GEO ExPro

GEOSCIENCE & TECHNOLOGY EXPLAINED Vol. 4, No. 4 - 2007

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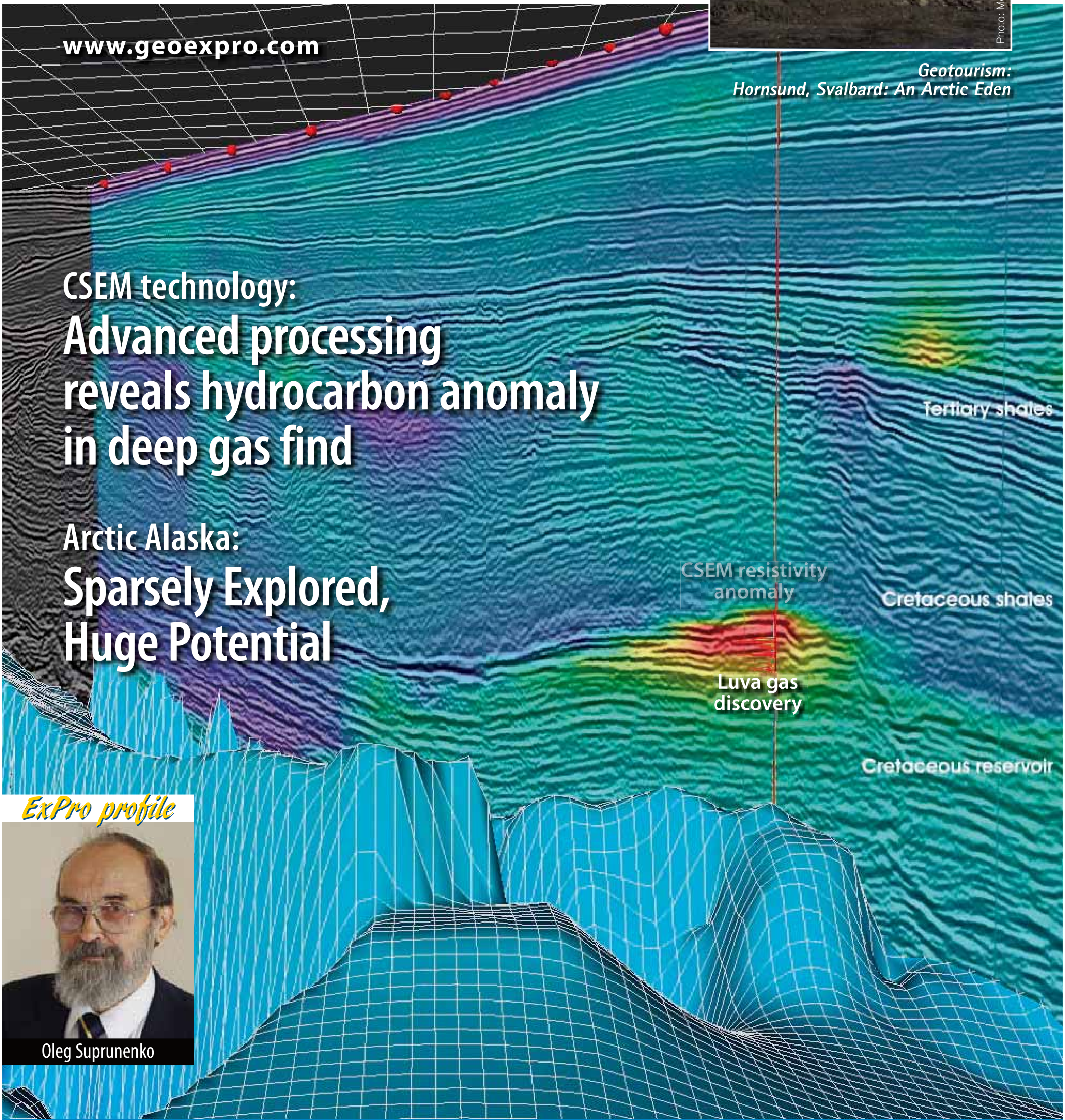

CSEM technology:
Advanced processing reveals hydrocarbon anomaly in deep gas find

Arctic Alaska:
Sparsely Explored, Huge Potential

ExPro profile

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The Luva Gas Field:

Detailed Analyses Reveal Subtle Anomaly

This case study from the Luva gas field in the Norwegian Sea clearly demonstrates the potential of controlled-source electromagnetic (CSEM) technology for hydrocarbon exploration purposes. The example also illustrates the complexity associated with the processing of such data.

