Volume 2
2017 June

SPE International
Norway Council
www.spe.no

The First

SPE Norway magazine

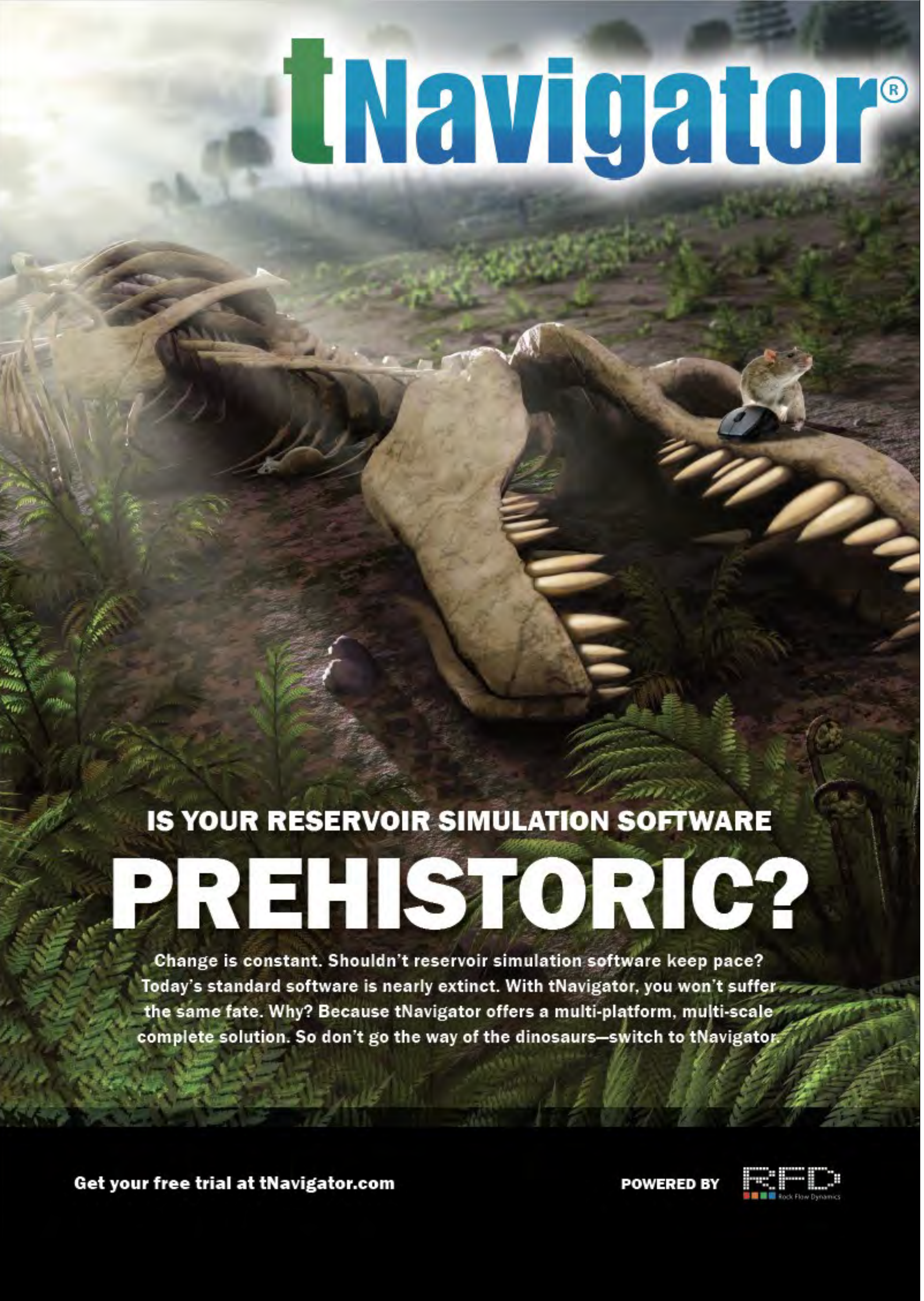
To gather members
To share knowledge

In this issue

Special topic - Electromagnetic Exploration

The electronic version is available on the page of your section website.

Picture: Polarcus Asima Arctic



Inside this issue

www.spe.no

Dear SPE The First reader,

The SPE Norway 2016/2017 Season is coming to its end. Filled with awards, surprises and wonderful moments, it has allowed us to learn, inspire and progress. The incredible Bergen One Day Seminar and Harstad Workshop in the Artic proved one more time they deserve to be listed as international SPE events, gathering many members and followers and giving valuable knowledge exchange. Technical nights, games, breakfast/lunch/dinner, social events like BBQ, Sailing etc. are only a few of the various events that the SPE Norway offers us. We can be proud of SPE Norway programme. Do not miss the last event at your section this Season, before going on holidays!

Our young Magazine is celebrating its two years' anniversary as SPE Norway regional publication, and three years since it was first lunched by the Oslo section. Looking back at the history – we have grown a lot! It is incredible, after just two years we have been noticed: the SPE Presidents writing for us, having been mentioned at the annual main SPE conference (ATCE), articles from our members and SPE friends sharing their passion within the SPE Norway community.

As The First editors, we try to invite authors from abroad to share their ideas with our industry sector. We have published articles from authors from our neighboring countries, some of whom have even become our regular contributors, some from West and Middle East.

This issue is no exception! The Australian experience in the concepts of exploration chance of success predictions are shared with the Northern society. In addition, High Resolution Electromagnetic Exploration method and approach from neighboring Russia and from the local and leading EM marine companies are shared in this issue.

If I may reserve of your time for one more thought. In the search for interesting ideas to share in The First and looking for possible authors, I scan regularly updates in social media and in particular, LinkedIn. Being a woman in the industry and having working experience from some of the harshest environments like working behind the Arctic Circle on the rig with outside temperatures -37 C and wind 17 m/s, or in desert with +55C, I do appreciate seeing many events organized for women in the industry. Large oil&gas companies continuously post on LinkedIn and Facebook events like "Women in industry days", or special events at conferences just for women, women recognition and awards. But! I cannot see anything being organized for men! Are there no men on the platforms? Do they not feel cold and tired? Do they not work in hard conditions? Do they not work under stress? Do they not make discoveries? I respect and will always remember my first male field manager. He was supposed to be working just in the office, but facing shortage of field personnel available, he could as easily work in the workshop and run it at the rig being at the same time a FSM, Supervisor, operator and any other function needed - all of that in one person!

I believe men in our industry are not enough appreciated. Especially those born in the 90es, and making their careers in the interesting time of trending "Women in the industry" events.

So, our dear men, we, professional women in the industry, would like to invite you to celebrate yourself and your great achievements! We cherish you, we support you and we appreciate you. To balance the injustice, come and join us

"Celebration of the Men in Industry", September 7, Oslo, Beer Palace. The sponsor Rock Flow Dynamics offers the first drink for free.

More information will follow.

Let us organize events and reward on merit and not by gender.

Enjoy reading The First and as usual, do not forget to provide us feedback!

On behave of editorial team,
Vita Kalashnikova

SPE The First Editorial team:

Vita Kalashnikova
QI Geophysicist,
PSS-Geo AS

Maria Djomina
Communications Manager,
AGR

Editorial content

SPE Oslo
SPE Stavanger
SPE Bergen
SPE Northern Norway
SPE Trondheim

The First is SPE Norway Regional publication and is distributed to a multidiscipline audience. Circulation: 200 printed copies, 4,500 electronic copies The electronic version of this Issue and previous Issues are available on SPE Norway websites.

The editorial team takes no responsibility for accuracy or content of the articles provided. Technical articles, professional overviews and SPE section news have no editorial fee. The editors are working on voluntary basis.

If you would like to support production of our magazine by publishing commercial information about your product/company, please contact editorial team.
Editors: Vita V Kalashnikova vita@pss-geo.com
Maria Djomina Maria.Djomina@agr.com

Congratulations!

WINNERS OF 2017 SPE REGIONAL AWARDS

For their outstanding contribution in the North Sea area at the regional level :

Jafar Fathi, Point Resources
Regional Service Award

Vegard Stenerud, Statoil
Regional Service Award

Jayantha Liyanage, University of Stavanger
Management and Information Award

Henning Dypvik, University of Oslo
Distinguished Achievement Award for Petroleum Engineering Faculty

4 awards to SPE Norway community—thank you for your engagement!

SPE's regional awards are designed to recognize those members who have contributed exceptional service and leadership to the society, as well as those who've made major professional contributions to their technical disciplines at the regional level.

Volume 2 2017 June

SPE Norway — The Council

Dear Colleagues and Friends,
The whole oil and gas industry including Norwegian market has been adjusting for the past year and currently we probably see the price level which is acceptable for customers and country/companies - producers. Together we went through the revolutionary times of reshaping the future of oil and gas industry. Now we can clearly state that Our Industry is in a new era, era of completely new opportunities with more clear goals towards excellent technologies, improved efficiency, high safety standards and best professional. We collaborate closely with other high-tech industries as airspace, renewables and IT industry towards the bright and exiting future.
SPE Norway together with our five sections and our 4500 members and followers has been also challenged by new conditions. We experienced changing activity level, a reduction of members, cuts in funding and reduced participation in the major SPE Norway events including one of the best technical event such as Bergen One Day Seminar.
However, it is a reminder for everyone that SPE is a unique platform established many decades ago and proven to be alive, adaptive and capable to serve for the best to the industry in good or difficult times. That fact motivated SPE to rethink the strategy how we can work and contribute to petroleum society in the new conditions and improve life for everyone.
Therefore, we would like to state few corner points for future development:

- Standardization;
- Digitalization and Big Data;
- Broader skills and areas of expertise;
- Not just Networking but work better together.

Standardization
We work with the huge number of projects with big number of people and copious technologies on the market. Oil and gas is moving towards that to improve quality and reduce cost. Standardization is not making everyone the same, it makes the best to be selected to work at the right places.
In SPE Norway Council, we try to work more on having more standard approach to handle sections to get better-quality meetings and involve the best experiences from SPE International. We hope to get the best from each individual chapter and improve standards of the outputs, so at the moment we are running experience transfer between sections and you will see the new outcomes at your locations.

Digitalization and Big Data Science
More and more companies seek on improvements in digitalization and how to involve more big data science. Almost every major has a department to handle big data and improve performance of the companies and we see that frontiers are exceeding.
SPE Norway was one of the first focusing and organizing Big Data in Petroleum Industry and yearly Technical days in Oslo on the topic. We invite you to be active and improve your knowledge in that exciting topic for the next SPE meetings, check the agenda.

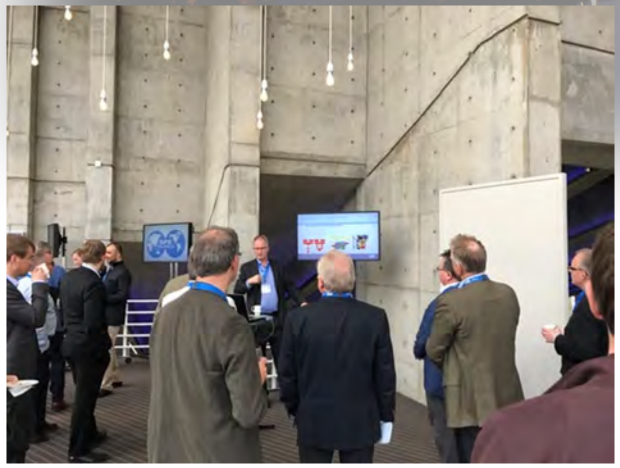
Broader skills and areas of expertise
Tendency from the last few decades was to narrow the expertise and to get specialized on special topics for professionals. Current two years lead toward new career path, towards wider areas and be a specialist in few topics as we've seen many gurus in early time of oil and gas. That is exciting and never boring!
Let's learn together and share knowledge, SPE courses and workshops are valuable addition to internal or external training and of course Distinguished Lectures. Our sections are very active to organise technical meetings and we aim to arrange internet streaming of the most interesting events and in addition of course The First Magazine publish high quality articles from local professionals.

Not just Networking
There is an area where Norwegian Petroleum business can improve and that is how to work better together and how to use networking. Norway is very different from North America Oil and Gas Market, where networking takes significant part of your time as an expert. From SPE Norway point of view, we focus to improve on networking and to make it fun and improve on knowledge transfer between professionals and towards students. This year we try to inform you more about events in the overall Norway to make our members who travels from parent location more aware about events in the different part of the country. Please look at the event schedule and drop by to one of the many interesting evenings in Norway, it available for every member.
We would like to encourage members to be active, go to the seminars, talk to each other, write articles, exchange knowledge, to do more and it will give you more energy back. Rethink the meaning of networking for you and use SPE venue for your best.
At the end, I personally would like to congratulate you with the upcoming summer days, that is time to be positive, get more energy and celebrate not only great weather, it is time to celebrate new opportunities.

Your sincerely, Igor Orlov
SPE Norway Council Chairman

The SPE President Jeneen Judah will visit Norway between 14-16 June (Oslo, Bergen, Stavanger). Several events in each region will be arranged associated with her visit. Please contact your section if you wish to attend.

News from SPE Bergen Section



Highlights from the SPE International One Day Seminar in Bergen

SPE One Day Seminar in Bergen has already established itself as a strong tradition. SPE ODS brings high level technical presentations and latest research to Grieghallen, Bergen every year and facilitates meetings between international oil and gas community.
This year's opening panel session had top management from Statoil, Faroe Petroleum and Wintershall Norway discussing possibilities to maximize recovery on the Norwegian Continental Shel and the key factors as influencers.
Despite downturn in the market, the attendance of international speakers, visitors and exhibitors proved once again that it's crucial for the industry to focus on technological developments and best practice exchange. With over 200 participants, Statoil as a main sponsor and multiple service companies as exhibitors the event has met this year's expectations.

And if you did not have a chance to visit SPE ODS this year we hope to see you in Bergen next year!

SPE Bergen TechNights

SPE Bergen Section organizes monthly TechNights for members of SPE and other Oil&Gas professionals. TechNights feature both, Distinguished Lecturer presentations, SPE papers and technology presentations. Our TechNights in Bergen gather around 50 participants from across the industry including students.
Do you have a SPE paper you would like to present at one of our TechNights? Has your company developed a ground-breaking technology or maybe performed a project with extraordinary results? SPE Bergen TechNights welcome presentation proposals from across the country.

For more information, contact: Jørn Opsahl
opsahl@tomax.no

SPE Bergen Sailing with Statsraad Lehmkuhl

SPE Bergen Sailing with Statsraad Lehmkuhl is one of the most important industry networking events in Bergen and this year it took place on the 31st of May.
This year the event was kicked off with a presentation by Jim Kvamme from Wintershall: «Wintershall - Brage – Preparing for the future».
The annual sailing is always a sell-out, and participants including students enjoy a full evening at sea with excellent food, drinks and networking on, what many say, is Norway's most beautiful ship. With many students attending this is a great opportunity for companies to meet the most perspective graduates aiming for a career in oil and gas industry.

Is your company interested in attending next year's sailing?

Contact SPE Bergen Section:
eirik.walle@spebergen.no

News from SPE Oslo Section

Oslo Student Chapter

SPE Spring Games by the Oslo Student Chapter

Finally, on Friday the 12th of May, it was once again time for the annual SPE Spring Games. This has become a strong tradition for the student members at UiO and something we look forward to every year. Big thanks go to the SPE Oslo Section for their financial support that made this year's event possible.

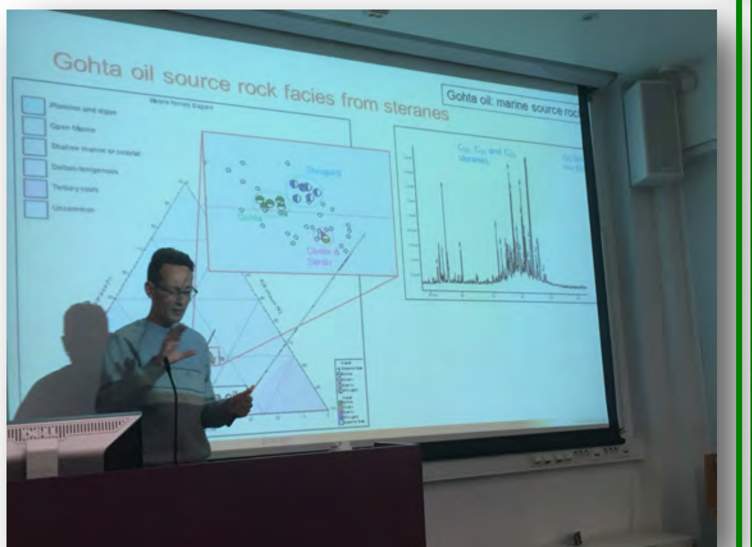
The event started with three exciting presentations from Dr Reidar Müeller, Prof Dag A. Karlsen and PhD candidate Arve Sleveland. Compared to previous years more technical themes, the focus this year was the state of the industry and the role of both professionals and students in the future. The presentations were both interesting and enjoyable and we thank all three presenters for their participating.

Barbeque, drinks and games followed. In great weather, six teams gave their all in various games, including sack race and potato spoon race. A well-deserved prize awaited the winning team. As always, the event ended with a party in the Geology building.

All in all, the event was a great success and the work on getting sponsors for next year has already begun.

Company presentation by Lundin Norway

The SPE Oslo Student Chapter had the pleasure of hosting Lundin Norway at the University of Oslo on April 20th. Despite having a strong research cooperation with UiO, it was their first company presentation here. Begin one of the most successful companies on the NCS, they attracted many eager students to the presentation. Petroleum system analyst Jon Halvard Pedersen was in charge. He shared success stories, insights about the future and available jobs. They presented a new recruitment strategy involving one-year internships for graduates. Pizza and networking concluded a lovely evening.



Award!!!

Our **Prof Henning Dypvik** received the 2017 Distinguished Achievement Award for Petroleum Engineering Faculty. Henning played a vital role in establishing the SPE Oslo Student Chapter years back and has held the role of faculty advisor ever since. The Student Chapter is forever grateful for his contributions and friendly manners.

The SPE Oslo Section aims to arrange programs covering almost all disciplines within the oil and gas industry. We actively encourage the members to share their knowledge and to network with other professionals within the industry through our programs and meetings. Here are the highlights of the events in the past season:

- Modelling a Naturally Fractured Carbonate Reservoir with FMI Well Data
- Status of CO2 Capture and Storage and CO2 Enhanced Oil Recovery (EOR)
- A Walk-through of Major Development Projects by Mid-sized Norwegian E&P Companies
  - VNG Norge: Pil and Bue
  - AKER BP: Ivar Aasen
  - Lundin Norway: Altha-Gotha
- Lessons Learned: How NOT To Do Drilling Automation
- Resource Classification System and Reserve Reporting, RNB Reporting, and Annual Status Reporting
- The Digital Oilfield: Collaborative Working at Global Scale
- Unlocking seismic amplitudes for facies prediction using seismic petrophysics – A Goliat case study
- Statoil New Energy Solutions – Opportunities in Energy Transition
- Health, Safety, Security, Environment and Social Responsibility: Human Factors in Barrier Thinking

In the past season, there were also two joint venture quiz nights between SPE YP and SPE UiO student chapter. The quiz nights were well received by both the students and Young Professionals. The student chapter at the University of Oslo is very active and has arranged several events, technical presentations and quiz nights for the students on a regular basis. Furthermore, the SPE student chapter regularly organizes company presentations to provide a platform for the companies to introduce themselves, discuss the required expertise in the industry and to attract and recruit the young talents.

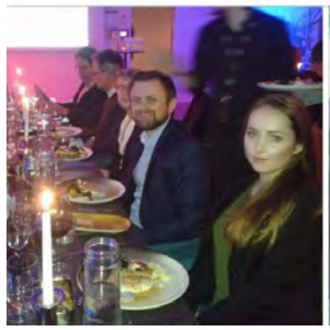
The SPE Oslo section is always open for new members, sponsors and comments. If you are interested to get involved in the section, please contact one of the other board members. We would be happy to give you additional information.

Christopher Trzeciak
Senior Drilling Engineer, VNG
Programme Chairman – SPE Oslo Section

News from Stavanger Section

50 guests attended the March meeting and discussion about 'big data applications' led by Corporate VP and CTO of NOV, Hege Kverneland. 25 guests enjoyed the following lavish 3-course meal, accompanied by the SPE North Sea Director, Karl Ludvig Heskestad of AkerBP.

The April meeting and presentation of Shale Gas and Shale Oil PVT by Distinguished Lecturer Tao Yang of Statoil was attended by 35 guests. 16 stayed for the delicious dinner.



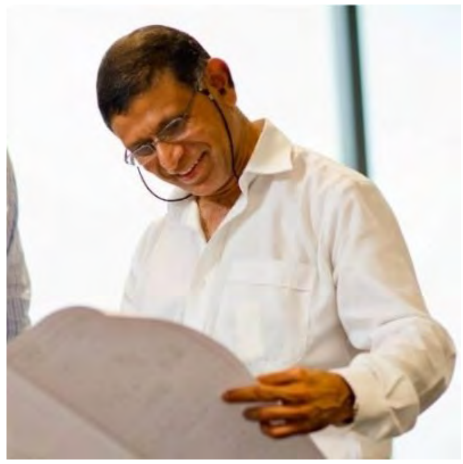
SPE Stavanger has elected a NEW BOARD for the 2017/2018 season.

The list of officers can be found on our websites http://connect.spe.org/stavanger/

Vidar Strand is the new SPE Stavanger Section Chair.

Exploration Chance of Success Predictions - Meanings, Perplexities and Impact

by Balakrishnan Kunjan



Balakrishnan Kunjan
balakunjan@gmail.com

There is much confusion in the conceptualisation and application of Chance of Success (COS) Predictions in oil and gas exploration. Although the basic statistical underpinnings of COS predictions are not mathematically complicated, in practice, there appear to be significant difficulties. The consequences of this in many cases include misplaced expectations and hence morale problems from results of exploration which fall outside expectations. In reality, commercial exploration success rates worldwide range from 30-40%. So, there is more pain than not in our industry with the unfolding of expectations. As a result of this, companies have many times reacted in a knee jerk fashion to 'correct' their course which sometimes results in restructuring exploration teams and also changing the course of exploration. Much of the misunderstandings appear to arise from the fact that most small companies are involved in limited trials campaigns where budgets allow the drilling of only a handful of wells over 1-5 years. Realistic COS' can only be based on expectations related to drilling a statistically significant large number of wells. In this article, the various probabilistic aspects of exploration expectations and outcomes are reviewed. Within the context of the intrinsic difficulty of not being able to guarantee any specific success, it will be shown how companies can choose the COS range inside which they should explore, to ensure survival and hence ensure sustainable growth over the longer term within chosen aggregate wells/ prospects drilled.

