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Large Scale Multi-2D PreStack Depth Migration: A Gulf of Mexico Deep Water Case Study

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ABSTRACT

The attraction of the deep water Gulf has increased over recent years due to the advancement of several core technologies. Foremost within these new applications is the use of pre-stack depth migration for illuminating the sub-salt structure, at water depths in excess of 3300 meters. Large scale 2D depth migration projects (e.g. > 3000 miles) provide a cost effect way of ascertaining the regional sub-salt geology and highlighting areas for prospect evaluation. The results from three large multi-2D, prestack depth migration projects are presented. The unique problems associated with depth migrating in the deep water province are highlighted in terms of acquisition, time processing and specifically the application of depth imaging technology for imaging of the sub-salt. It is shown that a combination of long streamer acquisition with prestack depth imaging can provide an adequate image of the sub-salt, suitable for prospect evaluation in a short period of time.

INTRODUCTION

With the need for increased reservoir resolution the use of prestack depth migration has been instrumental in the delineation of potential hydrocarbon fields. Even downgrading of prospects that at one time looked attractive to the prospector on conventional time processed data have been re-evaluated with depth imaging. It is fair to say that the importance placed on the use of prestack depth imaging at lease sales has often pushed the argument in favor of the technologically minded! The cost issues involved and the time spent in pursuit of the required depth perspective have dropped significantly over the years. Given both of these factors, prestack depth migration now presents an attractive processing route with reasonable returns.

The results from three large-scale two dimensional, prestack depth migration projects involving over 7000 miles (11300 km) of data are presented. The project areas cover the entire deep-water salt province extending from the western boundary of Keathley Canyon area to the eastern edge of the Walker Ridge region within the Gulf of Mexico (Fig. 1). Extensions to the project lines into the eastern half of Green Canyon and across the boundary into the Atwater region, track the Sigsbee Escarpment across the area.

Each project involved a consortium of oil companies with vested interests in the sub-salt geology of the salt canopy area, leading upto and culminating in a Gulf lease sale.

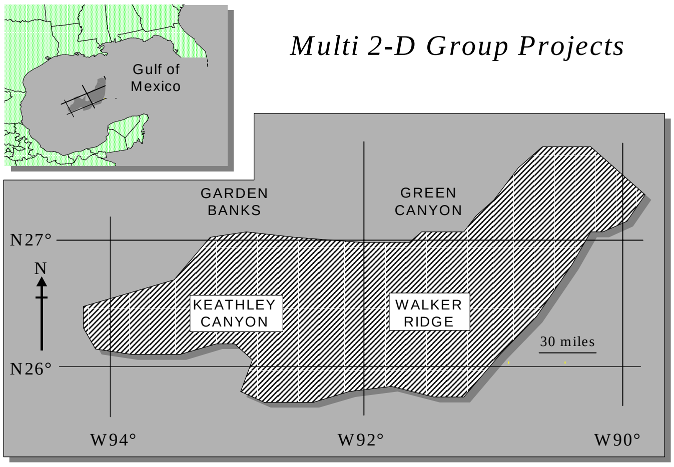


Figure 1. Location of the survey areas.

ACQUISITION AND TIME PROCESSING CONSIDERATIONS

The complex architecture of the salt canopy within the deep water results in strong wave-front attenuation culminating in low signal with respect to noise below the salt (Figure 2). Normally, in such geologically complex areas 3-D acquisition is required to provide sufficient sampling and energy penetration below the salt. However, the use of close grid 2D acquisition provides a realistic view of the potential problems involved in shooting 3-D surveys and helps companies focus on targets at drillable depths. Furthermore, there are currently few 3D datasets available in this part of the Gulf, which makes 2D data the only viable route.