Halfdan Carstens

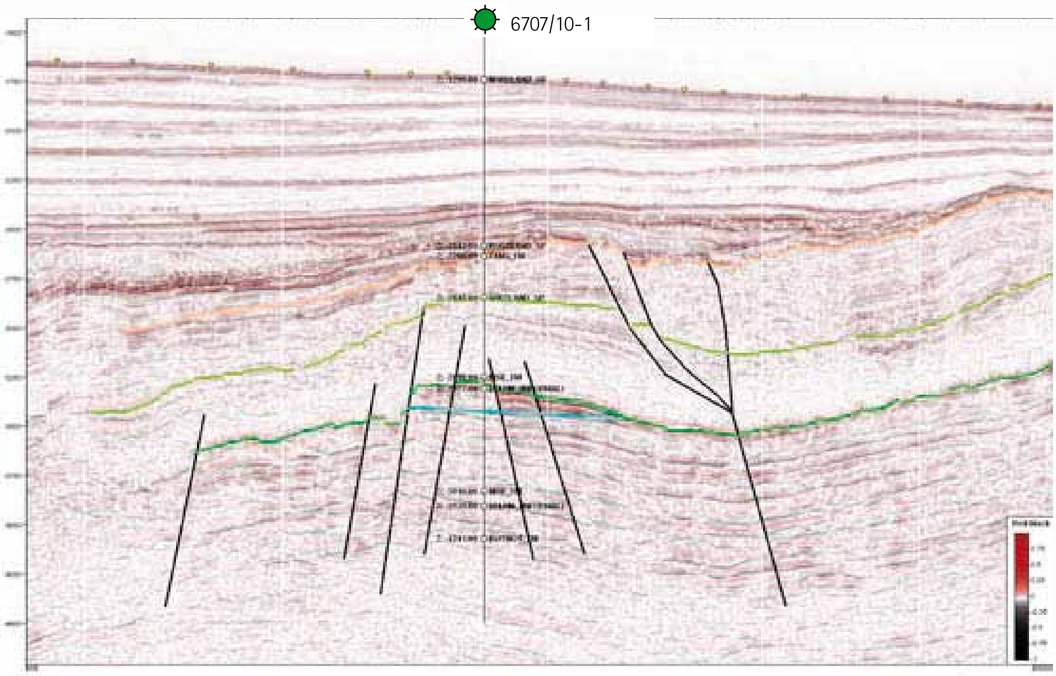
While 2D and 3D seismic methods are now widely accepted and considered as proven technology for hydrocarbon exploration and reservoir characterization, the use of controlled-source electromagnetic (CSEM or EM) surveying is still in its infancy and is frequently met by scepticism by geologist, geophysicists and managers.

"One reason for this scepticism may be that the CSEM technology is brand new to most petroleum geoscientists and it takes time to accept that the rules of exploration are changing. This necessitates an understanding of the fundamental concepts," says professor in applied geophysics Martin Landrø at the Norwegian University of Science and Technology.

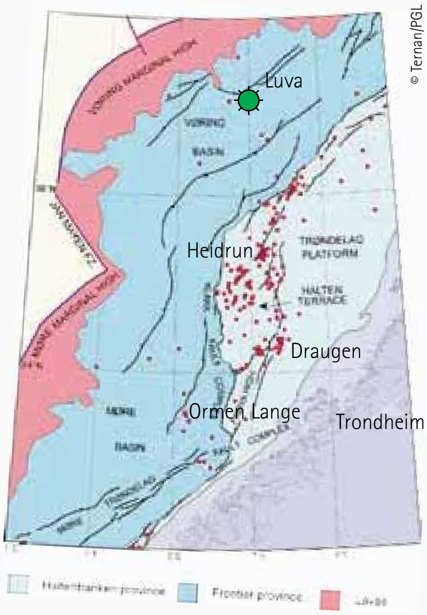
"Geologists and geophysicists have been using the seismic technology for decades with great success and are familiar with the pitfalls. This is not yet true for CSEM. Also, negative case studies have, in this early phase of developing the CSEM technology, a tendency to be frequently cited and taken as evidence that the technology is far from reliable. Nevertheless, we are experiencing a rapid evolution going from simple display of anomalies at the sea-bottom to more reliable depth estimates of the anomalies through inversion and migration."