All the concepts and thoughts presented here are those of the author's and do not necessarily represent the author's employer Cue Energy's views on this matter.

Mr Kunjan is visiting Oslo in September

SPE Oslo section would like to invite everyone interested in understanding the concepts of exploration chance of success predictions to come listen to Mr. Kunjan on the 21st September.

"I'm hoping that my experiences gained from small, limited funds companies in the Aussie/ Australasian region provides the right masala mix for some of the companies operating in North Europe. Or I might find my curry offering too hot and spicy up North!!'

Further details will be announced.

Introduction

What does a person making a probabilistic prediction actually mean? What does it mean to the person/s to whom this prediction is being conveyed? What are the impacts of the understanding/ misunderstanding between the probabilistic predictions made by the predictor and the person/s receiving these predictions?

Having written on this subject, presented it many forums, and debated it, the author has found it to be a rather 'slippery' subject that has to be handled as tightly as possible. It is useful to discuss probabilistic predictions in a generic way first, then take it to probabilistic prediction of Geologic Chance of Success (GCOS) and then to Commercial Chance of Success (CCOS).

Basic Probabilistics

A probabilistic prediction appears to have a real and at the same time unreal feel about it which might best be described by predicting the outcome of the throw of a six sided dice. For most people, the real part of the prediction would be the number put on the probability of a given outcome, say the number one on the dice, after one throw. That number which has a feeling of reality to it is 1/6 or 16.7%. ***The unreal component of such a prediction is that the predictor can never know exactly when that expected outcome number one will occur in reality.***

Figure 1 shows the results of two experiments of throwing a 6 sided 'fair' dice 100 times. Success here has been defined as the outcome 1 and failure is defined as the outcome of the numbers 2-6. For each throw, the number of throws to that point ***n*** are noted and each time a success with outcome of the number 1 occurs, a value of 1 is recorded for that nth throw. The remaining outcomes with numbers 2-6 are assigned values zero. At each throw ***n***, the cumulative success value, say ***x***, up to that point is also calculated. Thus at each point ***n***, the average success rate up to that point is calculated by the formula ***x/n***. The first set of throws in Blue shows a 100% success rate at the first throw because the first throw came in as a success with the number 1. In the second set of throws shown in Purple, the first throw did not deliver success, so it starts with a 0% success rate. Both graphs however converge towards the average value of 1/6 = 16.7% in the long run after the 100 throws, showing that for all intents and purposes, the dice is 'fair'. However, note that long runs of no success can occur even in a simple dice. Especially note the purple graph where in succession, more than 20 throws did not deliver the success number 1. And it is worth reiterating that this is the result with an obvious simple six sided 'fair' Dice. Exploration realities are much more complex.

To illustrate a wider range of COS' than a Dice can afford, the Microsoft Excel spreadsheet has been used to create Perfect Predictors for 10%, 20%, 30%, 40% and 50% COS'. At the heart of it is Excel's random number generator function.* Figures 2(a), 2(b) and 2(c) show the outcome of these COS computations. It is to be noted that the Excel random number generator does produce a 'fair dice throw' for all the COS' because despite early oscillations, in the long run (Figure 2(a)), the COS' converge to the predicted values. However when we zoom into the first one hundred trials (Figure 2(b)), the 'noise' in prediction become clearer for smaller number of trials. In the early period, the COS' criss cross each other before starting to settle by the 100th trial. Figure 2(c) shows that within a window of the first 10 tries, there is a great deal of confusion between predicted and actual outcomes. And to think that all of this 'confusion' can occur in a 'Perfect Predictor'. This is only one of many sets of 5,000 trials that one could attempt. In reality, all of such simulations will

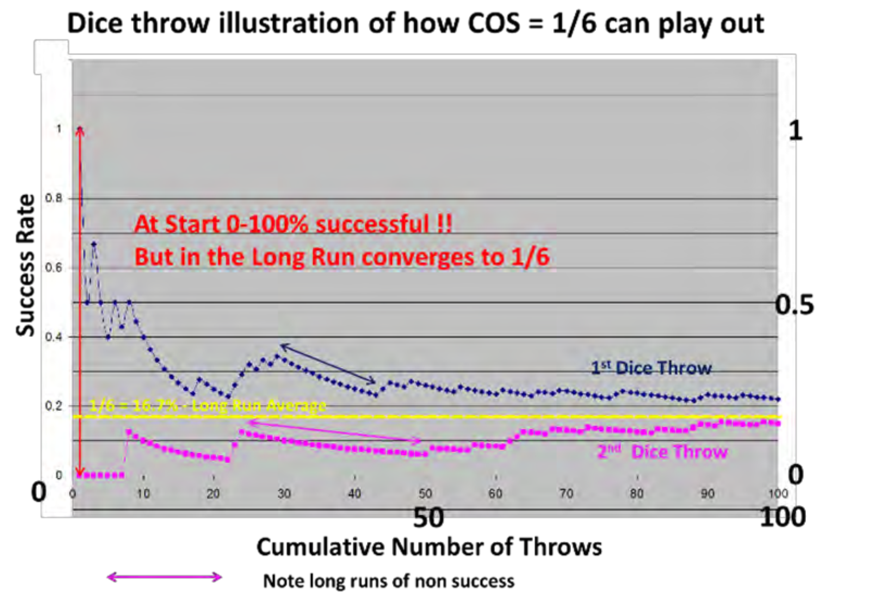


Figure 1⁺. Graphs of two sets of 100 dice throws representing average Success Rates of 1 out of 6 (16.7 %). Note that the average rates of success settle to the predicted success rate only later in the throws, and even in 100 throws, does not achieve the 'Perfect Prediction' of 16.7 %.

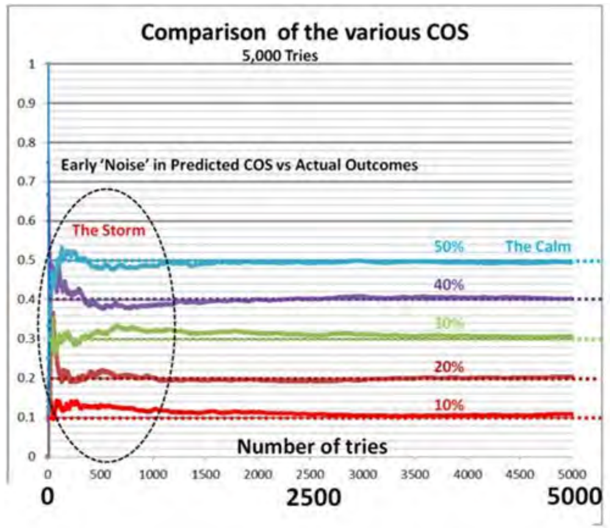


Figure 2 (a)

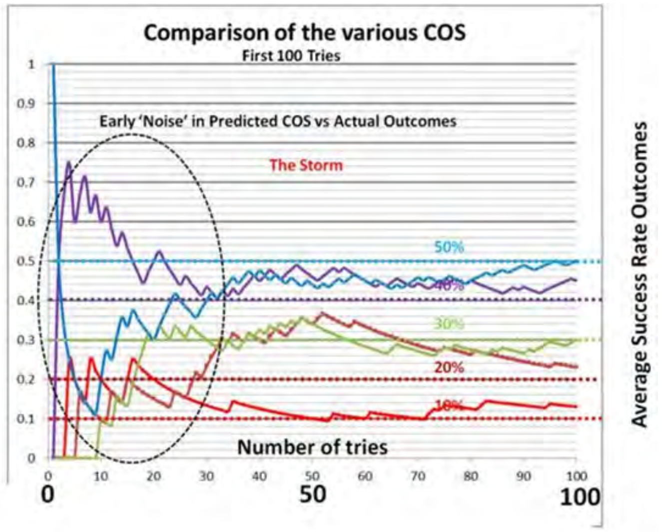


Figure 2 (b)

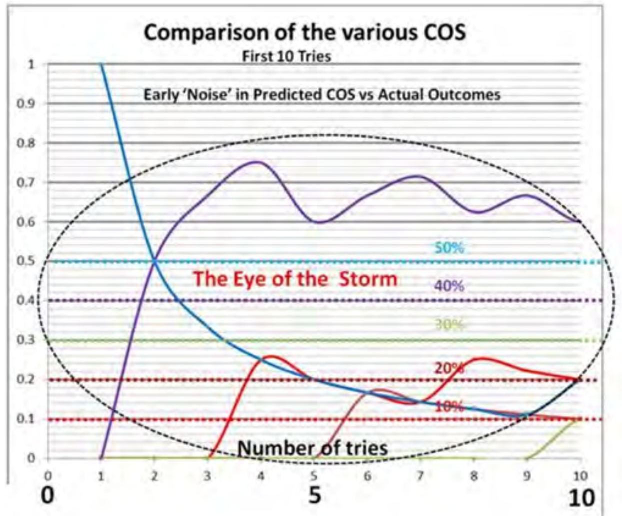


Figure 2 (c)

Figure 2. Results of simulations for 10%, 20%, 30%, 40% & 50% COS using Excel Random Number Generator.

Figure 2(a) shows outcomes to 5000 trials confirming that the simulation is a Fair Simulation because the predicted COS converges to the actual in the long run - 'The Calm'.

Figure 2(b) Zooming the first 100 trials shows the early criss crossing of predictions and illustrates the statistical 'Storm' and noise in this early part of the trials.

Figure 2(c) Zooming the first 10 trials shows total confusion between the various predictions and actual outcomes. What is labelled here as 'The Eye of the Storm'.

* Please refer to my paper "Exploration Chance of Success Predictions – Statistical Concepts and Realities" for examples of how these outcomes are calculated using Excel.

Levels of certainty on the constituent risk parameters

	Source	Reservoir	Trap	COS	COS %	
A	0.4	0.4	0.4	0.06	6	Less certain than not
B	0.5	0.5	0.5	0.13	13	Between certain and uncertain
C	0.6	0.6	0.6	0.22	22	Slightly more certain than not
D	0.7	0.7	0.7	0.34	34	More certain than not
E	0.8	0.8	0.8	0.51	51	Much more certain than not

Figure 3. This is a simplified form of GCOS evaluation just to illustrate how the constituent components impact the overall GCOS. In reality, in most cases, the Trap is better understood than the other components, especially if seismic imaging is good. Source and reservoir generally tend to be more challenging in terms of achieving improvements in the GCOS.

tend to show differences in details but similar results to those presented here, in the longer term. The longer term behaviour has been labelled as 'The Calm' and the shorter term behaviours as 'The Storm' and 'The Eye of the Storm' for obvious reasons.

G&G Evaluation - Geologic Chance of Success (GCOS)

The Geologic Chance of Success (GCOS) is the pre drill probability that the petroleum geology model we put forward for a given prospect is successful. The Geologic Chance of Success (GCOS) is obtained by studying the chance of presence/ effectiveness of source rocks/migration, reservoir rocks, seals and trapping configurations. The details of how GCOS is calculated can vary and differs between companies. It is presented in Figure 3 in a simplified form and can be very much more involved in detail depending on who is doing it. It is recognised that this subject is a big topic in itself. At the end of all these studies, the GCOS represents the probability that a Prospect, if it contains hydrocarbons, will have a Field Size Distribution as discussed later below.

Presented in Figures 4 and 5, in a simplified manner, is the case of fictitious Prospect A in which the title 'Morphing of the Dice' illustrates the changes in the GCOS as we proceed through the various stages of prospect evaluation.

Our first impressions of the GCOS of a Prospect can either be lower or higher from our very final one post all the analyses we intend to do on it. This fictitious example shows how when progressing from Early to Middle to Mature Stage Evaluations, the GCOS increases, i.e. the number of sides to the dice decreases.

Prospect A, a fault controlled structure, is defined by only five 2D lines two of which pass through wells. At the very earliest stage, quick structural maps on key horizons are made. In conjunction with this, a rapid evaluation of the wells 1 & 2 and any wells outside

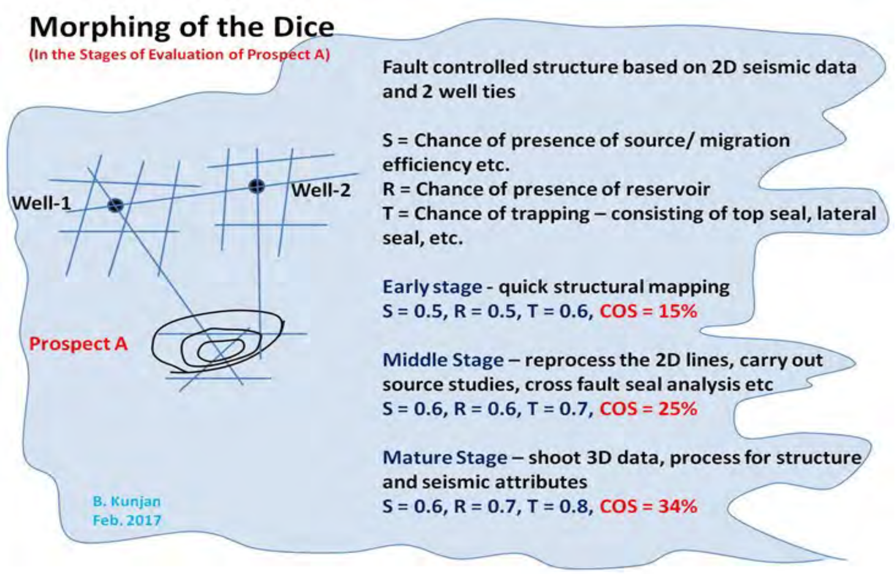


Figure 4. The GCOS of a given prospect changes at various phases with additional analyses and data.

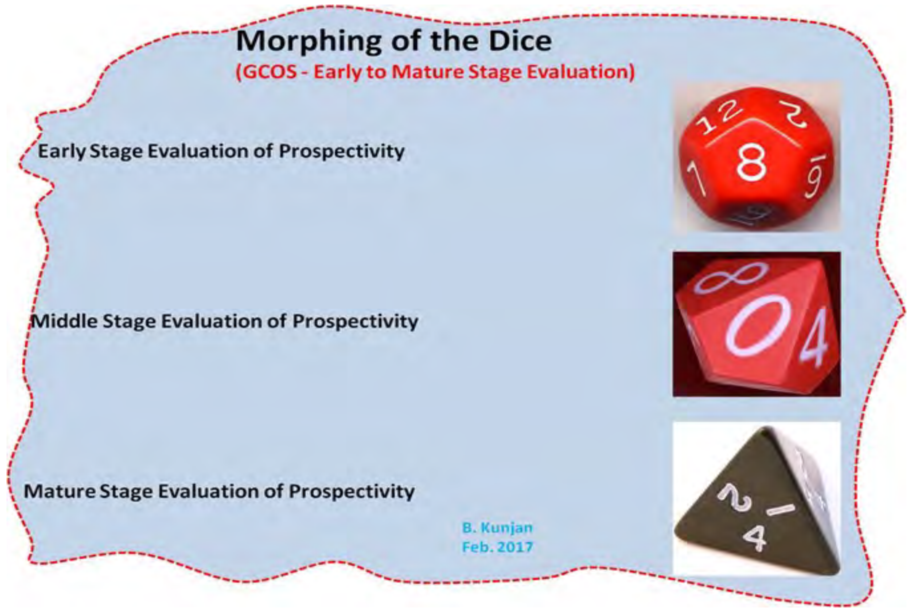


Figure 5. This change of the GCOS over the different phases of evaluation is illustrated with a correspondent change in the shape of the dice representing the probabilities (Note: the dice shapes are only illustrative and not meant to represent the GCOS numbers in Figure 4).

the immediate area are carried out which will give an idea of presence, quantity, maturity, etc. of the source rocks, the presence and effectiveness of reservoir rocks, and the presence and quality of sealing rocks. If more regional data is available, further analyses can be done including the evaluation of the presence/ effectiveness of source and migration pathways, reservoir and seal rocks etc.

Early lack of knowledge usually should lead to a more cautionary, lower GCOS. At the Middle Stage, usually, reprocessing of seismic data with emphasis on structural, stratigraphic and possible seismic attributes is carried out. At this stage, the GCOS has the possibility of either going up or down from the initial GCOS but in this case the GCOS increases because the structural definition, especially of the fault improved and the ability to map the reservoir units more confidently increased with better seismic data. In the Mature Stage, 3D seismic data which is not necessarily a must in all prospects, was acquired specifically to enable further enhancement of structural/ stratigraphic definition and also for seismic attributes that might help define reservoir and fluid content better. And in this case, structural, stratigraphic and fluid content understanding was improved with the 3D data.

The GCOS numbers offered, though fictitious, are not unrealistic in a real world setting. In fact, one of the valuable skills of seasoned explorationists is the ability to predict ahead of time how we expect the GCOS to move from Early to Mid to Mature evaluation of a given prospect. Each stage of the evaluation involves the spending of money and management would need justification for spending additional money on the basis of Value of Information.

G&G Evaluation - Prospect Field Size Distribution

The other part of the evaluation of prospectivity is the Field Size Distribution which is illustrated in Figure 6. It is basically the measure of the physical size of the hydrocarbon volume expected in a prospect. The most important component of this measure is the mapped size of the prospect in terms of the Gross Rock Volume (GRV) within the structure that could potentially hold hydrocarbons.

The truth here is that an exploration well is not promising any one particular Field Size but a Probability Distribution of outcome of Field Sizes prior to drilling. But any pool size discovered will give very important information on the elements of the Petroleum System. As you can see, the input into the Monte Carlo calculations has many elements of the Petroleum System that goes into it.

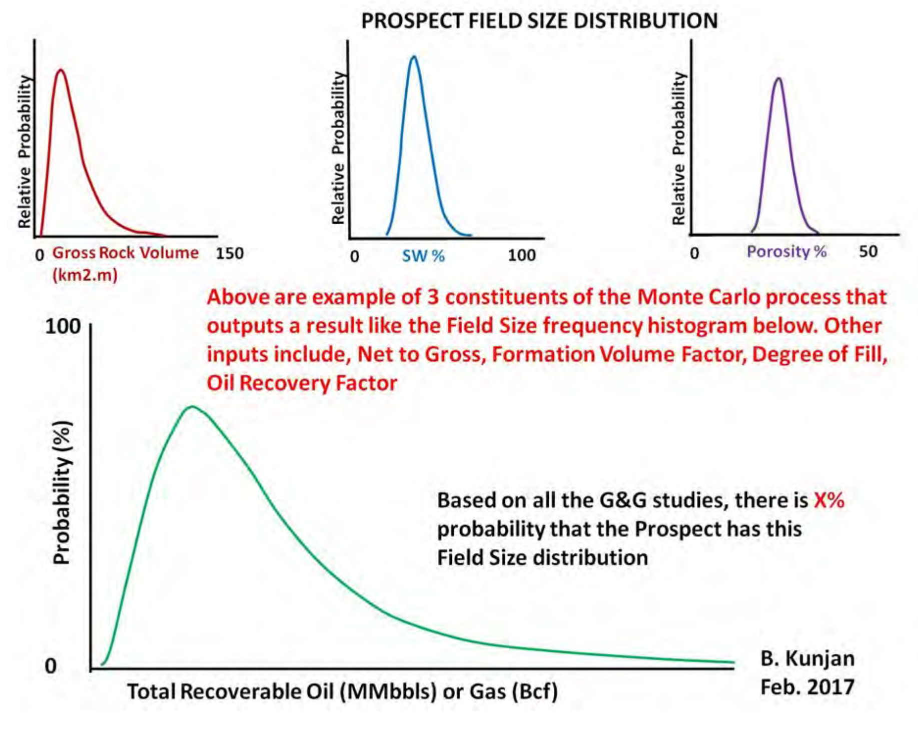


Figure 6. The Field Size Distribution for a given prospect is determined by input parameters that include Gross Rock Volume (GRV) that is derived from the maps of the prospect, and the reservoir porosities and water saturations obtained from nearby well control. The common method of estimating probabilistic reserves is to utilise the Monte Carlo method using all the input parameters described to output the probabilistic reserves curve shown .

Commercial Chance of Success (CCOS)

In parallel, or post the G&G evaluation, a team of engineers and economists working together will help figure out whether a discovery can be made commercial. Considerations will include the location of a discovery, distance from infrastructure, development methodology, capex/ opex, oil/gas price/ currency movements, etc. Based on these considerations, it is possible to work out the Minimum Economic Pool Size (MEPS) which would make a discovery commercial in that location. Based on the G&G team's predicted field size distribution, it is possible to obtain the probability of finding a field with at least MEPS for a given prospect. The Commercial Chance of Success (CCOS) is a product of the GCOS and the probability of finding at least the MEPS in the given prospect. The exact details of how all of this is done varies from company to company. It is presented in a simplified manner here for illustration purposes.

It has to be noted here that a company that chooses to drill a well targeted to prove a Commercial sized field with the first well on a prospect by drilling down dip is making a very important decision in this regard. The implication is that it is willing to accept the consequences of not knowing the information that would be obtained from a sub commercial accumulation up dip in a more crestal position.

With this approach of going for a Commercial success in the first well, even an extraordinary exploration team cannot prove its capabilities in terms of finding hydrocarbons. Because the GCOS is not only about finding Commercial hydrocarbons. And more importantly, if a company has plans to continue drilling in an area, the team will miss important petroleum systems information by not drilling optimally for this purpose. This has to be a calculated risk by the company. At the end of the day, it also ties the hands of the Explorationists in terms of limiting the crucial data that they have to gather for the longer term.

Exploration Realities and Challenges

Pre drill chance of success (COS) predictions appear to mean different things to different people. Although on the surface most professionals involved in oil and gas exploration appear to have an understanding of COS, when venturing deeper into what it actually means, there appears to be confusion both in the conceptualisation and the communication of it's meaning to others. It is the author's observation, having worked with various teams within various organisations around the world that this confusion leads to ineffective approaches at exploration, inefficiencies in exploration execution, anxieties from the actual outcomes from well results, negative impact on team morale, and eventually loss of shareholder value.

