The Influence of Velocity Field on Wave Equation Migration

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Abstract

HOW DENSE IS DENSE ENOUGH FOR A VELOCITY FIELD?

Because of the recent discoveries of giant fields in provinces located beneath the salt layer (subsalt leads), exploratory interpreters are increasingly requesting geophysical techniques to enable better definition, higher resolution, and better imaging of the oil field. The most advanced geophysical method is the PreStack Depth Migration (PDSM) technique, which uses the wave equation. It enables an improved confidence level in the geological model and better delineation of the reservoir.

Velocity and tomography analyses are labor-intensive processes. This study provides an analysis of how a dense velocity field affects the wave equation migration results. We will decimate the velocity field and migrate the same data on a similar image grid. This will help the people who process the data to determine how many velocity interpretations are needed to obtain the expected seismic image.

The primary challenge of technique has been the cost of the PSDM by wave equation; however, this challenge has been overcome as a result of the availability of powerful hardware and smart algorithms. The availability of the PSDM technique will enable more reliable geological models, which will result in more discoveries.

Introduction

Petrobras has discovered very large oil fields in the subsalt layers of Brazil. Those deepwater discoveries, such as the Tupi field, have encouraged geological and geophysical studies to prospect below the salt layer. Given of the uncertainties of deepwater and subsalt prospects, many efforts are taking a multidisciplinary approach. Between the acquisition of the seismic data and the selection of the drilling technologies, all resources are being used to mitigate the risks involved in the activity.

Subsalt imaging is an important concern for oil and gas exploration in some areas, such as the Gulf of Mexico and North Sea. It presents a great technical challenge to imaging methods. Strong velocity contrast between the salt body and the surrounding medium, irregular surfaces of the salt body, steep salt flanks, and steep faults create difficulties in subsalt imaging (Wu et al., 1998).

Traditionally, pre-stack depth seismic migration has used the Kirchhoff method to simplify implementation and performance. Limitations of the method, however, include the imaging of dips of more 90 degrees and difficulties in complex geological situations, such as imaging below the thick layer of salt has leveraged wave equation migration (WEM).

Although WEM is well-known, several aspects have affected its industrial application. The time required for computation and its performance were factors that have prohibited its application. Recent improvements resulting from technological advances in hardware, new implementations of algorithms, and the optimization of the processing workflows make the increased use of this method possible.

The detectability of the steep subsalt structures has raised questions, such as can we image the steep subsalt structures? To answer this question, we first address the following problem:

- Can the signals from the steep subsalt structures be recorded on the surface? If so, what are the characteristics of these signals?
- Can the steep subsalt structures be reconstructed? What are the prerequisites for the imaging methods to do the reconstruction? (Wu et al., 1998)

This work focuses on the aspects of the density of the velocity field. The migration is highly dependent on the reliability of velocity field and the determination of this field is subject to discussion. Various techniques for the velocity interpretation are used to imaging; however, the spatial resolution is directly determined in terms of computational time and the amount of time required by processors for their analysis. In general, a velocity field with high definition and resolution is the primary data required to obtain a reliable seismic image. If we reduce the spatial resolution, however, how will this reduction affect the final result?

Analysis, design, and construction of the velocity field are extremely time-consuming. The techniques used to determine the migration velocity use tomography algorithms or updates through a residual velocity. Several iterations to a fine adjustment are necessary to obtain a field that should be as close as possible to the reality. To get a better cost/benefit on seismic image, an analysis of the velocity field interval should be considered.

This work highlights the subject of velocity field decimations without damage the final quality of the seismic image after WEM. A good seismic migration is a key element for the understanding the geological models and crucial on complex geologies.

Methodology

We used Sigsbee2A (Paffenholz et al., 2002) model and the original velocity field. Decimations were performed, simulating variations in the spatial resolution. In the real world, the velocity analysis increment is empirical based on the processor experience. Various spatial resolutions were generated, but we only present the most significant ones, which are 11.5 m, 92.0 m, and 184.0 m, between each velocity field cdp. We ran WEM in all shots. All gathers had application of spherical divergence. Depth sections are shown regarding the different velocity field spatial resolutions with no post-processing. Sections of differences are presented to corroborate the final conclusions. A linear interpolation in the velocity field was used to fill the gaps.

The field seismograms were generated to simulate a marine seismic acquisition (end-on spread). One-way WEM algorithm was used to perform the prestack depth migration. The back propagation of the wave field was performed by using a screen propagator (Jin et al., 1998) and the cross-correlation imaging condition was applied. One-way WEM downward extrapolates the source and receiver wavefields individually. It correctly handles the multi-pathing arrivals. However, one-way WEM cannot migrate overturned waves that propagate beyond 90 degrees. Also, one-way WEM does not preserve the imaging amplitudes of the reflectors (Zhang et al., 2003). In most cases, however, one-way WEM still provides good results (Mulder et al., 2004).