The Luva gas field in the Norwegian Sea certainly has certainly served as an example of a negative case study. It has gained a reputation for being a significant gas discovery which shows only a very small and enigmatic EM response. This "false negative" response could easily have lead to the discovery being missed by a company that was using CSEM to guide "drill or drop" decisions. This example has been commonly cited by sceptics as evidence that CSEM technology does not work.

However, by developing new advanced processing algorithms, integrated work flows, and a comprehensive understanding of the new technology, Rocksource has been able to not only explain the apparent false-negative response, but also to



The interpreted seismic line across the Nyk High shows the Top Nise Formation reflector overlying a thick Cretaceous sequence with a characteristic seismic response. The Luva discovery is on the Nyk High, a north-to-northeast-trending three-way dip-closed structure, bounded on the northwest by a major fault. The yellow triangles on the sea floor show the location of emgs seabed logging receivers used in the study.



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The Luva Field was discovered ten years ago (1997) when BP hit gas in deep water (1274m) in the Vøring Basin of the Norwegian Sea (GEO ExPro Vol. 2, No. 2). The well (6707/10-1) targeted a tilted fault block on the Nyk High comprised of Upper Cretaceous sandstones encased in shales. A pronounced flat spot was evident on the seismic data. The main objectives of the well were to establish the presence, quality, and fluid content of the Campanian (Upper Cretaceous) aged Nise Formation. Gas was encountered in a 156m interval from 2957m to 3113m subsea. Current operator, Statoil, took over from BP following a farm-out last year, estimate recoverable reserves in the field at some 38 Bm^3 (1.34 Tcf).

process the data in such a way that an EM anomaly is now clearly visible. This illustrates that many CSEM data sets contain valuable information that is key to obtaining the correct interpretation. Much of this information is hidden in the data and this example demonstrates that much of the oil-industry still has a long way to go before mastering this technology.

Game Changing Technology

"Rocksource considers CSEM to be a proven technology with game changing potential. Properly used, it can contribute significantly to our exploration success. This is why we recently engaged the leading provider of marine controlled-source electromagnetic data, emgs, in a large acquisition programme on the Norwegian Continental Shelf," says Jonny Hesthammer, Vice President Technology of Rocksource, the newly formed independent oil company that is in the process of building an EM based exploration portfolio.

Rocksource has developed proprietary software and a state-of-the-art analytical approach to successfully deal with EM data. This is the core of their business model and exploration programme. Their short-term strategy is to build a cash flow position in the US developing onshore producing fields, while at the same time building a low-risk, high-return offshore portfolio through the integration of EM technology into their exploration workflow.

CSEM

Controlled Source ElectroMagnetic

"In the long term we aim to build further reserves and production in basins where we can leverage our EM and reservoir technology," Hesthammer says, who in June this year was the proud winner of the prestigious EAGE Alfred Wegener award for his contributions to the geoscience community.

While improving and testing their skills in CSEM processing and interpretation, explaining the apparent Luva false negative response became an interesting challenge. The enigma was solved after just 3 weeks of obtaining the data. "The application of our proprietary technology, which is the result of several years of research, has now led to a positive result. The example illustrates Rocksource's competitive edge when it comes to dealing with EM data," claims Hesthammer.

"It is a common misperception amongst many individuals in the petroleum industry that the CSEM technology often fails. Luva has been cited as a key example of such failure. However, geoscientists need to understand that it is not the technology itself that fails. The CSEM receivers on the seabed make a detailed recording of the resistivity distribution within the subsurface. The challenge is to correctly handle the data in order to decompose the EM response into its basic energy components and attribute the appropriate energy levels to each contributing factor," Hesthammer says.

