

Seabed logging acquisition as a tool in exploration decision-making

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For medium to larger-sized oil companies, decreasing production has made production well drilling, rather than exploration wells, a priority. Regulations have historically been strict for smaller energy companies that wanted to prequalify as licensed partners in fields offshore Norway. However, different regulations and changes in the fiscal policy have made it possible for a number of new companies, Norwegian and foreign, to enter the Norwegian sector over the last couple of years.

The annual "award of predefined areas" (APA), launched in the first part of this decade, is an attempt to stimulate the exploration of near-field, near-infrastructure prospectivity, in addition to awards in licensing rounds on a more irregular basis. One reason for this is that the Norwegian-controlled areas of the North Sea and Norwegian Sea are maturing. Numbers from the Norwegian Petroleum Directorate (NPD) indicate that offshore Norway, 4.6 GSm³ oil equivalents (billions Sm³ o.e) were produced as of 31 December 2006. Forty-nine discoveries and nearly 300 improved recovery projects, together with approved projects, yielded a portfolio of 5.2 GSm³ o.e. of remaining proven resources. 2006 saw only a slight increase in gross petroleum reserves. In spite of increased reserves in several fields, as well as the maturing of resources to reserves, the reserve reductions on existing fields increased to just 1 MSm³ o.e. gross gas and liquid reserves. During 2006, gross oil reserves declined by 16 MSm³. In relation to the authorities' new goal of maturing 800 MSm³ oil to reserves by 2015, 155 MSm³ oil (or nearly 1 billion barrels) were entered as new reserves in 2005. The accounts for 2006 revealed a reduction in achieved reserve growth amounting to 16 MSm³.

Mature areas around existing infrastructure have been extensively explored, with scientists using new seismic acquisition and reprocessing older vintage surveys to improve the overall imaging of these areas. However, reprocessing older seismic vintages may only improve the overall picture of the subsurface to a certain degree. Consequently, new ways of reviewing the subsurface are vital in the exploration of an increasingly mature Norwegian sector. Additional tools and processes are needed to assess the subsurface from a different perspective.

Measurements of electrical resistivity beneath the seafloor traditionally have played a crucial role in hydrocarbon exploration and reservoir assessment and development. In the past, the oil and gas industry has obtained subsea floor resistivity data almost exclusively by wireline well logging. However, developing noninvasive geophysical methods that provide this information holds clear advantages. Although these methods do not provide the vertical resolution of wireline logging, the savings from eliminating test-well drilling into structures that do not contain economically recoverable hydrocarbons could present major economic advantages.

This paper discusses how newly developed acquisition and processing techniques in seabed logging (SBL) and a special controlled-source electromagnetic energy (CSEM) technique developed by Statoil have been used to scan larger areas. In the past, SBL has been used in risking mapped prospects; however, with new scanning techniques, SBL can

