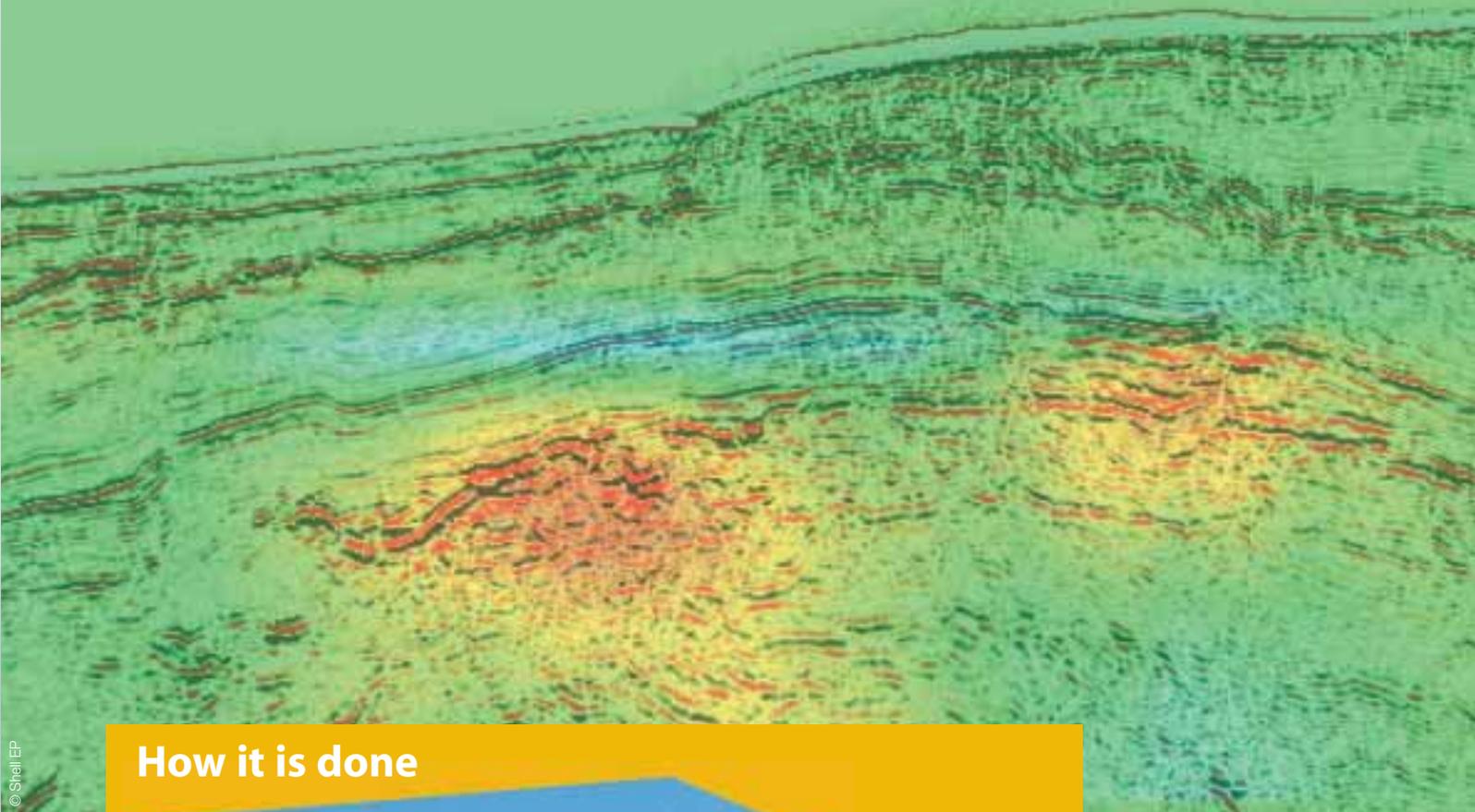
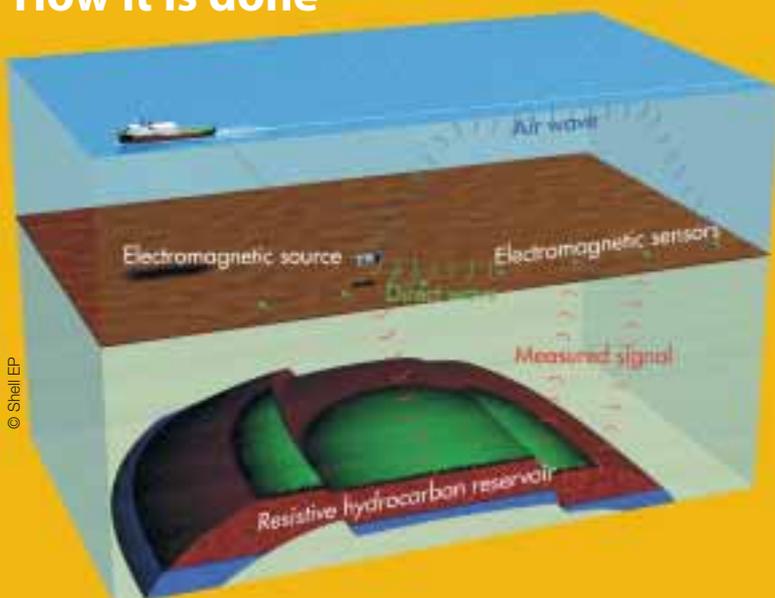