"This process is well known in the seismic industry. However, the much higher level of complexity that governs the propagation of EM energy through the subsurface, forces us to think more creatively. Our way of dealing with this problem is an integrated approach consisting of an iterative interpretation process which brings ▶

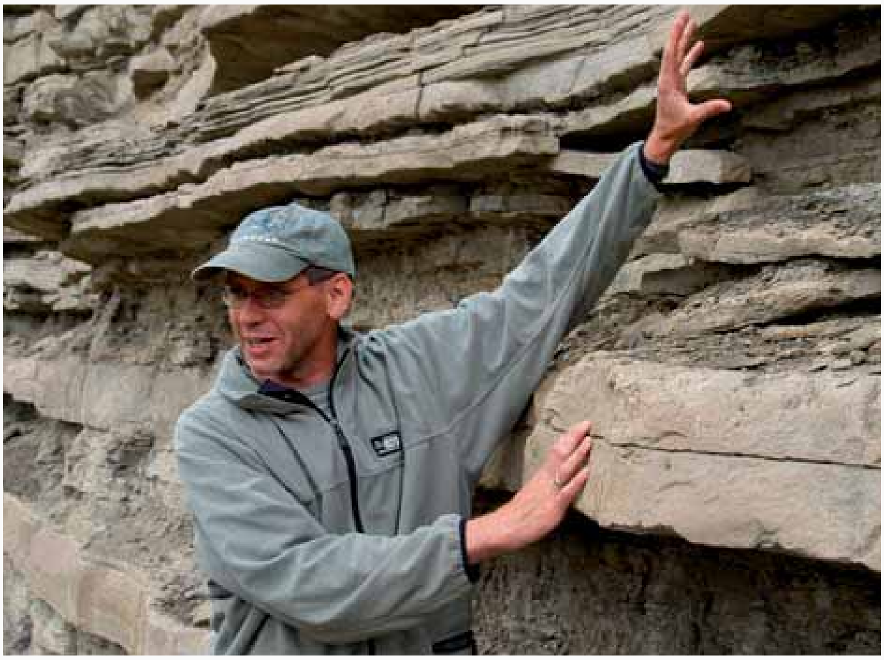
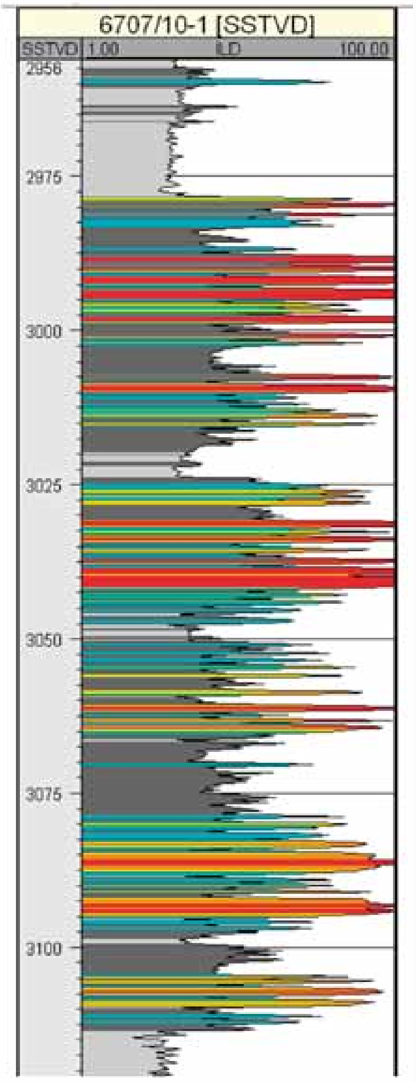


Photo: Halfdan Carstens

Dr. Jonny Hesthammer is Vice President Technology in the technology focussed, independent oil company Rocksource. The core of Rocksource's technological abilities is related to the use of electromagnetic (EM) data to reduce risk in exploration. In June of this year Jonny received the EAGE Alfred Wegener Award "in recognition of his achievements as a researcher focusing on the use of electromagnetic and seismic data for hydrocarbon detection and as an educator in rekindling student enthusiasm for the geological, geophysical and reservoir technology aspects of oil and gas operations". His photo was taken in Utah where each May he leads a pack of students to their first field seminar in petroleum geology.

in available geological data and repeatedly processes the data until a solution is converged upon. Rocksource's proprietary technology allows us to process data up to the level of constrained full 3D inversion, faster than ever before. Through very fast algorithms we are able to combine much more information, which through the structured iterative interpretation process we have developed, allows us to effectively constrain each contributing factor individually and simplify the complexity of the problem."