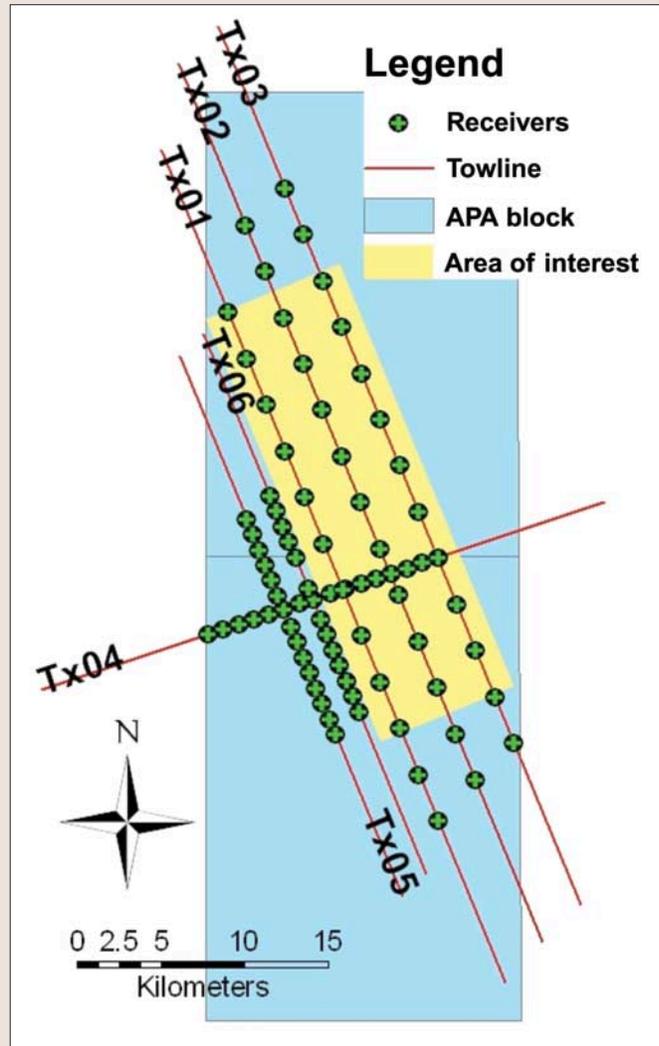


Figure 1. Receiver layout and towline pattern from the North Sea case example. Receivers along towlines Tx01 to Tx03 were deployed and towed during the initial scan, and receivers and towlines along Tx04 to Tx06 were deployed and towed to investigate the results of the initial scanning survey.

be used to identify new prospects. This is partly why Aker Exploration ASA, as a newcomer on the Norwegian continental shelf, decided to use SBL extensively in their decision for obtaining their first licenses through licensing rounds in the 2007 APA.

SBL scanning has been used extensively by Aker Exploration ASA in mature as well as in frontier areas to identify areas of interest. Hence, this paper will briefly introduce the developed acquisition and processing technologies and how to use them in exploration decision-making. The paper also includes one example from the North Sea that highlights the various aspects of this process (Figure 1).

Electromagnetic energy attenuates rapidly in conductive media, such as seawater and sediment where the pore fluid is seawater. In air and high-resistive layers such as hydro-

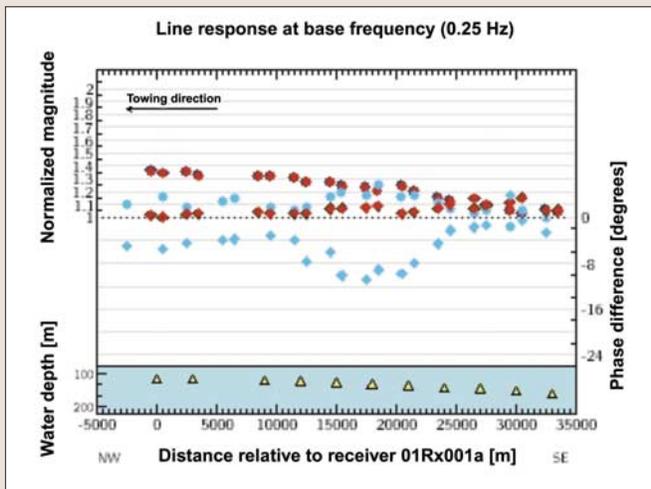


Figure 2. Normalized magnitude (circles) and phase-difference response (diamonds) along line Tx01 (Figure 1) at 1-km offset (red symbols) and 5-km offset (blue symbols). The increased magnitude and reduced-phase response at medium-to-long offset indicate that the increased resistive body is at some depth.

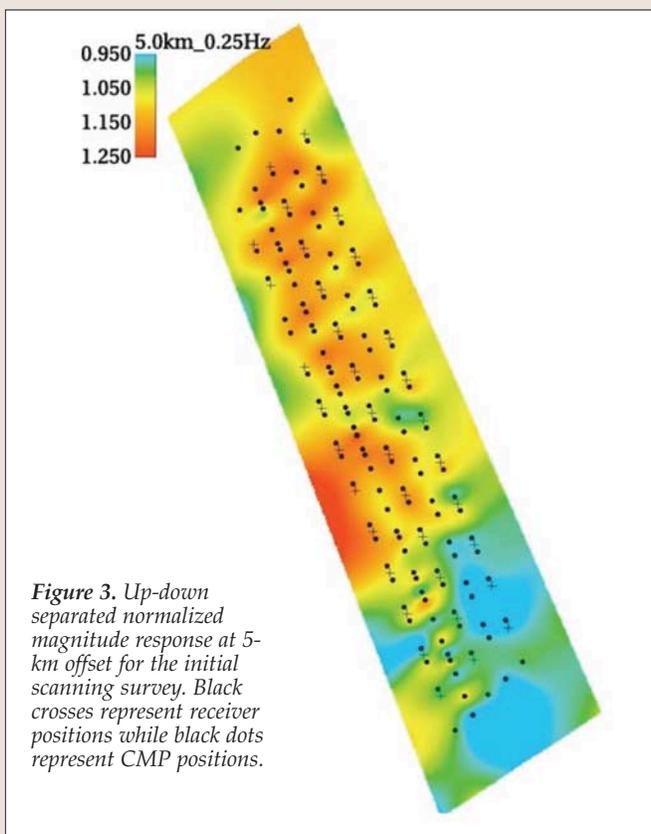


Figure 3. Up-down separated normalized magnitude response at 5-km offset for the initial scanning survey. Black crosses represent receiver positions while black dots represent CMP positions.

