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Electromagnetic Prospect
Scanning - Seabed Logging Moves from Risk Reduction to Value Creation

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Abstract

Seabed logging is an emerging technology that measures subsurface resistivity prior to drilling. The technique has been commercially available for over 5 years, and has been proven to reduce drilling risk in many offshore geologic environments.

Electromagnetic scanning is a new application of this proven technology. Sparse spatial sampling and wide azimuth geometry can be used to apply seabed logging to find and accelerate delivery of new prospects in frontier areas.

In this paper, we evaluate the costs and benefits of various geometries and show results from the Campos basin in Brasil.
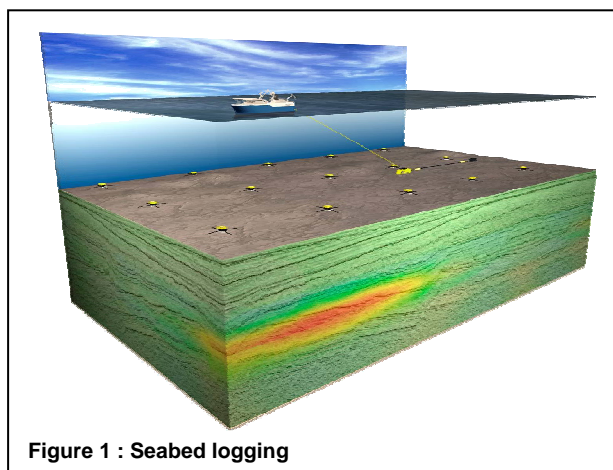
Figure 1 : Seabed logging

Introduction

The traditional approach to frontier exploration is to use seismic data to identify structures that are likely to contain hydrocarbons, and then test the structures through exploration drilling. As exploration is driven to increasingly challenging environments, particularly deep water, this approach involves massive investment and risk to operators.

Over the past 5 years, seabed logging has emerged as a major new tool to reduce drilling risk. The physics underpinning this technology is well known. The electrical resistivity of a formation is determined primarily by the pore fluid. Hydrocarbon charged rocks exhibit significantly higher resistivity than water filled rocks. If we can measure the resistivity, we can infer the pore fluid. This principle has been understood for many years, and has been used for the interpretation of borehole resistivity logs.

In recent years, it has become possible to measure the resistivity of the subsurface prior to drilling a borehole[1,2,3]. Seabed logging is defined as the use of controlled source electromagnetics (CSEM) for the purpose of finding hydrocarbons. Figure 1 illustrates the technique. A powerful horizontal electric dipole source is towed close to the seabed. This source generates electric and magnetic fields which are perturbed by any buried resistors. Careful measurement and analysis of the resultant fields allows the location of buried resistors to be estimated. It should be noted that not all buried resistors are hydrocarbon reservoirs, and the technique requires careful co-interpretation with other forms of data, such as seismic, well logs etc.
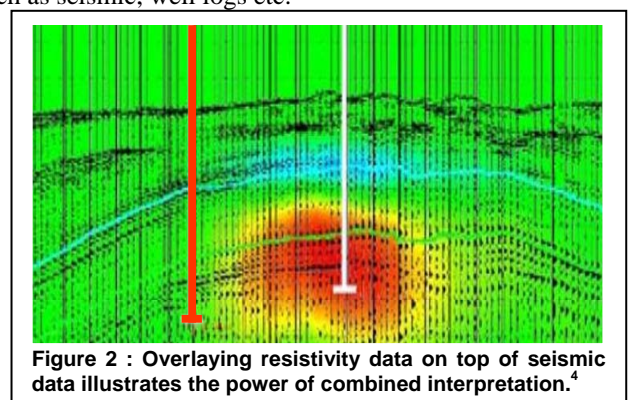
Figure 2 : Overlaying resistivity data on top of seismic data illustrates the power of combined interpretation.[4]

Figure 2 illustrates the power of combining seabed logging data with traditional seismic data. The red well on the left was drilled based on seismic data alone, but no commercial discovery was made. A subsequent seabed logging survey revealed a major resistive anomaly below the crest of a large adjacent structure, which was poorly imaged on P-wave seismic due to the gas cloud above the prospect[4].

