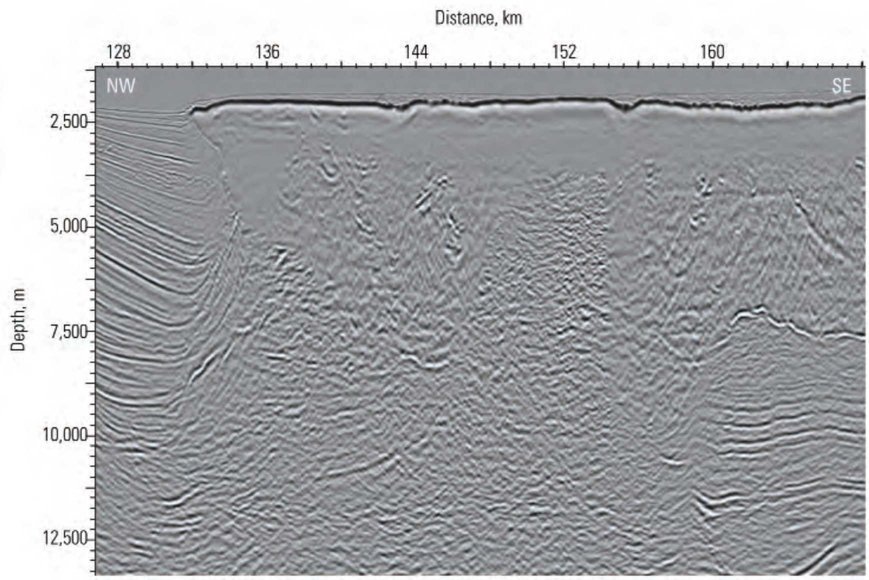
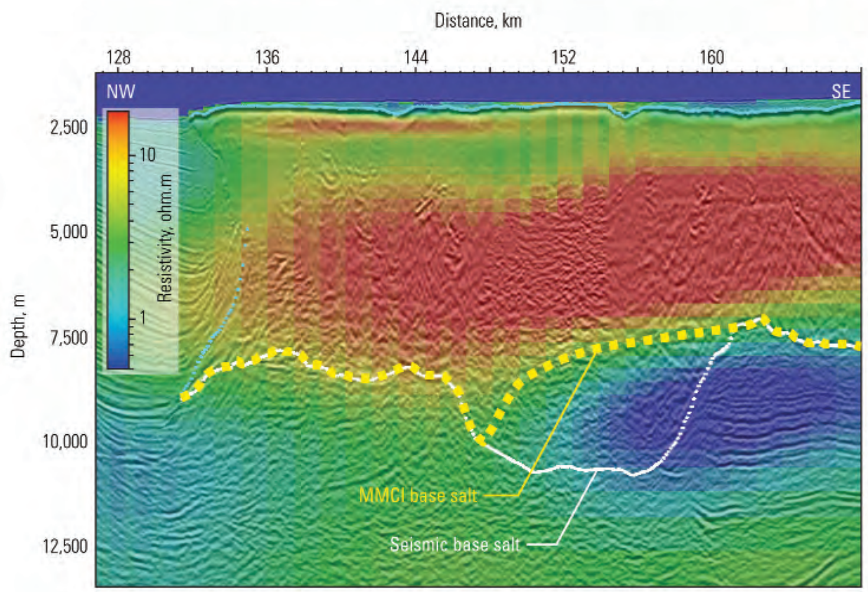
Electromagnetics takes on deepwater risk

Integrating seismic with non-seismic techniques has proven to lower exploration risk, particularly in deepwater frontiers where challenges, logistics, and costs can be formidable.

AUTHORS
Marcus Ganz *and* ***Jim Thomas****,*
WesternGeco





The base of salt is difficult to find in the WAZ seismic section (top). The best pick based on the seismic data had a thick section to the right of middle (white outline, bottom). MMT resistivity data (colors) add significant new information. Combining seismic, MMT, and gravity data in the MMCI evaluation improves the previous interpretations of the base of salt and gives interpreters greater confidence in their result (yellow dashed line). (Images courtesy of WesternGeco)

Exploration is moving into deeper waters, and while the rewards for moving further from the coastline have proven to be huge, the risk involved has also been amplified dramatically. The oil and gas industry has long realized that information is the greatest tool in mitigating risk. By understanding more about what lies beneath the surface, the risk of drilling a dry hole is reduced.

With deepwater marine drilling costs topping US $1 million per day, anything that can increase the margin of success is welcomed. A balance must be struck between the cost of gathering more information and the impact this information will have on decisions made further along in the process. Several exploration methods have been proven to add significant value, some of them very traditional but with some new technologies as well.