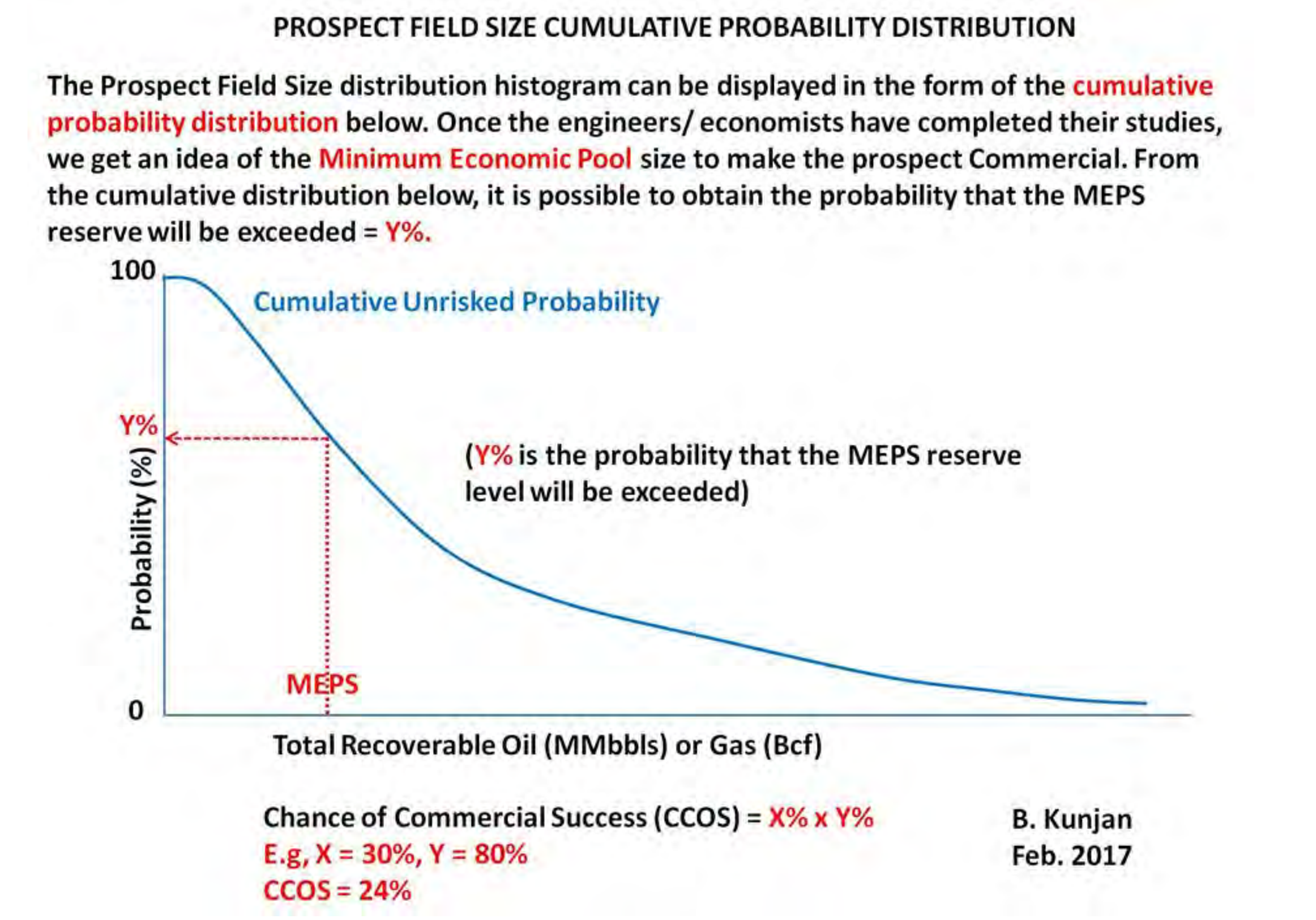


Figure 7. The Commercial Chance of Success (CCOS) is obtained from the GCOS and the probability of finding at least the Minimum Economic Pool Size of hydrocarbon reserves

By nature, Geoscientists like to believe that their methodologies are objective. However, at the end of all scientific analyses, a COS prediction is still subjective. Those who have worked in teams trying to obtain consensus on a COS would have an understanding of this. This subjectivity is also revealed by the different valuations that different teams/ companies make in block bids, though it is recognised that strategic considerations do have an overlay on this.

Once a COS is 'finalised' pre drill, say 30%, it is in a sense fascinating how a negative drill result still takes everyone by 'surprise'. This, despite the pre drill knowledge that on a single well basis the well has 70% chance of a negative outcome. There are real examples of negative impacts on team morale and the structures of teams.

Figures 8 shows the actual exploration success rates from a worldwide sample. It is sobering to note that worldwide our commercial success rates are averaging between 30-40%.

Much of the troubles we face seem to stem from the fact that well results are seen as single events, when actually, in an essentially

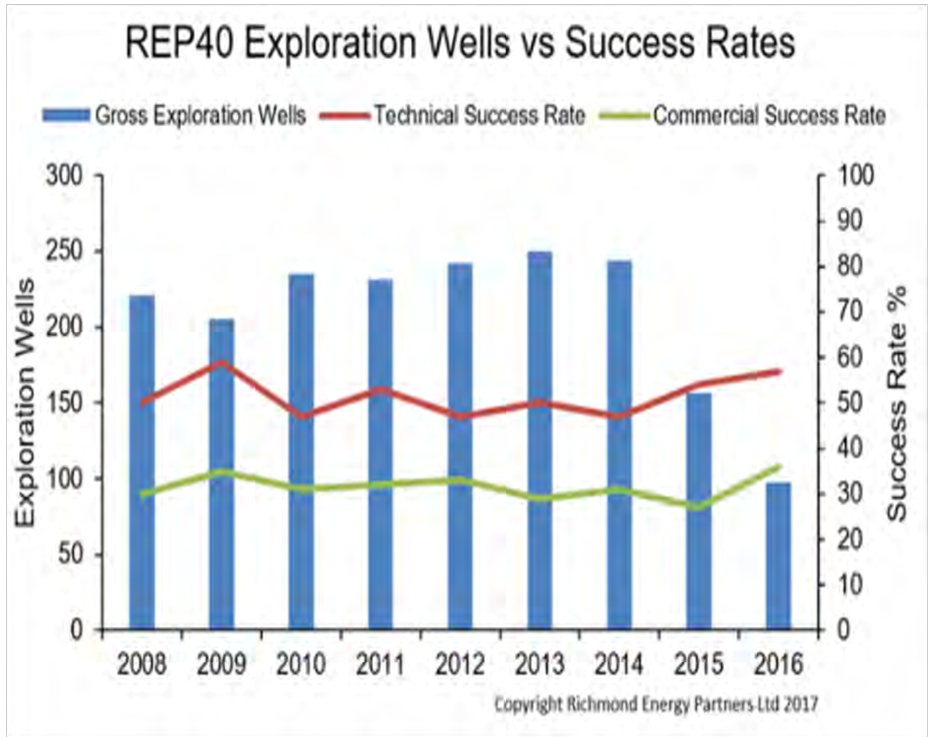


Figure 8. These results show that 60-70% of discoveries were not commercial over the period 2008 to 2015, but it appears that commercial success rates started to rise in 2016 as a result of high grading of portfolios and the drilling of 'less risky' exploration wells. The figure was offered by Richmond Energy Partners via personal communication.

probabilistic world of random trials, well results should be seen in aggregates. Figure 9 shows an alternative way to look at COS'. The line annotated as "The Survival Frontier" shows the number of wells required at any given COS for 90% certainty of at least one success.

Small to medium size companies typically have limited budgets over their 0-5 years corporate horizon. The ability to fund a given number of wells should guide where each company wants to play, to initially survive, then to grow. It is suggested that if funding is only available for 3 wells, then these companies should stick initially to wells with COS = 50%. Typically, lower risk would mean lower reserves. When the corporate budget increases, then materiality considerations may encourage a company to move 'up the risk curve'. Note that at COS = 25%, you need 8* wells for 90% certainty of at least one success. It is important also to note that the 3 or 8 wells referred here does not mean sequential drilling regardless of outcome of any given well. If any well result downgrades any future prospect, then it is suggested that the company drills the next alternative acceptable COS prospect which may take some time to firm up in the same play or elsewhere.

Although risk, costs and rewards must be considered, the assumption made here is that survival is of utmost importance for small companies, while building up materiality. Any form of comparing prospects on risk weighting or on the basis of EMVs is not discussed here because 'expectations' are only achieved after a statistically significant number of wells are drilled. It is implicitly assumed here that all wells drilled will make enough money to cover all costs, i.e. the wells are all of positive NPV in the success case.

Conclusion

There exists a great deal of confusion on the conceptualisation, communication and interpretation of Chance of Success predictions in our exploration business. These challenges are non trivial and do affect the efficiency and effectiveness of the exploration effort to various degrees in various companies. Given the probabilistic nature of our business, there has to be the greatest clarity in what we mean by our predictions and how we operate within this realm of uncertainty. The better the flow of understanding at all levels, the less the losses, and more the gains from our exploration effort for the money expended.

In summary, with a broader perspective of looking at exploration as an aggregate effort rather than a well by well effort, a more efficient and effective exploration program can be laid out and executed, thereby increasing shareholder wealth at the same time as keeping company morale intact.

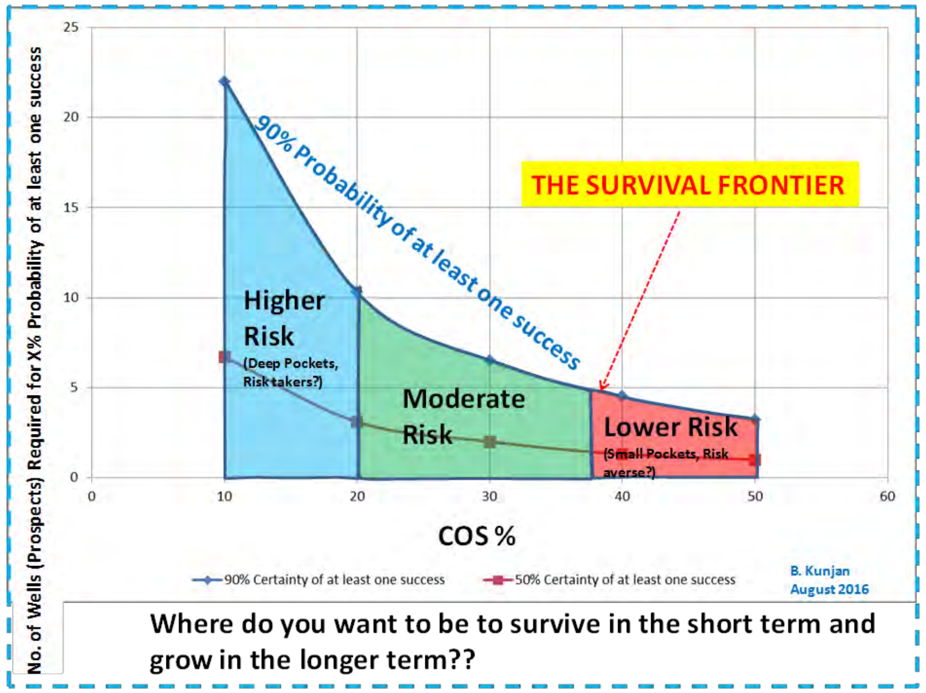


Figure 9. This graph shows an alternative way to look at COS'. The line annotated as "The Survival Frontier" shows the number of wells required at any given COS for 90% certainty of at least one success.

Acknowledgement

This article is a further development of a paper entitled "Exploration Chance of Success Predictions – Statistical Concepts and Realities" presented at the ASEG-PESA Conference in Adelaide on August 2016. (http://www.publish.csiro.au/EX/pdf/ASEG2016ab150).

There are many who have contributed to this paper via discussions and peer review and are acknowledged in my paper. However, I take full responsibility for the contents of this paper.

Figure 1+ - This graph is from my consulting days in India where in trying to convey these concepts, I enlisted the assistance of our then young daughters Priya and Sharmini, who in a Mumbai Hotel assisted me with throwing Rupee coins and Dice when I was writing the early part of this paper in the mid 2000's. I remain indebted to them for assisting in this experiment.

This paper also includes many of the concepts developed by the author in LinkedIn articles since December 2016.

About the author

Bala Kunjan *has 40 years G&G experience in exploration and development across the Oil and Gas Industry in Asia-Pacific Basins of Malaysia, Indonesia, India, Australia, New Zealand, and the USA. He has worked within integrated teams of geologists, geophysicists, and reservoir engineers, leading to significant field developments and discoveries such as the Ravva Oil Field (India), Krishna Godavari Basin (East Coast India) Deepwater Discoveries, East Spar Gas/Condensate Field (Carnarvon Basin, Australia), Tui Oil Field (Taranaki Basin, New Zealand), Casino/Henry/Netherby Gas Fields (Otway Basin), Yolla Gas/Condensate Field (Bass Strait), many Cooper Basin Gas and Oil Fields and the Oyong and Wortel oil and gas fields in the Madura Straits, Indonesia. He has been noted for mentoring younger geoscientists since 2004. His core area of interest is in visualizing/communicating exploration risk, and planning for sustainable long term success through anticipated probabilistic outcomes from given assets/portfolios. He has a BSc Hons in Geophysics from the Science University of Malaysia, Penang, 1977 and an MBA from the Australian Graduate School of Management (AGSM), University of New South Wales, Australia, 1990.*

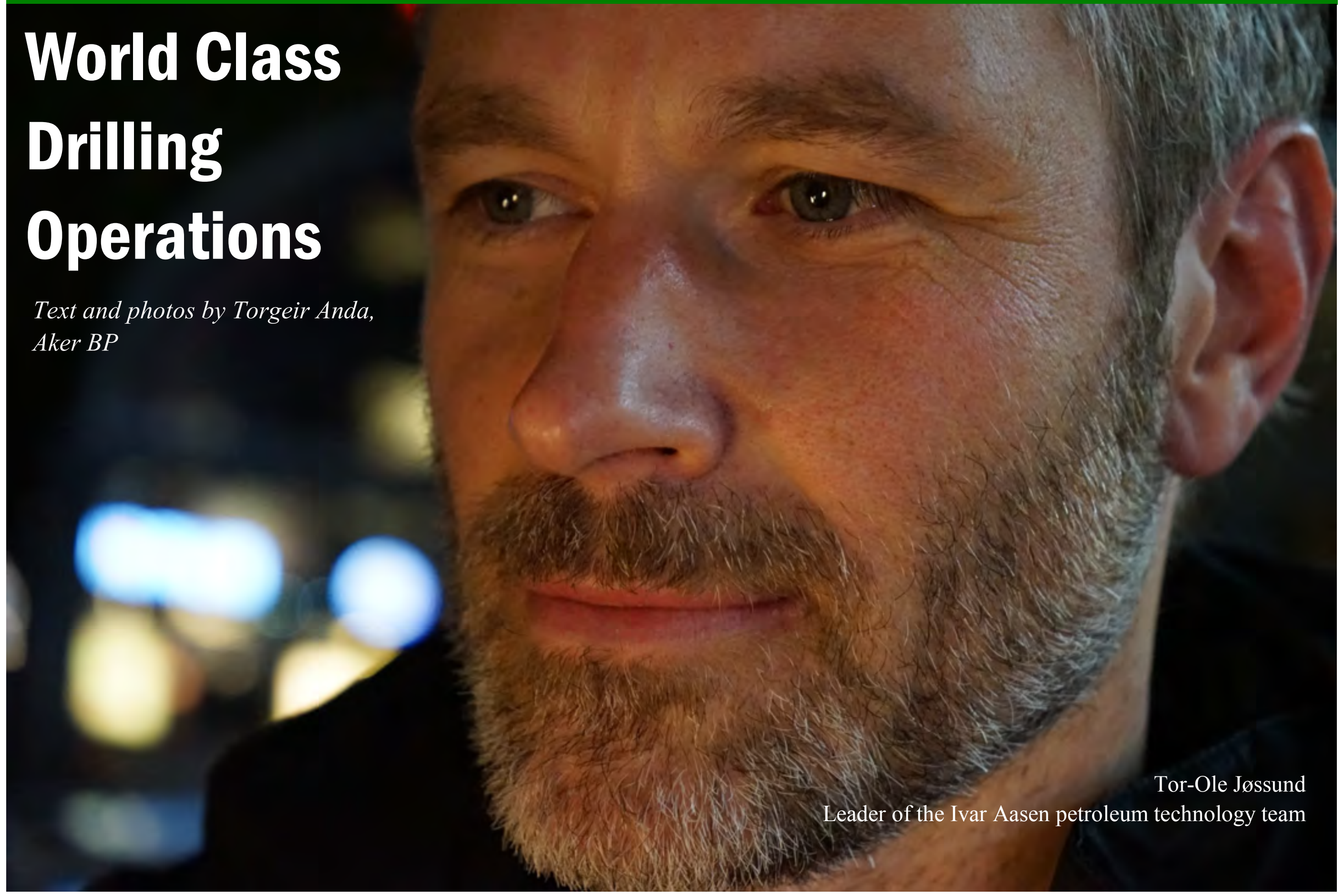
Having started his career with Esso in Malaysia (1977-1985), he has worked as an employee as well as a consultant with various companies including Delhi Petroleum (Adelaide), Santos (Adelaide), Western Mining (Perth), Command Petroleum/ Cairn India (Sydney/Edinburgh/Chennai), Reliance Industries (Mumbai), AWE (Sydney) and Drillsearch (Sydney). Currently he works with Cue Energy in Melbourne.

Bala is a member of the AAPG Visiting

* If COS = 25%, Chance of back to back failures drilling 8 wells = (1-25%)^8 ~ 10%. Therefore, the Probability of at least one success after drilling 8 wells is 90%. You could choose to drill higher COS numbers as at 50% COS where the 90% chance of at least one success is delivered with 3 wells.

World Class Drilling Operations

Text and photos by Torgeir Anda, Aker BP



Tor-Ole Jøssund
Leader of the Ivar Aasen petroleum technology team

Ivar Aasen's start-up is a huge milestone for Aker BP. As operator, the company has completed the development in a challenging period for the industry. It is therefore particularly satisfying that the project was delivered within total budget and on schedule.

Around 17 million working hours were invested in the project and there were no serious HSE incidents. This means that the project has satisfied the four main goals:

- no serious incidents
- a high-quality delivery
- delivery on time
- within budget.

Drilling operations on Ivar Aasen have been world-class in terms of the speed of the drilling, its high quality and good safety. Statistics from Rushmore confirm this (Pic 1). The excellent progress on drilling operations has so far contributed close to NOK 2 billion in savings for the project. This has been an important factor in the completion of the project within the total budget. The drilling has taken place in close cooperation with the Department of Petroleum Technology and the Department of Drilling and Well Operations, along with Maersk Drilling, Schlumberger and other service companies.

The wells on Ivar Aasen are drilled using geo steering. Maersk Interceptor's every move on the Ivar Aasen field is closely monitored from a dedicated office in Trondheim – two kilometres into the ground and two kilometres horizontally through shale, conglomerates and, preferably, through oil-bearing porous sandstone. The sandstone's density and resistance are measured here. The information is checked against the seismic data and interpreted on a continuous basis. Geo steering and close follow-up have contributed to optimising the well locations, which is an important factor in maximising reservoir exposure and achieving the best possible production from the wells.

Best equipment

Maersk Interceptor is the name of the rig that are used on the Ivar Aasen field. It is an impressive sight, with three 'legs' extending almost 200 metres. There are deck spaces the size of football pitches, steel rope as thick as a footballer's calves, with a smoking room for 'non-smokers', a laundry, tanks, winches and drill pipes. The equipment on board is all state-of-the-art. The drilling machine, with its 2,300 horsepower, is the biggest ever made. The degree of automation has increased even further – everything is controlled from the most modern control rooms. Most of it is operated as if it were a computer game. However, it is first and foremost a tool for recovering as much oil from the field as possible – at the right time. The rig can operate in depths of up to 150 metres – the depth on the Ivar Aasen field is 112 metres.

Chaos pilots

The project started drilling five pilots in order to learn more about what is hidden deep below the depths. This clarified whether the reserve estimates for Ivar Aasen could increase or whether they were lower than current estimates. It is the petroleum technology team, known as 'Petek', which is directing where to drill the pilots and they know what questions they want answers to. The test pilots determined whether there is gas in the uppermost section of the reservoir on Ivar Aasen. If gas was present, this will reduce the volumes and hence the value of the field. The drilling of pilots also provided more extensive information at an earlier stage, resulting in swifter clarification of geomodels and drainage strategies programme.

The pilots were a success and provided a lot of new information. The drilling went so swiftly that there was time to drill five pilots, resulting

in important knowledge. The leader of Petek Tor-Ole Jøssund emphasises that a model is always a simplification: *'When we drill, it always turns out differently than we expected. It is more surprising if we do not encounter any surprises. The only thing we know in advance is that we have probably got it wrong. It is always different than we thought. The most important thing in that situation is to know what to do about it.'*

All the knowledge led to a reassessment of the reservoir. Although the volume of hydrocarbons in place (STOIP) was smaller, the reserves amounted to between 200 and 210 million barrels because the properties of the reservoir were better than expected.

Geosteering

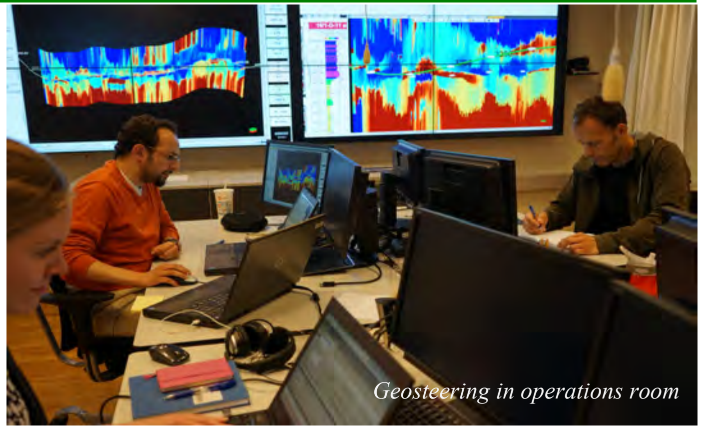
After five swift pilot wells, it was time to drill production and injection wells.