Seabed logging has now been used by over 40 operators on over 250 projects. Projects typically comprise a few lines acquired over a prospect identified from seismic data. During the course of some of these projects, unexpected hydrocarbon related resistive anomalies have been detected. This phenomenon has led several companies to re-think the application of seabed logging technology. Should seabed logging be used to verify the presence of hydrocarbons in prospects identified on seismic data, or should we try to apply seabed logging on a wide area basis to seek out new prospects? The answer, of course, is that both applications have a place in the exploration workflow. In this paper, we will look specifically at issues relating to the use of seabed logging to cover large areas.

This technique has been called scanning. The principle product of a scanning survey is an areal measurement of subsurface resistivity, providing information about fluids contained in structures. Scanning offers the potential to create a number of key benefits to different stakeholders.

(a) Operators benefit because exploration effort is focused on most prospective areas early in the explorations cycle, resulting in : -
- Reduced exploration cost
- More efficient use of resources such as capital, personnel, seismic crews, drilling crews etc.
- Earlier delivery of prospects and reduced time to first oil.

(b) Local communities benefit from reduced environmental impact through a reduction in the amount of seismic activity and dry holes drilled on prospects that ultimately contain no hydrocarbons.

The potential benefits of scanning are significant, but must be measured against the likely costs. Whereas seismic exploration techniques have evolved over many years, based on well understood sampling theory, scanning is a new concept, and this paper seeks to address some fundamental questions about the sampling requirements and operational techniques that will deliver the most cost-effective scanning solution to an exploration problem.

Method – Grid modeling for scanning

Traditional seabed logging surveys are designed based on a thorough understanding of the structure under investigation. For scanning surveys the design process is fundamentally different in 2 ways : -

(i) There is minimal requirement to characterize the target. The goal is simply to detect potential targets, and then focus additional exploration effort (seismic and/or seabed logging) on the targets.

(ii) The goal is to detect unknown reservoirs, so the same level of detailed, target specific modeling is not possible.

This first point simply means that the geometry of the survey is minimally sufficient if a reservoir is detectable. The challenge for survey design is to define which targets will be detectable, and with what confidence. Since modeling of seabed logging is largely accurate, it is a fairly simple process to model a dense grid of source and receivers, and then decimate the data to determine the most operationally efficient and robust acquisition geometry.

The problem still remains that for a frontier area, there may be multiple known and unknown targets, so the question remains what reservoir should be modeled ? To answer this question, two basic principles must be applied[5] : -

(a) One or more artificial reservoirs, typical of the geology of the basin should be designed.

(b) For frontier areas, the artificial reservoir must be of sufficient size to justify construction of production and transportation infrastructure. A scanning survey may be a success if it finds a small reservoir in shallow water, close to a producing platform. However, a survey might be a failure if it finds the same field in deep water 200km from the nearest production infrastructure.

Once a "typical" economic reservoir has been defined, a dense grid of sources and receivers is defined, and the data is modeled. Note that it is important to include the realities of the instrumentation and the earth's response. This means that noise should be included in the modeling, and signals below the threshold of detection of the instruments should not be included in the results presented.

Figure 3 : Simplified scanning survey design workflow
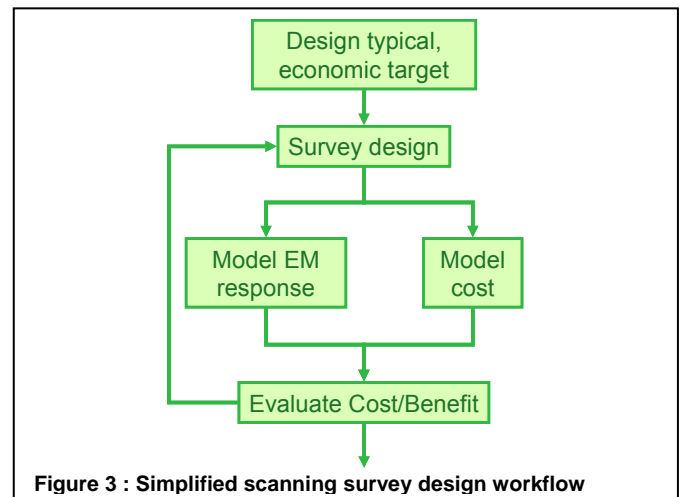
One other challenge of the technique is that there are literally thousands of potential acquisition geometries, and some means of rapid evaluation of modeling results is required. In this paper, we evaluate the response using a geometric response indicator[6] (GRI). This is a reasonably robust measure of the overall response of a given geometry to a given target, and can be used to narrow down the range of possible parameters for a survey. Final optimization of survey parameters requires more detailed consideration of multiple attributes to ensure that the selected survey design will be robust in the presence of reasonable variations in target burial depth, water depth, size, orientation, thickness and resistivity contrast. Consideration must also be given to the possibility of irregularities in acquisition geometries, potentially including occasional receiver failures. Figure 3 summarizes the survey design workflow.

