An integrated approach to frontier exploration

Combining gravity gradiometry with other exploration technologies can unlock new reserves.

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The last few years have seen a renaissance in frontier exploration with a resulting growth in advanced geophysical techniques. Three-D seismic, subsalt imaging, electromagnetics, and velocity modeling have all come to the fore as means of generating accurate information from increasingly complex and remote reservoirs.

Yet there is clearly much more that can be achieved. The fact remains that the reserve replacement ratio in 2008 was only 88% of production despite a 23% increase in development spending that year. The credit crisis in 2009 is unlikely to have improved that figure.

For the majority of operators, 2-D and 3-D seismic continue to be the technology of choice in frontier exploration – both onshore and offshore. However, the deeper and more complex geological settings, the challenging and environmentally sensitive conditions, and the need to explore large areas while controlling costs have focused attention toward other technologies in addition to seismic.

Seismic limitations include the environmental impact and large-scale infrastructure, the cost and long turnaround times, and the fact that many of the world's frontier regions are characterized by poor seismic responses – deserts, mountains, or presalt reservoirs, for example.

Having spent more than 25 years in oil and gas exploration with seismic having been the preeminent technology throughout, I have realized that seismic reveals some, but not all, of the answers in frontier exploration today. It is only through the utilization of data from as many different sources and technologies as possible that the operator will be able to economically image structures quickly, resolve geological uncertainties, and develop a more complete picture of the subsurface.

Key technology success factors

What are the key technology success factors in frontier exploration today? They consist of geophysical techniques such as seismic, gravity, and magnetics alongside geological-driven techniques focusing on the lithological, stratigraphic, and structural elements.

One non-seismic technology that has made significant steps over the last few years is gravity gradiometry imaging (GGI), a technique that maps small density variations in underlying rocks by measuring the gradient of the earth's gravity field.

Once considered a niche technology, GGI is today becoming a significant line item in exploration budgets, with well-known supporters including former Exploration Head at BP, David Bamford, who described GGI as a "potentially transformational technology." GGI is playing an important role in frontier exploration in several ways.

Firstly, airborne and marine GGI surveys and the non-invasive passive technology allow the exploration of vast regions quickly, accurately, and efficiently. By flying above the terrain, large areas can be cost-effectively surveyed, and areas can be pre-screened for additional spend with no adverse environmental impact.

Secondly, the data generated can be an important complement to traditional seismic, allowing operators to hone in on areas which require further seismic exploration. Whereas conventional gravity techniques were considered limited in terms of bandwidth, resolution, and accuracy, GGI comes with high resolution and

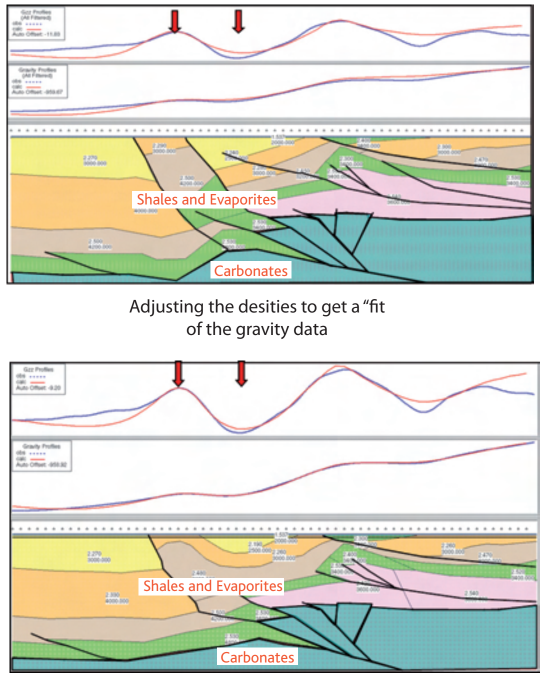

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Figure 1. A series of 2-D seismic lines were interpreted by integrating acquired GGI data with existing seismic interpretations and well data. (Images courtesy of ARKeX)