Two kilometres into the ground and two kilometres horizontally through shale, conglomerates and preferably oil-bearing porous sandstone. The sandstone's density and resistance are being measured. The information is checked against the seismic data and interpreted on a continuous basis. There are darcy and net gross, sections and faults. The changes cannot be too sudden, as sand screens must be installed that are not very flexible: Should we drill straight forward, should we go up or down? The cost of every hour runs into millions, but if things are done correctly, hundreds of millions can be saved or made. It is like guessing the next card in a deck – up or down. Tor-Ole Jøssund was responsible for ensuring that the decisions made are the right ones: 'It's like driving a car while only looking through the rear-view mirror. The information we receive from the drillbit is often one hour behind – we are always about 30 metres behind. This means that we have to make choices that in hindsight may prove to be wrong. You do not get the full picture until the next day. That is the nature of geosteering. Ivar Aasen is just as uncertain and complicated as we had envisioned. It will not be plain sailing to produce the oil from this field – but we will manage. The management has told us to lead the way in Petek on the Aasen field. What we do here is world-class; I do not know of anyone else doing the same as us. Here we make important decisions 24 hours a day, 7 days a week – including on public holidays.' *'The Petek team cooperates very well with the drilling team. They are efficient and do an excellent job. We are one excellent team. I'm really proud of what we've achieved together.'*

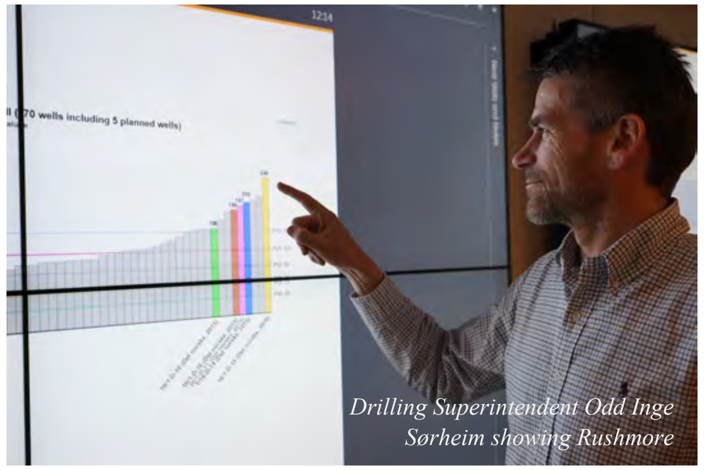
Probably the best

'We shouldn't really say it out loud, but we've probably set a world record in drilling on Ivar Aasen.' Nonetheless, Odd Inge Sørheim is proud of having drilled 246 metres on Ivar Aasen in one day. Now the goal is to be even better.

We are in the control room for the drilling team in the Føniks building in Trondheim. Drilling Superintendent on Ivar Aasen/Maersk Interceptor, Odd Inge Sørheim shows graphs that he believe says it all. A total of 246 metres of drilling progress per day for D-19 and an average of 201 per day for all the six wells combined. The average on the Norwegian continental shelf is about 100 metres: 'The figures don't lie; they show that we're twice as good as the average. That's not bad, but we could do even better.' When it comes to completion of the drilling holes, so that they can produce the oil, the results are perhaps even more impressive. It took 9 days on average on Aasen, compared with an average of 21 days on the Norwegian continental shelf. There is certainly nothing ordinary about it. Maersk Interceptor has completed 528 metres a day, while the average on the continental shelf is 234 metres. 'There's no doubt that we're the best – by far. I'm sure our completion speed constitutes a world record.' 'Of course, we have a great rig with an excellent crew, but so do others – without achieving results like these. The success is because we have chosen to work in an integrated team together with Schlumberger, TechnipFMC and Maersk. We all work together and quickly deal with problems as they arise.'



Geosteering in operations room



Drilling Superintendent Odd Inge Sørheim showing Rushmore

Maersk Interceptor

Removal of solids from well flow using dynamic desander technology boosts production and simplifies interventions

by Dmitri Gorski, Senior Process Engineer, BRI Cleanup

Dmitri Gorski
PhD, Senior Process Engineer,
BRI Cleanup
dg@bricu.no

Sand and other solids are present in the production flow of most of the producing wells today. Statoil highlighted the value of dealing with solids production topside instead of using expensive well completions more than 10 years ago (Andrews at al.; 2005). In this SPE paper, the Statoil engineers reported that the use of sand control completions was minimized when developing the Statfjord and Gullfaks fields. This strategy was described as a success. Not only the predicted significant gain in production acceleration could be realized, but also an increase in reserves (IOR) could be demonstrated. The authors did not propose any methods for separation and disposal of sand topside upon the utilization of the above described production strategy. Back then, few options for dealing with produced sand topside were available. The approach was rather to establish a Maximum Acceptable Sand Rate (MASR) value based on the capacity of the process system on-board to deal with the incoming sand. This paper suggests a way of significantly increasing the MASR value using novel technology for continuous removal of sand from the well flow topside. The technology is based on hydrocyclone separation, enhanced using a motor-powered impeller. The method has been extensively tested in Norway and abroad during the past 14 years.

Most of us know how much damage produced solids can do to the topside facilities. Sandblasting of piping systems and various downstream equipment will soon enough lead to erosion damage. In worst case, this can result in loss of containment and hydrocarbons on deck. Sand and solids also tend to plug process systems, leading to a need of cleanouts. A common example of this is production separators, where a lot of sand accumulate if not taken care of upstream. In the case of separators, there are now online jetting systems which help flush the sand out. However, this does not eliminate the risk of erosion upstream, and the jetting does lead to production disturbances.

Hydrocyclones are traditionally used for inline separation of solids from liquids. A hydrocyclone is a simple equipment that has been in use, virtually without modifications, since the end of the 19th century. Today, hydrocyclones are used everywhere: from the automotive industry and mining to home appliances. The principle of operation is simple: an orifice at the inlet of the hydrocyclone increases the velocity of the fluid flow to a point where sufficient centrifugal force is created in the hydrocyclone vessel to force most of the solids particles to the walls. There the particles sink to the bottom, where they are discharged. The “clean” liquid overflow contains significantly less solids and can be sent to the next processing stage. High fluid velocity is detrimental for the performance of the conventional hydrocyclone. Any separation process requires energy, and in a conventional hydrocyclone this energy comes from the well flow itself. This energy conversion is always associated with a pressure drop, where pressure loss is translated into increased velocity of the fluid. There is no way around this fundamental disadvantage of conventional hydrocyclones. In fact, Statoil's own technical guideline (TR3006) requires a pressure drop of 2-3 bars over a conventional sand hydrocy-

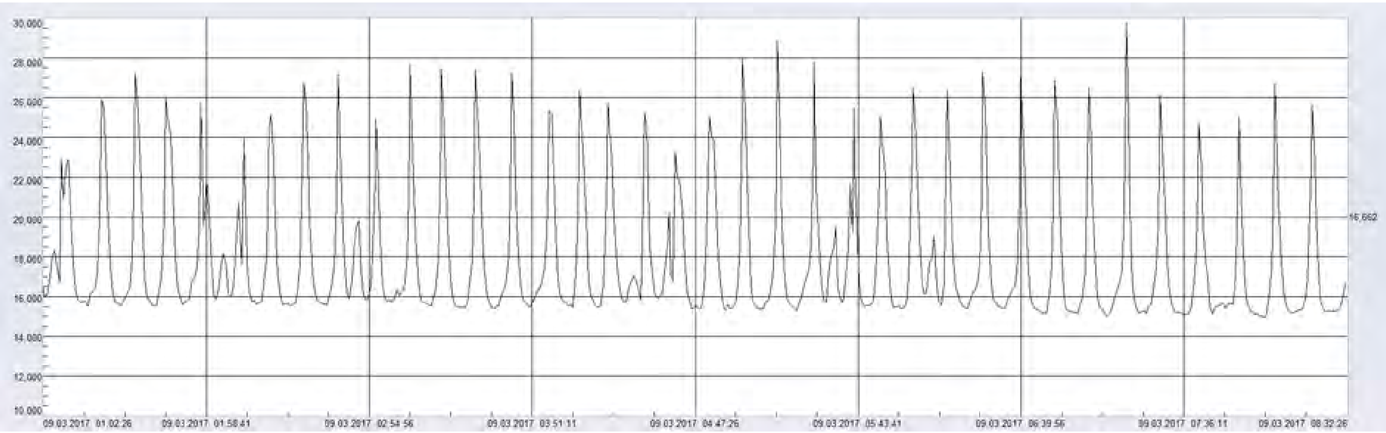


Figure 1. Example of pressure variations in a slugging well at the North Sea

clone to ensure efficient separation. Another disadvantage is the high velocity of flow itself which leads to equipment erosion. Several cases of hydrocarbon containment loss occurring due to this phenomenon have been registered on the Norwegian shelf in the past years. Liners or inserts are used to protect the inside of the hydrocyclone from the erosive flow, although they get worn out and need to be exchanged periodically. Flow orifice, located at the inlet of a conventional hydrocyclone, is optimized only for a narrow range of well flow and pressure. If flow and pressure changes, the orifice must be exchanged as well. Flow and pressure are very seldom stable in a producing well, here illustrated with an example from a Norwegian installation (see Figure 1). Laws of physics dictate that separation in a conventional hydrocyclone, where inlet flow is subject to large variations, will be just as unstable.

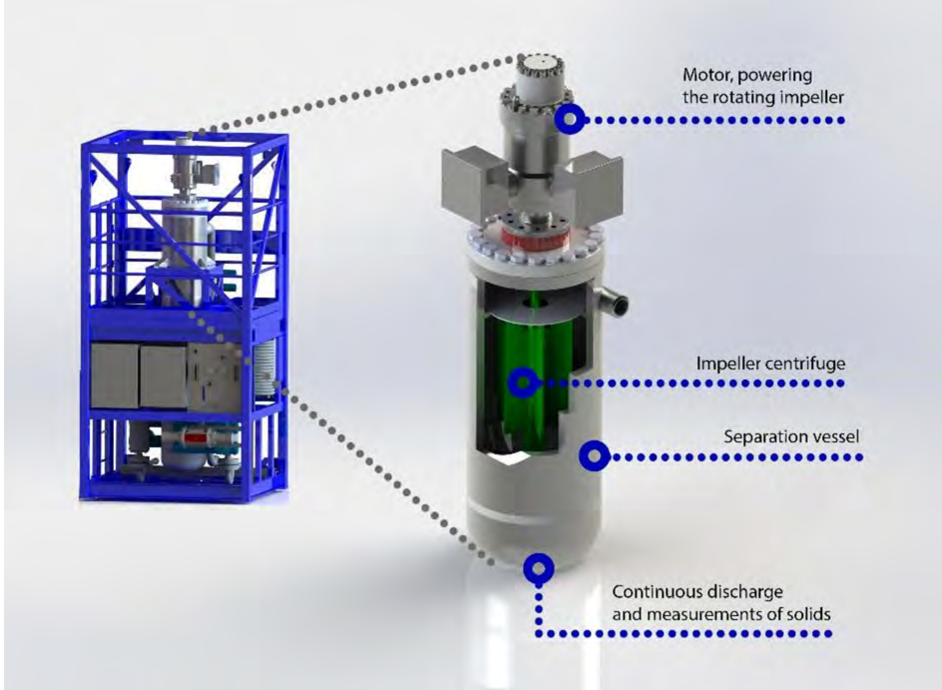


Figure 2. Figure 2 Dynamic Desander System™ with enhanced view of the separation chamber. Solids are disposed in the lower collector tank, which is periodically isolated and flushed while the system is in continuous operation. This process is completely automated.

At the same time, it is becoming more and more clear that significant savings can be made by integrating a desanding hydrocyclone into a topside processing facility. A lot of trials, where hydrocyclones have been used for inline cleaning of process stream from solids, have been carried out over the past 15-20 years. The first wellhead desander was deployed in 1996 on the Shell Brent field in UK, and since then there have been several installations worldwide (Rawlings; 2014). Trials with a bulk desander on Gullfaks C platform on the Norwegian shelf showed savings of at least 20 million NOK due to reduced need of well interventions alone (FourPhase; 2016). Numbers from multiple wellhead desander installations in Asia are not officially available, but a significant increase in production can be assumed there. However, most of the conventional hydrocyclones that exist on the market today are bulky, manually operated, and lack automation and integrated monitoring of separated solids (Halliburton; 2017, Schlumberger, 2017; eProcess; 2017). Additional washing systems are often required to remove oil rests from the separated sand. Some of the existing conventional hydrocyclones are more compact than others, and some are equipped with a certain degree of automation and monitoring (FourPhase, 2015). Yet none of the conventional hydrocyclones employ a separation principle that is significantly different compared to hydrocyclones of the 19th century. The need to improve shortcomings of conventional hydrocyclones to overcome their disadvantages has been there for some time.

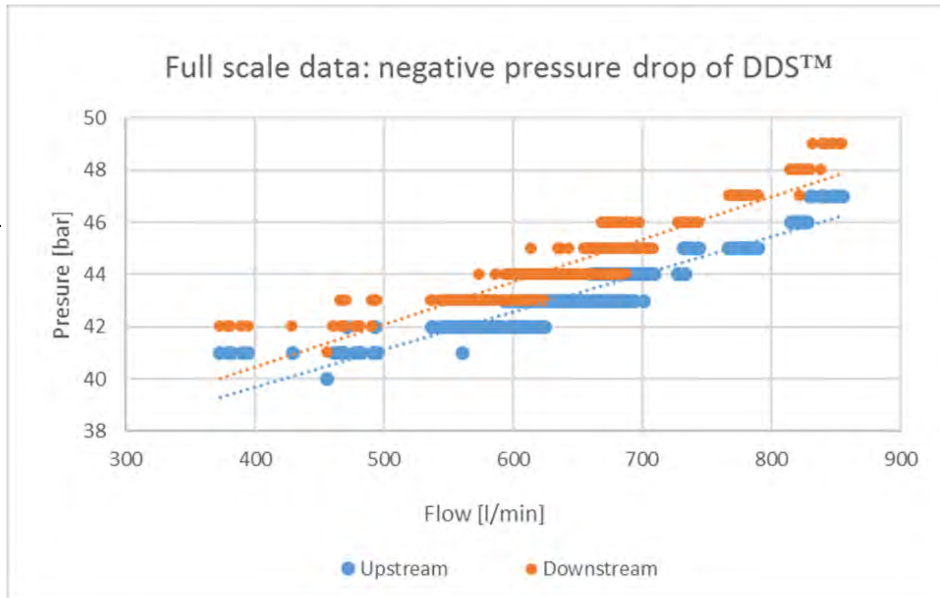


Figure 3 Approximately 1-2 bar of pressure is generated in Dynamic Desander (offshore data), while conventional hydrocyclones are bound by the laws of physics to operate with a pressure drop.

Finding a way to decouple the energy driving the separation of solids from the energy of the well stream would vastly improve the fundamental working principles of a hydrocyclone. If this is achieved, the separation process would no longer be as unstable due to instabilities of the well flow. A possibility of providing additional energy to the separation process would also open up, thus making the separation potentially more efficient and controllable. Finally, dependence on the unreliable inlet nozzles, and the need of protective liners, might be eliminated. The first idea of how to achieve all this formed in the late 1990s in Norway. Experiments where an impeller, powered by an electric motor, was inserted into a hydrocyclone vessel led to the development of the first dynamic hydrocyclone. Further research into this concept elsewhere firmly defined the term “dynamic hydrocyclone” as describing motor-powered impeller in a hydrocyclone vessel (Jiao et al.; 2006, Zhou et al., 2014). This approach represented first principal improvement of the hydrocyclone separation principle in more than a century. The patent granted for dynamic hydrocyclone technology was sold several times, and is now owned by BRI Cleanup, a small Norwegian company located in Ågotnes outside of Bergen. BRI Cleanup is the only company offering dynamic hydrocyclones today under the brand of Dynamic Desander System™, see Figure 2.

The advantages of Dynamic Desander technology over conventional hydrocyclones include:

Two-stage separation in one vessel (hydrocyclonic separation is enhanced with centrifugal action of the impeller), which guarantees superior performance independently of the flow.

No need for inlet nozzles and liners, which significantly improves HSE aspects as well as leading to better operational characteristics.

No pressure drop (and in fact an increase in pressure as illustrated in Figure 3).

Dynamic Desander System units are highly automated and provide real-time data on the weight of separated solids and other process parameters. They are fully integratable into platform systems. Each unit consists of upper separation vessel and lower accumulator vessel. The sand, separated in the upper vessel, sinks into the lower vessel, which can be discharged to a recipient of choice (e.g. sand skip or rig's cutting reinjection system). The separation process is continuous and does not stop even during the sand discharge sequence, which only takes a few minutes. Another unique characteristic of DDS™ is its ability to clean the sand while it is separated and discharged. No additional cleaning equipment is normally required, which simplifies the disposal of the sand if brought to shore. In some parts of the world, where it is permitted to discharge the sand overboard, the sand even meets the strict authority cleanliness standard without the need of additional treatment.

When a conventional hydrocyclone is utilized, there is often a need to install subsequent filter unit to remove the smallest particles (Arefjord and Malinauskaite; 2017). This auxiliary equipment is most often not required when DDS™ is employed and removal of particles with sizes down to 5 microns have been recorded.

Deployment of the Dynamic Desander System™ on an offshore platform in Malaysia led to doubling of production for some of the connected wells. In Norway, the system is often in use on well interventions and flowback operations. Integrated into a coiled tubing (CT) package, the DDS™ gives coiled tubing operators real-time information about the amount of solids coming from the well. It also prevents any solids in the returns from entering coiled tubing fluid circulation or platform processing systems. Recently, dynamic hydrocyclones made an appearance on the US market, where efficient dealing with the return of solids has been an unresolved issue for unconventional fracking operations.

A unique capability of the DDS™ is to handle variations in flow and large amounts of gas, while simultaneously maintaining high separation efficiency due to dual separation action proved to be detrimental for its success. Based on the proven track record of the DDS™ technology, its compact size and the potential for automated continuous operation, it could be suggested that there finally is a permanent solution to the topside solids issue. Benefits described by Statoil engineers back in 2005 can finally be realized.

Figure 4. BRI Cleanup Dynamic Desander unit in unconventional fracking operation in USA.

References

1. *Andrews, J. S., Kjorholt, H., & Joranson, H. (2005, January). Production enhancement from sand management philosophy. A Case Study from Statfjord and Gullfaks. In SPE European Formation Damage Conference. Society of Petroleum Engineers.*
2. *Arefjord A. and Malinauskaite G. (2017). "Using Dual Desander and Stackable Filter Unit for Cleanout after Concentric Coiled Tubing Operation". SPE International Bergen One Day seminar, SPE paper SPE-185940-MS*
3. *eProcess (2017). "Wellhead desander". Retrieved from http://eprocess-tech.com/products/facilities-sand-management/wellhead-desander/*
4. *FourPhase (2015). "5k DualFlow unit". Retrieved from http://www.fourphase.com/4phase/wp-content/uploads/2015/04/FourPhase_DualFlow_TechSheet_Web.pdf*
5. *FourPhase (2016). "Overcoming offshore production challenges – what are your production objectives?". Retrieved from http://www.fourphase.com/4phase/wp-content/uploads/2015/10/Offsnet_FOURPHASE_Whitepaper.pdf*
6. *FourPhase (2017). "Interventionless kickstart & sand cleanout of well C-19 & C03". Retrieved from http://www.fourphase.com/interventionless-kickstart-sand-cleanout-of-well-c-19-c-03-2*
7. *Jiao, J., Zheng, Y., Sun, G., & Wang, J. (2006). Study of the separation efficiency and the flow field of a dynamic cyclone. Separation and Purification Technology, 49(2), 157-166.*
8. *Schlumberger (2017). "Cyclonic Desander". Retrieved from http://www.slb.com/~/media/Files/testing/product_sheets/surface/cyclondesand_ps.pdf*
9. *Halliburton (2017). "Wellhead desander and accumulator". Retrieved from http://www.halliburton.com/public/ts/contents/Data_Sheets/web/H/SWT-WellheadDesander-H010995.pdf*
10. *Zhou, Y., Mingfei, Z., & Ma, C. (2014). Experimental and numerical investigations of a dynamic cyclone. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 228(5), 536-549.*

WELL CLEAN OUT AFTER REPERFORATION 98% SEPARATION EFFICIENCY

Shell Gannet, North Sea

Challenge

Two wells were planned for cleanup flow after reperforation using wireline intervention. The aim of performing the cleanup was to enhance production from the wells post reperforating. Once the FourPhase solids removal system was mobilized, the scope of the operation was expanded by two additional wells.

Operational considerations:
– High expectation of sand during the initial cleanup

Solution

There was a high expectation of sand during the initial cleanup, therefore the use of the FourPhase DualFlow solids removal system was chosen for the collection of any sand produced to surface assuring high separation efficiency and minimal space requirements due to system's compact design. The FourPhase system continuously separated and removed solids which were then flushed to external skips on the hatch deck. The cleaned return fluids were routed to an unused wellhead to allow access back into the production stream.

Result

– No recorded HSE incidents.
– No recorded equipment downtime
– 912 kg of solids separated during the cleanout operation.

Successful reperforation operation met clients' expectations and resulted in FourPhase solids removal system being requested for upcoming operations.

Text provided by Giedre Malinauskaite
Marketing Manager, FourPhase

tNavigator scales to GPU's

by Dmitry Eydinov, Rock Flow Dynamics

Dmitry Eydinov
PhD, Business Development Director
Rock Flow Dynamics

In 1965 Gordon Moore, one of the Intel co-founders, predicted that the number of transistors in a dense integrated circuit doubles approximately every two years. This is known as Moore's law and the statement has proved to be true over the last 40+ years. These days we have technology that grows even faster than the CPU's – graphical processing units (GPU).

Recently, new generation of GPU became available for general purpose computing with the support of double precision floating point operations, necessary for dynamic reservoir simulations. The graphics cards currently available on the market have thousands of computational cores that can be efficiently utilized for high-performance simulations, Figure 1.

In addition to the number of cores, the latest GPU's also have significantly greater memory bandwidth, which is equally important for efficient parallel simulations as it is effectively the speed of communication between the cores. The progress in this component is so rapid that we can expect further breakthroughs in this direction and significant changes in the hardware world in the nearest future.

The software development team in Rock Flow Dynamics has recently implemented capabilities to run simulations in hybrid CPU-GPU mode, utilizing all computational power available. The hybrid parallelization algorithms distribute the workload between CPU and GPU hardware components so that all computer resources are utilized for the best simulation performance.