Towards a new era

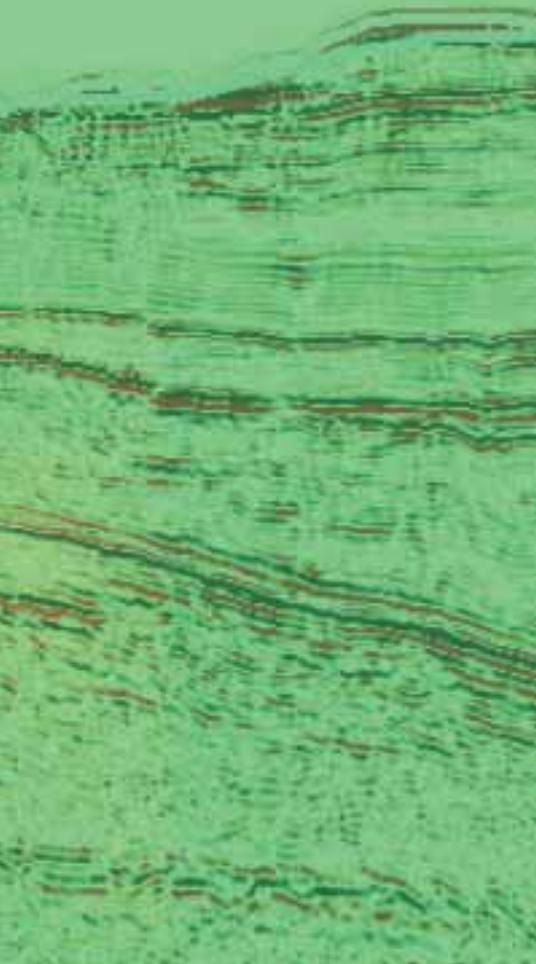
Sea Bed Logging is a new technology that offers the opportunity to detect trapped hydrocarbons in the subsurface prior to drilling. Shell EP has recently conducted a number of very successful data acquisition campaigns throughout the world based on this technology, leading it to substantially expand its use of this technique in the future.



How it is done



The receivers are first placed on the seabed. Then a vessel with a transmitter passes over them. Signals arrive directly through the water (green line), through air (blue line) and through the reservoir (red line).



Seismic section and possible interpreted resistive body (red and yellow colours) indicating the presence of hydrocarbons in an imaginary prospect.



More than 180 electromagnetic surveys have been carried out by emgs alone worldwide. Shell, which has recently embarked on a joint research and development initiative with emgs to develop this technique further, has participated in over 50 surveys, the vast majority contracted directly with emgs. Geological provinces surveyed include the North Sea, the Norwegian Sea, the Barents Sea, the US Gulf of Mexico, offshore Brazil, offshore West Africa, the Nile Delta, offshore India and the South China Sea.

Halfdan Carstens

Seabed logging, which is the application of Controlled Source Electro-Magnetic surveying (CSEM) to finding hydrocarbons, has proved to be a rewarding tool to add complementary information to the seismic interpretation. The introduction of this innovative technology only four years ago has been proven to give oil companies a much better chance of finding oil and gas in frontier as well as mature basins.