In the northern half of Walker Ridge the geology is dominated by salt withdrawal synclines which in areas weld the salt forming mini-basins. Here the steep top salt produces a high degree of wavefront attenuation resulting in poor sub-salt sampling (Figure 3). Even at modest propagation angles (30^o) energy reaches the critical angle of reflection and is returned back off the top of the salt (Ogilvie and Purnell, 1996). Energy penetrating the salt is therefore largely confined to small source/receiver offsets. Large offset ranges are of use where the propagation path contains several mini-basins separated by only a thin wall of salt. Despite these geometrically related aspects of the data, longer offset information is necessary to provide focal resolution at depth. For example, figure four shows a comparison between two focusing panels situated through similar geology but generated using different cable lengths. The shorter cable acquisition (3270m) results in a considerable amount of dispersion in the focusing panel compared with the longer cable (7900m) version. As there is less move-out on a gather at these depths for a limited offset range, the interval velocity derived during prestack velocity analysis is generally much higher and open to greater mis-interpretation than with longer source/receiver offsets.

Of great importance to the successful depth imaging within this environment is the pre-conditioning that is applied to the data prior to migration. By far the most important component of this process is the handling of multiple events. At water depths in excess of 3300m long period water bottom multiples dominate. However, these are often accompanied by top and base salt multiples, which may be supra-salt or intra-salt in origin. Successful elimination of these multiples can be achieved using various algorithms. For the purposes of this study, the Radon transform has been applied (Foster and Mosher, 1992) successfully (Fig 5).

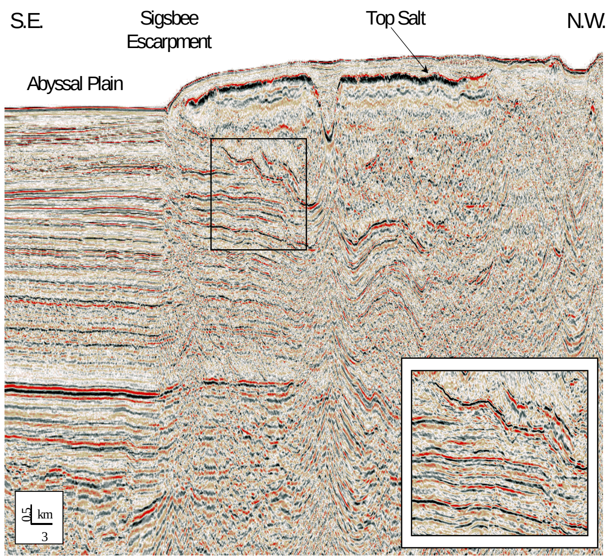


Figure 2. Prestack depth migrated section through the front of the salt canopy. Detail of the base salt and subsalt sediment truncations are shown in the inset.