The reservoir in the Luva field is characterized by sandstone layers interbedded with claystone, implying that the overall resistivity will be significantly lower than in many "clean" reservoirs. We may compare this to the seismic response from a reservoir that has acoustic impedance (the product of velocity and density) similar to the overlying rocks, thereby giving little or no seismic response. In both cases the technology may fail in meeting their objectives unless proper measures are taken through advanced processing.

Knowing the Reservoir

In 2003, just after emgs (Electromagnetic Geoservices; GEO ExPro Vol. 1, No. 1, 2004) was established, a CSEM line was acquired to test the response from the Luva discovery. This line was one of many 2D lines that emgs acquired in the early phase of the development of the method. The purpose was to test the technology on proven discoveries in a multitude of geological settings.

While most of these lines proved that the technology worked, no significant EM anomaly was detected from Luva. This was quite disappointing, partially because the technology appeared to be unreliable and partially because sceptics latched on to this one failure to dismiss the entire approach. For Rocksource this was simply seen as a challenge.

"Although Luva was one of emgs' first datasets, we found that the quality of the data were good. This encouraged us to proceed with further analyses, and try to explain the apparent false negative response", Hesthammer says.

As part of their own evaluation study, Rocksource scientists thus started by looking at the reservoir section in detail. The reservoir interval is part of a 1200m thick section dominated by sheet sandstones with excellent reservoir quality deposited in a basin floor fan complex. The sands are separated by shales that were deposited from suspension during breaks in the sand supply.

Although the reservoir is of generally high quality, well logs show significant anisotropy in the resistivity, with peaks up to 200 Ωm and several sections with less than 10 Ωm resistivity.

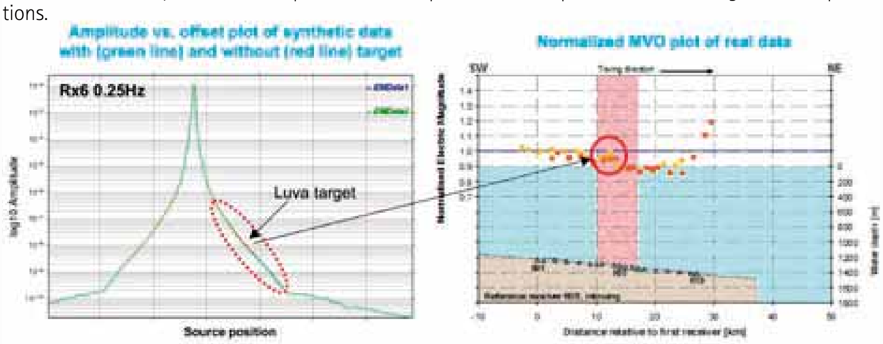
Low overall target resistivity will significantly reduce the electromagnetic response. In cases where EM works well, such as the widely published case study from the Troll oil field in the North Sea, the 300m thick reservoir has a resistivity of more than 100 Ωm, with a background resistivity of around 1 Ωm. In the case of Luva, Rocksource scientists calculated that the effective resistivity that will contribute to any EM anomaly for the interval is less than 20 Ωm, while the surrounding rocks have resistivities varying between 1-7 Ωm. This not only helped explain the difficulties, but also provided insight to how to deal with them.

With synthetic modelling, based on a realistic target and background geology, Rocksource was able to show that the response from the Luva discovery, when compared to background resistivity, will be less than 10%, compared to a response of 250% from the Troll Field reservoir.

"The Luva target is hard to detect due to the low effective resistivity of the discovery which results in a low resistivity-contrast between the reservoir and the overlying shales. This problem is compounded by lateral and vertical resistivity changes above and below the discovery, including shallow resistivity anomalies caused by glacial deposits," Hesthammer says.