Sigsbee Velocity Model

The Sigsbee velocity model simulates structures in deepwater Gulf of Mexico. Figure 1 shows a stratigraphic model illustrating the large number of layers in the model. The velocities of the stratigraphic sequence vary from 1560 m/s, immediately below the water level to 3500 m/s at the deepest region. An irregular salt body, with a velocity of 4500 m/s, is located in the middle of the stratigraphic sequence. This velocity creates a high contrast if it is compared to the velocities around the salt.

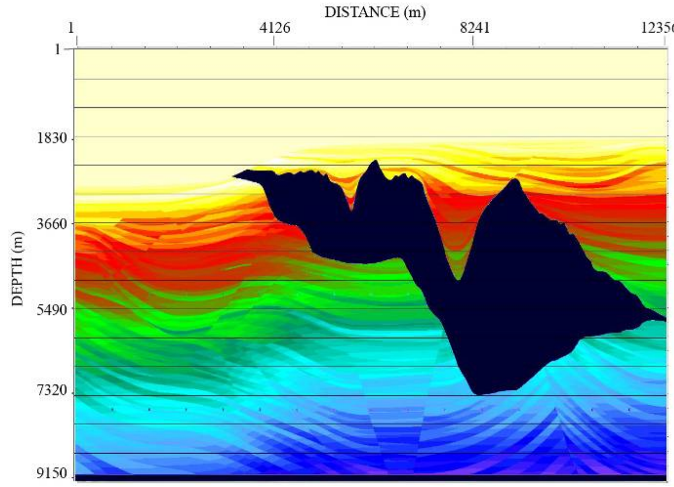

Figure 1: Sigsbee2A velocity model. The dimensions are 12356 meters (horizontal) by 9150 meters (vertical).

Results

Figure 2 shows the migrated section using the original Sigsbee velocity model (Figure 1) (cdp increment = 11,5 m). The stratigraphic sequence is relatively easy to interpret; the ocean bottom and the salt body are well outlined, and the same image shown beneath the salt layer in Figure 1 also displays in Figure 2.

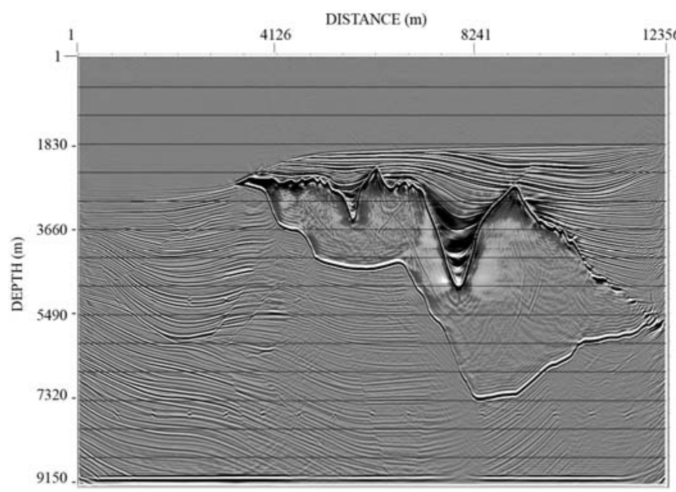

Figure 2: Migrated section with the original migration velocity model (cdp increment = 11,5 m).

Figure 3 and Figure 4 show the migrated section related to cdp increment equal to 92 m and 184 m. The stratigraphic sequence is still interpretable in Figure 3 (cdp increment: 92 m), as well as the ocean bottom. In the middle of the salt body (selected region in yellow), however, the interpretation becomes difficult because of the strong lateral velocity contrast, but it is still acceptable. In Figure 4 (cdp increment: 184 m), the layers below the salt are very difficult to interpret. The selected region of the salt body is not clear and is difficult to use for exploration or development.

Figure 5 and Figure 6 show the decimated velocity models with cdp increment equal to 92 m and 184 m, respectively. In comparison to the original model (Figure 1), the degradation of the velocity model (Figure 6) is obvious.