Systematic approach improves odds

Deepwater exploration used to begin and end with 2-D seismic acquisition. Today the quality and accuracy of seismic surveys has improved markedly, as has the post-processing and interpretation tools at the explorationist's disposal. Prestack depth migration (PSDM), amplitude variation with offset (AVO), and 3-D visualization have enabled geoscientists to image large volumes of reservoir quality rocks, even those lying beneath thick salt and basalt deposits. Acquisition techniques now include wide-azimuth (WAZ), multi-azimuth (MAZ), rich-azimuth (RAZ), and full-azimuth (FAZ) surveys that maximize existing technologies. Still, even with all these advanced techniques, certain exploration challenges remain.

Today, workflows are being developed to integrate technologies that reduce the exploration risk in demanding deepwater environments. The basic approach is to create a geological model from all available information, then enhance the model by the systematic application of complementary measurements until exploration risk is reduced to acceptable levels. While all of the seismic tools mentioned above tell a large part of the exploration story, many information gaps may be filled in with non-seismic methods. Seismic techniques may predict the presence of hydrocarbons in a formation, but one of the biggest pre-drill knowledge gaps is formation resistivity. Formation resistivity is one of the most reliable indicators of hydrocarbon saturation levels within a formation structure. Previously this information has only been available through well logs, but now electromagnetics is providing subsurface resistivity information before drilling.

Electromagnetic techniques are natural complements to seismic and can be integrated into the seismic model to enhance knowledge and reduce exploration risk. There are two prominent methods: marine magnetotelluric (MMT) surveys and controlled-source electromagnetic (CSEM) surveys.

MMT is a natural-source electromagnetic method of imaging subsurface structures. Natural variations in the earth's magnetic field induce electric (telluric) currents to flow under the surface. Measurements of the orthogonal components of the electrical and magnetic fields formed by these currents can be processed and modeled to image the resistivity structure of the subsurface on a macro scale.

CSEM receivers are deployed from the survey vessel; after the survey they are released from their anchors and float to the surface, where they can be retrieved and data downloaded.

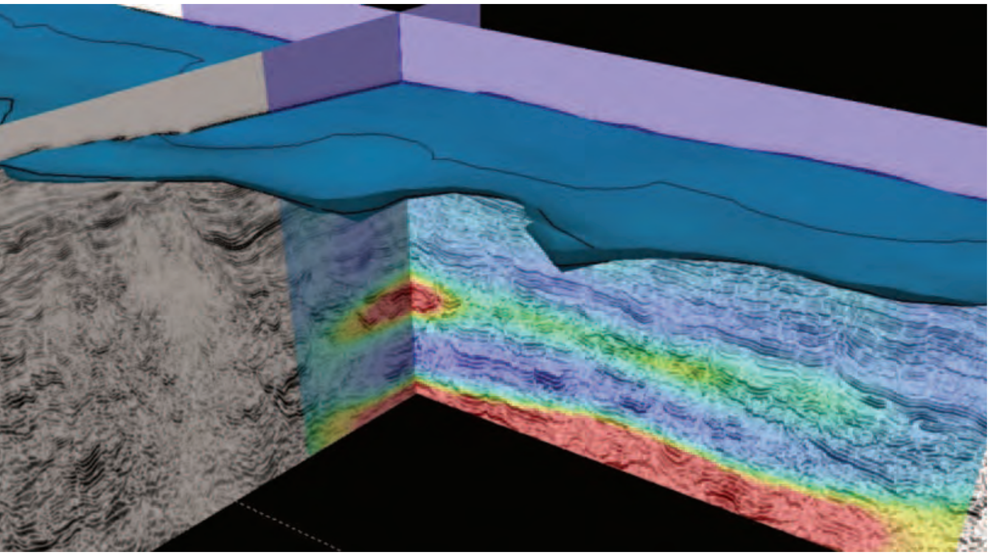
Very sensitive seabed nodes are deployed in water depths between 305 and 13,124 ft (100 and 4,000 m). These receivers are held in place on the seafloor with degradable anchors. The receivers measure tiny variations in the earth's electromagnetic field caused by the field's interaction with the underlying geology. After recording their measurements, the modules are released from their anchors using an acoustic modem. They then rise to the sea surface, where they are retrieved and data is downloaded by technicians working on the survey vessel. The newly acquired data is processed onboard, and resistivity as a function of depth and lateral position is calculated and interpreted using both time-tested and novel proprietary techniques. The interpretation is then plotted as an attribute within the 3-D geologic model, where it can be correlated with the seismic data, well logs, and any other data that may exist.