"If the Luva case was to be solved, the ability to handle low resistivity contrasts in the processing was crucial. This required an advanced, integrated approach. Our conclusion, following this exercise, is that systematic testing, including detailed comparisons of subsurface geometries and likely resistivity distribution, before processing and inverting the data, is essential to avoid potential false-positive or false negative interpretations".

Synthetic modelling based on a realistic target and background geology shows that the response from the Luva discovery will be less than 10% (left - © Rocksource). This is consistent with observations from the normalized magnitude versus offset (MVO) plot of real data (right - © emgs). As a consequence, the target will be hard to detect without including additional information on subsurface resistivity distribution. Detailed analyses will be required to avoid potential false-positive or false negative interpretations.



The solution

Based on the reservoir studies combined with synthetic modelling, Rocksource went on to solve the enigma of the presumed false-negative EM response from Luva.

The starting point for the analyses was to investigate synthetic data. A representative 3D model was built based on a geological understanding of the area. A synthetic 3D CSEM dataset was then generated and inverted. As a starting point for the inversion, no seismic constraints were used. The results clearly indicate that the Luva hydrocarbon column cannot be expected to be detected using a basic approach.

The next step was to do a similar inversion with real data as input. The inversion result was very similar to that of the synthetic data, indicating that the geological model was representative of the real geology and further demonstrating that the Luva discovery could not be identified using this approach.

The next step in the analyses was to provide regional constraints based on the geological understanding of the area. Seismic data were particularly important at this stage as they enabled resistivity values to be attributed to particular intervals. This part of the process is time-consuming and requires detailed geological and geophysical knowledge of the area under investigation.

"In this instance, the well data from Luva were not used to create the constraints. This could of course have been done, but it was considered that prior to discovery such data would not have been available and to best recreate an exploration scenario the well data should be ignored," Hesthammer says.

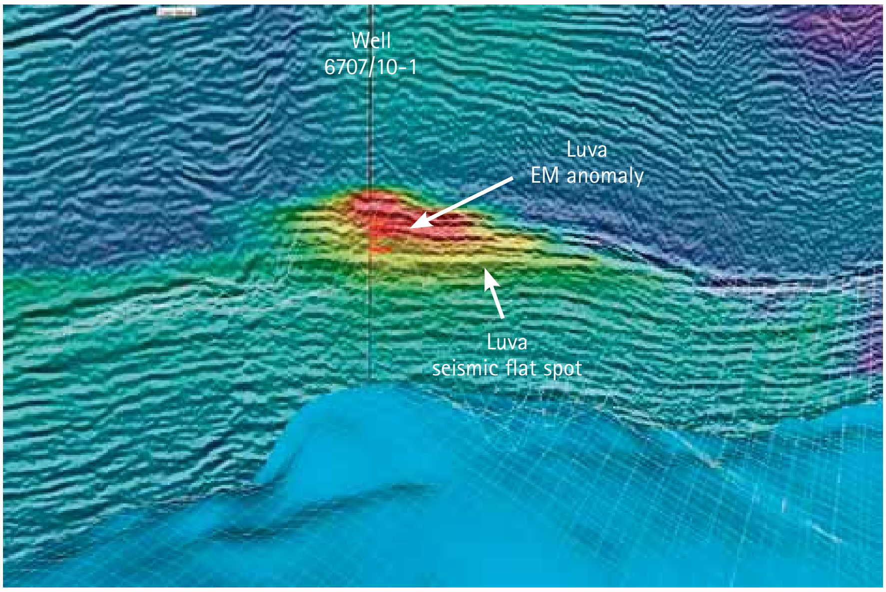
By applying the constraints, the inversion was guided towards what the geoscientist considers to be a more appropriate solution. The integrated approach applied to the synthetic data indicated that the Luva discovery could be identified using this workflow provided that the input geological model was representative.

The last stage involved using the same guided approach as for the synthetic example, but this time with real data. Again, the inputs to the constraints were taken from the interpretation of regional seismic data and a sound geological understanding of the area. No well information was used, and no constraints were used for the target itself (including parameters such as geometry, depth, thickness, lateral extent and resistivity).

The final result was that the Luva discovery was clearly identified with a pronounced resistivity anomaly. The similarities to the synthetic example suggest that the synthetic model is realistic and consistent with observations from the real data.

