y/N)	Yes		
Play name (NPD)	bru-2	Proven Play (Y/N)	Yes	New Play (Y/N)	No	Outside Play (Y/N)	No		
Oil, Gas or O&G case:	Gas	Company	Rocksource	Assessment year	2008	Numbered rounds/APA	20. Round	Seismic database (2D/3D)	2D & 3D
This case no.:		Structural element (NPD)	Bjarmeland Platform	Type of trap	4-way closure	Water depth [m MSL]	390	CSEM database	2D & 3D

Reseources IN PLACE and RECOVERABLE Volumes, this case		Main phase				Associated phase			
		Low (P90)	Base, Mode	Base, Mean	High (P10)	Low (P90)	Base, Mode	Base, Mean	High (P10)
In place resources	Gas [10^9 Sm^3]	1,11		2,04	3,09	0,1		0,3	0,5
	Gas [10^9 Sm^3]	4,0		9,2	15,0				
Recovarable resources	Oil [10^6 Sm^3]					0,1		0,1	0,2
	Gas [10^9 Sm^3]	2,7		6,4	10,6				

Timing									
Reservoir (from)	Carnian	Reservoir (from)	Snadd Fm	Source Rock (primary)	Anisian-Ladinian	Source Rock (primary)	Kobbe Fm	Seal	Norian-Rhaetian
Reservoir (to)		Reservoir (to)		Source Rock (secondary)		Source Rock (secondary)		Seal	Fruholmen Fm

Probability (0-1)									
Technical (oil + gas + O&G)	0,15	Oil case	0,40	Gas case	0,60	O&G case		Uplift seismic	
Reservoir (P1)	0,68	Trap (P2)	0,70	Charge (P3)	0,80	Retention (P4)	0,40	Uplift CSEM	0,21

Parameters	Application input			Well results			Comments
Parameter	Low (P90)	Base	High (P10)	Norvarg 1	Base	Norvarg 2	
Depth to top of prospect [m MSL] (>0)		767		760		781	
Area of closure [km^2] (>0)	20,0	47,5	75,0	55			
Reservoir thickness [m] (>0)	27	35	43	29		32	
HC column [m] (>0)	70	120	145	120			
Gross rock volume [10^9 Sm^3] (>0)	0,528	1,17	1,96	1,73			
Net/Gross (0-1)	0,55	0,60	0,66	0,72		0,5	
Porosity (0-1)	0,17	0,20	0,23	0,14		0,18	
Permability [mD] (>0)							
Water saturation (0-1)	0,34	0,26	0,21	0,44		1	
Bg [Rm^3/Sm^3] (<1)	0,0126	0,0118	0,0110				
1/Bo [Sm^3/Sm^3] (<1)							
GOR, free gas [Sm^3/Sm^3] (>0)							
GOR, oil [Sm^3/Sm^3] (>0)	106,5	112	117,5				
Recovery factor, oil main phase (0-1)							
Recovery factor, gas ass. main (0-1)							
Recovery factor, gas main phase (0-1)	0,65	0,70	0,75				
Recovery factor, liquid ass. phase (0-1)	0,45	0,50	0,55				
Temperature, top reservoir [^oC] (>0)		10,00		22,5		19	
Pressure, top reservoir [bar] (>0)		70,00		86			
Cut off criteria for N/G calculation				Vsh<0.40, Phie>0.08, Swe<0.4		Vsh<0.40, Phie>0.08, Swe<0.4	



Prospect data

Block	7225/3 & 7226/1	Prospect name	Norvarg Intra Snadd	Discovery/Prospect/Lead	Prospect	Additional block potential (Y/N)	Yes		
Play name (NPD)	bru-2	Proven Play (Y/N)	Yes	New Play (Y/N)	No	Outside Play (Y/N)	No		
Oil, Gas or O&G case:	Oil	Company	Rocksource	Assessment year	2008	Numbered rounds/APA	20. Round	Seismic database (2D/3D)	2D & 3D
This case no.:		Structural element (NPD)	Bjarmeland Platform	Type of trap	4-way closure	Water depth [m MSL]	390	CSEM database	2D & 3D