Increased competition

The research department of Statoil developed seabed logging from the late 1990's onwards, and in 2002 formed a separate company, Electromagnetic Geoservices (emgs), to implement the technology (GEO ExPro, No. 1, 2004). emgs is headquartered in Trondheim, Norway, with fully staffed operational and technical support offices in Houston and Kuala Lumpur, and with sales offices in Stavanger, Paris, London, Rio de Janeiro and Mumbai. To date it has recorded more than 180 surveys, with a total distance logged close to 15,000km, under a wide range of conditions, and in water depths ranging from 50m to more than 3,000m. The client list now encompasses in excess of 30 operating companies, including supermajors like Shell and ExxonMobil, independents as well as national oil companies (NOC's).

emgs, however, is not the only provider

of CSEM-data. At least three other companies are offering these services, including AOA Geomarine Operations LLC (AGO, GEO ExPro No. 3, 2004), now owned by Schlumberger, MTEM, a spin-off from Edinburgh University (operating on land only so far, but working their way into the offshore), and OHM (Offshore Hydrocarbon Mapping), formed in 2002 as a spinout from the UK's prestigious National Oceanography Centre at Southampton University. OHM has completed in excess of 50 surveys as well as numerous reprocessing and interpretation projects using data collected by third parties.

ExxonMobil has also been developing its own technology, named Remote Reservoir Resistivity Mapping (R3M), which it has already used on more than a hundred surveys worldwide.

Successful testing

Since its introduction, seabed logging has been shown time and again to improve exploration efficiency. Several cases have been published to prove this. Most renowned is the Troll case (North Sea) in which the technology was demonstrated to successfully detect the gas field, and at the same time proving that seabed logging can be used in shallower water (350m) than previously thought (>500m). In fact, a later survey across the Grane oil field in the North Sea, where the water depth is only 100m, also proved successful.

While the Troll case was "after the fact",



Photo: Halldan Carstens

Saad Saleh joined Shell in 1991 after receiving a PhD in electrical engineering from the University of Wisconsin. In the 1991-95 period, he worked on the development and implementation of a variety of seismic processing algorithms at the Bellaire Technology Center and at Shell Western E&P, Inc. in Houston. From 1996 to 2004 he worked on direct hydrocarbon detection research problems, such as seismic AVO, with emphasis on the application of statistical detection and estimation techniques. He is currently project leader of the New Detection Methods team at the Bellaire Technology Center, investigating the application of electromagnetic, potential fields, and remote sensing techniques in frontier exploration areas.

another published case in the Norwegian Sea clearly demonstrated seabed logging as a valuable tool in exploration. Based on 3D and 4C data, the Linerle prospect, in about 300m water depth was considered promising. With evidence of hydrocarbons nearby, a seabed logging survey was conducted that showed high resistivities in the subsurface. Drilling subsequently confirmed the presence of hydrocarbons in a 20m column.

Further breakthrough in the acceptance of this technology came when the Norwegian Ministry of Petroleum and Energy recently included seabed logging modelling and acquisition in the work commitments attached to selected licenses. Another petroleum agency has also used seabed logging as a tool in the administration of offshore licenses. An operator was released from a drilling obligation on condition that a seabed logging survey was conducted.

Lately, it has also become known that Falklands Oil & Gas has signed a letter of

intent with OHM to assess a series of prospects in the frontier South and East Falklands Basins. Seabed logging "is an extremely cost effective method of high grading an extensive inventory of exploration prospects and leads. This programme has the potential to indicate which of our numerous prospects may contain hydrocarbons," the company says.

Tim Bushell, Chief Executive Officer of Falklands Oil & Gas, commented that the method "can help to significantly reduce risk, improve the chance of success and allow us to focus on the best prospects for drilling in 2008."

Nevertheless, it is important to point out that electromagnetic surveying is not a tool that should be used in isolation. "Average exploration success rates of less than 20% demonstrate the pitfalls of trying to solve several unknowns with a single measurement technique, although until recently explorationists had no choice. In the borehole domain, geoscientists enjoy the benefits of using many different measurements in an integrated manner (e.g. resistivity, density, neutron porosity, acoustic, NMR) to evaluate reservoir and fluid properties more accurately. And whilst each measurement has its own particular strengths, individual measurements are rarely used in isolation from the rest. It's time for the exploration industry to embrace the same integrated approach, not stopping at seabed logging, but continuing to incorporate other reservoir scale diagnostics as they become available," says Ken Feather, Vice President Marketing in emgs.

Shell gets involved

Shell has been involved with SBL since 2001, and early in 2004 the company con-

tracted emgs to carry out a global campaign. Surveys were carried out in a multitude of geological settings in north-west Europe, West Africa, South America, the Far East, the Mediterranean, and the Gulf of Mexico.