Inversion

Inversion is the mathematical process of determining which combination of physical characteristics of rocks and fluids produces the particular seismic or EM record you are studying. Inversion, the opposite of forward modelling, has become an essential part of integrated geological interpretation of geophysical data.



The inversion result of the real CSEM data based on an advanced processing approach clearly matches the seismic data, including the spectacular flat spot caused by the gas-water contact at 3113m. Note that the strength of the EM anomaly correlates with the thickness of the gas column (red being strong, yellow to green being weaker). As the gas column becomes thinner, the EM response becomes weaker. There is also a good match between the EM anomaly and the well data considering the difference in resolution. Sceptics should note that there is no significant anomaly outside the reservoir.

No Magic, no Manipulation

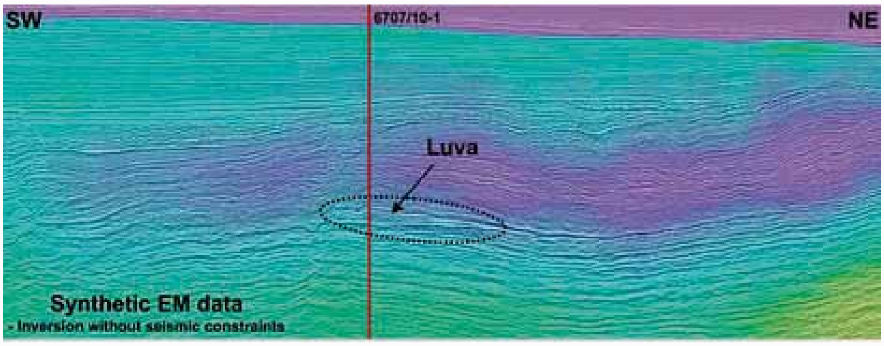
"There is no magic involved in this," Hesthammer claims, "what we are doing makes perfect scientific sense in that we include all pertinent data that are available to us. We then use our tailor-suited and proprietary inversion algorithms to process the data. We are by no means manipulating the analyses. Rather, we use our geological understanding of an area, and this is what explorationists are trained to do. EM data are just one more piece of information, just as the well data and seismic data are. No explorationist would treat seismic data in isolation, and similarly, EM data should not be treated independently either. Even the odd exceptions such as the Troll field (GEO ExPro, Vol. 3, No. 4/5), where the EM anomaly stands out like a light house, need to be tested for false-positives which may be caused by cemented sandstones or other resistive bodies."

"This is why the geologist has a very important role to play when analysing EM responses. Their input to the inversion algorithms is absolutely crucial; as the algorithms do not themselves understand geology, although "they" are able to learn. However, integration is not always easy. Geoscientists worldwide need to educate themselves in the new technology and this will take time," Hesthammer says.

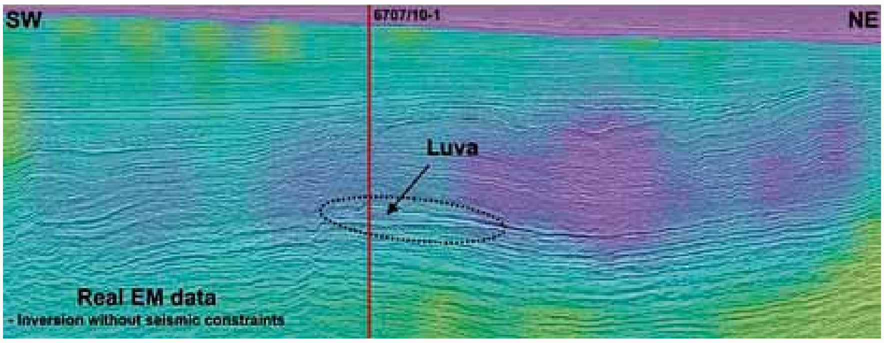
Too Good to be True

"If the oil and gas industry is to succeed with the use of EM technology, it must understand the complexities involved. Basic analyses only form a starting point for the investigation," Hesthammer says.