Reseources IN PLACE and RECOVERABLE Volumes, this case		Main phase: Low (P90)	Main phase: Base, Mode	Main phase: Base, Mean	Main phase: High (P10)	Associated phase: Low (P90)	Associated phase: Base, Mode	Associated phase: Base, Mean	Associated phase: High (P10)
In place resources	Oil [10^6 Sm^3]	24,3		93,7	177,6				
	Gas [10^9 Sm^3]	2,59		4,76	7,21	3,0		11,7	22,1
Recovarable resources	Oil [10^6 Sm^3]	9,7		37,2	73,4				
	Gas [10^9 Sm^3]					1,5		5,9	11,1

Timing

Reservoir (from)	Carnian	Reservoir (from)	Snadd Fm	Source Rock (primary)	Anisian-Ladinian	Source Rock (primary)	Kobbe Fm	Seal	Carnian-Rhaetian
Reservoir (to)		Reservoir (to)		Source Rock (secondary)		Source Rock (secondary)		Seal	Fruholmen Fm

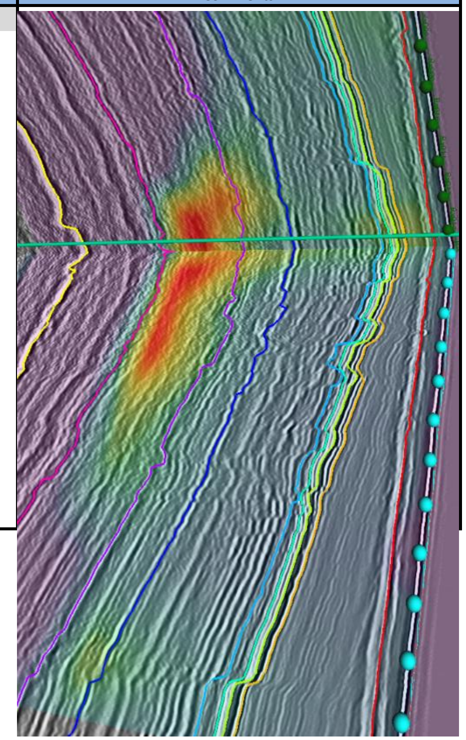
Probability (0-1)

Technical (oil + gas + O&G)	0,26	Oil case	60	Gas case	40	O&G case		Uplift seismic	0,23
Reservoir (P1)	0,81	Trap (P2)	0,9	Charge (P3)	0,7	Retention (P4)	0,5	Uplift CSEM	0,25

Parameters

Parameter	Application input: Low (P90)	Application input: Base	Application input: High (P10)	Well results: Norvarg 1	Well results: Base	Well results: Norvarg 2
Depth to top of prospect [m MSL] (>0)		1110		1166		
Area of closure [km^2] (>0)	12,0	42,0	72,0	4,3		
Reservoir thickness [m] (>0)	21,0	35,0	49,0	56		
HC column [m] (>0)	80,0	120,0	160,0	50		
Gross rock volume [10^9 Sm^3] (>0)	0,369	1,02	1,95	0,61		
Net/Gross (0-1)	0,51	0,65	0,79	0,76		
Porosity (0-1)	0,18	0,23	0,27	0,22		
Permability (mD) (>0)				200		
Water saturation (0-1)	0,43	0,35	0,27	0,47		
Bg [Rm^3/Sm^3] (<1)						
1/Bo [Sm^3/Sm^3] (<1)	0,93	0,94	0,95			
GOR, free gas [Sm^3/Sm^3] (>0)						
GOR, oil [Sm^3/Sm^3] (>0)	119,5	125	130,5			
Recovery factor, oil main phase (0-1)	0,35	0,4	0,45			
Recovery factor, gas ass. main (0-1)	0,45	0,5	0,55			
Recovery factor, gas main phase (0-1)						
Recovery factor, liquid ass. phase (0-1)						
Temperature, top reservoir [°C] (>0)		25,0		37		
Pressure, top reservoir [bar] (>0)		105,0		129		
Cut off criteria for N/G calculation				Vsh<0.40, Phie>0.08, Swe<0.4		