Examples – Spatial Sampling

For our initial study of sampling geometries, we selected the model shown in Figure 4. This comprises a structure having 3 fault blocks. The northern and southern fault blocks are assumed to be hydrocarbon charged, whilst the central block is assumed to be brine charged.
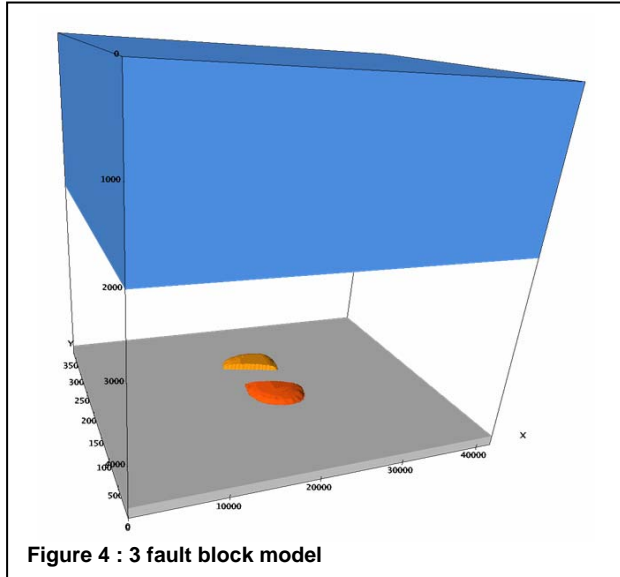

Figure 4 : 3 fault block model

For the purposes of this survey design, a number of different depths of burial were evaluated, demonstrating detection capability at burial depths in excess of 2.5km.

Figure 5 illustrates results for a shallower target (1km burial depth) with a simple, parallel line, north-south scanning geometry. The initial modeling was performed based on a fully sampled 1km source and receiver spacing. The GRI plots for this geometry show a target which is clearly detectable. With this dense sampling, it would be possible to depth migrate[7] or invert the data to place the target at the correct depth, and obtain a reasonable delineation of the three fault blocks. However, this is beyond the scope of this paper.