"The campaign had two main objectives," says Saad Saleh, project leader of Shell's R&D efforts in seabed logging. "First, to confirm that the technology works in clear cases of large, relatively shallow hydrocarbon accumulations, and second, and more important, to interpret data in conjunction with other data such as seismic attributes in more difficult settings where advanced processing would be required."

Most surveys were acquired over prospects not yet drilled. With Shell's reputation at stake, this, one should think, would be the ultimate test of the technology that was introduced as a commercial product only four years ago.

Hard to find more

Finding oil and gas is no longer an easy business. Most of the giants have been found. This is true for the North Sea, West Africa, the Gulf of Mexico, and many other mature, prolific offshore provinces. As a result, oil companies are now moving into new geological provinces including ultra-deep water and ultra-hostile areas, while at the same time they need to find the remaining oil in mature basins.

"In the next exploration wave, technology integration is the key, in particular merging non-seismic with seismic methods," says Mike Naylor, Shell's exploration technical director to *Changes* magazine.

"We are now approaching the limits of what exploration-scale seismic can tell us.



Depth migrated image from a one line survey across the giant Troll field in the North Sea. The reservoir is in Upper Jurassic sandstones situated below the prominent reflector in the middle of the section. The hydrocarbon filled reservoir at a depth of approximately 1000m has resistivities approaching 250 Ω m, while water wet sandstones and overburden shales have resistivities in the order of 1-2.5 Ω m.

Drilling is becoming more costly, so we need independent techniques to back the seismic up, telling us more about the conditions several kilometres below the Earth's surface. This embraces not just the structure, but the nature of the rocks, and the type of fluid they contain," Naylor explains.

Seabed logging now proves to be just such an independent technique, giving information on the types of fluids the reservoirs may contain.

Three successful cases

As of today, Shell has acquired more than 50 surveys over a wide range of reservoir and subsurface conditions. Three examples illustrate how this new innovative technology may cause a significant reduction in exploration risk and drilling success.