Comments



Prospect data

Block	7225/3 & 7226/1	Prospect name	Norvarg Kobbe	Discovery/Prospect/Lead	Prospect	Additional block potential (Y/N)	Yes		
Play name (NPD)	brl,rm-5	Proven Play (Y/N)	Yes	New Play (Y/N)	No	Outside Play (Y/N)	No		
Oil, Gas or O&G case:	Oil	Company	Rocksource	Assessment year	2008	Numbered rounds/APA	20. Round	Seismic database (2D/3D)	2D & 3D
This case no.:		Structural element (NPD)	Bjarmeland Platform	Type of trap	4-way closure	Water depth [m MSL]	390	CSEM database	2D & 3D

Reseources IN PLACE and RECOVERABLE Volumes, this case		Main phase Low (P90)	Main phase Base, Mode	Main phase Base, Mean	Main phase High (P10)	Associated phase Low (P90)	Associated phase Base, Mode	Associated phase Base, Mean	Associated phase High (P10)
In place resources	Oil [10^6 Sm^3]	27,7		76,3	130,2				
	Gas [10^9 Sm^3]	51,6		133,0	212,8	3,9		10,7	18,2
Recovarable resources	Oil [10^6 Sm^3]	10,2		30,3	52,8				
	Gas [10^9 Sm^3]					1,9		5,4	9,4

Timing

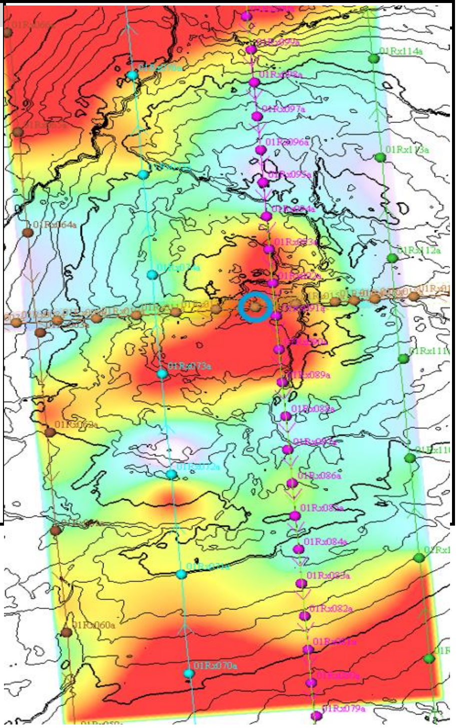
Reservoir (from)	Anisian	Reservoir (from)	Kobbe Fm	Source Rock (primary)	Anisian-Ladinian	Source Rock (primary)	Kobbe Fm	Seal	Anisian-Carnian
Reservoir (to)		Reservoir (to)		Source Rock (secondary)		Source Rock (secondary)		Seal	Kobbe-Snadd fms

Probability (0-1)

Technical (oil + gas + O&G)	0,21	Oil case	80	Gas case	20	O&G case		Uplift seismic	
Reservoir (P1)	0,48	Trap (P2)	1	Charge (P3)	0,72	Retention (P4)	0,6	Uplift CSEM	0,19

Parameters	Application input Low (P90)	Application input Base	Application input High (P10)	Well results Norvarg 1	Well results Base	Well results Norvarg 2
Depth to top of prospect [m MSL] (>0)		1515		1518		
Area of closure [km^2] (>0)	15,0	38,5	62,0	546		
Reservoir thickness [m] (>0)	27,0	35,0	43,0	26		
HC column [m] (>0)	60,0	100,0	130,0	460		
Gross rock volume [10^9 Sm^3] (>0)	0,396	0,987	1,59	113		
Net/Gross (0-1)	0,56	0,62	0,67	0,28		
Porosity (0-1)	0,18	0,22	0,25	0,12		
Permability [mD) (>0)				0,1		
Water saturation (0-1)	0,43	0,35	0,27	0,67		
Bg [Rm^3/Sm^3] (<1)						
1/Bo [Sm^3/Sm^3] (<1)	0,93	0,94	0,95			
GOR, free gas [Sm^3/Sm^3] (>0)						
GOR, oil [Sm^3/Sm^3] (>0)	134,5	140,0	145,5			
Recovery factor, oil main phase (0-1)	0,35	0,40	0,45			
Recovery factor, gas ass. main (0-1)	0,45	0,50	0,55			
Recovery factor, gas main phase (0-1)						
Recovery factor, liquid ass. phase (0-1)						
Temperature, top reservoir [^oC] (>0)		30,0		fgh		
Pressure, top reservoir [bar] (>0)		150,0		175		
Cut off criteria for N/G calculation				Vsh<0.40, Phie>0.08, Swe<0.4		