The results have shown that utilizing of combination of CPU and GPU in the simulations, balancing the workload between them, significantly improves the simulation time. For example, let us consider the well known SPE10 case, which is often used as a benchmark for simulation performance. The model is strongly heterogeneous and has large differences in the reservoir properties, which is always quite a challenge for the simulation software. The figure 2 shows comparison of the simulation time on 3 various platforms: regular laptop

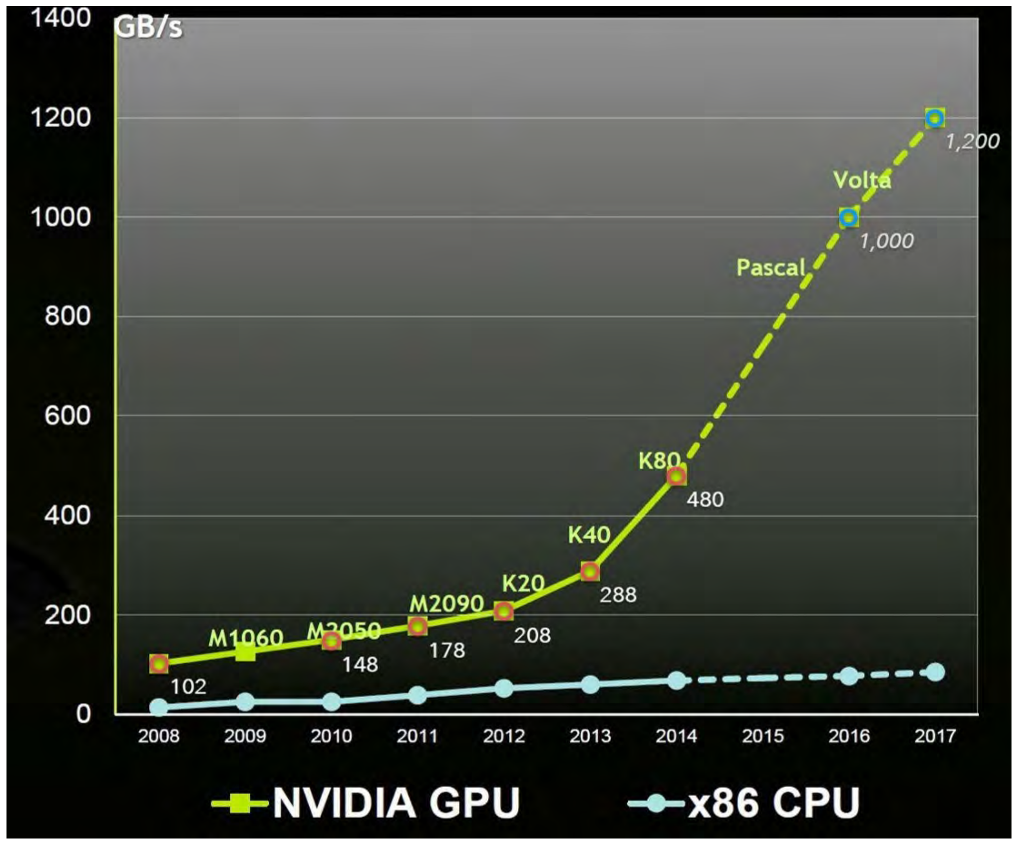


Figure 1. Memory bandwidth progress for GPU and CPU platforms

SPE Norway — Reservoir simulation

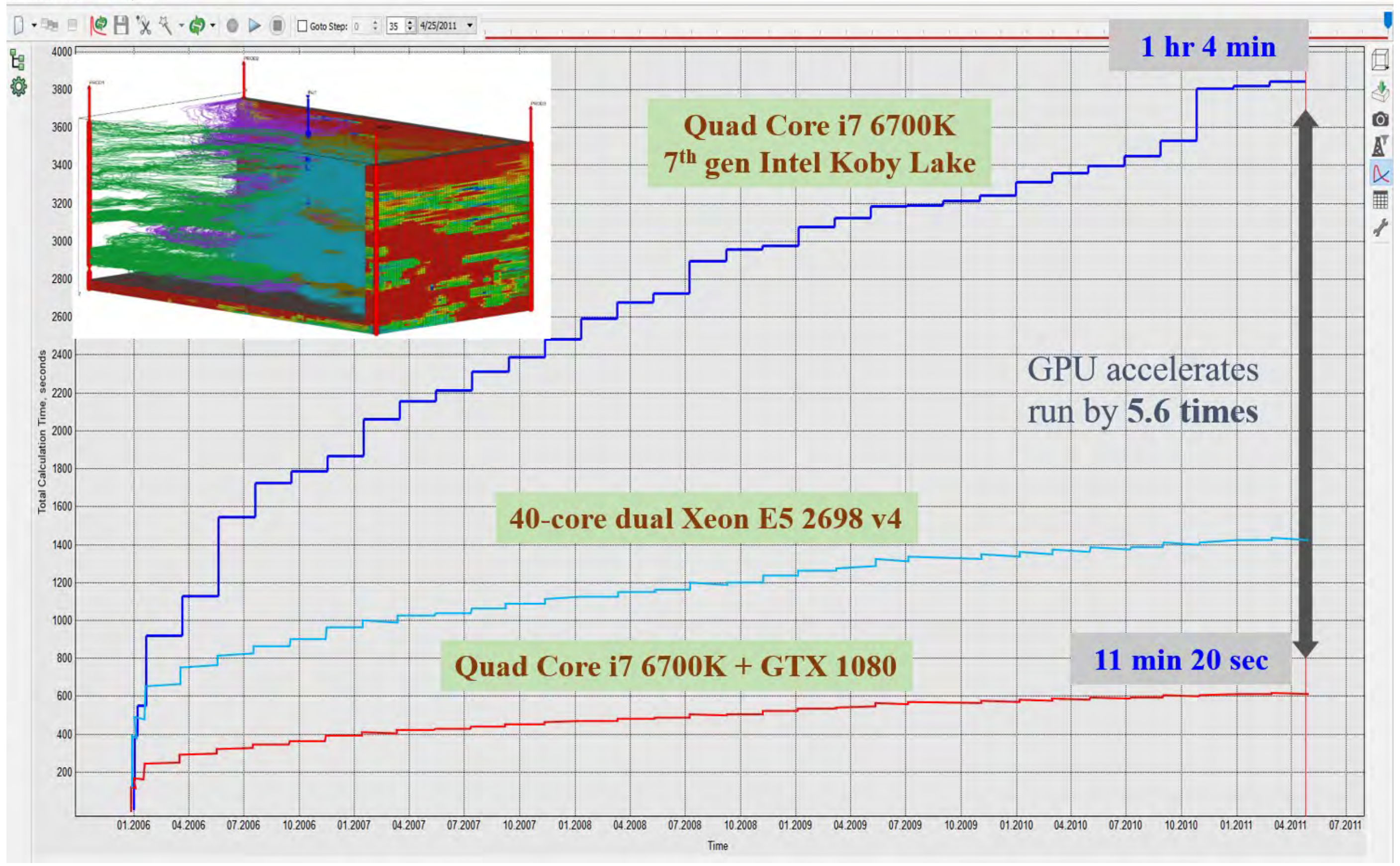
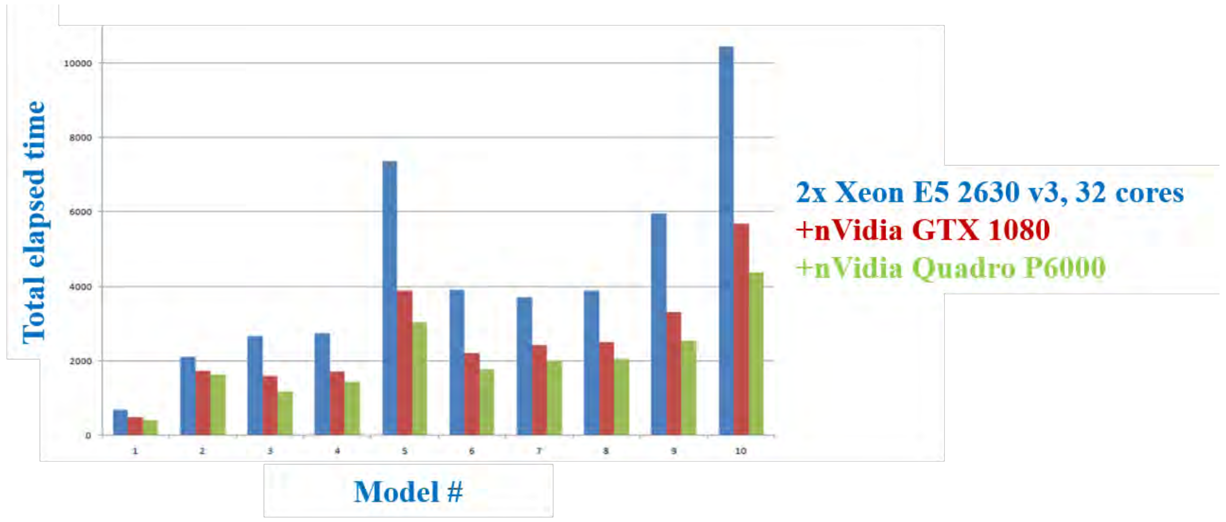


Figure 2. SPE 10 benchmark for simulation time. 4-cores laptop – dark blue line; Dual-CPU workstation – light blue line; 4-cores laptop with GPU – red line.

with 4-cores CPU, powerful dual-CPU workstation (somewhat like HP z840) and the laptop from the first test but with GPU enabled for computations. As you can see form the figures, the difference in the simulation time between the cases with and without GPU is 5-6 times. The simulation time is reduced significantly, without too much investment in hardware. You can find a laptop of this kind in any hardware shop for about $2000. It is also worth mentioning that a machine like this outperforms a significantly more expensive workstation with 40 CPU cores (~$15000) by about 2 times.

It is actually quite difficult to predict where the hardware competition is going to go in the near future. Even before the end of this year we can expect several releases of the new chips by Intel, NVidia and AMD. Time will tell who is going to deliver the best results, but there is no doubt that the high-performance hardware world is changing rapidly these days and we can expect reservoir simulations to run significantly faster in the near future. The race is definitely going to be interesting…

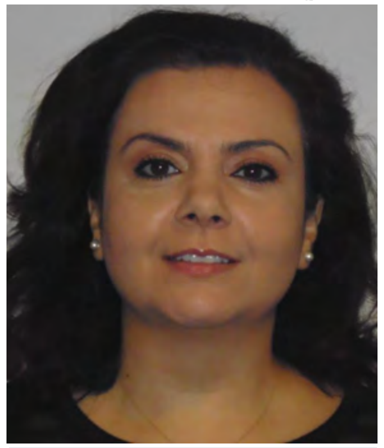


Comparison of the simulation time on 10 random real-field 3-phase black-oil models.

Cased Hole Reservoir Layer Pressure

by Remke Ellis and Rita-Michel Greiss, TGT Oilfield Services

Remke Ellis
Reservoir Engineer
Domain Champion



Rita-Michel Greiss
Business Development Manager

One of the most critical measurements for reservoir management is that of formation layer pressure. Various methods are employed to determine reservoir pressure however many techniques only measure average reservoir pressure and should not be used for multi-zone reservoirs that are differentially depleted. Multi-rate PLT method is used to measure formation pressure across individual perforation intervals, but the assumptions that all fluid exiting / entering a perforation interval is confined to a particular unit (i.e. there is no fluid redistribution behind pipe) and uncertainties in unit thickness can result in significant errors. Triple Rate Spectral Noise Log method (TSNL), measures the pressure for each active layer independently, regardless of behind pipe fluid redistribution. TSNL, is based on the same hydraulic diffusivity equations as multi-rate PLT method but uses reservoir flow Noise Powers (NP) instead of transperforation flow rates (Q). This means that flowing reservoir units are evaluated independently even when fluid from multiple layers commingle to the same perforation intervals. Furthermore SNL directly measures effective formation (flowing) thicknesses behind pipe[1], which is an important input for the technique and also enables assessment of reservoir performance and helps refine estimation of reserves.

Triple Rate SNL (TSNL) Technology

SNL-HD is a passive tool, comprising of a battery, electronics and hydrophone with unrivalled sensitivity. The tool records the frequencies and amplitudes of acoustic energy associated with movement of fluid. Frequencies in range of 8 to 58,500 Hz are recorded in 115 Hz wide bands (512 channels). Each band has its own specific noise intensity. The tools dynamic range is 90 dB. This means that even when certain frequencies are very intense the less intense frequencies are not masked. The frequency bands and associated intensities / amplitudes for each station depth are then displayed on a SNL data panel (see figure 1).

Analysis of the data panel provides insight to the origin and character of fluid flow. The frequency of fluid movement is inversely proportional to the size, or aperture, of the flow path. For example, flow through large pores generates lower frequency noise than flow through small pores. Flow through open pipe will generate lower frequencies than that through a fracture. This principle enables High Definition Spectral Noise Tool (SNL-HD) to distinguish between the different sources and pathways of fluid movement, so commingled channelling and borehole noise can be separated from actual formation layer noise. The noise pattern geometry helps reveal the source of the noise; reservoir noise is characterized by wide frequency range streaks over discrete depth intervals, while borehole or cement channelling noise have much lower frequencies, narrower frequency range and are tracked over long depth intervals (parallel with wellbore).

The SNL-HD panel shows noise data in three dimensions: Depth, Frequency and Amplitude. Figure 1 illustrates noise acquired by SNL-HD for different fluid movement pathways. Displaying the SNL-HD data like this means that the noise associated with individual unit reservoir flow can be distinguished from that associated with the commingled borehole and cement channelling noise, allowing for each layer to be assessed independently[2]. The intensity (amplitude) of fluid flow noise is directly proportional to the product of flow rate and differential pressure. These relationships that determine frequency and intensity form the basis of TSNL technique.

TSNL Concept of Measurement

This technique uses hydraulic diffusivity equations in conjunction with SNL noise power ratios in order to determine external boundary pressure of reservoir zones under flowing conditions. McKinley[1] pioneered the first

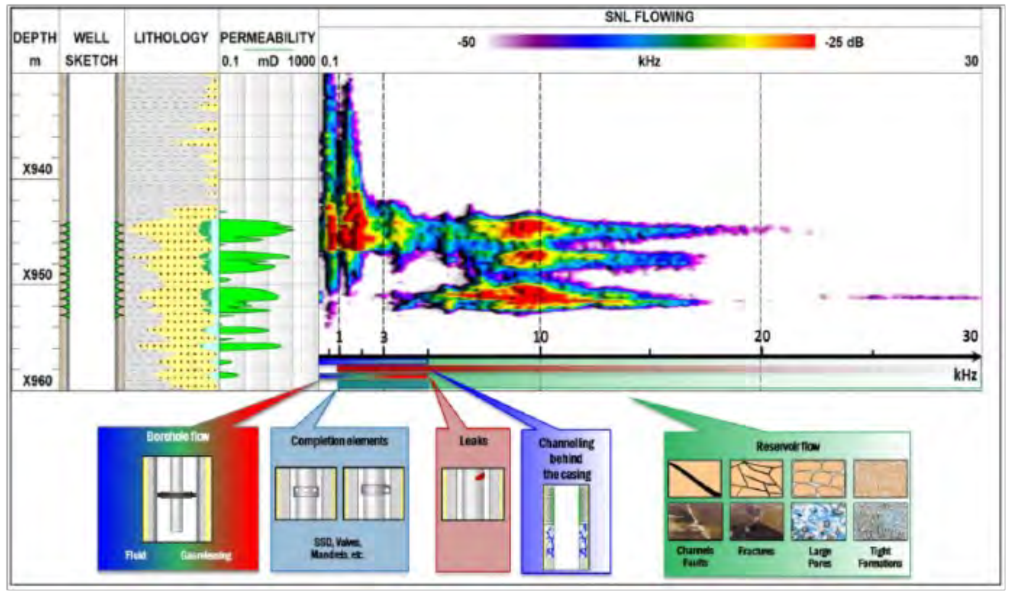


Figure 1 SNL-HD Interpretation Fundamentals

[1] A.Aslanyan and I.Aslanyan, TGT Oil and Gas Services, Assessing Macroscopic Dynamical Permeability Through Pressure and Noise Analysis
[2] Yu.S.Maslennikova, V.V.Bochkarev, A.V.Savinkov and D.A.Davydov, TGT Prime. Spectral Noise Logging Data Processing Technology, SPE 162081, 2012

laboratory studies investigating the relationship between energy dissipated by fluid flow through a media (equivalent to the product of flow rate and pressure differential) and the strength of associated acoustic signal generated (noise power). Figure 2 presents McKinley's results, revealing a linear though scattered relationship. The scattered distribution of McKinley's data is linked to limitations of the equipment used at the time. Noise Power (NP) represents a fraction of kinetic energy that is lost from the system as noise, so it is not surprising that it varies linearly with system enthalpy. Little or no research work has been done since the McKinley experiments, until 2012 when the implications of what the study revealed were realised.

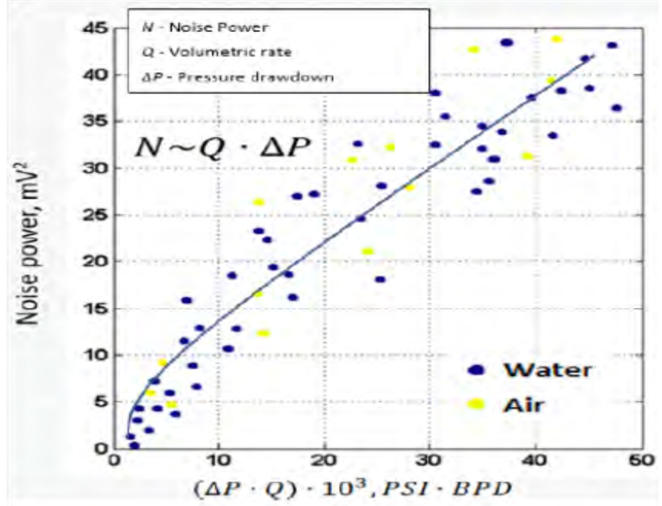


Fig 2: First realization of linear Q.dP vs NP relationship (McKinley[2])

Proportionality of NP with energy dissipation (Q.dP) allows for the substitution of Q with NP in hydraulic diffusivity equations (*see SPE 177892*). This means that a producing / injecting well can be kept on line, and simply by varying the flow rates one can determine pressure of flowing units. Unlike PTA with downhole gauges or multi-rate PLT method, TSNL records NP specific to discrete flow units, and can therefore determine individual layer pressures, even behind pipe.

Examples in Silicacious Deltaic Environment - SPE 177620 – MS

Spectral Noise Logging technique has been utilized to estimate the average reservoir pressure for each perforated layer in a multi-zone single completion oil producer. The noise logging survey has been carried out under flowing conditions with 3 different rates (see figure 3).

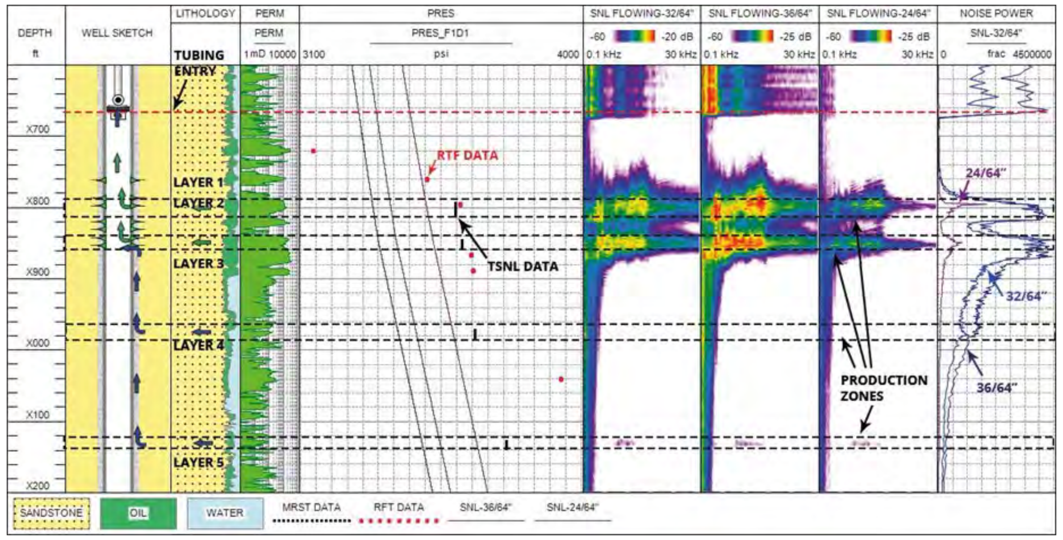


Fig 3: Tracks from left to right: depth, well schematic, lithology and saturation, permeability, pressure data (orange dot from RFT, black from TSNL, 3 pressure curves for each flow rate), SNL data for flow rate 1, 2 and 3, Noise Power curves derived from each SNL profile

The main conclusions were as follows:

(1) The pressures estimated by the TSNL technique without shutting-in the well were in good agreement with the Open Hole Formation Tester pressures. Additionally SNL determined the effective flow thicknesses of all layers, identified the source of produced water and also tested intervals untested by RFT;

(2) The technology does not require shutting in the well, although it requires stable flow at conditions above fluid saturation point (single phase);

(3) This technology is particularly suited for when target zone is behind a tubing, such as in dual string well completions with a need for pressure measurement of the formation producing through the short tubing string, or for a non-perforated reservoir communicating with the wellbore through a cement channel.

The below table details some jobs where TSNL method has been used in various settings (sandstone, limestone, producers, injectors, etc) and calculated pressures has been verified.

Table 1: Verified TSNL Job Summary

Company	Formation Type	Fluid Type	Permeability mD	Prod Rate bpd	Inj Rate bpd	No. of Layers	Flowing Pressure psi	Determined Pressure psi	Offset Pressure psi
na[1]	heterogeneous sstn	Water	19		157 - 1270	1	3980 - 5147	2980	SIBHP 2926
KOC[2]	sstn	Oil	700	1200 - 1900		3	3316 - 3485	3598 , 3617, 3761	RFT 3611 , 3648, not tested
ADMA[3]	lmstn	Oil	90 - 100				3104 - 3326	3360	RFT 3403
na	semi-cemented sstn	Oil w/ high GOR	200	circa 2500		14	1810 - 1880	1837 - 1916	cross well verification
na	semi-cemented sstn	Oil	200	circa 1900		11	1860 - 1960	1882 - 1962	cross well verification
na	sstn	Oil	106 & 35	circa 300		2	3000 - 3060	3267 & 3092	3233 SIBHP

1 – SPE 182856, Formation Pressure Evaluation for Producing Wells Without Shutting Down the Well, Using Triple Spectral Noise Logging TSNL, 2016
2 – SPE 177620, Quantification of Reservoir Pressure in Multi-Zone Well under Flowing Conditions Using Spectral Noise Logging Technique, Zubair Reservoir, Raudhatain Field, North Kuwait, 2015
3 – SPE 177892, Formation Pressure Evaluation for Producing Wells Without Shutting Down the Well, Using Multi Rate High Precision Temperature and Spectral Noise Logging (HPT-SNL), 2015

[1] R.M. McKinley, F.M. Bower, R.C. Rumble. The Structure and Interpretation of Noise from Flow Behind Cemented Casing, Journal of Petroleum Technology, 3999-PA

Exceptional Data, Swift Turnaround, Reduced Exposure

by Marc Rocke, Geophysicist, Polarcus

Marc Rocke
Geophysicist
Polarcus

New technology often comes at a premium. Development and marketing costs, upgrades to manufacturing infrastructure and the overall hype surrounding a new product entering the market usually translates into a price uplift for end-users. Improved data quality, along with increased safety and efficiency, can sometimes rationalize the extra costs. However during an industry downturn these justifications are less likely to be accepted, motivating service providers to become more creative with technology that is already available in order to surpass project objectives.