In the real world, this densely sampled geometry would take a long time to acquire, and in many cases data must be acquired quickly to meet licensing or drilling deadlines, or to maximize the area covered during a brief period of favorable weather. Consequently we must investigate the effectiveness of sparser geometries. As the data density is reduced, it can be seen that the representation of the target becomes less intense, and its apparent location and shape become increasingly influenced by the placement of the individual receivers. Furthermore, as the sampling becomes sparser determination of the correct depth becomes more problematic, because a smaller and smaller range of offsets are able to sample the target.
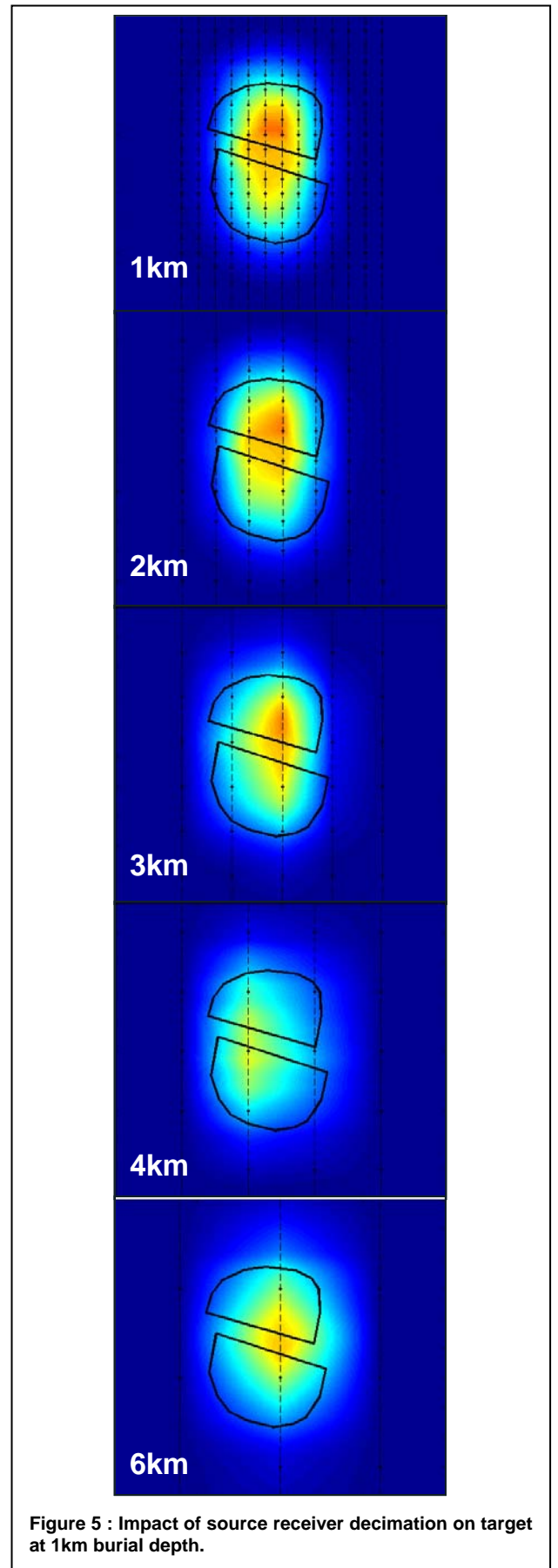

Figure 5 : Impact of source receiver decimation on target at 1km burial depth.

Even with 6km geometry, the target is detectable, and acquisition time is reduced significantly relative to the 1km geometry. In practice, a 4km geometry would retain most of the desired time savings, whilst being more robust in the presence of an occasional failed receiver, and having more ability to detect smaller reservoirs (thinner, less resistive contrast etc.)

Examples – Azimuthal effects

One obvious way to improve the probability of detection of targets, particularly with regard to targets having some orientation is to acquire some wide azimuth data. One approach is to acquire lines of data on an orthogonal grid – effectively repeating the geometry shown in Figure 5, with a second set of acquisition orthogonal to the first. Whilst this can be shown to provide a significant improvement in data quality (Figure 6) it may not be the most effective solution, since it almost doubles the time to acquire the data.
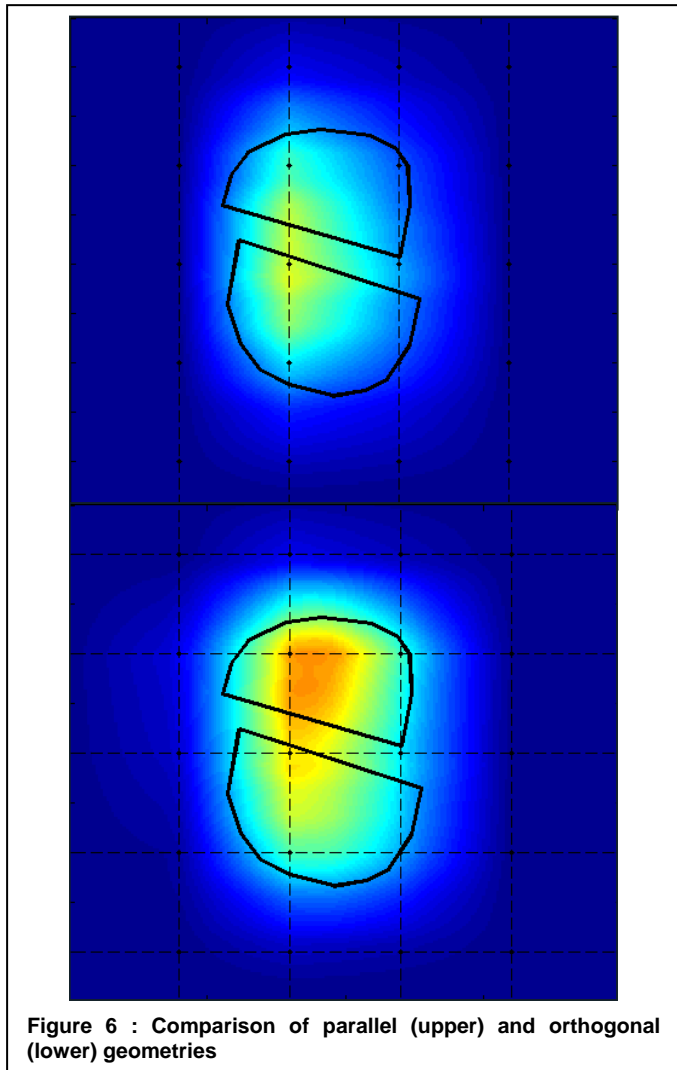