carbon-filled sandstone, the energy is guided along the layers and is less attenuated (Kong et al., 2002). Energy is constantly refracted to the seafloor and is detected by the receivers. At greater depth, the refracted energy is affected by the resistive layers as the source-receiver offset increases. The refracted energy from a resistive layer will dominate over directly transmitted energy. The detection of the refracted energy is the basis of SBL (Ellingsrud et al., 2001).

Electromagnetic energy is also transmitted upwards and along the air-water interface, which is referred to as the airwave. In shallow water and at longer offsets in medium water depth, the airwave will dominate the recorded field.

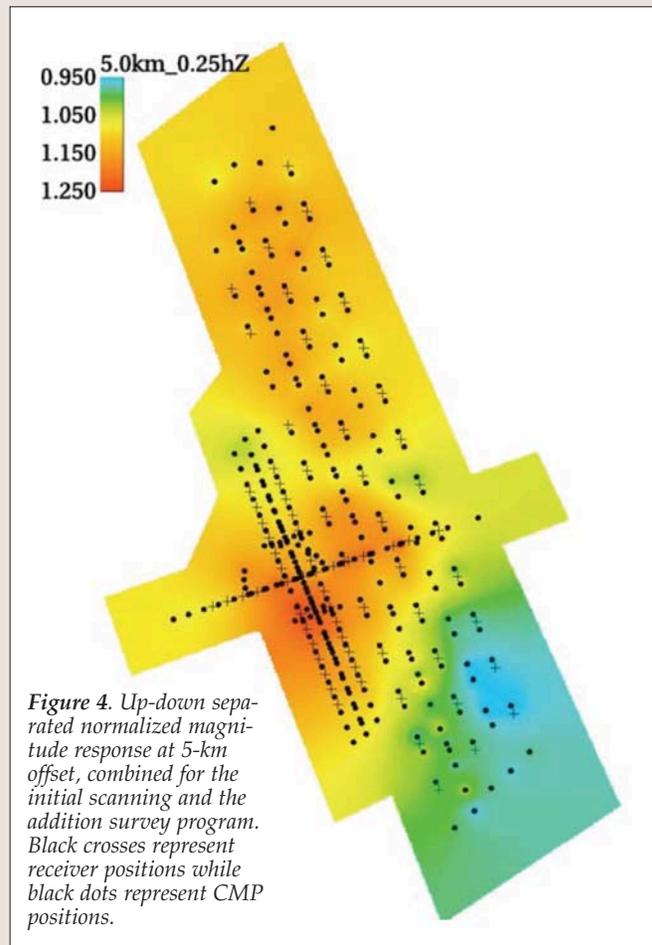


Figure 4. Up-down separated normalized magnitude response at 5-km offset, combined for the initial scanning and the addition survey program. Black crosses represent receiver positions while black dots represent CMP positions.

The SBL method was for a long period restricted to deep-water areas and targets buried in relatively shallow areas, as these targets are observed at shorter offsets than the airwave. Amundsen et al. (2006) introduced methods to decompose the electromagnetic field into upgoing and downgoing components. This method reduces the influence of the airwave and has successfully enabled SBL surveys in shallow waters. Data shown in this paper are from a survey between 150 and 250 m of water. Up-down separation was successfully applied to reduce the influence of the airwave.

The up-down separation made it possible to use SBL in shallow water. However, it was only with the introduction of azimuth decomposition of SBL data (Maaø et al., 2007) that SBL data could be used efficiently to scan larger areas to identify new prospects.

Scanning can be subdivided into two types—initial scanning or detailed scanning. Initial scanning covers large areas aimed at identifying potential prospects by mapping areas of increased resistivity. This type of scanning is normally accomplished by the deployment of receivers on the sea floor in a staggered grid formation, which delivers the highest data density (Figure 1). In the case shown, a receiver spacing of 3 km is used, and the source is towed along the longest axis. A data density of 0.31 points/km² at a 5-km offset is obtained using only inline receivers. In the case shown, an increased magnitude and reduced phase response can be observed in the central part of the two western lines (Figure 2). No known prospect is defined in the area, as other data sources were not extensively examined. The distance between the SBL lines makes it difficult to link these observations. Data from offline receivers provide information between the survey lines and thereby increase the possibil-