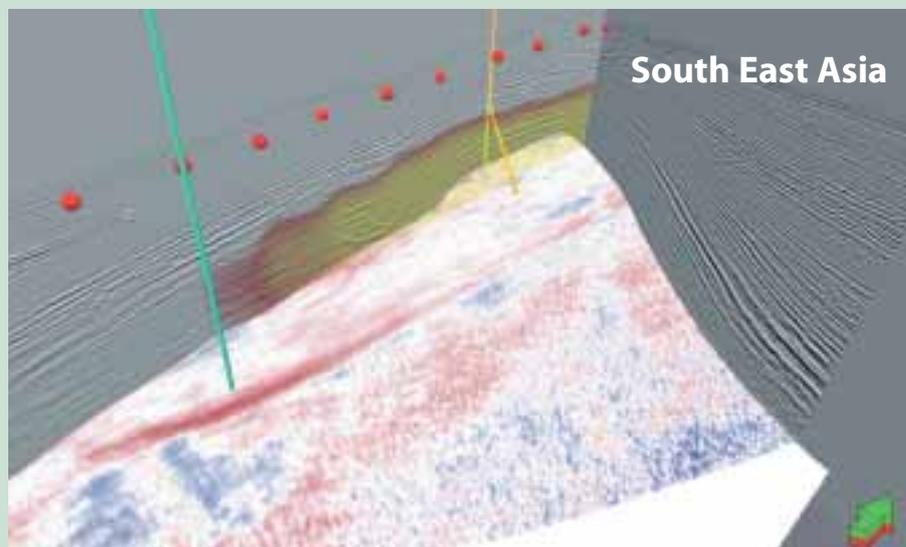
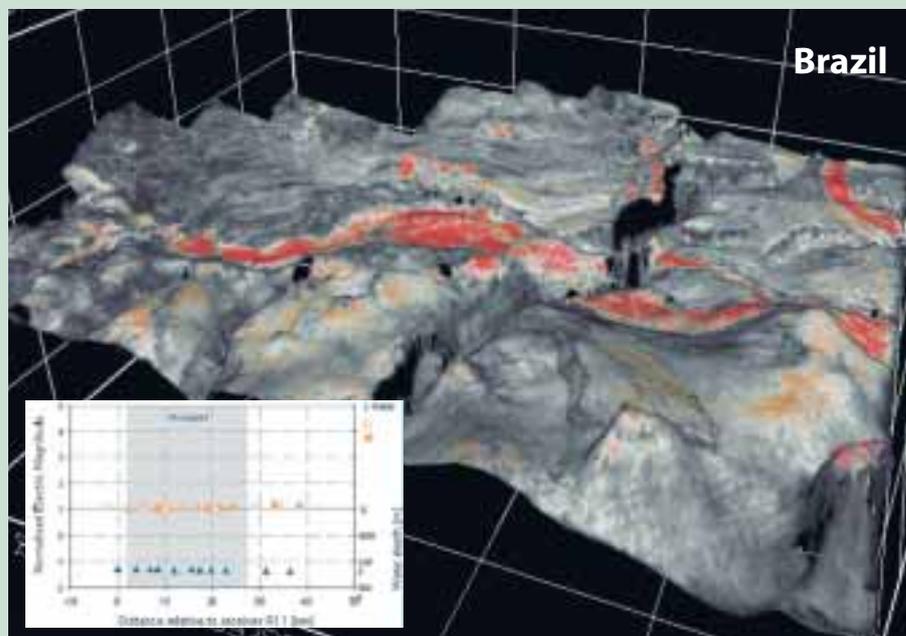
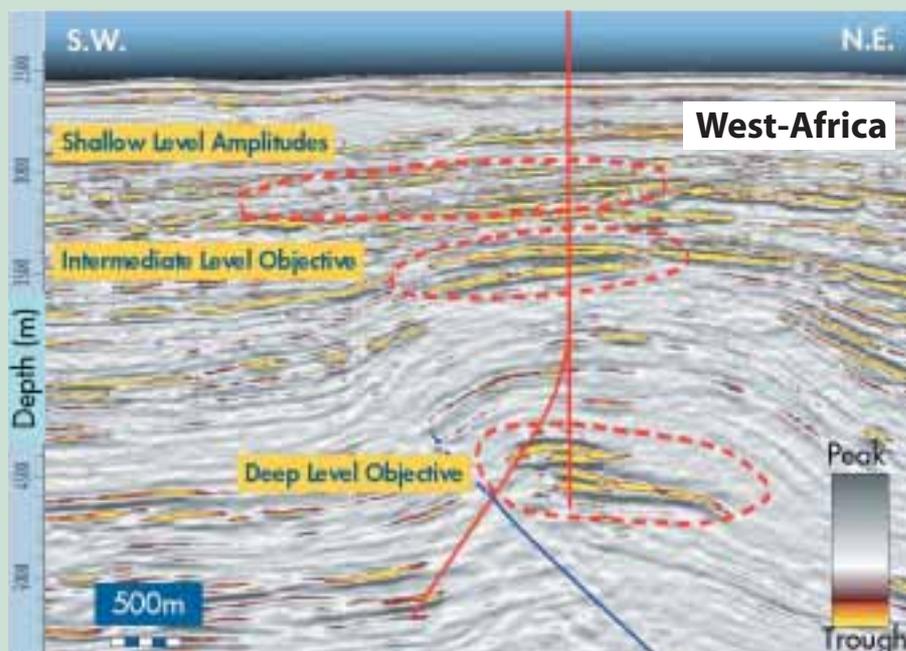
Offshore West Africa, Shell evaluated a prospect with several different fill possibilities. Three models with shallow and deep reservoirs were developed based on the seismic interpretation. The first model included hydrocarbons in both reservoirs, in the second model only the deep reservoir was filled with hydrocarbons, and in the third model a shallow gas layer was removed.

"The measured response matched a model in which only the lower reservoir was hydrocarbon saturated. The result was later verified through drilling, demonstrating that the technology can also be used where multiple reservoir beds are present," says Saleh.

In Brazil, Shell identified a potentially large prospect in a block that would become available in a forthcoming licence round. While a reservoir model could be developed based on the seismic data, detailed seismic amplitude studies were inconclusive with respect to hydrocarbon saturation. A seabed logging survey was therefore acquired, but no anomaly was identified, suggesting that the reservoir is water-wet.

"This evidence, when combined with hydrocarbon charge evaluation studies, was sufficient to make the decision not to pursue this opportunity which would have involved considerable licensing and drilling costs," says Saleh. The company therefore felt comfortable walking away from this prospect.

"This is a tremendous step forward in the acceptance and confidence placed in seabed logging results. Shell made an intelligent choice in walking away. The



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prospect became very high risk and they were able to eliminate it from their portfolio, thus improving overall valuation and at the same time prioritising finite exploration resources, comments Ken Feather.