Comments



Prospect data

Block	7225/3 & 7226/1	Prospect name	Norvarg Havert	Discovery/Prospect/Lead	Lead	Additional block potential (Y/N)			
Play name (NPD)	brl,rm-5	Proven Play (Y/N)	Yes	New Play (Y/N)	No	Outside Play (Y/N)	No		
Oil, Gas or O&G case:	Gas	Company	Rocksource	Assessment year	2008	Numbered rounds/APA	20. Round	Seismic database (2D/3D)	2D & 3D
This case no.:		Structural element (NPD)	Bjarmeland Platform	Type of trap	4-way closure	Water depth [m MSL]	390	CSEM database	2D & 3D

Reseources IN PLACE and RECOVERABLE Volumes, this case		Main phase				Associated phase			
		Low (P90)	Base, Mode	Base, Mean	High (P10)	Low (P90)	Base, Mode	Base, Mean	High (P10)
In place resources	Gas [10^9 Sm^3]			0					
	Gas [10^9 Sm^3]	8,2		20,8	34,1				
Recovarable resources	Oil [10^6 Sm^3]								
	Gas [10^9 Sm^3]	5,6		14,6	23,9				

Timing

Reservoir (from)	Induan	Reservoir (from)	Havert Fm	Source Rock (primary)	Lopingian	Source Rock (primary)	Ørret Fm	Seal	Induan
Reservoir (to)		Reservoir (to)		Source Rock (secondary)		Source Rock (secondary)		Seal	Havert Fm

Probability (0-1)

Technical (oil + gas + O&G)	0,17	Oil case	0	Gas case	100	O&G case		Uplift seismic	
Reservoir (P1)	0,4	Trap (P2)	0,9	Charge (P3)	0,6	Retention (P4)	0,8	Uplift CSEM	0

Parameters	Application input			Well results			Comments
Parameter	Low (P90)	Base	High (P10)	Low (P90)	Base	High (P10)	
Depth to top of prospect [m MSL] (>0)		2568			2563		
Area of closure [km^2] (>0)	17,0	40,0	85,0		10,7		
Reservoir thickness [m] (>0)	26,0	35,0	43,3		36		
HC column [m] (>0)	45,0	80,0	110,0		36		
Gross rock volume [10^9 Sm^3] (>0)	0,61	1,27	2,1		0,18		
Net/Gross (0-1)	0,545	0,6	0,655		0,43		
Porosity (0-1)	0,16	0,175	0,19		0,1		
Permability [mD] (>0)					0,05		
Water saturation (0-1)	0,405	0,35	0,295		0,57		
Bg [Rm^3/Sm^3] (<1)	0,00452	0,0043	0,004				
1/Bo [Sm^3/Sm^3] (<1)							
GOR, free gas [Sm^3/Sm^3] (>0)							
GOR, oil [Sm^3/Sm^3] (>0)							
Recovery factor, oil main phase (0-1)							
Recovery factor, gas ass. main (0-1)							
Recovery factor, gas main phase (0-1)	0,645	0,7	0,755				
Recovery factor, liquid ass. phase (0-1)							
Temperature, top reservoir [°C] (>0)		75,0			95		
Pressure, top reservoir [bar] (>0)		250,0			No data		
Cut off criteria for N/G calculation