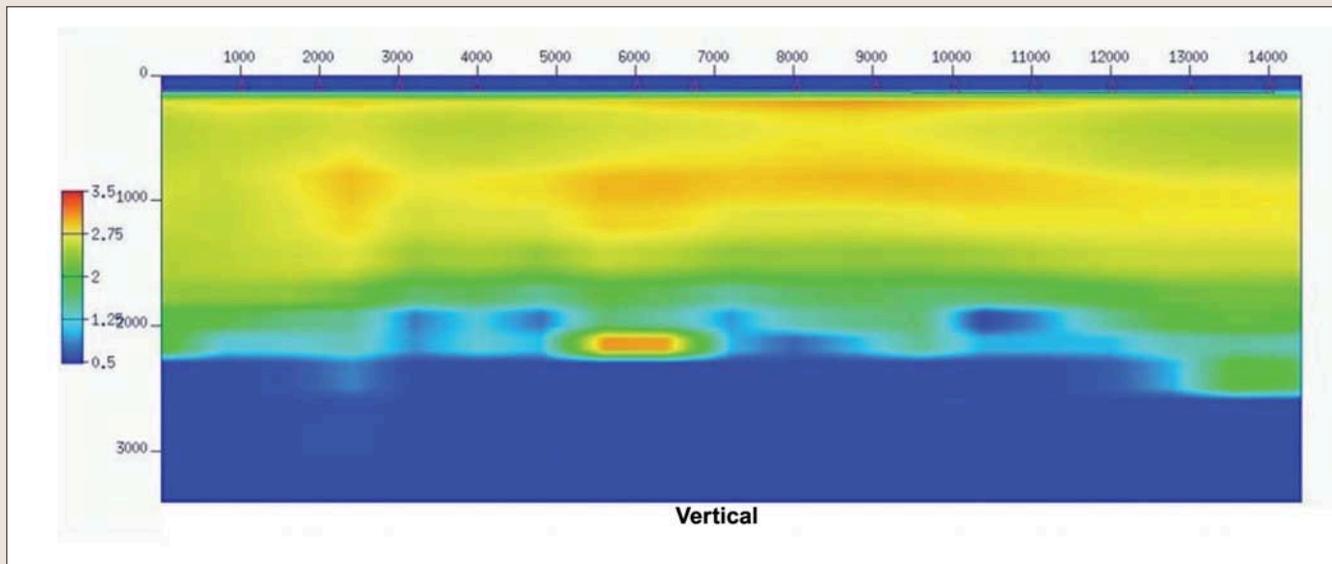


Figure 5. CMP inversion result from receivers along line Tx06 (Figure 1). The x-axis is horizontal scale in meters, while the y-axis is depth in meters and the color represents the resistivity.

ity to link observations between lines, reducing the uncertainties in mapping areas of increased resistivities.

Wide-azimuth data from offline receivers are incorporated by decomposing the horizontal components of the electric source into one transverse magnetic (TM) mode component and one transverse electric (TE) mode component. The horizontal electric field measured in the inline direction is caused by the TM component of the source, while the horizontal electric field measured normal to the inline direction (the broadline direction) is caused by the TE component of the source (Maaø et al., 2007). These two field components have different sensitivities, as the inline electric field is more than 20 times more sensitive to thin resistors compared to broadline data (Constable and Weiss, 2006). Data for each individual survey must therefore be examined for the sensitivity compared to the azimuth angle. In order to maintain the sensitivity to thin layers, wide-azimuth broadline data are muted. In the example shown, wide-azimuth data to an angle of 55° are maintained. In this case, the data density increased from the 0.31 points/km² to 0.72 points/km² at 5 km offset. This increase is relatively low compared to what is obtained at even larger offset and in larger surveys.

Scanning data can be displayed in a map view (Figure 3) or in 3D cubes. Incorporating azimuth data makes it possible to obtain an improved image of the area of increased response. Modeling has shown that incorporating wide-azimuth data produces an improved representation of the structures compared to pure inline data (Ridyard et al., 2006). The increased resistive response observed on the inline data (Figure 2) can now be linked as well as extended further to the east (Figure 3). Towing in two orthogonal directions, which requires a regular grid, could further improve the sensitivity and resolution of a structure (Ridyard et al., 2006). Regular grid and dual towing is common in detailed scanning where a closer receiver spacing is used. The closer receiver spacing allows advanced processing, while the increased sensitivity obtained by dual-towing is handled best through 3D inversion.

