A MAZ case study from the Jequitinhonha basin, Brazil; Benefits of advanced methods to imaging results

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Abstract

It is typical that several iterations of data acquisition and seismic techniques are applied to a particular hydrocarbon prospect in the course of its economic life. Investment of the additional time and effort must be justified according to the expected practical benefits. Sometimes those benefits are best assessed when viewed across of the continuum of an entire range of possibilities.

A recent exercise in offshore Brazil's Jequitinhonha Basin presents a good example of what can be recognized by increased effort. Over a short period of time, a series of additional field acquisition and advanced processing technologies have been applied in an effort to improve subsurface imaging.

This case history illustrates the relative value that increased effort can produce.

Introduction

The area in question is in the Jequitinhonha Basin, Offshore Brazil, one of a chain of narrow passive margin basins along the eastern coast. Significant features of the Basin's geology include a structurally complex basement which is overlain by clastic sediments with hydrocarbon interest. These draping sediments are themselves overlain by salt flows and carbonate rafts. Seismic images of the prospective sediments are severely challenged due of the distortions caused by the high velocity overburden.

Industry methods are available to address the problems, all involving at least an incremental increase in cost and effort. Justification of the increased investment should always be reconciled.

A case history is presented here which outlines the improvement in the quality of seismic images after several stages of increasing geophysical sophistication. The exercise provides the opportunity to view several important iterations in context of a full suite of alternatives.

Method

Irregularity of high velocity bodies creates distortions in the propagation of seismic energy which diminish the images of reflections. Such conditions require upgraded methods to produce useful images. Techniques more sophisticated than basic acquisition and time domain algorithms are required.

Irregularity in overburden also causes seismic waves to travel downward and return to the surface in very uneven patterns. The consequence of this is that energy needed to image a particular horizon is not necessarily reflected and recorded by a conventional narrow streamer spread towed directly behind the vessel.

Among the methodologies that have been used to address this deficiency in illumination is Multi-Azimuth (MAZ) acquisition. This is a method where several conventional surveys, generally referred to in this context as narrow-azimuth (NAZ), are collected repeatedly over the same area, each oriented at differing compass heading (Keggin *et al*., 2006), (Long *et al*., 2006). Given the particular characteristics of the distorting geology, a sufficient number of acquisition directions will eventually record sufficient reflected energy to adequately illuminate horizons of interest.

Apart from considerations of data acquisition, data processing must accommodate the consequences of wave field propagation introduced by these very same geologic challenges. Imaging methods ranging in sophistication from isotropic Pre-Stack Time Migration (PSTM), through Kirchhoff Pre-Stack Depth Migration (PSDM) with Tilted Transverse Isotropy (TTI) anisotropic correction, to Reverse Time Migration (RTM) are in common practice today. In this case study these imaging algorithms were applied in turn.

Technologies involving all of these ideas have been practiced and widely published. In this instance, they will all be applied in relatively rapid succession. The case history offers an opportunity to make value comparisons of the benefits achieved by the investment of effort.

BM-J 4/5 MAZ

The story begins with relatively recent acquisition and processing, conventional for the day, 2006. An East/West 3D survey was acquired with 10 6km streamers, at 9m depth and 100m separation. Dual 3090 in^3 sources were towed a 7m depth. The images created from this data are via isotropic PSTM, as seen in a West-> East profile from the original isotropic Kirchhoff PSTM (Figure 1). Reflections in the shallow section are quite nice, but interpretation below the high velocity overburden is problematic.

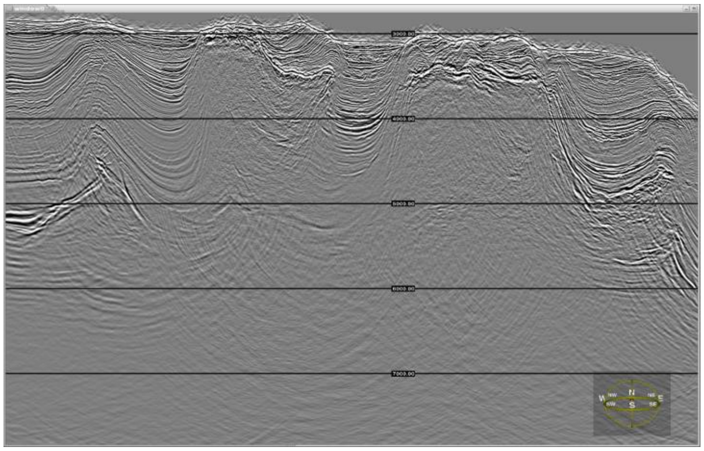

Figure 1: 2006 3D Time Migrated seismic data.

At least some of the difficulties in producing good reflections can be attributed to well know problems related to salt bodies. First, Time imaging cannot resolve the irregularities caused by propagation through locally anomalous velocity fields. Second, the conventional NAZ streamer arrangement cannot record all the necessary reflections from the horizons below such bodies.

In 2011 a 1000km^2 area was overshot with two new 3D surveys. Most specifications were similar to the original, but with some important differences. The new surveys used 8km Dual Sensor streamers; and larger 4135 in^3 sources, in line with more current practice.