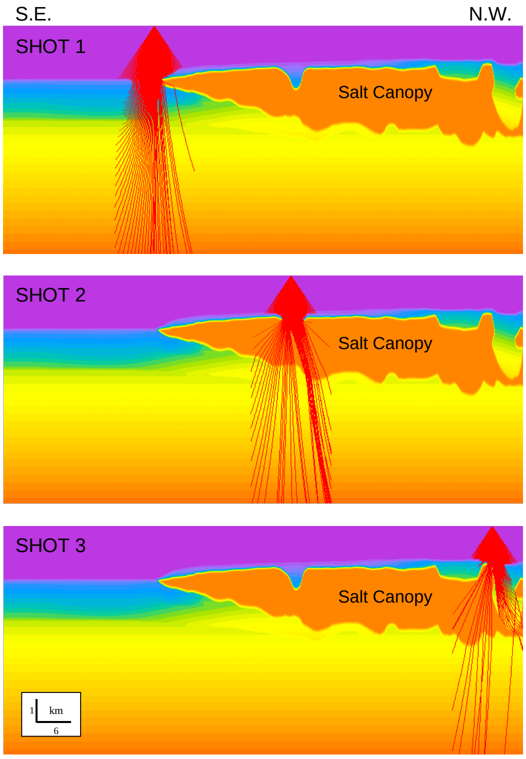


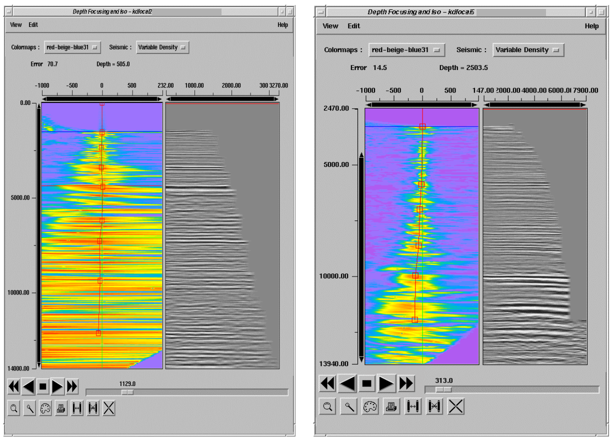
Figure 3. Pertrubation of a cone of rays shot within the migration aperture, through the velocity/depth model. The sub-salt sampling is dramatically reduced at extreme velocity variations related to the salt topography.

PRESTACK DEPTH IMAGING

Prestack depth migration seeks to optimally focus the sub-surface via the derivation of a velocity/depth model. In the area of Walker Ridge the image quality and derivation of the velocity model is dependent on many factors, in particular the amount of energy that can pass through the salt and return to the surface. Under the salt canopy traditional velocity analysis like Dix inversion of stacking velocities is problematic due to many factors including the presence of converted waves, low fold and migration noise. Of all the velocity analyses currently available tomographic inversion is by far the most robust method for deriving interval velocities under these conditions. Tomography's strengths lie in its rapid execution and on the fundamental constraint of observable data. Coupled with a Kirchhoff migration tomography facilitates cost effect depth migration.

Whilst sub-salt imaging in the Gulf of Mexico remains the current focus of a large proportion of the industries activity, supra-salt traps are much more economically attractive as hydrocarbon plays and carry a lower risk. The frequency content of the dataset coupled with a high resolution depth migration results in unprecedented detail in the supra-salt section (Fig. 6). The lateral coherency of the stratigraphy makes fault interpretation a straightforward exercise.

One of the main concerns with using 2-D data is the level of mis-tie, which should be present due to 3-D effects. Out-of plane events are common at the Sigsbee Escarpment and where seismic line orientations are oblique to the flanks of mini-basins. These events provide us with valid information for future acquisition. After analyzing a total of 150 dip and strike lines the top and base salt mis-ties were found to be in general very low (e.g. ~<1%). This value is unexpected for 2-D data over such complicated geology. The largest errors observed are at extreme depths (beyond effective streamer depth > 8000m) where the velocity resolution is low.



Short Streamer Acquisition

Depth Focusing and Iso – kdfocal2

Colormaps : red-beige-blue31

Seismic : Variable Density

Error 70.7

Depth = 505.0

Long Streamer Acquisition

Depth Focusing and Iso – kdfocal5

Colormaps : red-beige-blue31

Seismic : Variable Density

Error 14.5

Depth = 2503.5

Figure 4. Depth focusing panels and CRP gathers for short (3270m) and long (7900m) streamer acquisition. Note the dispersion in the coherency panel for the short streamer dataset.

PROCESSED TIME GATHERS

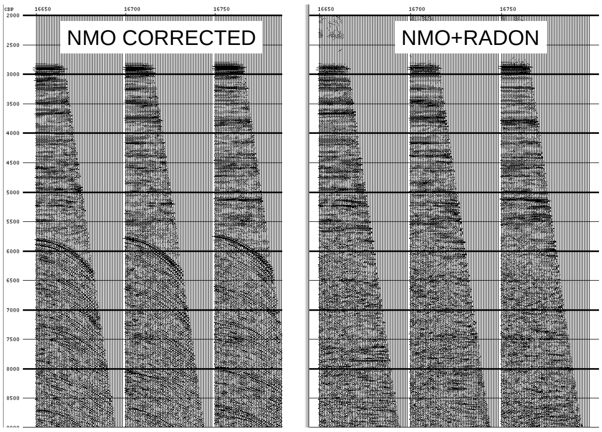


Fig 5. CDP gathes before and the application of Randon demultiple.

THE SEARCH FOR HYDRCARBONS

The quality of the imaging towards the front of the Sigsbee Escarpment is generally very good, revealing important structural and stratigraphic relationships favorable for hydrocarbon traps (Fig. 2). Hydrocarbon migration pathways above the salt can be identified not just in a structural sense but by the imaging of direct hydrocarbon indicators (Fig. 7), the presence of which indicates deeper source locations.