The western limit of the increased resistive response could not be resolved from the initial scanning; the challenge, in time for the APA 2007 application, was to determine and interpret the exact nature of the increased resistive response and its associated depth. CMP (common midpoint) inver-

sion was later used for analysis. An SBL response, associated with the reservoir sandstones, was detected on the SBL data at an offset of 5000 m, and SBL data defined a four-way dip closure present on the basis of the SBL response. Regional mapping of the reservoir sandstones later enabled the application team to match the geographical location of the sandstones and the SBL response, indicating that the lead was present.

Consequently, an additional program comprising three SBL lines with 1-km receiver spacing was deployed to investigate the extension of the area with increased resistivity. This was planned and executed weeks after the original program. The receiver spacing used not only improved the lateral resolution, but also made inversion possible. Inversion provides resistivity profiles along the lines. In this case, CMP inversion, which is a quick and robust approach to obtain subsurface resistivity sections, was used. The main advantage of this method is that it is numerically very efficient due to plane-layer modeling of data in the CMP domain (Mittet et al., 2007). In the CMP inversion, the SBL data are sorted in the CMP domain, where each CMP gather is inverted simultaneously. A regularization term is utilized, which has a smoothing effect between the CMP gathers and also allows a limited number of sharp resistivity changes. The CMP inversion indicates a weak resistivity increase at 1-km depth (Figure 4). The extension of this increased resistivity corresponds to the observation that can be made on the map view of all inline and wide-azimuth data (Figure 5), which show a relatively large and well-defined area with increased resistivity in the western part of the survey area.

The described case was one of eight scanning surveys acquired by Aker Exploration ASA in 2007. In addition, two infill surveys were acquired for the APA 2007 application (97 days of operation). Subsequently, two surveys have been acquired for the 20th licensing round screening process. Aker Exploration ASA has used the SBL data both in mature areas for potential bypassed pay close to existing infrastructure not easily identified on seismic, and in frontier areas where large accumulations need to be detected to justify the development of sufficient infrastructure in the area for potential production. The purpose of this approach was to provide an additional tool for exploration decision-making for prospect ranking, as well as an additional data acquisition strategy

for the APA 2007 and for the first phase of screening and nomination of blocks for the 20th licensing round.

When leads are identified on the basis of a scanning survey at such an early stage, it is possible for the operator to better assess the leads and make decisions for acquisition of additional data, either SBL infill data or acquisition of focused seismic. Conceptual modeling has been used, based on petroleum play analysis, to optimize the acquisition design for an optimal SBL response. A typical grid size of 3 × 3 km enables the operator to scan larger areas, obtain results quickly, and make exploration decisions accordingly. Whereas grid sizes of 3 × 3 km can only identify the potential presence of resistive anomalies, a more detailed infill survey is required to perform more advanced geophysical processing, such as CMP inversion, depth migration, and 3D inversion. With a grid size of 1 × 1 km, the operator can investigate anomalies in more detail and hence identify potential prospects with respect to depth and strength.

Although a resistive anomaly may have been obtained from both the scanning survey and the infill survey, it is critical in exploration decision-making to challenge the initial model that formed the survey design. The initial model is derived from knowledge around the regional geology and logs from available relevant wells. Challenging the initial model should include testing it against depositional models, presence of certain minerals locally and regionally, and comparison with possible well logs in the area. If the model

survives being tested against possible alternative models, it may represent a good basis for the next exploration phase of the prospect, which may include acquisition of additional seismic data for a better prospect definition, or, potentially, drilling the prospect.

Ultimately, the time from data acquisition to first oil has the potential of being reduced compared to a more conventional exploration approach.

Suggested reading. "Seabed logging: A possible direct hydrocarbon indicator for deep sea prospects using EM energy" by Kong et al. (*TLE*, 2002). "Remote sensing of hydrocarbon layers by sea bed logging (SBL): Results from a cruise offshore Angola" by Ellingsrud (*TLE*, 2002). "Reservoir identification using refracted wave" by Ellingsrud (Patent application number WO 01/57555, 2001). "Azimuth decomposition of SBL data" by Amundsen et al. (*GEOPHYSICS*, 2006). "Decomposition of electromagnetic fields into upgoing and downgoing components" by Maaø et al. (*SEG 2007 Expanded Abstracts*). "Mapping thin resistors and hydrocarbons with marine EM methods: Insights from 1D modeling" by Constable and Weiss (*GEOPHYSICS*, 2006). "Electromagnetic prospect scanning moves seabed logging from risk reduction to opportunity creation" by Ridyard et al. (*First Break*, 2006). "CMP inversion of marine CSEM data" by Mittet (*EAGE Extended Abstracts*, 2007). [T|E](#)

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