But most importantly, the new surveys were oriented in different acquisition directions: one North/South, the other 30deg counter clockwise of N/S. This combination of recordings allows the application of Multi-Azimuth processing techniques to achieve more uniform illumination of the horizons of interest.

The three surveys were processed simultaneously as one to form a MAZ result. Modern seismic processing often accommodates adjoining surveys, so techniques exist to match them. Similar procedures were followed here. The conventional survey data was ‘uplifted’ to be combined with the new data in a fashion consistent with proper Dual Sensor de-ghosting (Burren *et al.*, 2013). All further displays of the conventional acquisition are with the benefit of the survey matching processes.

Given the distortion to the imaging of horizons of interest, Depth domain imaging is applied. It almost goes without saying: the complications which cause un-even illumination almost always demand Depth methods to produce suitable images. In this instance, imaging was upgraded to TTI.

Most important to achieve successful depth migrated results is the development of the Velocity Model used to drive imaging. In this instance a rather conventional work flow was employed, with care taken that only one velocity model was used to migrate all data at any stage. Errors calculated from each azimuth were simultaneously inverted in the tomographic updates.

Complete details of the processing involved to create this result are indeed interesting, but not a focus of this paper. Instead, we focus on the improvement in the event interpretability due to contribution of added effort.

First Results

Comparison of results in this discussion will be from the point of view ‘Best that can be done’ with Single Azimuth vs Mult-Azimuth. Not necessarily arbitrarily, the conventional acquisition has been chosen to represent the single azimuth result.

Figures 2a & 2b compare a South->North profile taken from Kirchhoff TTI Pre-stack Depth Migrated volumes. 2a is single NAZ, composed only of the East/West acquisition; 2b is the complete MAZ result. The flat lying reflectors below the highly structured overburden correspond to the pre-salt clastic interval, precisely the zone of high exploration interest.

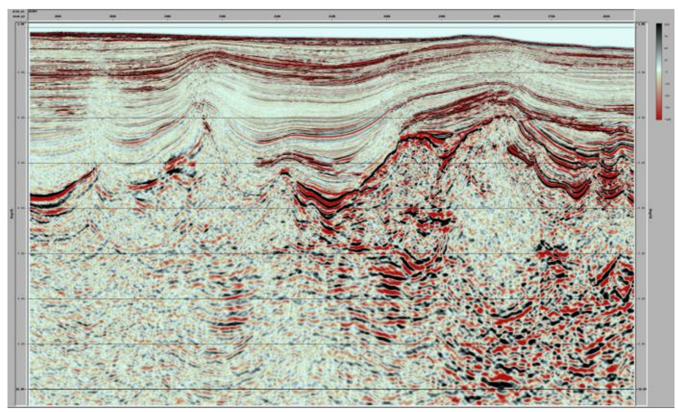

Figure 2a: Single NAZ 3D Depth Migrated seismic data. Reflections below salt are difficult to interpret.

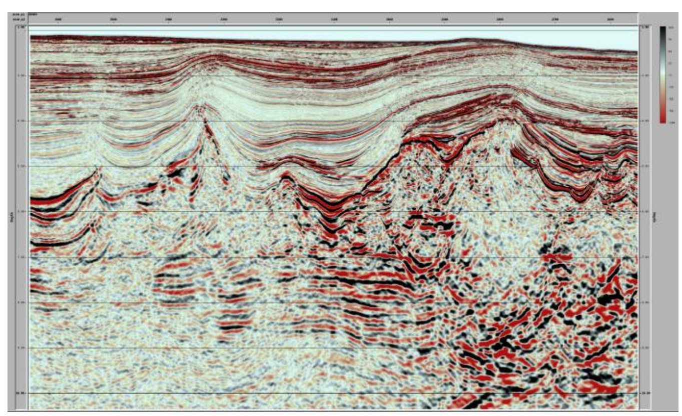

Figure 2b: MAZ 3D Depth Migrated seismic data. Substantial improvement is evident in reflections below salt.

Onward Results

These versions of results are significant, but not yet representative of the full extent to which investment in improved technology can be beneficial. Further to the Kirchhoff method, the next level of sophistication would be RTM. In this particular case, TTI RTM, performed to 25hz, would be expected to improve images very near rapidly varying velocity anomalies.

A comparison is made of an West->East profile taken from Depth Migrated MAZ volumes; one Kirchhoff, the other RTM (Figure 3a and 3b). Flat lying reflectors are most improved below the greatest structural variation in the salt.

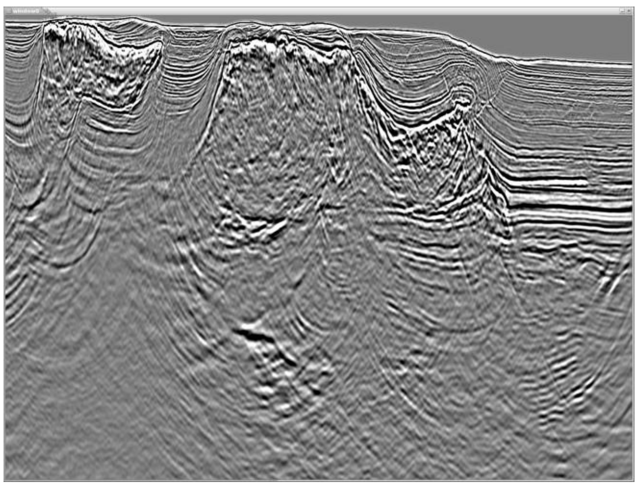

Figure 3a: Kirchhoff Depth Migrated MAZ volume.