In South East Asia, Shell is actively exploring a thrust belt play in which the main exploration uncertainty is trap integrity. Shallow gas reduces the quality of seismic imaging, in particular over the crest of the structures. Down flank, data quality improves and direct hydrocarbon indicators such as flat spots can be observed. However, the pitfall is that such flat spots may be paleo oil-water or gas-water contacts.

"Our seabed logging data indicated that hydrocarbons would be present updip from a dry well with only residual hydrocarbons. This was confirmed by a second exploration well, a well that may not have been drilled if there was no independent, complementary information available in the form of resistivity data," Saleh says.

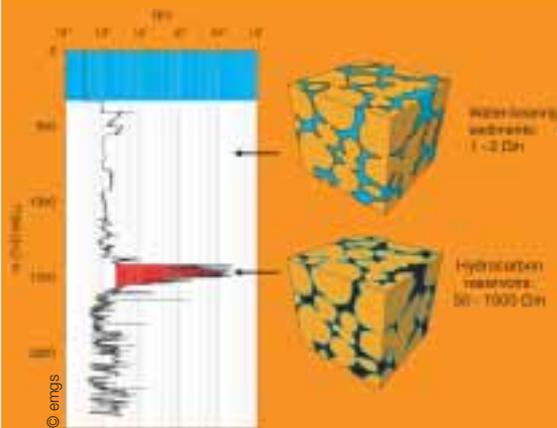
The survey results also demonstrate that seabed logging, in cases where it was used across known fields, shows the locations of those fields. Further, in several cases the depths of the reservoirs can be measured with reasonable accuracy.

"The technology holds a great potential, although we stress that the technology is not a "silver-bullet", and as with any new technology, not all examples allow for a



Svein Ellingsrud (left), VP R&D emgs and co-inventor of seabed logging, receives the prestigious Harts Meritorious Engineering Award in the "exploration system" category, for its seabed logging survey method, from Bill Pike (middle), editor of Hart's E&P, accompanied by Stuart Goldstein, business development manager, emgs Americas, at OTC in Houston, May 2006.

What is seabed logging?



All fluid-filled rocks are characterised by electrical conductivity. The difference in conductivity between, for example, shale and sandstone is relatively small when these rocks are water-saturated (resistivity 0.2-5 Ωm). If the sandstone is filled with oil or gas, however, its conductivity falls markedly (resistivity 20 - >200 Ωm). This is the principle applied in well resistivity logging.

The Schlumberger brothers introduced well resistivity logging to the oil and gas industry almost 80 years ago following their first measurements in an oil well in France. Measurements of the conductivity of a rock, based on a transmitter and receiver lowered into a borehole, can tell whether the reservoir contains water or hydrocarbons, and resistivity has since the 1920's been the de facto hydrocarbon indicator used by the industry. Acoustic measurements were first introduced to the borehole measurement portfolio in the 1960's.

emgs has shown that the principle of resistivity borehole logging also functions on a much bigger scale. With the electromagnetic field generated from a transmitter towed approximately 30m *above* the seabed and registered by a receiver placed *on* the seabed it is now possible to "view"

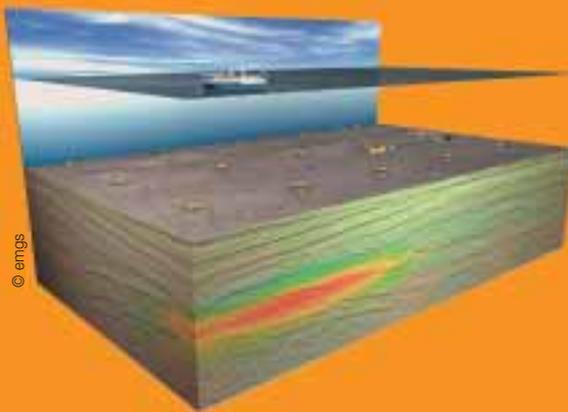
the reservoir from above and not just from an instrument in a borehole. To achieve deep penetration – several thousands of metres down – it is necessary to have a powerful source and low frequencies (typically 0.25-10 Hz) in the outgoing signal.

The source is an electric dipole consisting of two poles, a lead and a tail electrode, each about 10m long. The two poles are located 300-400m apart and connected by a cable. Passing an oscillating high-power current from the lead to tail electrode creates an electromagnetic field that sends out waves in all directions. When a wave meets a low-resistivity layer, it passes through and becomes slightly weakened or attenuated. Encountering a high resistivity layer, the wave is deflected along it and attenuated to a much lesser degree.