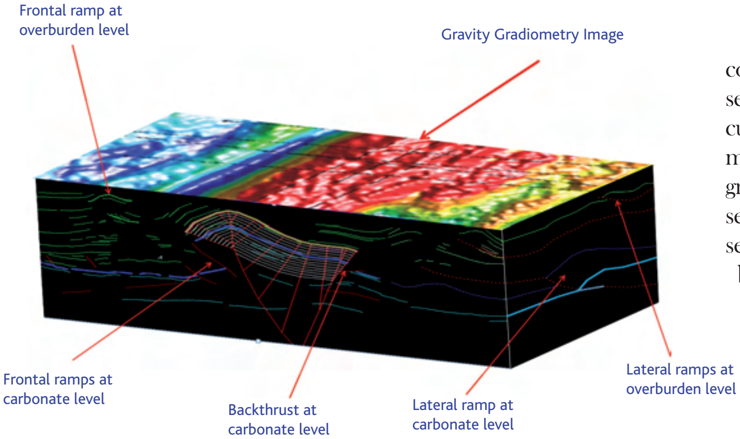

Figure 2.A 3-D cube image links the 2-D modeled lines with a gravity gradiometry image. The anticlines on the seismic-based cross section can be traced along the gravity gradiometry surface.

bandwidth capabilities, typically obtaining <2.5 Eotvos (a unit of gravity gradient) at 0.1 Hz. This helps operators support seismic imaging in correctly determining the velocity and density relationship.

GGI also measures all three components in all three directions of the gravitational force and is able to provide increased 3-D spatial awareness, viewing the influences on 2-D seismic data outside the plane of acquisition. In this way, it can be integrated with 2-D seismic data to provide an improved 3-D earth model and 3-D interpretations of the data.

Middle East frontier exploration

An example of how seismic and well data can be integrated with GGI in frontier exploration to provide a more complete understanding of the subsurface can be found in the Northern Oman Mountains in the United Arab Emirates.

The area has a complex geology with a complicated thrust environment and a poor seismic response, making conventional seismic-based frontier exploration challenging. Due to the significant density contrast between the reservoir interval (Lower Cretaceous carbonates) and the overlying sediments (Middle-Upper Cretaceous and Tertiary clastics), an airborne GGI survey was commissioned to improve exploration confidence in the top reservoir location.

GGI, magnetic, and LiDAR data were all acquired. Following data acquisition and processing, a series of 2-D seismic lines were iteratively interpreted by integrating acquired GGI data with existing seismic interpretations and well data.

The interpretation was driven by the need to match both the density profiles (guided by the gravity response) and the structurally balanced cross sections (Figure 1).

The integration of the data allowed for a better understanding of the thrust linkages at different levels and a better insight into the interaction of thrusts, backthrusts, detachment levels, imbricated zones, and lateral ramps.

The high-resolution GGI data also facilitated the accurate investigation of the 3-D shallow earth model (SEM). The modeling of seismic sections constrained by GGI and magnetic data helped to exploit their complementary nature and produced a more geologically realistic SEM.

The end result of the study was a 3-D earth model obtained by ensuring the constrained linkage of all data sets. Figure 2 illustrates a 3-D cube image linking the 2-D modeled lines with a gravity gradiometry image. One can see how the anticlines on the seismic-based cross section can be traced along the gravity gradiometry surface.

Figure 3.A well-constrained salt map has been developed in an area where seismic data is sparse and of poor quality.

There are also presalt exploration areas where GGI is complementing seismic and other geological and geophysical methods offshore Brazil, Angola, and Gabon. Here the operator requires as many datasets as possible to develop accurate velocity models with quantified uncertainty and to reduce risk parameters on presalt targets. GGI can accurately map the density contrast between salt and the surrounding rock and add 3-D velocity constraint to otherwise interpolated fields.

Figure 3 shows how a well-constrained salt map has been developed in an area where seismic data is sparse and of poor quality — often the case in presalt areas, where successful illumination of the target through seismic is a continuing challenge. The precision of the GGI-derived model, along with access to prestack seismic data, has led to the establishment of an accurate velocity/ density arrangement and development of the salt surface shown in blue.

Keeping an open mind

As frontier exploration moves into increasingly environmentally sensitive areas, such as the Arctic and the US Eastern Seaboard, it is clear that noninvasive techniques that can provide valuable geological information to aid the screening of such areas with next to no environmental impact will form the backbone of future exploration efforts.

GGI is one such example — a noninvasive technology that can complement more traditional methods, resulting in increased success in frontier exploration and improved reserve replacement ratios. E&P

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