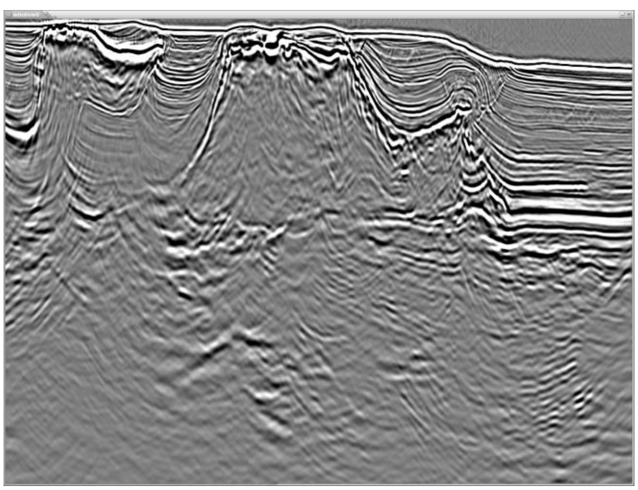

Figure 3a: RTM Depth Migrated MAZ volume.

Value

Improvement has been demonstrated for each technical element introduced. None of the benefits could be considered unexpected, but it is not often that such increments are applied in such rapid succession. It is prudent to be take advantage of the opportunity to view the value of advancement along this spectrum of effort, as this case history provides.

Returning to the original depiction the Single Azimuth data, which represents recent state of practice, we compare the Kirchhoff PSDM MAZ data, where the vertical axis has been time restored to Time in order to make the comparison feasible (Figures 4a & 4b).

The posting of Depth data in a Time scale certainly distorts deep structures, but it provides a fair opportunity to view the improvements in the quality of reflections. The interpretation of important sub-salt reflectors can be made with vastly greater confidence.

It should also be noted that interpretability of reflections in the shallow section are hardly affected. That is as it should be; those reflections were propagated through a velocity regime which should not introduce illumination and imaging difficulties.

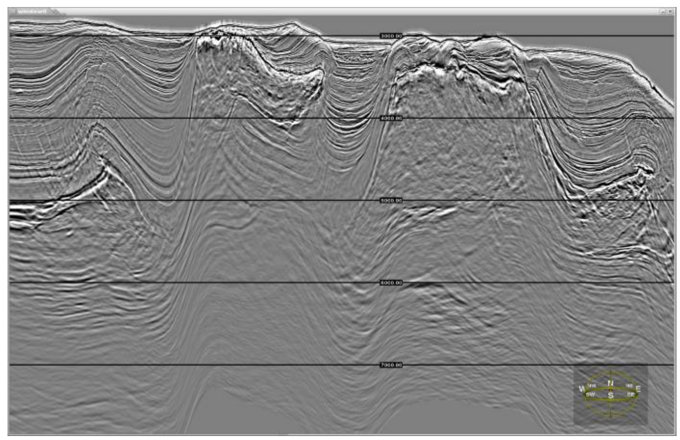

Figure 4a: Multi- Azimuth 3D Depth Migrated seismic data, represented in Time scale.

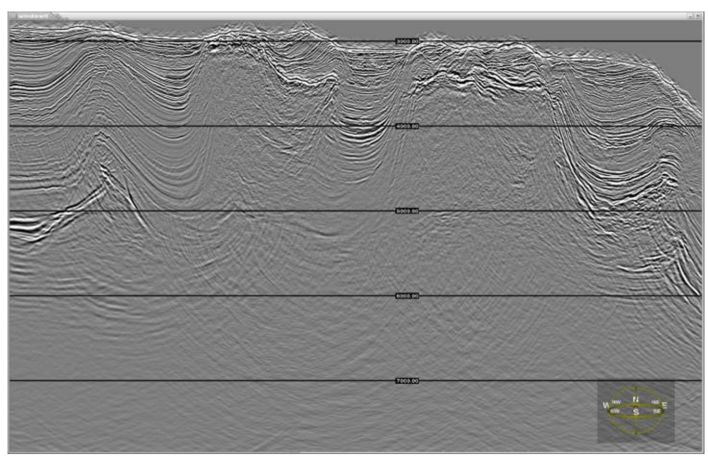

Figure 4b: Single Azimuth 3D Time Migrated seismic data, (Figure 1 repeated)

Conclusions

This case history illustrates how the effects of spatially varying high velocity layers can compromise the imaging of reflectors recorded by conventional marine surveys. By applying non-conventional methods designed to address particular difficulties caused by such structure, the quality of reflections can be substantially improved. This case history provides are rare opportunity to assess the value of utilizing a range of methods, from typical to novel.

Acknowledgments

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