XArray is one example of such innovation which, through harmonious integration of currently available technologies, provides a tailored solution to survey design. The result is increased efficiency of up to 50% along with significant improvement in data quality. As it uses technology that is already available and deployed in the fleet, it comes with no additional capital outlay, HSE exposure, or cost uplift to clients. This improved efficiency and data quality derives from leveraging dense shotpoint intervals and multiple sources to improve crossline sampling.

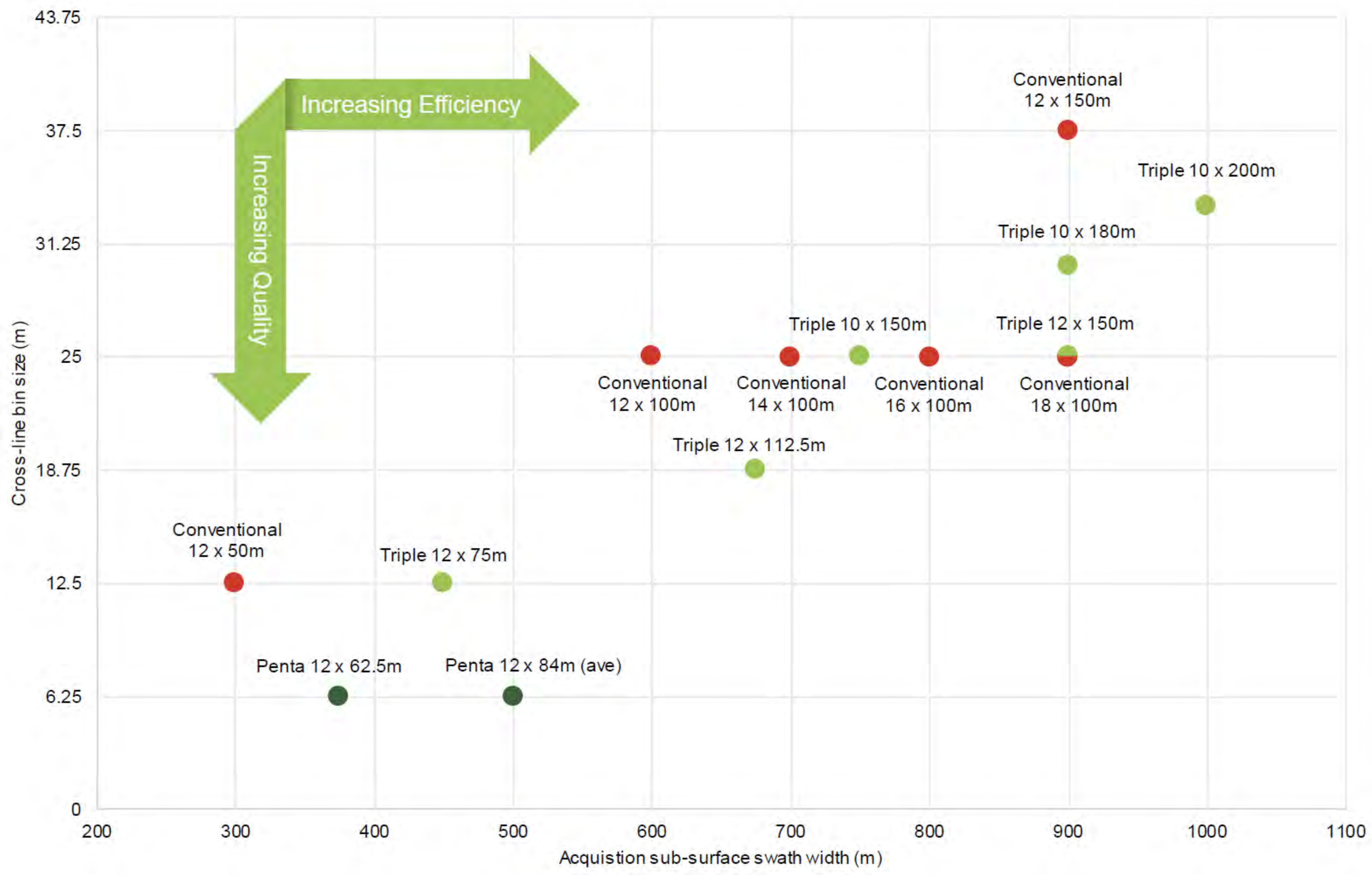
In towed streamer configurations, inline sampling is calculated by halving the distance between receiver groups on the streamer. The industry standard streamer receiver group intervals of 12.5m achieves an inline bin dimension of 6.25m. Crossline sampling on the other hand is the result of the streamer interval divided by twice the number of sources used. In the case of dual source acquisition, the crossline bin dimension is one quarter the streamer interval. In the case of XArray, crossline sampling is one sixth when three (Triple) sources are deployed and one tenth for five (Penta) sources, resulting in a considerable increase in crossline (CMP) sampling while using the same amount of in-sea equipment.

Several benefits become evident from this initiative. Apart from the resolution uplift that is achieved leading to enhanced imaging, XArray Triple works without restriction to spread width so high quality data can be acquired without increased acquisition time. Additionally with square bins at 6.25 x 6.25m, in the case of XArray Penta, it is no longer necessary to define line heading by the predominant direction of structural dip since sampling is equal in both inline and crossline directions. The survey azimuth can be chosen to maximize operational efficiency, adapting to survey geometry and operational restrictions. We have seen several cases where the survey economics are drastically improved, sometimes making the difference between a viable survey and not shooting at all.

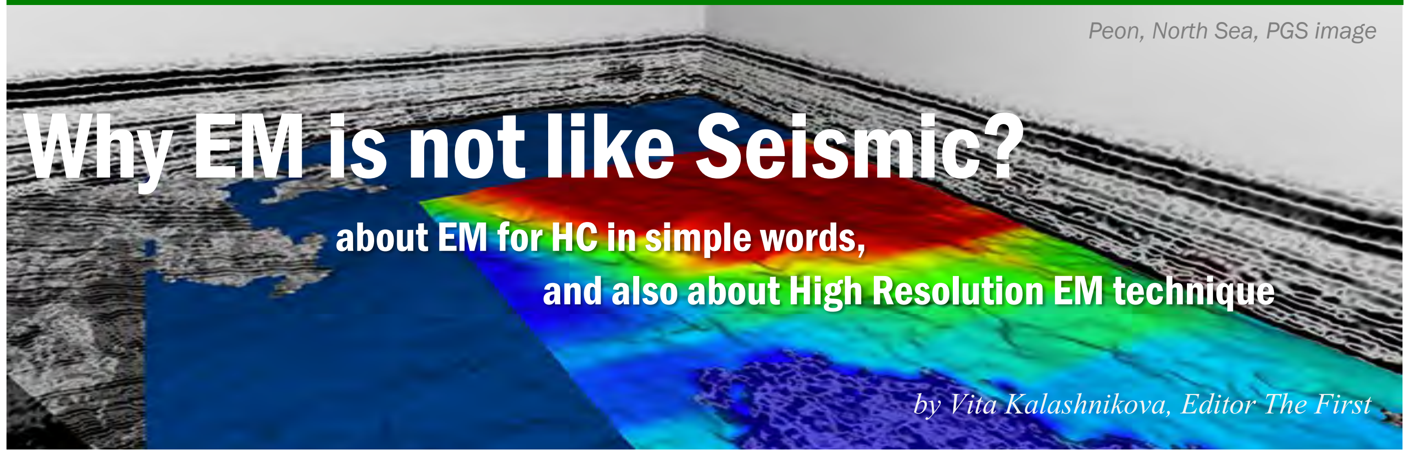
Shot de-blending is the most cutting edge of all the elements of XArray. Blended marine seismic acquisition emerged in the late-1990s and allowed shot interference (by means of continuous recording). However the blended data obviously needed to be separated in processing and the attempts to de-blend effectively have come in various flavors over the last ten years, driven by the general consensus that it will be an integral part of seismic acquisition. Recent technological advancements have made the process become a practical routine.

XArray uses what is more accurately referred to as 'near simultaneous shooting' (Berkhout et al, 2008) where shots are fired in distance mode according to a dense pre-plot of regularly spaced shotpoints. Although shot locations are regularly spaced in distance, there is a natural randomization in shot times that results from small variations in the time it takes a vessel to travel from one shotpoint to the next. This natural randomization of firing time is exploited to allow for effective separation in the de-blending process.

Combining the use of continuous recording technology, dense inline shotpoint intervals and multiple sources, Polarcus has leveraged survey design and de-blending in processing to provide tailor-made seismic solutions under the banner of XArray. The component technologies are well accepted in the industry and utilize equipment currently available onboard our vessels and familiar to our crews. The flexibility gained by the XArray method allows for reduced turnaround time from first shotpoint to drilling, reduced HSE exposure and improved data quality. Polarcus has acquired over 40,000 km2 of dense shotpoint and XArray data to date, and there remains growing interest in applying the method in basins around the world.



Plot showing efficiency and data quality comparison of common dual-source, triple-source and penta-source geometries. This is just a small subset of examples. The range of geometries that can be achieved on the quality–efficiency spectrum is limited only by the creativity of the survey design process.



Why EM is not like Seismic?

about EM for HC in simple words, and also about High Resolution EM technique

by Vita Kalashnikova, Editor The First

It is been a decades like EM methods tried to prove its deserved place on HC exploration market. Proved original techniques caused diverse opinion when it comes to the Norwegian explorations sector: from *"how brilliant it is!"* to *"it is totally failed on Norwegian shelf"*. Why are experiences so different? What makes disappointments as frequent as success stories - lack of explorationists experience in EM or may be absence of appropriate interpretation tools? The Editorial team of The First tried to understand and presenting here the challenges of EM exploration and precaution of what has to be taken into account when exploring with EM.

EM for Hydrocarbons Exploration

Electromagnetic (EM) methods are well know in implementation for geological structure investigation (from 1910) and ore exploration (1920s). First methods for hydrocarbons exploration were carried out in 1928-29.

The first use of **marine electrical prospecting** for oil and gas exploration dates back to the early 20th century (Schlumberger, Schlumberger and Leonardon, 1934). Late 1970s and the late 1990s of the 20th century are the turning points in the development of marine methods of electrical geo exploration [1]. In the late 1970s, the US military had to assess the resistance of the oceanic lithosphere to create radio communications with submarines. The development of a sounding technology, known as **Controlled-Source Electromagnetic (CSEM) method** [2] began with the financial support of the military departments at the Scripps Oceanographic Institute in the United States. This method had a huge impact on marine EM exploration. Until the late 1980s, studies of the EM properties of the lithosphere, carried out by western academic researchers in the framework of scientific projects. In the 1980s, Exxon explored possibilities of EM exploration for hydrocarbons detection (US Pat. No. 4,617,518 A, 1986). The beginning of mass commercial application of the method was related to the end of the 1990s, when oil companies began investing money in the development of the theory, equipment and methodology of **CSEM** due to high hydrocarbon prices and the start of deep sea drilling in the Gulf of Mexico. Since that time, the industrial application of electrical exploration in the oil and gas industry begins, and CSEM became the leading electro-prospecting method. After the global EM crisis, which erupted in 2008, the overestimated expectations for marine electrical reconnaissance have being corrected [3].

Introduction to EM techniques

EM exploration is a part of geophysical exploration aimed to study geological structures with help of electromagnetic fields. It allows solving many problems from shallow surface civil infrastructure needs and archaeological studies to deeper geological structures mapping including prospecting of ore deposits, geothermal resources and hydrocarbon resources. The most deep ground penetrated techniques allow studying conductivities zone in Earth crust and upper Mantle, and monitoring EM fields to study the process going in the Earth (e.g. Earthquakes).

Some of main physical groups for methods can be presented like:

- ***Resistivity*** methods use a constant EM field to determine resistivity (ρ)
- ***Low frequency*** methods use natural or artificial low frequent EM fields to determine resistivity (ρ) and in some cases electromagnetic permeability (μ)
- ***High frequency*** methods are based on high frequent EM field to determine dielectric permeability (ε) as well as ρ, μ
- ***Geoelectrochemical*** methods are based on secondary fields arising in two-phase media. The source of those fields is caused by natural electrochemical activities or polarization in the media and is depended on resistivity (ρ) in the Earth.

Acquisition can be conducted onshore, offshore, air, mines and boreholes.

In the theory of electrical prospecting, the main goal is to define and solve firstly ***direct* and** then ***inverse problems***. Simply speaking a ***direct*** problem of geophysics is to find a field for a known object with given physical properties; ***inverse*** is to find the parameters of the object using a given field. **The solution of the direct problem is unique, but this is not unique for inverse problem which is ill-posed.** Solutions can be found by solving the system of Maxwell's electrodynamics equations.

$$\mathrm{rot}\,\vec{H} = \vec{j} + \frac{\partial \vec{D}}{\partial t}$$
$$\mathrm{rot}\,\vec{E} = -\frac{\partial \vec{B}}{\partial t}$$
$$\mathrm{div}\,\vec{B} = 0$$
$$\mathrm{div}\,\vec{D} = q$$

Where, ***E*** and ***H*** are the electric and magnetic fields, ***D*** and ***B*** are electric and magnetic inductions, ***j*** is the density of conduction current, and ***q*** is the electric charge density. In addition,

$$\vec{j} = \sigma \cdot \vec{E} \quad \vec{B} = \mu \cdot \vec{H} \quad \vec{D} = \varepsilon \cdot \vec{E}$$

Where σ, ε and μ are the electromagnetic properties of the medium: electrical conductivity, dielectric and magnetic permeability. The first equation is Ohm's law in differential form.

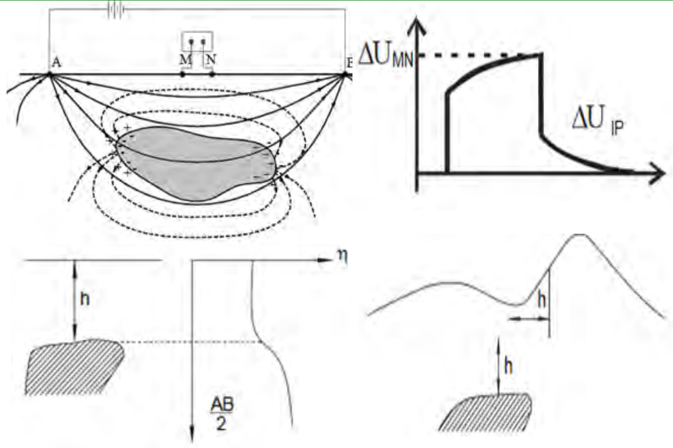
The main difficulties of EM studies compare to e.g. Seismic exploration is that in majority cases it is necessary to use algorithms for solving a direct and inverse problem corresponding to particular EM method with particular acquisition and configuration. While in Seismic, the method and configuration do not really matter for imaging, it is enough just to know acquisition geometry and configuration. **It is also important, that a chosen EM method will be always seen in context of the exploration problem.**

Various EM equipment for acquisition as well as mathematical algorithms for processing and interpretation have been developed quite extensively for onshore exploration. Last 15-20 years, there was a tendency to make recording equipment universal. There are several software companies on the marked today suggest software packages applicable to different EM methods. This software aims to solve ***inversion problem***, e.g ZOND[1], Interpex, KMS Technologies software, SCRIPPS Mare2DEM and others. It also possible to find online free software to conduct studies, e.g TDEM Geomodel.

Land and marine EM it is a different stories. Land data allows to work with high frequencies giving better resolution, while in water (in case of streamer acquisition), high frequencies have a tendency to be strongly attenuated.

There are several EM methods used in marina environments. The most practical became **CSEM.** This method measures resistivity, thereby the methodology is optimized to measure it as precise as possible. Typical **CSEM** used frequency range from 0.1 Hz to 5 Hz. Another method is **IP** (Induced polarization). It implies, that if there is a conductive body in the rocks, it can become polarized when the electric current goes trough it. In this case, a double electric layer forms on its surface. As a result, the body becomes a source of secondary (induced) currents. After switching off the current source, the secondary charge is released. Its measurement allows to evaluate not only resistivity (like in **CSEM**) but also bodies polarizability, Picture 1. **CSEM** tries to avoid IP effect to improve resistivity quality by using continuous alternated source signal and long source receiver offset.

There are a number of causes for IP effects documented, ranging from pyrite, presence of organic matter, hydrocarbon pollutions (environmental geophysics), to changes in clay properties and changes in grain size and etc. The **IP** marine method (e.g. DNME (Differentially-Normalizes method of Electrical Prospecting, used by ORG Geophysics), is used to detects **IP** anomalies of pyrite footprint somewhere above the reservoir in several layers. The method was very well proven in former Soviet Union firstly offshore (Baltic, Caspian, Black and Azov seas), later, got high success rate on land as well [4].

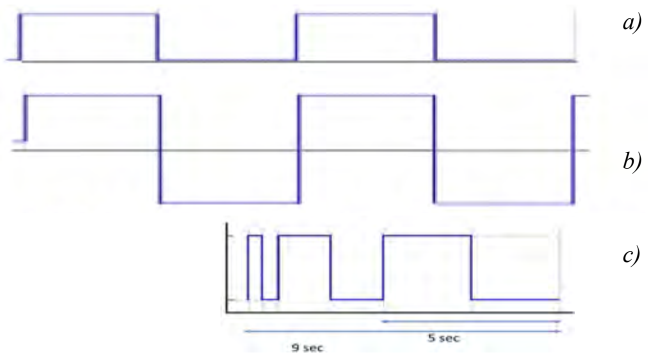


Picture1. One of the EM scheme.
a) Scheme of EM field caused by IP and its observation technique.
b) Impulse measurement of IP with Polarization effect

If ΔU_{MN} - measured potential difference, ΔU_{IP} - induced potential difference, when current is off, then Polarization is estimated as

$$\eta = (\Delta U_{MN}/\Delta U_{IP})*100\%$$

Estimation of the body depth ~AB/2 or a distance h from source electrode to inflection point



Picture 2. Simplified different sources of EM signal. a) IP source with constant On and Off current and period, b) Alternated polarity continuous current signal, used in CSEM. In practise, more advance waveforms are used [5], c) IP source with different harmonics to get wider frequency range and higher resolution (land).

Shape of the source signal is important part for EM exploration. For easier detection of IP effects, the source must be OFF for a certain time between pulses, while for **CSEM** the source must be ON all the time, to maximize transmitted energy, Picture 2. Picture 2*c* shows changing source period—modulated signal. One on the way to get additional frequencies.

According to Daniil Shantsev, Senior Scientist at EMGS, an optimal source waveform is shaped to focus most of the available source power on the optimal frequencies determined during the sensitivity modeling [5]. The latter takes into account the geological settings, type of potential targets, water depth, environmental and hardware noise levels etc. Typically, the optimal frequency band covers approximately one decade: *higher frequencies are attenuated too fast, while lower frequencies give too poor spatial resolution.* Within this optimal band EMGS usually chooses 4-8 frequencies and aims at distributing source energy more or less evenly between them. Using more than 6-8 frequencies within the optimal band does not provide much new information since the frequency coverage is already quite dense, but gives an extra computational load when running inversion. Besides, focusing all the energy on only few frequencies allows one to achieve higher signal-to-noise ratio and use longer source-receiver offsets.

Allan McKay PGS EM Manager, shares that PGS Towed Streamer EM source current waveform, and consequently frequency response data, is rich in frequency content as well as having a large frequency bandwidth typically covering at least 2 decades of frequency (e.g. 0.2 -10 Hz). PGS normally uses a specially coded broadband source current waveform that is tailored to the survey objectives. The benefits of frequency bandwidth, and multiple frequencies covering a given band -width, are recognized as necessary in the CSEM community to determine anisotropic sub-surface resistivity reliably [6,7]

According to *RALF 1* inversion software developer for HRES-IP[2] method Vadim Chernov, acquiring data with modular signal (Picture 2*c*) allows to increase EM resolution. **Using modular signal in CSEM and free RALF 1 for inversion will give high resolution EM image in marine exploration as well.**

HRES-IP technology (land) has advantages of studying a non-stationary process of high resolution of the geoelectric section and measuring the phase parameters of the harmonic field in order to obtain information about the anomalies of the induced polarization related to hydrocarbons.

[1] *One of the World leaders in EM software with strong physics background and top notch mathematics, providing high quality solutions for EM exploration techniques.*
[2] *High-Resolution Sounding with Induces Polarization.*

High Resolution EM and RALF 1 software

The Editorial team of The First Magazine was the first who met Vadim Chernov in Norway. The geoscientist who has many publications and experience in thousands of kilometers of of processed data, sensationally attacked the exploration world in LinkedIn by giving away his core software free and offered his expertise to Norwegian society, since the end of April 2017. We wanted to use the chance to ask Vadim Chernov about the High Resolution EM method he worked on and advantages of his software.

Also, the editorial team contacted former colleagues of Vadim Chernov, Peter Dubinin, leading Geophysicist in Geoneftegaz and present Chief Specialist KruKO (HRES-IP EM equipment developer) to tell us about Vadim achievements and to comment HRES-IP method and its advantages.

Vadim Chernov, *independent geoscientist in 4th generation, the author of the original inversion program for a high-resolution inversion of the electromagnetic (EM) field, certified author of the computer program RALF 1[3] (cert.№2011612714) and certified co-author of EPIS 2.0 (cert.№2002611378) by Russian state registration for prospecting fossil fuels. He holds Master of Sciences in Geology from the Moscow State University. 2000-2010, he worked in the Scientific Production Centre of JSC RPC Geoneftegaz where he developed the original program. The base of inversion program forms the part of the software system for data processing and interpretation of a high-resolution induced polarization exploration method (HRES-IP). He has been awarded a Diploma of Merits by the Russian Federal Ministry of Natural Resources for his work.*

High Resolution Geoelectric Prospecting, Inversion Software RALF 1 and Its Success Rate

The history of method presented in this article began in 1970s. Alexander Kulikov is Russian scientist who worked at the Research Institute of Geophysics in Moscow, created the IP based method with phase measurements at infra-low frequencies (near 1 Hz), one of the most effective method to search for ore deposits. He discovered relationship between phase of the IP and the apparent polarizability. This analysis allowed to determine the presence of polarized objects in the geological structures. Later, Andrey Goryunov and Evgeny Kiselev from the same institute, suggested using this method for exploring hydrocarbons (HC). They believed that HC rocks behave as polarized objects on the edges. Since 1995, Vadim Chernov has been working on development of this method. The method was the basis of later created inversion EPIS program complex (2002), where Vadim Chernov is co-author, and the method was renamed to High-Resolution Sounding with Induces Polarization (HRES-IP). The HRES-IP was applied from 2002 to 2011 in different regions of Russia and abroad. The rights to the method belonged to the company JSC RPC Geoneftegaz (not active today). Now this technology is under Russian Federal State Unitary Enterprise FGUP VEI («VEI GEO»)

In 2011, the set of programs RALF-1 was developed to process and interpret the field material as result of Vadim Chernov's many years' experience. RALF-1 was tested in Western Poland, Iran, Kazakhstan, Moscow region. The set allows to make changes depending on EM acquisition geometry. Vadim Chernov was adjusting developed method being directly involved in conducting many field studies in Russia and abroad. The method was used in conjunction study with 3D and 2D seismic surveys. Studies were conducted on 60 prospects and acquisition length exceeded 20 000 km. The rights for the RALF 1 software belong to Vadim Chernov, Picture 3.