The source thus generates a signal that is distorted by resistive bodies in the subsurface. The distorted response shows as anomalous readings that differ from the background. The resistive bodies showing these anomalies could be oil or gas reservoirs.

The strength of the electric field, for a specific receiver placed on the seabed, is measured and registered as a function of distance between transmitter and receiver ("offset"). When the distance from the transmitter to the receiver increases (the boat moves away from the receiver), the signals diminish in strength. All measurements above the reservoir are compared with reference measurements outside it.

Signal strength from resistive bodies increase with offset up to a point; at offsets approximately equal or greater than 3x the burial depth, the energy from the resistive body dominates all the other energy paths.



The electromagnetic source is towed near the seabed, while receivers are placed on the seabed in a regular grid. Depth migrated data can be presented as an image (compare also illustration on page 40) with resistive bodies correctly located in depth. When overlain on depth-migrated seismic data, seabed logging can indicate the presence of hydrocarbons.

clear and unambiguous interpretation. The optimal impact comes through careful integration with complementary data such as seismic", Saleh says.

Multipurpose use

Terje Eidesmo, managing director of emgs, recently gave a presentation of the company to the Norwegian Minister of Oil and Energy, Odd Roger Enoksen.

Referring to the close cooperation with Shell and their successful application of the methodology worldwide, he emphasized three different applications of seabed logging in exploration.

"First, the method can be used to reduce exploration costs by avoiding drilling prospects that appear not to contain hydrocarbons," Eidesmo said. "Furthermore, extensive use of seabed logging data can assist in making better decisions when prioritizing a drilling campaign in a given sedimentary basin, thereby making seabed logging a valuable technology that can assist in risk assessment significantly. Thirdly, by running surveys in areas where previous disappointments have increased the risk considerably, hydrocarbons can be found in prospects that would otherwise not have been drilled."

Svein Ellingsrud, Vice President Research and Development, added that the future use of seabed logging might play a significant role in reservoir delineation and reservoir monitoring. In fact, a calibration survey in 2002 on the giant Ormen Lange gas field in the Norwegian Sea successfully located the field boundaries as defined by seismic amplitude anomalies.



The Innovators

Electromagnetic surveying was proposed in the academic world in the 1970's and has been used for years by researchers to carry out lithosphere studies and examine hydrothermal and volcanic systems on mid-ocean ridges. The technique involved towing an electromagnetic source close to the seabed and recording the responses on detectors, also placed on the seabed.

In the late 1990's, two research scientists then working at Statoil, Terje Eidesmo and Svein Ellingsrud (GEO ExPro No. 5/6, 2005) evolved the method and advanced the technology to enable the detection of hydrocarbon reservoirs. They introduced the technology to the oil and gas exploration industry after having learned about a powerful new source with the potential to propagate electromagnetic energy more than 2 km into the subsurface. They termed the new technique seabed logging because of its similarities with borehole resistivity logging that they were actively working with at that time.

The idea was that electromagnetic measurements could give information about the resistivity profile of the subsurface, a profile which to a large extent is controlled by the resistivity of the saturating fluids. The concept is thus based on the principle that an electromagnetic field is rapidly attenuated in a conductive media (water-wet reservoir rocks) but less attenuated in highly resistive media (hydrocarbon saturated reservoir rocks).

A test survey, carried out by Statoil offshore Angola in 2000 in collaboration with Scripps Institution of Oceanography and Southampton Oceanography Centre, in about 1200m of water and above a known shallow hydrocarbon