MMT cannot locate oil directly, but it can be used to understand the overall geometry of the structure beneath the seafloor, including problematic formations of salt and basalt. It's a way to get a little closer to the prize. The maximum power of MMT is realized when it is combined with seismic and other measurements like gravity to more accurately delineate the shape and thickness of large resistive bodies that could not be imaged by seismic alone.

More detail improves the picture

Using the same receivers as MMT, CSEM is an active system that images resistive bodies beneath the surface. While the electromagnetic field measured using MMT is limited to the frequencies and geometry of the earth's natural fields, CSEM uses a man-made source to control and fine-tune the measured field to the target being imaged. The fine-tuning of the source allows the geophysicist to precisely design a survey to illuminate rocks that are suspected of bearing hydrocarbons.

An array of CSEM receivers is deployed on the seabed in a comple-



Dataset shows CSEM data integrated with seismic from the Potiguar basin offshore Brazil.

mentary grid pattern. However, this time the survey vessel tows a very powerful electromagnetic dipole source through the water in a pattern across the receiver grid and several dozen feet above it. The receivers measure the electrical and magnetic field responses to the illumination of the subsurface strata by the source. The receivers are retrieved in a similar fashion to MMT receivers, and the recorded data are downloaded by the technicians on the survey vessel. From these data CSEM reveals information about subsurface resistivity. When correlated with seismic data, resistive structures can be imaged and discriminated from host rocks. After integration into the geologic model, CSEM data can reduce the uncertainty of promising drilling targets.

Deep water is the perfect environment for CSEM. When early surveys were conducted in shallow water, source energy could become omnidirectional. Accordingly, it propagates upwards as well as downwards. In shallow water, the air above the water acts as an infinitely resistive body; the resulting airwave complicates the interpretation of the subsurface signal or occludes it altogether. This "airwave" effect has been largely nullified by using advanced acquisition and inversion techniques to understand the data.

Arctic possibilities tempt explorers

One such example of an effective CSEM response was in the waters off the West coast of Greenland. In 2008, 3-D seismic and gravimetry were used to map a series of exploration prospects in two blocks lying in 1,148 to 5,900 ft (350 to 1,800 m) of water about 75 to 125 miles (120 to 200 km) west of Nuuk, Greenland's capital city. The nearest offset wells were more than 75 miles (120 km) away.

Using structural models developed from 3-D seismic, CSEM data were used to help prioritize the prospects. The targets were Cretaceous reservoirs lying 9,840 ft (3,000 m) beneath the surface. Forward modeling and inversion of 3-D seismic data was used to design the optimum measurement parameters, and a complex survey utilizing 182 receiver locations was designed. This survey included 24 transmitter lines mapped with towlines designed to generate data from multiple angles as the source passed over the grid. CSEM amplitude and phase responses were recorded as a function of transmitter-receiver offset at each location.

The combination of seismic and CSEM clearly delineated several resistive bodies within the 14 prospects. Further confidence was obtained by correlation with known resistive Paleocene volcanic rocks and when inversion coincided with structural closure. The combination of all the geophysical measurements when integrated into the geological model allowed the exploration team to identify lithological structures such as basement and volcanics. It also enabled the team members to prioritize their attention on structures of interest and assist in the task of ranking potential drilling prospects.

Deepwater Brazil

The deepwater Potiguar and Ceará Basins offshore Brazil are possible targets for the next Brazilian licensing rounds. The area has already been surveyed extensively with seismic, and approximately 7,500 miles (12,000 km) of multiclient 2-D data exists in the Schlumberger library in this area.

A model was built using PetroMod petroleum systems modeling software. This software uses seismic data for structural control, then integrates log data and overall geologic knowledge with the evolutionary data for the basin to predict how traps are formed and how likely they are to be charged with hydrocarbons. This involves identifying the source rock, hydrocarbon migration patterns, quantities, and hydrocarbon types in the subsurface. When combined with Petrel seismic-to-simulation software and VISAGE geomechanics software, the modeling software offers a near-complete set of tools for modeling and integrating measurements in an exploration workflow.

Using a systematic workflow, PSDM seismic data were used to select prospective areas; these were correlated with oil seep maps to select the most promising prospects, and sensitivity studies were made to confirm their suitability for CSEM surveying. Three-D CSEM data were acquired over a number of prospects confirmed by the software model. The result is a multiclient dataset comprised of a 3-D volume of petroleum systems attributes integrated with PSDM seismic and 3-D CSEM inversions over the most promising prospects. E&P