Figure 6 : Comparison of parallel (upper) and orthogonal (lower) geometries

Even more data can be acquired, and the volume can be sampled more fully if all receivers are active throughout the acquisition of both the orthogonal sets of source lines. However, for large areas (2,000 sq.km. or more) this becomes increasingly impractical due to the requirement for hundreds of receivers, and a battery life requirement of many weeks.

An alternative, more practical, geometry is to acquire parallel lines, but to deploy the receivers for the acquisition of the adjacent source lines, resulting in 3 times the data for very little increase in acquisition time. It should be noted that the beam pattern for a horizontal electric dipole source is such that there is little or no useful energy transmitted orthogonally. As a rule of thumb, the useable energy lies within +/-45 degrees of the inline direction, so the minimum useable offset for azimuthal data is approximately $\sqrt{2}$ x line spacing. Figure 7 shows the GRI result for the 3 line acquisition geometry. In this case, the inclusion of the azimuthal data improves the view of the target both in amplitude (an indicator of probability of detection) and in location and shape. Note that even the non charged central block has now become apparent.
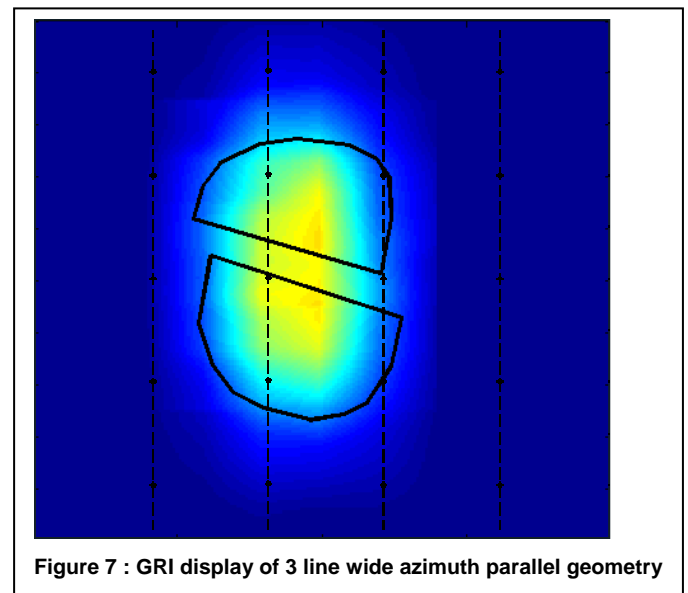
Figure 7 : GRI display of 3 line wide azimuth parallel geometry