Forecasts for HC presence were confirmed by drilling more than two hundred wells with more than 80% success rate. As the result of this work about 30 new oil and gas deposits were discovered for commercial exploitation.

Picture 4 illustrates Geoneftegaz accomplished projects. They presented statistical work of performed studies in the book [8] including HRES-IP method. Authors describe several methods there, and refer to the HRES-IP method which is managed to get wide approbation. Effectiveness was proved on the fields for Lukoil (acquired EM data 6500 km2), YUKOS, Rosneft (in Kazakhstan acquired EM data 2000 km2), Gazprom (acquired EM data 3000 km2), Surgutneftegaz, MNR RF, TNK BP, FIOK (Kazakhstan), NIOC (Iran), EPR and BGP CNPC (China) and others. The largest of these companies have their own research institutes and scientific centers. Companies which performed at least 1-2 thousand km2 data studies based on HRES-IP provided their independent examination jointly with well and seismic studies, and proved it by "carpet" drilling (hundreds of wells per year). The Table 1 shows available statistic for HRES-IP method.

Today the basis of HRES-IP is registered as FTEM-3D under RU patent (2446417 and US Trade Mark, 2011).

THE CERTIFICATE

About the state registration of the computer program

№2011612714

Reflection on Actions of Lorentz Forces-1 (RALF-1)

(Whether) the legal owner: *Chernov Vadim Vadimovich (RU)*

The author (s): *Chernov Vadim Vadimovich (RU)*

The demand № 2011611050 Date of receipt on February, 22nd, 2011

It is registered in the Register of the computer programs

On April, 6th, 2011

The head of Federal Agency of intellectual property, patents and trade marks

Picture 3. Vadim Chernov's certificate for RALF 1 software

Picture 4. Sours JSC RPC Geoneftegaz. Area of performed work

[3] RALF-1 - Reflection on Actions of Lorentz Forces-1

Table 1. Recorded success rate statistic for HRES-IP method

Company (Fields)	Number of Objects	Discovery, wells	Success %	Dry well , %	Missed reservoir ,%
UdmurtNIPINeft (Eseney, Kaysegurt, Baikuzin, Chuzhegovsk and Zaborsk areas - tops: Tula, Tournaisian, Visei, Bashkir)	41	18	>70	<20	-
Rosneft daughter (in complex tectonic lithological traps of the northern side of the West Kuban trough)	21	-	>67	14	19

Software complex RALF 1. Main principles for solution

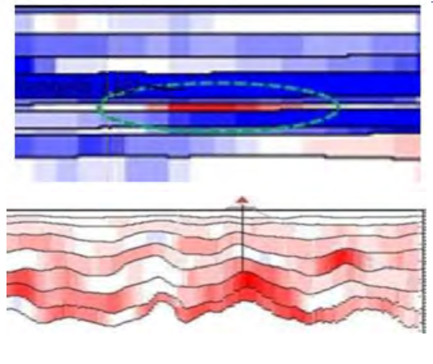
The author claims that accuracy of performed studies is more than 85%, and the possible layer resolution 3-5 meters for land data. In the sea this complex has no experiences prior to 2017.

Method principle

HC saturated rocks have very low polarizabilities compared to surrounded rocks, and mineral water with just a small HC mix have a very big polarizabilities in a low frequency range, Picture 5. The accumulated electrostatic charge in a changed polarity external field causes currents, which looks like an appearance of negative resistances in the section or an appearance of zones with negative polarizabilities. In same zone such system can be considered as current emitter. HC rocks behaves like a condenser and is distinguished by minimal polarizabilities at frequencies of 1 Hz. At the same time, surrounded rocks behave like rocks having double dialectical layer properties and can be described by Cole-Cole formulas with constant time relaxation in 1 second [9]. In addition, the oil-saturated layer is very anisotropic object. Vadim Chernov refers to Kerr effect (NOLIMOKE) [10] as a variant of this nature interpretation. It has a magneto-optical properties (heavy oil is optically anisotropic substance in the electromagnetic field). It is known that the electromagnetic field in a layered medium has two components: flat incident wave (wave part) and the current component, which are connected to each other through a system of Maxwell's equations, and can be associated non-linearly in the presence of rocks exposed to Kerr effect.

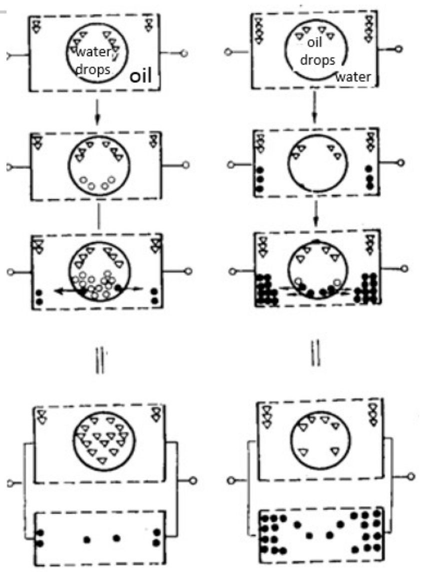
Thus, if to calculate the components of the electromagnetic field **Ex** (compare to ***dBz/dt***[4]) over a multilayer medium, a recurrent functions are used simultaneously, and these functions describe the laws of the horizontal and vertical distribution of resistivity in a section. In this case, there is an opportunity to study both directions. Also, if rocks contain thing high resistivity HC layer then longitudinal resistance does not give a noticeable changes, but transverse resistance increasing making rock layer super anisotropic. Noticeable changes in anisotropy also can be caused by fraction and optical active C19-C35 HC components that cause already mentioned Kerr effect. In fact, an actual received amount of change of the anisotropy is 30-50% rather than obtained in the simulation- 2-3%.

Summarizing it, the simultaneous analysis of vertical and horizontal current components of EM field, make possible to find an area of such non-uniformity at reservoir. As result, it makes a conclusion about the presence or absence of HC at a given point of geological section, Picture 6.



Picture 6. Examples of inverted result. a) Section of Polarizability for very thin layers (3-5 m), where red means low polarizabilities- HC indication (proved gas). b) Anisotropy. Red colour means high anisotropy - HC indication. Rough estimation (500-1000ms thickness, proved oil)

Stage	Time after constant current field applied	Charge distribution	Corresponding field of alternating current
a	t=0	Inducted charge	High frequency
b	↓	Conductive charges	↓
c	t=∞	Many conductivity charges, its minority only can left the drops	Low frequency
d	t=∞	Equivalent condition, observed on acquisition equipment	Components which are not able to be born; Components which are able to discharge



Picture 5. Explanation of interphase polarization in dispersed system of spherical particles.

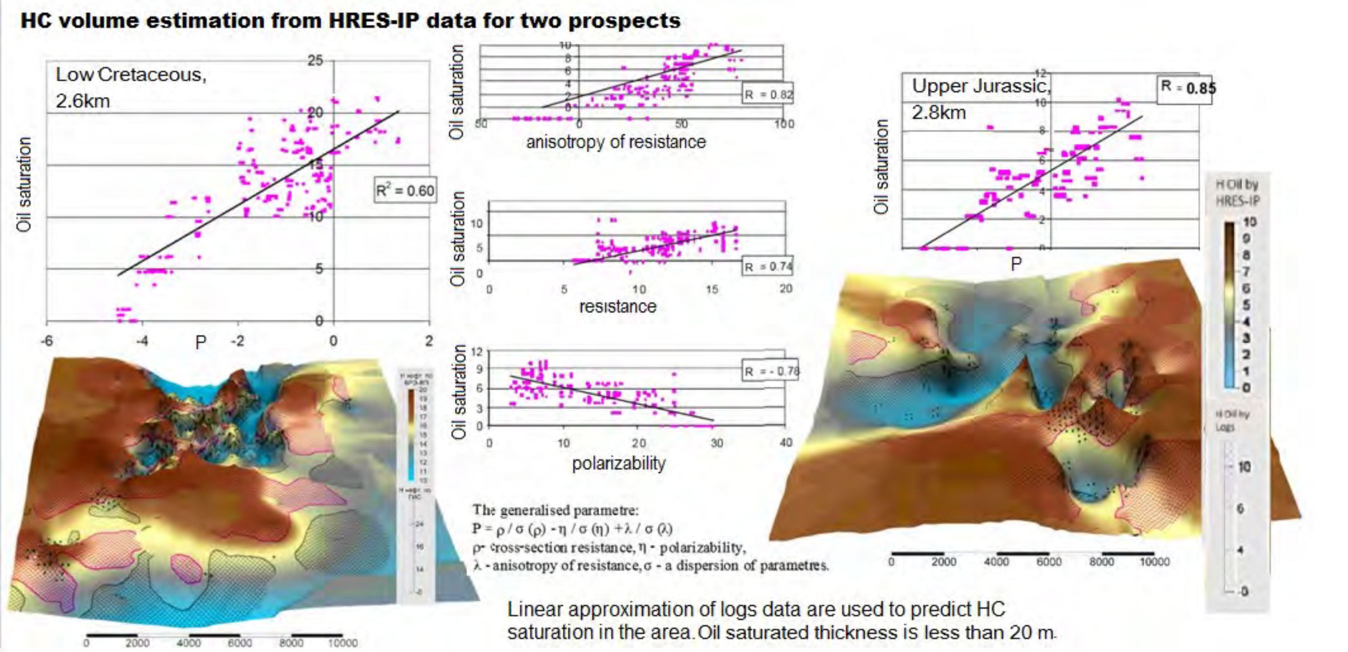
∇ - Electrostatic inducted charge.

● - Conductive charge which is able to move through phase borders.

○ - Conductive charge which is not able to move through phase borders

From the book Emulsion Science [11], as a basis of explanation why we study effects on the frequencies less than 1 Hz.

[4] dBz/dt– changes in magnetic component of the field



Picture 7. Tevlinsky area (Western Siberia), Kogalymneftegaz & Lukoil-Western Siberia. Acquisition - 750-800km, increments 50m, distance between profiles 300-600m. The results contain distributions over the area resistance, polarizability and anisotropy of resistance in perspective layers. The predicted thickness by the method and real thickness of the reservoir match consistently. Source of this picture — NefteGasTEK, Tumen International Innovation Forum-Exhibition, September 2010

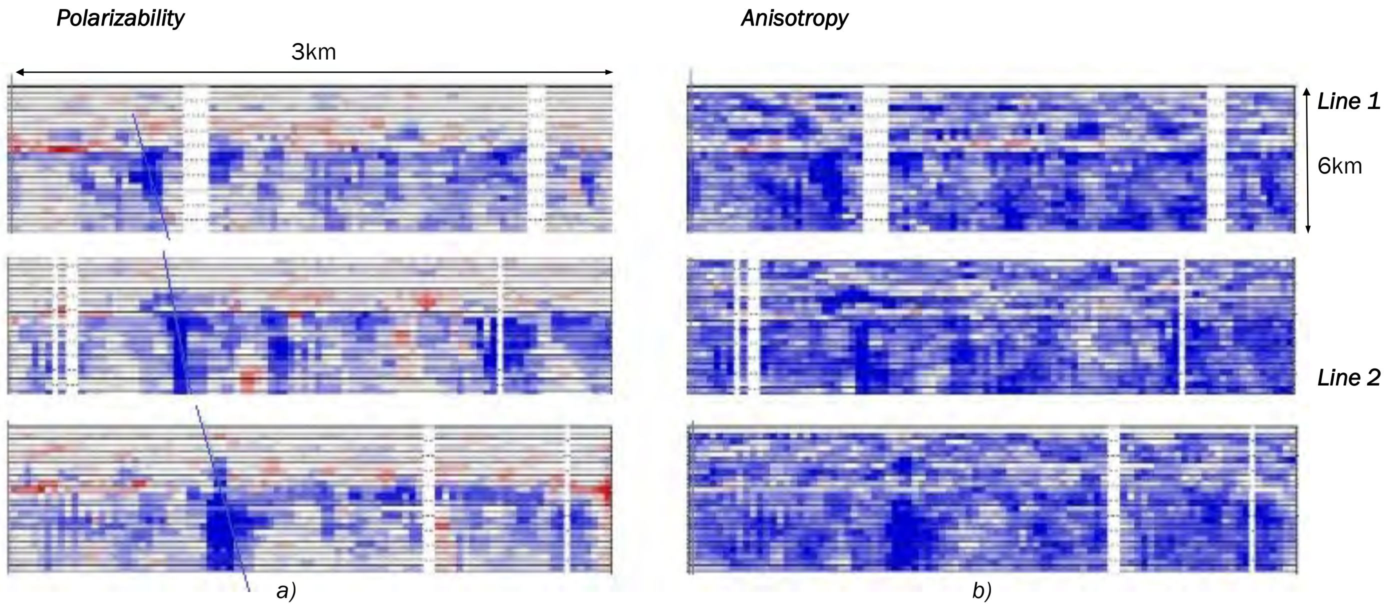
Inversion principle of RALF 1 which makes solution precise

"Everyone knows that inverse problems are incorrect, and the effects that we observe are just decimals of a degree. Even its derivatives with respect to the desired parameters are smooth and weakly differentiated functions. Many scientists gave up their work because of this. I did not give up for many years. And I know how to work with these smooth functions so that they give such a differentiated picture. ***Now it is not only me, who can do it. My inversion software of RALF 1 is in the public domain. This can be done by everyone in an automatic mode.***[5] *Another question - how does it work? But this is not physics problem, but mathematics", - says Vadim Chernov.*

RALF 1 makes possible to obtain the distribution resistances, resistance anisotropy, and the IP processes for 2D and 3D. The algorithm can give not only electrical parameters of geological layers but also quite precise depths. Using big samples of parameters is making solution of inversion problem more clear in borders of Shennon theorem[6] [12].

"The uniqueness of my solution is that I get independent solutions for all unknown parameters that are not correlated with coefficient of correlation 100%. On the RALF 1, you can see not the most exact solution, but something that does not correlate, Picture 7, 8, 9. This is specific of each parameter. So, I remove the background. It is some kind of filtering, not spatial, not time-frequency, but logical. Based on the formula you saw[6] (but note that formula is incomplete). Nonetheless, the exact solution is sought for every point of probing. In the program table you see the exact solution, but it does not mean that the 2D section should look like an exact solution. You can always remove the background. This is standard practice. The background prevents seeing details. To prove it, enter into this formula[6] Ki=1 the inverse problem that you have, and compare the results without this formula. We checked this in 2007. It was another 3 years, before RALF 1. I think that even with Ki=1 you will get an indelible impression. In fact, my help won't be needed.

May be, 90% of EM land based on high-frequency induced polarization. It means, we are looking for polarizability in the upper layers. Usually, a zone of oxidation-reduction reactions and pyrites zone are formed above HC reservoirs. People do not bother and look for pyrites in the upper 500 meters. But what about situations of multi-layer deposits? The problem is that nobody tried to solve inverse EM problem for such volume of frequencies and parameters as we did it. Now we can get information about more than 100 parameters from one sounding in one physical point. Such parameters as polarizabilities, anisotropies, resistivity and thicknesses for each layers. In most cases of EM frequency probing all polarizabilities are fixed, except one in the perspective depth interval. I suggested mathematical solution. My depths increment is 100-200 m, and for each layer polarizability, resistivity, anisotropy of resistance and polarizability are selected. It is an incorrect problem and hard to understand how is possible in principle. For example, I have 45 parameters are searched on 70 frequencies, which differ very little in derivatives. 2.6 km and 2.8 km are completely different contours. Normally EM can see only one common contour. I see everything separately in a frame of Shannon theorem. This is possible because there is a difference still present between the derivatives of the parameters, when there is enough measured data. This difference is enough to work with. For most of EM methods, granite rocks will be something unified without precise depths, but not for my method. And now, you can see it too. That is the difference. RALF 1 also can see anomalies in prospective layers as low polarizabilities in small areas in a big massive of rocks with highly saturated mineral water and in high level of polarizabilities. RALF 1 can also see hydrocarbon reservoirs in depths of 3-4 km under 1 km of granites, Picture 9." - says Vadim Chernov.



Picture 8. Data Available to test RALF 1 by public. Inversion result. a) Polarizability. Red and blue colours mean low and high polarizabilities. b) Anisotropy. Red colour means high anisotropy (possible HC). Blue and white colours mean low anisotropy. Blue line indicates detected fault

[5]Test data given by Vadim Chernov to test his RALF 1 software is presented on Picture 8.
[6]Shannon's theorem - information capacity, i.e. "volume" of the observed data, should not be less than the "volume" of the desired data. It means that the "more complex" geophysical profile, the more sustained is the result of its interpretation (if the observed data capacity is sufficient). Shannon's theorem also asserts the principle of "block" encoding and decoding as universal means of interference elimination. On a practical level, there is an understanding that block coding and decoding in geophysics is not only speed up the process of interpretation, but also makes it more resistant - the modern theory of inverse problems of geophysics [12]. Thus, the instability of the inverse problem solution decreases with increasing complexity of the explored section.

AFSIP3D[7] Method and its main features

Today Vadim Chernov suggests AFSIP3D method. It is modern technique based on RALF 1 program algorithm, allows producing a layer-by-layer analysis of IP, including an anisotropy of resistivity.

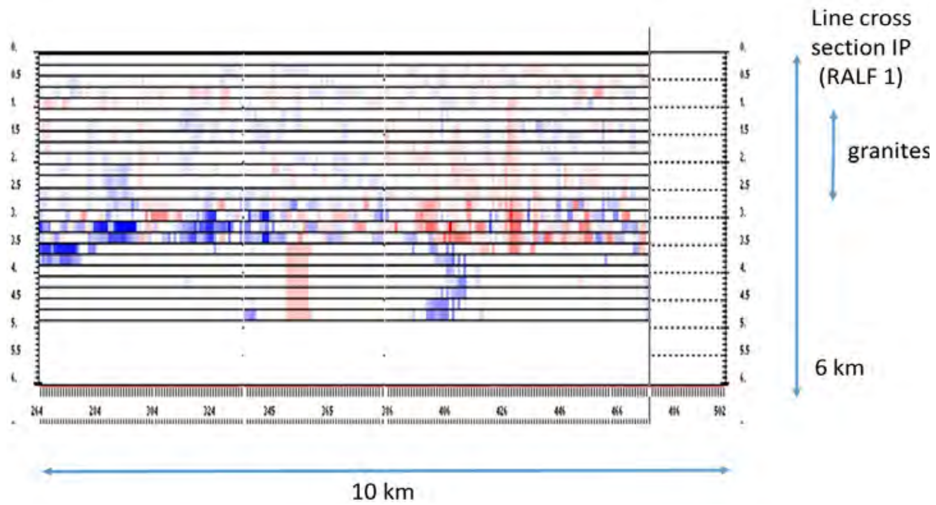
The main feature of the AFSIP3D is a possibility to obtain stratification in three-dimensional space of the three main characteristics of reservoir interval - *resistivity, resistivity anisotropy, polarizability, and additionally, thickness for each layer.*

It is analogous to the High-Resolution Time-frequency EM Surveying Method, but modified in accordance with the technical features of MHD[8] generators to increase the power of the generated signal. It is intended to calculate HC reserves at the work site, and to perform measurements on an irregular grid.

Analogues and their limitations

Editorial team asked Vadim Chernov if there are any analogues of his method and inversion techniques are present in the World, and what is their success rate. He told, that there is an analogue. Induced polarization used in different configuration. For example, Spectral Induced Polarization - Resistance Complex - SIP - CR (SIP or CR) is an electrical method that can be used to display changes in the electrical properties of the rocks that are associated with geochemical phenomena of alteration and associated with HC. Positive anomalies caused by polarization in oil fields have been long time observed in Russia. Since 1990 China conducted detailed studies with 74% success rate. More than 103 structures were drilled in the Eastern part. They used high-power SSIP method. In North America technique were used in Cement, Chickasha, Velma and in Oklahoma (USA), and the David Field site was one of the first successes in Alberta (Canada).

"It would be very interesting to work in Norway. EM marina task, e.g. in Arctic region, is very interesting way for RALF-1 hydrocarbon exploration. Here is future. I would like to prove it",– said Vadim.



Picture 9. HC indication under ***granites*** *in red (low polarizabilities zones)*

[6] The additional step which were added to the RALF1 algorithms in order to increase an accuracy of depth computation. The step has an automatic limitation of a weak-effect parameter selection and subsequent comparison of a standard and modified algorithm results. Mathematically, this was done by means of introducing all parameters of average increment in each increment of residual parameter. The formula is presented here:

$$\Delta'_i = K_i \cdot \left[\Delta_i + \bar{\Delta} \cdot \left(\frac{\sigma(\Delta_i - \bar{\Delta})}{\sigma(\bar{\Delta})} - 1\right)\right]$$

where

Δ_i - original increment of the residual on the i-th parameter,
Δ'_i - changed increment of the residual on the i-th parameter,
$\bar{\Delta}$ - average increase residuals for all parameters,
$\sigma(\ )$ - operator variance,
K_i - normalization factor for the modified residual

[7]Anisotropic Frequency Sounding of Induced Polarization
[8]The invention relates to geophysical methods for oil and gas exploration. A three-dimensional time-frequency exploration method, where an arbitrary shape electric current flows through a mounted supply source made as a grounded line, and generated by a powerful source such as a type magnetohydrodynamic (MHD) generator or similar.

Peter Dubinin, the Chief specialist, KruKo LLC (ООО "Фирма КруКо"), independent expert in electrical prospecting, formerly leading geophysicist in Geoneftegaz provided information about HRES-IP technique and Inversion solution of Vadim Chernov on the request of The First Editors.

Russian geophysicist, researcher Vadim Chernov, after graduating the Geological Faculty of the Moscow State University, joined like-minded team of JSC RPC Geoneftegaz, electrical exploration department in 1998. HRES-IP was developed at JSC RPC Geoneftegaz, combining the most promising EM methods used in the world practice for HC prediction.

The basis for the development of this technology was the theoretical and methodological development of the Russian leading research institutes of the early 1990s: VNIIGeoofizika (Moscow), NVIIGG (Saratov), SNIIGGiMS (Novosibirsk). The technology allows to study a specific electric conductivity and an induced polarization of rocks which anomalies are associated with hydrocarbon deposits, in the frequency domain. In the time domain, it allows to perform an analysis of the time and dynamic characteristics of the nonstationary field, and to perform depth tie of electrical anomalies, based on a joint analysis of EM exploration, logs data and seismic surveys.