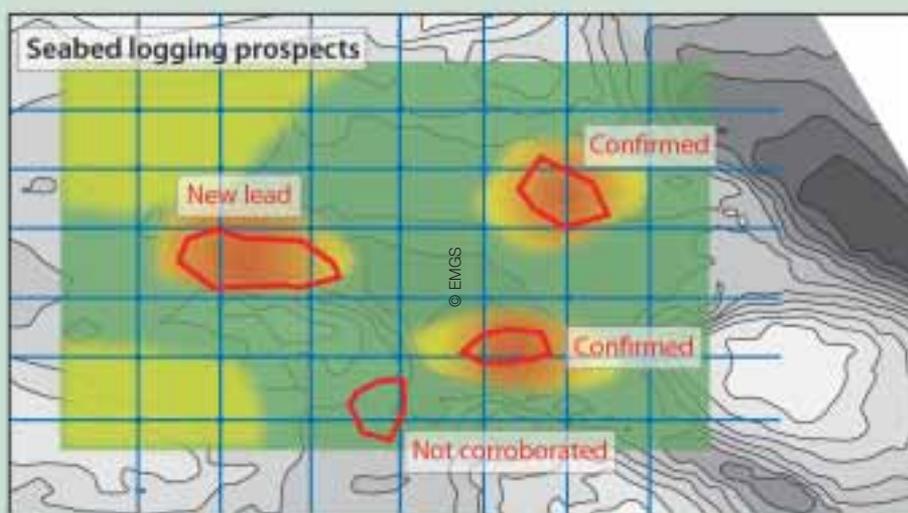
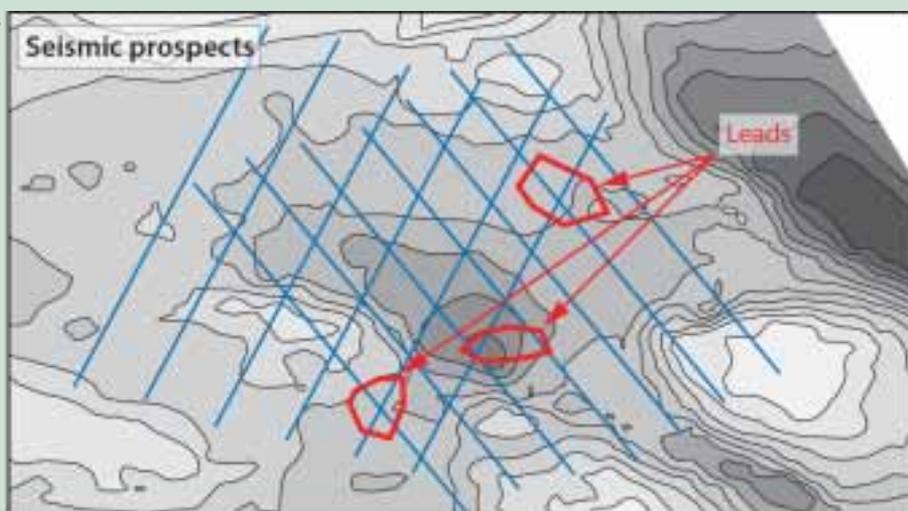
Nine years after the idea struck on a flight out of Houston, Svein Ellingsrud (left) and Terje Eidesmo, both with a strong background in geophysics, can claim that seabed logging has been accepted by the conservative oil industry. Eidesmo and Ellingsrud were portrayed in GEO ExPro No. 5/6, 2005 (www.geoexpro.com [people])

reservoir, turned out to be successful and laid the ground for further development. This event, a mere six years ago, is also the true start of seabed logging as we know it today.

Eidesmo and Ellingsrud demonstrated that electromagnetic energy is guided, with low attenuation over long distances, by resistive subsurface bodies such as oil and gas reservoirs. They also showed that low-frequency electromagnetic energy, emitted by a source close to the seabed, can propagate to the depths of typical reservoirs, and that, by applying tailor-made survey design, the signals can be large enough to dominate energy arriving by other propagation modes.

Government recognition: Ståle Johansen (right) of emgs explains seabed logging to the Norwegian Petroleum and Energy Minister, Odd Roger Enoksen, during the Minister's recent visit to the company's headquarters in Trondheim, Norway.

© emgs



While seismic data define prospects and leads, seabed logging is capable of confirming the presence of hydrocarbons. In this example, two of three leads seem to be promising. A fourth area, which is missed by the seismic, should be pursued. The figure thus illustrates how seabed logging helps to prioritize an exploration campaign.

Less restrictions

"We expect further advances based on 3D acquisition, imaging and inversion. Shell and emgs have therefore recently embarked on a joint research and development initiative to develop such techniques," Saleh says about the future of seabed logging.

"At present, the use of the seabed logging technology is largely restricted to water depths in excess of 200m, but through ongoing R&D efforts, techniques will be developed that remove the depth restriction. Also, the depth of investigation below seabed will be extended from today's 3000m+ restriction. We will also focus our research on ways of removing the influence of distorting bodies such as salt and volcanics that in some areas may be prohibiting the use of this technology.

Moreover, we will conduct experiments into methods of 3D surveying," says Saleh.

"Our examples from three different geological settings demonstrate that seabed logging will be part of a tool kit that explorationists can use when they evaluate prospects and associated risks. Seabed logging should, however, not be used in isolation, but as part of an integrated evaluation process," Saad Saleh concludes.

No doubt, exploring for hydrocarbons will never be what it used to be. We are moving fast into a new era.