Considered from the perspective of scanning, where we only seek to detect targets, this improvement in delineation is only marginally relevant. However, if we consider a different model, comprising a long thin target, perhaps a channel sand, lying between the acquired lines, the probability of detection is enhanced if wide azimuth data are used. (see Figure 8)
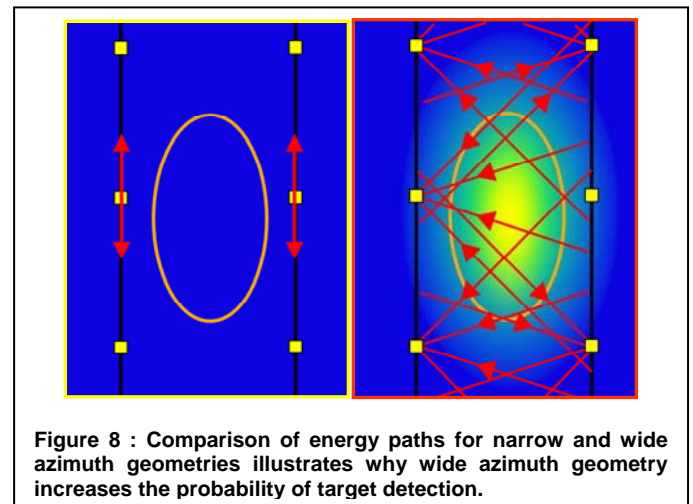

Figure 8 : Comparison of energy paths for narrow and wide azimuth geometries illustrates why wide azimuth geometry increases the probability of target detection.

Results – Campos

The Campos Basin is the most productive and prolific of the petroleum basins in Brazil. It underlies the continental shelf of the State of Rio de Janeiro and covers an area of about 100,000km^2. The oil fields discovered occur in water depths ranging from 80m to more then 2600m. The initiation of the basin was associated with the Early Cretaceous rift-valley system splitting Africa and South America. The most important potential reservoir intervals are taken to be the Tertiary and Upper Cretaceous deep water Turbidity sands. The typical thickness of these turbidity plays vary from 80 m to 150 m. When hydrocarbon filled the resistivity of these reservoir sands typically range from 40 to 100 ohm-m.

Seabed logging has already been proven to be effective in the Campos Basin[8]. Furthermore, a pilot scanning project acquired in 2005 indicated that scanning could be effective in identifying buried resistive anomalies in this area. (See Figure 10.)
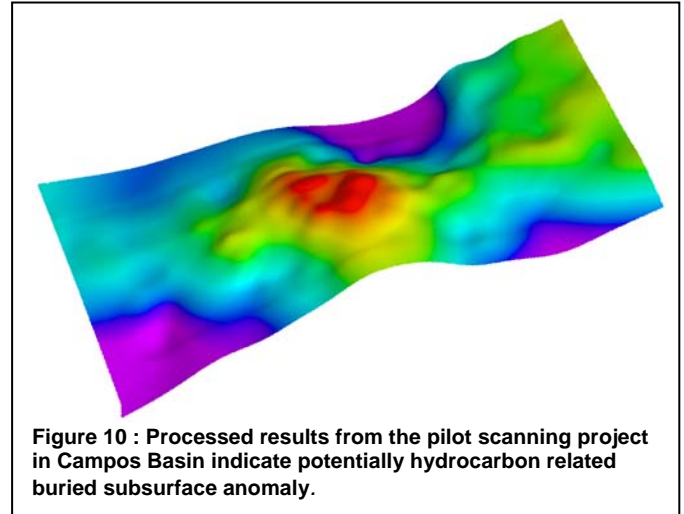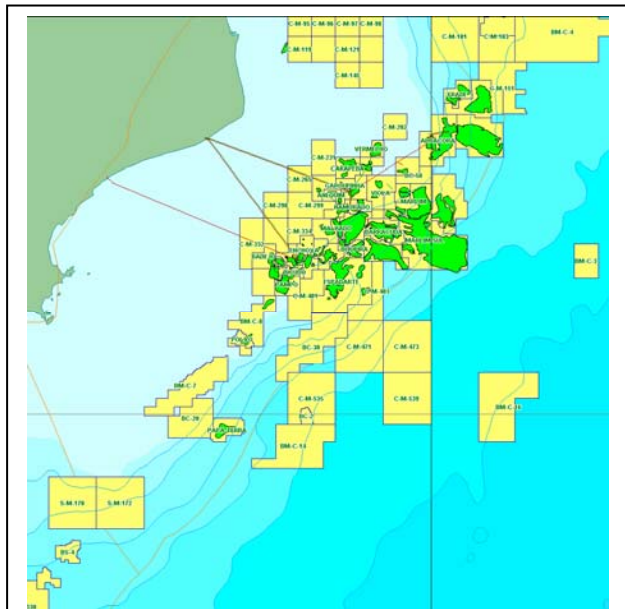

Figure 10 : Processed results from the pilot scanning project in Campos Basin indicate potentially hydrocarbon related buried subsurface anomaly.