Below the salt the analysis of AVO anomalies is complicated especially using 2D data. The true amplitudes removed by the depth migration process does not detract from the fact that if the migration is performed correctly, relative amplitude distributions may be sufficient to indicate the present of hydrocarbons. Velocity scan depth migrations enable potential AVO anomalies to be verified by perturbing the velocity model several times effectively producing CRP gathers as a function of velocity.

CONCLUSIONS

The results from these projects show that long streamer acquisition combined with state of the art processing provides adequate depth images for the purposes of prospect evaluation in the deep water environment. Combined with cost effectively migrating large amounts of 2-D seismic data, oil companies are provided with an advantage in the highly competitive deep water Gulf of Mexico.

With the costs of acquiring and processing 2-D data declining, can oil companies afford not to take advantage of 2-D data? Realistic turn around times (e.g. 3000 miles in 3 months, processing+depth imaging) make the use of large scale depth imaging an opportunity for companies to assess the risks and rewards involved in operating in the deep water salt province.

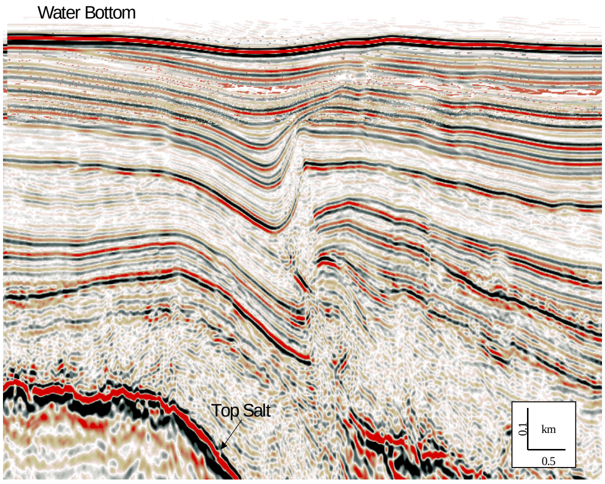


Figure 6. Prestack depth migrated section exhibiting fine structural detail around a supra-salt drape fold.

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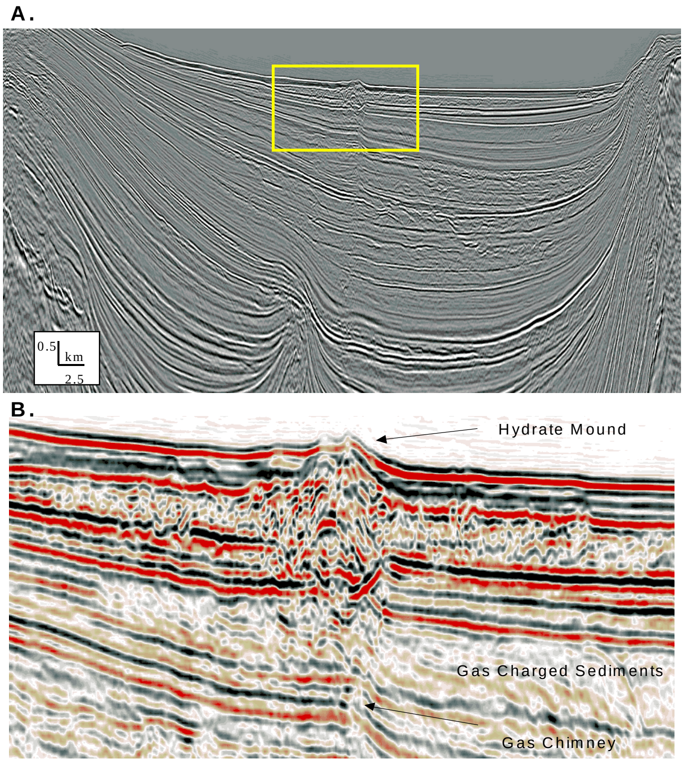

Figure 7. A) Direct hydrocarbon indicators can be observed in this high resolution depth migrated section. B) Enlargement of the hydrate mound and associated gas effects seen in A).