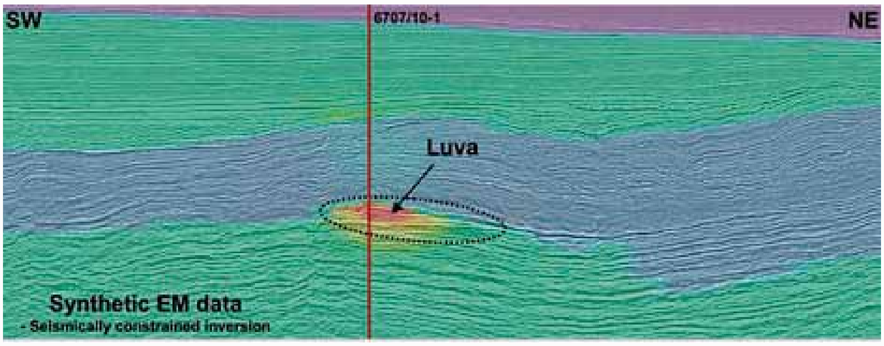
"Advanced processing and inversion are normally required to fully understand the data. In complex settings, it is essential to



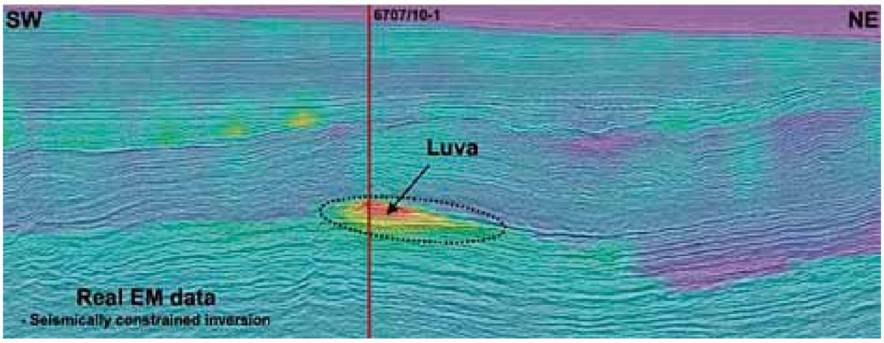
Inverted synthetic CSEM data superimposed on seismic data. Forward modelled CSEM data were generated based on a detailed geological understanding of the area (including the use of seismic data and well data). For the inversion, no geological or seismic constraints were used. Assuming that the geological model used to generate the synthetic CSEM data is correct, it is evident that the Luva discovery cannot be distinguished using this basic approach.



Inverted real CSEM data superimposed on seismic data. The inversion is exactly the same as above, but now with real data as input. The similarity between the two figures is striking, indicating that the synthetic model is representative and clearly demonstrating that without this approach, complex cases such as Luva would be impossible to discover using the EM technology.



Inverted synthetic CSEM data superimposed on seismic data. The geological model used to generate the EM data is unchanged. However, in this case, the inversion is constrained based on regional observations from seismic data and a sound geological understanding of the area. In this way, the inversion is guided towards what the geoscientist considers to be a more appropriate solution. It is important to point out that well data were not used to create the constraints. Assuming a correct geological model as input for generating the synthetic data, the Luva discovery should be clearly identified using this approach.



Inverted real CSEM data superimposed on seismic data. The inversion is again guided based on regional constraints similar to that used in the synthetic example, also excluding well data. The Luva discovery is now clearly identified with a marked resistivity anomaly that closely matches both seismic and well data. The similarity with the synthetic example is clear and suggests that the synthetic model is representative of the real geology.

use all the available information such as input from seismic data, borehole data as well as our geological understanding of an area."

"The Luva case demonstrates elegantly the potential that this technology has in future hydrocarbon exploration. It is almost too good to be true," Jonny Hesthammer of Rocksource concludes.

Acknowledgements

The SBL data used in this study was provided to Rocksource by emgs. Rocksource are grateful as it allows them to demonstrate some of the tremendous potential of the CSEM technology. The public domain (DISKOS) seismic data were collected in 1996 by CGG for BP and are maintained by Statoil. The well information was obtained from Norwegian Petroleum Directorate. The advanced workflow used to solve the Luva enigma is a result of efforts by numerous Rocksource scientists. This particular study was carried out by Jonny Hesthammer, Alexander Verechtchaguine, Peter Gelting, Mikhail Boulaenko, Roy Davies and Torolf Wedberg.