Figure 9 : The Campos Basin. Cost and risk of exploration will increase as new license areas become available in the deep water areas to the south and east.
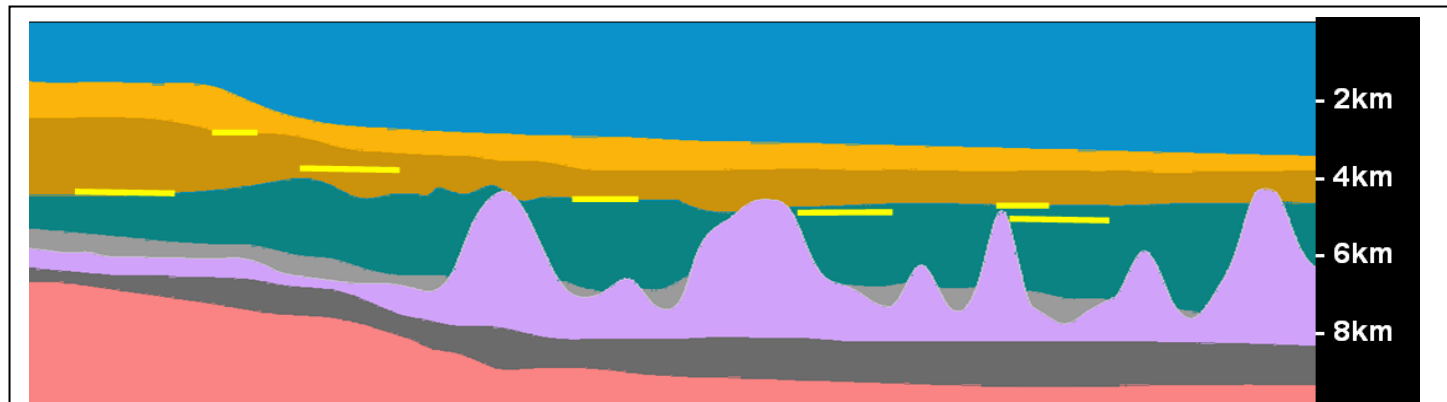
As new deep water areas in the Campos Basin are licensed for exploration, this is an area where scanning could have considerable merit.

In order to optimize the acquisition parameters for a large scale scanning project in the Campos Basin a model was constructed based on input from operators with experience in the area. The principal parameters of the model (structure, background resistivity etc.) were based on knowledge of regional geology and bathymetry. A number of potential reservoirs typical of the area were then placed in the model. These reservoirs were designed to have size, shape, burial depth and resistivity comparable to other structures already discovered in the area. (See Figure 11)

A process known as grid modeling for scanning was then performed. In this process a dense grid of source lines and receiver locations was modeled, and successive decimation of the modeled data was performed to develop the best compromise between confidence of detection and cost/time to acquire.

Figure 11 : Transect through 3D model used to evaluate parameters for Campos Basin scanning project. Geology and reservoir parameters where selected to be typical for the region.

Conclusions

Seabed logging has become a routine tool to reduce drilling risk, especially in deep water applications.

Scanning is the next stage in the development of seabed logging, it represents an important tool to identify new leads early in the exploration cycle.

The Campos Basin contains geologic settings that are conducive to the application of seabed logging in both its traditional and scanning form.

The scanning technique is a 2 phase process. In the first phase, the goal is only to detect the existence and location of buried resistors. The second phase is to acquire more detailed data to vertically and laterally delineate the target, and classify the anomaly as hydrocarbon related or non-hydrocarbon related.

In the first phase of this process, the technique is quite robust, and allows significant decimation of source and receiver data, making it rapid and cost effective using typical source and receiver spacings of 3-6km.

For these sparse geometries, wide azimuth recording is important to ensure that the earth volume under investigation is thoroughly investigated.

Thorough co-interpretation of seabed logging and seismic data is required to maximize the probability of success.

Acknowledgments

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