To carry out field exploration, a hardware-software complex developed by KruKo company (by the order of JSC RPC Geoneftegaz) was used. The complex includes a set of field meters AGE-xxl and a number of universal current switches for generator set.

The processing and interpretation of the HRES-IP data is carried out on the basis of a specialized software package for processing and interpreting - EPIS developed by the specialists of JSC RPC Geoneftegaz (Volkova NB, Dubinin PA, Kalachev AA, and Chernov VV).

In the team, Vadim Chernov was responsible for developing the program of electrical exploration inversion, an extremely important tool for interpretation. In the period of 1998-2010, Chernov developed a one-dimensional inversion program in frequency domain FSIT widely used as part of the EPIS complex to interpret the data of the HRES-IP both in Russia and abroad. Continuously improving the inversion algorithms, he achieved significant success in solving the basic problem of inversion - increasing the accuracy of specifying geoelectric parameters, their depth and lateral tie, even in conditions of a three-dimensional inhomogeneous medium. The results of his research of HRES-IP field interpretation were repeatedly published and reported at international conferences.

It should be emphasized once again that Chernov's program of FSIT inversion is an integral part of the EPIS program complex and the HRES-IP technology, which are methodically integrated in on piece.

Literature

1. Constable S., Srnka L.J., An introduction to marine controlled-source electromagnetic methods for hydrocarbon exploration. Geophysics, March-April 2007, vol.72, no.2, P. WA3-WA12.

2. Cox, C. S., Electromagnetic induction in the oceans and inferences on the constitution of the earth. Geophysical Surveys, 1980.vol. 4, no.1-2, P. 137-156.

3. Constable, S., Ten years of marine CSEM for hydrocarbon exploration, Geophysics, Sept -Oct. 2010. vol.75, no.5, P. 75A67-75A8.

4. Yurchenko V., Induced Polarization: detecting HC signatures in reservoir overburden, The First, SPE Norway Magazine, December 2015.

5. Mittetl R., Schaug-Pettersen1 T., Shaping optimal transmitter waveforms for marine CSEM surveys. Geophysics, May-June 2008, vol. 73, no. 3, P. F97–F104, 6 FIGS.10.1190/1.2898410.

6. MacGregor L., Tomlinson1 J., Marine controlled-source electromagnetic methods in the hydrocarbon industry: A tutorial on method and practice, SH32 Interpretation / August 2014.

7. Key, K. 1D inversion of multicomponent, multifrequency marine CSEM data: Methodology and synthetic studies for resolving thin resistive layers. Geophysics, 2009, 74:F9-F20.

8. Kisilev E, Larionav E, Safronov A, Electrical properties of HC reserves. Search signs of hydrocarbon deposits in methods of high-resolution electrical prospecting. Science World, 2007, P. 172 (in Russian).

9. Vanian L.L. Electromagnetic sounding. Moscow Scientific World 1997, 219p.

10. Pustogowa U., Luce T.A., Hübner W, and K. H. Bennemann, Theory of Nonlinear Magneto-Optics, Journal of Applied Physics May 1996, 6177 - 6180.

11. Emulsion Science, Academic Press. London and New York 1968, Edited by Philip Sherman, p 387.

12. Svetov B.S., Two notes on the modern theory of inverse problems in geophysics, Izvestiya, Physics of the Solid Earth, January 2010, Volume 46, Issue 1, pp 83–86.

Additional

**Electromagnetic geometric sensing with bottom nodes streamers for HC exploration in shallow water. Dissertation, M. Malovichko for HRES methods.*

** A. Gorunov, E. Kiselev, I. Kondratiev, A. Safonov, K. Tertyshnikov and V. Chernov, The role of high-resolution electrical survey (HRES-IP) in complex of geophysical methods during exploration, prospecting and exploitation of oil and gas deposits. Geophysics of the 21st Century - The Leap into the Future.*

** V. Chernov, and A. Goruonv, HC Exploration in the crystalline basement by high-resolution electrical survey methods in the example of the Kurgan region. Tyumen 2009 - EAGE International Conference and Exhibition (in Russian).*

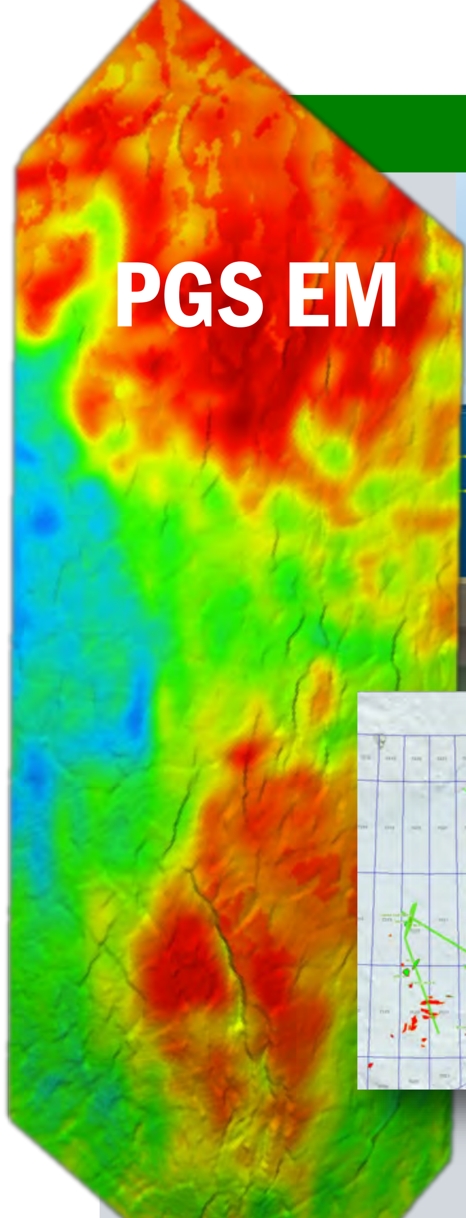
** Modern search of oil fields and gas a method of high resolution electroinvestigation in Russia, V. V. Chernov, 9th EAGE International Conference on Geoinformatics - Theoretical and Applied Aspects, 11 May 2010.*

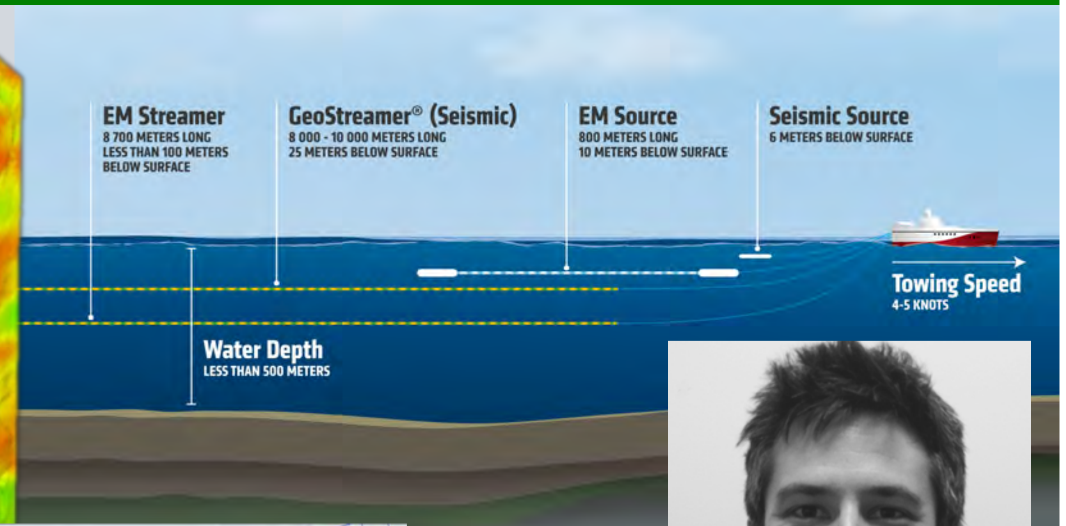
Acknowledgment

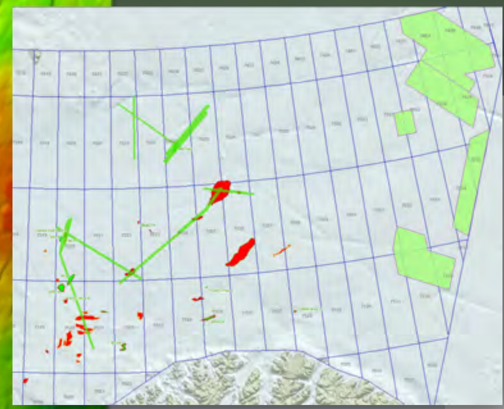
*The Editorial Team of The First would like to thank PhD **Daniil Shantsev**, Senior Scientist at EMGS; **Lars Lorenz**, independent EM expert; PhD, **Vitaliy V. Yurchenko**, Senior VP of Sales and Marketing, OGR Geophysics, **Peter Dubinin**, Chief specialist, KruKo, independent EM expert; **Joshua May**, EM Sales and Marketing Manager PGS and **Allan McKaym**, EM Manager PGS for the advice and comments provided during writing this article.*

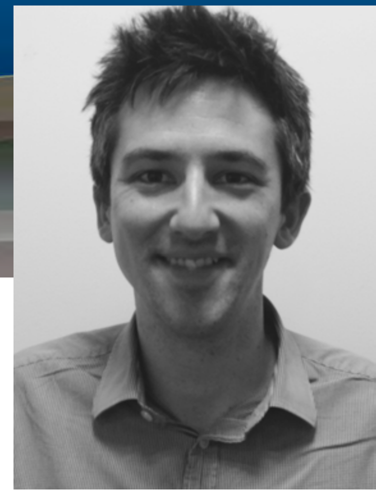
If you order EM data, remember

1. **Method shows resistivity properties, not HC. HC related anomalies are interpretation.**
2. **QC your inversions carefully before interpreting.**
3. **If you've never dealt with EM before, take your time to understand the data.**
4. **Use the expertise available to you (service provider, in-house specialist, consultant) to discuss your interpretation.**









Joshua May
Sales and Marketing Manager
Marine Contract / EM
Provided answers to our questions

What is the history of EM method(s) you use?
PGS developed the highly efficient Towed Streamer CSEM technology. The EM source and receivers are both towed behind a single acquisition vessel which is capable of acquiring 2D broadband seismic at the same time as the resistivity data. The driving force for advancing EM acquisition technology was to improve efficiency and to enable resistivity and seismic data to be acquired simultaneously.

What geometrical configuration do you use to acquire data?
Towed streamer EM technology is based on tried and tested streamer seismic operations, the EM cable is 8700 m long and contains 72 electrode pairs (receivers), it is towed at a depth of up to 100 m. The EM source is 800 m in length and is towed by the same vessel as the EM streamer (image above). When acquiring 3D EM data PGS designs EM surveys with a line spacing of <1.5 km, enabling the delivery of both 2.5D resistivity sections, and 3D resistivity volumes.

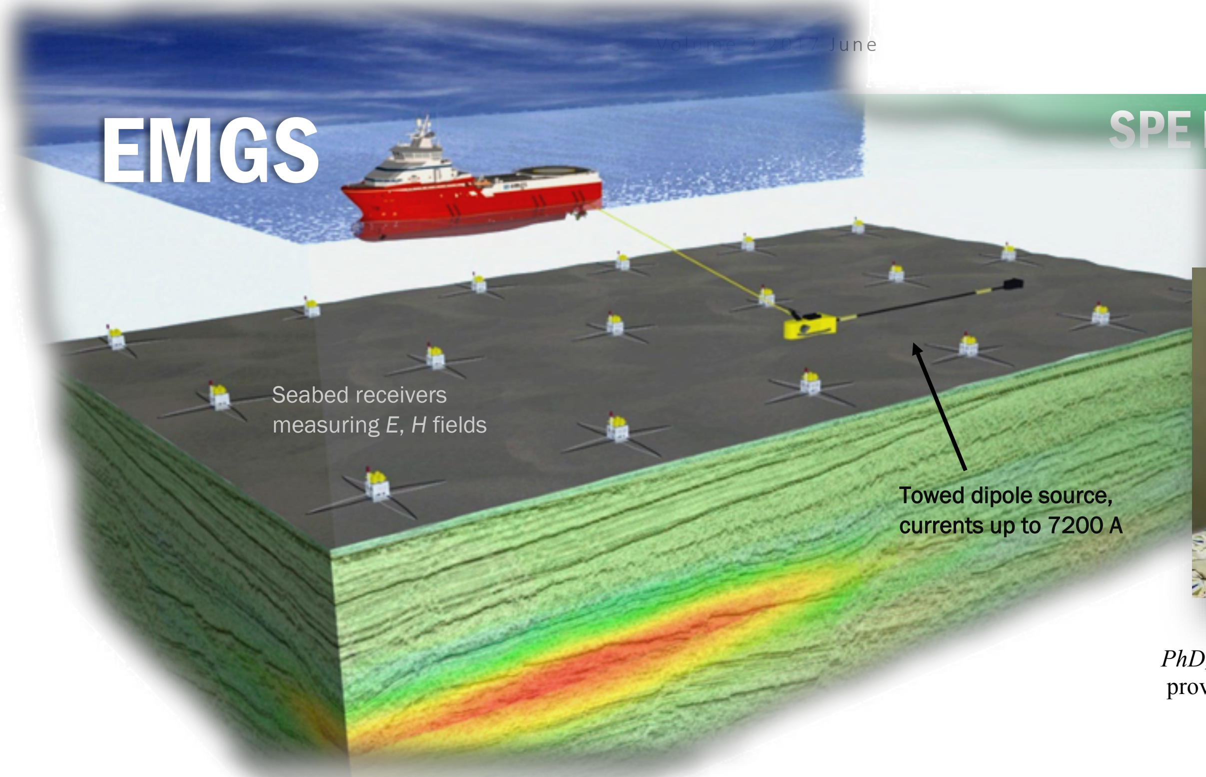
Who and when solved direct and inverse problem used for PGS EM configuration?
Inversion codes have been developed internally (3D Gauss-Newton code) and externally (2.5D MARE2DEM from the SCRIPPS Institute of Oceanography) with a focus on efficient and accurate implementation, PGS has worked closely with third parties to ensure optimal inversion code performance for high density Towed Streamer EM data. This flexible approach enables PGS to deliver unconstrained and seismically guided resistivity sections and volumes while also enabling our customers to invert and analyze the field data themselves.

What are the challenges for EM *Mariner* inversion?
One challenge relates to the relatively low transverse resistance of the overlying Heimdal channel sands and injectites, this results in a low resistivity contrast between the Heimdal sands and the background resistivity which can make imaging more challenging. With regard to the Maureen reservoir, proximity to highly resistive underlying geology is the primary challenge. This is a good example of imaging uplift provided by Towed Streamer EM data, the high density data acquired simultaneously with seismic enables PGS to integrate the two to distinguish and characterize more challenging targets than when more sparse data is acquired.

Does your software (name it) allow flexibility to invert other acquired configuration sets?
PGS' own internal code (iTEM) has been designed specifically for Towed Streamer EM data, but as we recognize that the market wants flexibility it has potential to be able to handle node based data as well.

What is the total data acreage PGS acquired today and what is the success rate for Confirmed discoveries, Missed aims, False predictions %?
PGS' 3D EM MultiClient data library currently stands at >15000 sq. km, plus >3000 line km of 2D EM data. We have conducted EM surveys over known discoveries as well as in frontier areas like the Barents Sea Southeast (see attached image) but as a service provider we do not record success rates. There are however many published articles which address this questions and it's well accepted in the industry that the addition and integration of complementary resistivity data to seismic when exploring for hydrocarbons significantly improves chances of success.

SPE Norway — EM

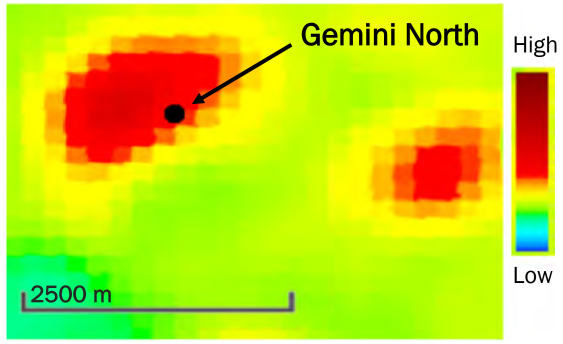


Daniil Shantsev
PhD, Senior Scientist at EMGS,
provided expert information on
request from *The First*

Electromagnetic Geoservices (EMGS) was founded in 2002 and has acquired over 800 marine CSEM surveys worldwide, in water depths ranging from 20 to 3500 m. The method uses a 300 m horizontal electric dipole source towed close to the seabed, generating currents up to 7,200 A. A grid of receivers is placed on the seafloor allowing to record directly the response from the sub-surface as well as minimize the noise levels and positioning errors. The receivers measure inline and broadside components of both electric and magnetic fields, resulting in a low-noise, wide-azimuth 3D dataset designed to provide optimal sub-surface illumination.

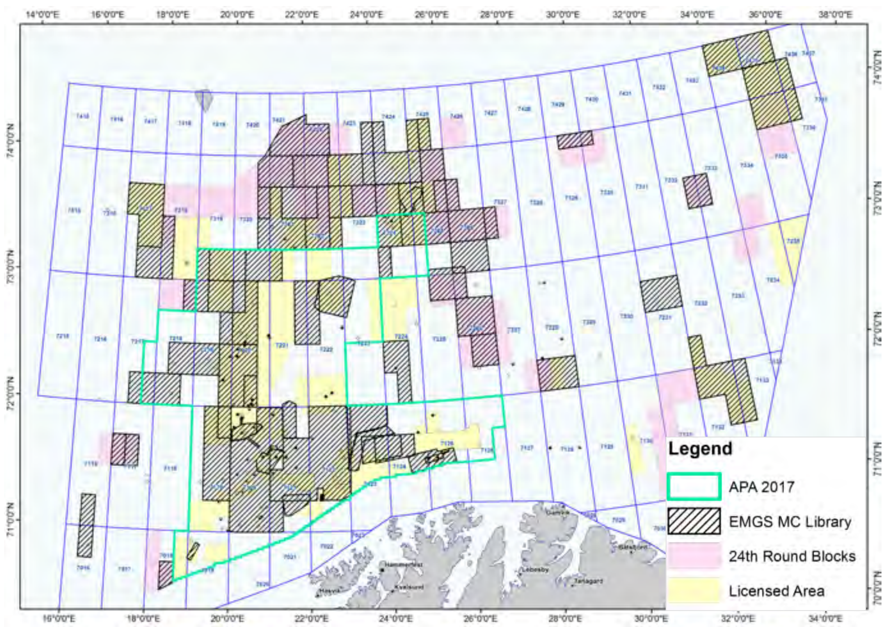
Tools for **CSEM** processing and imaging have matured significantly since 2002. Today, all data are processed through in-house anisotropic inversion software, generating 3D images of both vertical and horizontal subsurface resistivity. EMGS's 3D inversion has now been in production for almost 10 years, during which time it has undergone continuous improvement addressing, among others regularization, data uncertainty, air-wave mitigation methods, etc. The most recent breakthroughs came last year with the introduction of 3D TTI inversion for steeply-dipping geology [Hansen et al. SEG 2016], and a 3D Gauss-Newton update scheme for greater model robustness in complex geological settings [Nguyen et al. SEG 2016].

The final piece of the puzzle to successful use of CSEM information lies with our customers: the additional subsurface information must be successfully embedded into existing interpretation workflows, leading to quantitative updates to exploration predictions. To assist with this task, EMGS has developed a suite of software tools and workflows [e.g., Baltar & Barker, FB 2015]. Today, with the combination of wide-azimuth 3D data, mature anisotropic inversion schemes, and integrated, quantitative interpretation, we see our customers achieving an excellent return on their investment in CSEM [e.g., Zweidler et al, 2015].



Vertical resistivity averaged over 600 – 770 m TVD, in the Barents Sea PL855 area obtained by an unconstrained 3D inversion using CSEM data from 4 to 48 Hz.

EMGS's global multiclient library covers over 70,000 km^2. In the Barents Sea, CSEM data are available for all major discoveries and show clear responses. Smaller discoveries (<100 mmbls) are visible if they fall within the sensitivity limit (which can be assessed in each case of interest). The data library covers many of the 24th round and APA 2017 blocks.



A small data example shown in the figure comes from a recent survey in the Hoop area. In most surveys, the CSEM source energy, optimized to achieve both a good spatial resolution and a sufficient penetration depth, is distributed within the frequency range 0.1 – 4 Hz. However, the Hoop area is characterized by exceptionally high subsurface resistivities and shallow target depths, hence the optimal frequency range here is higher. With some hardware and processing improvements, EMGS was able to acquire data at the record high frequency of 48 Hz, which resulted in an improved spatial resolution. The figure demonstrates sensitivity to hydrocarbon reservoirs of only 1-2 km^2 area, and gives an optimistic prediction about the soon-to-be-drilled Gemini North well.

Referenced EMGS publications are available at http://www.emgs.com/technical_papers/

Thank you to SPE Norway sponsors!

ALTUS Intervention
add energy
AkerSolutions
AkerBP
ACONA
ABB
Ace Oil Tools
agr
engie
bayerngas norge
BAKER HUGHES
CHURCHILL DRILLING TOOLS
concedo
ConocoPhillips
CLAMPON
CABOT
CANNSEAL Annular Isolation Technology
Chevron Human Energy
DNV·GL
DNO
dana PETROLEUM
DEA
DOMINION GAS

EV
EXPRO
ENVENTURE EXPAND YOUR POSSIBILITIES
ENHANCED DRILLING
E PLUG ADDING NEW WAYS
Faroe
FOUR PHASE
Greene Tweed
gyrodata
GE Oil & Gas
HESS
Huisman
HALLIBURTON
IFE
IRIS
Independent Oil Tools as
interwell
Idemitsu Petroleum Norge
KONGSBERG
Lloyd's Register
Lundin Norway
MAERSK OIL
NAMTVEDT SEALMAKER SERVICES

nexen
NAMTVEDT SEALMAKER SERVICES
NCE Subsea
OREC
OFFSHORE MEDIA GROUP
Omega Completion Technology AS
petoro
pwc
Ridge
RMN
RFD
roxar
REPSOL
RaMEX a·s
Schlumberger
sopra steria
Scientific Drilling
SINTEF
Shell
Seal-Tite International Engineered Sealing Solutions
Statoil

Tomax
twma
TechnipFMC
TGT
TENDEKA
Tracerco Providing Insight Onsite
TOTAL
VISURAY
VNG Norge
wellbore
Weatherford
Welltec
welcem
wintershall
ardyne
Logtek

For sponsoring the printing of our magazine, please contact Vita@pss-geo.com or Maria.Djomina@agr.com