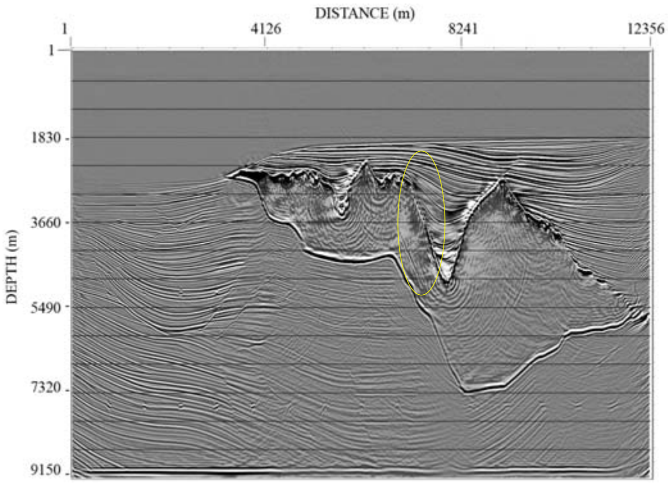

Figure 3: Migrated section (cdp increment: 92 m).

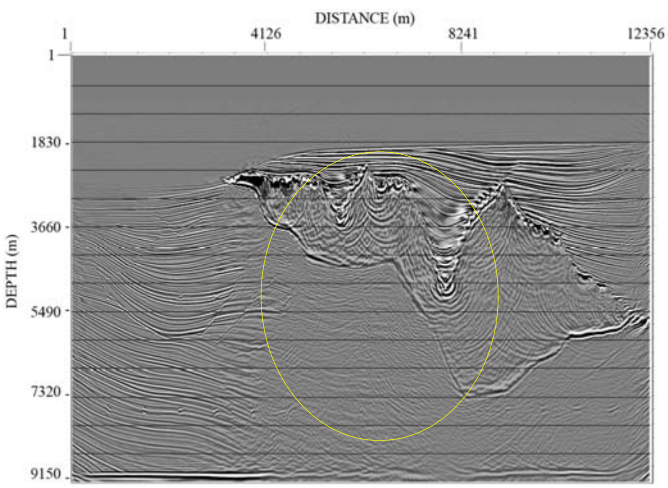

Figure 4: Migrated section (cdp increment: 184 m).

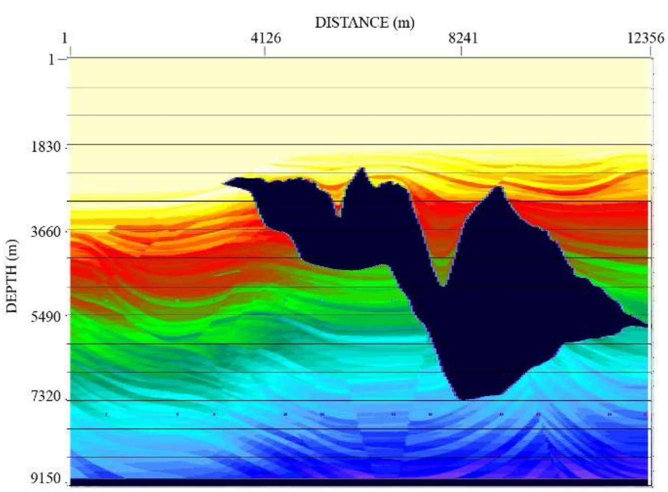

Figure 5: Velocity model (cdp increment: 92 m).

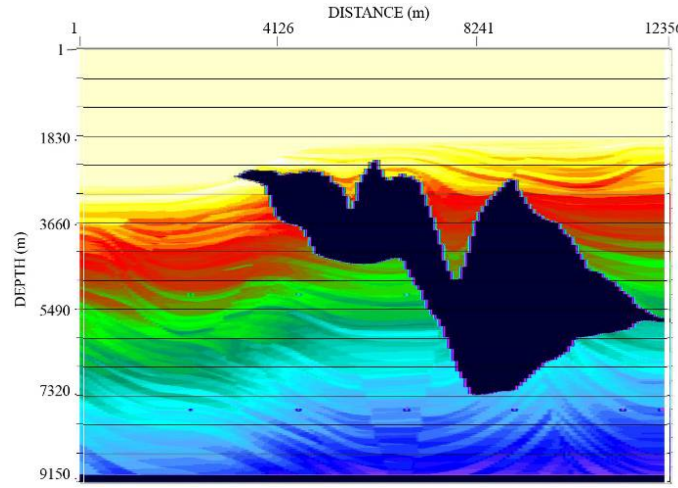

Figure 6: Velocity model (cdp increment: 184 m).

To analyze the difference between the migrated sections, a good procedure to, literally, subtract them to show the amplitude differences. Figure 7 shows the result of the subtraction between Figure 2 (cdp increment: 11,5 m) and Figure 3 (cdp increment: 92 m). Figure 8 shows the result of the subtraction between Figure 2 and Figure 4 (cdp increment: 184 m).

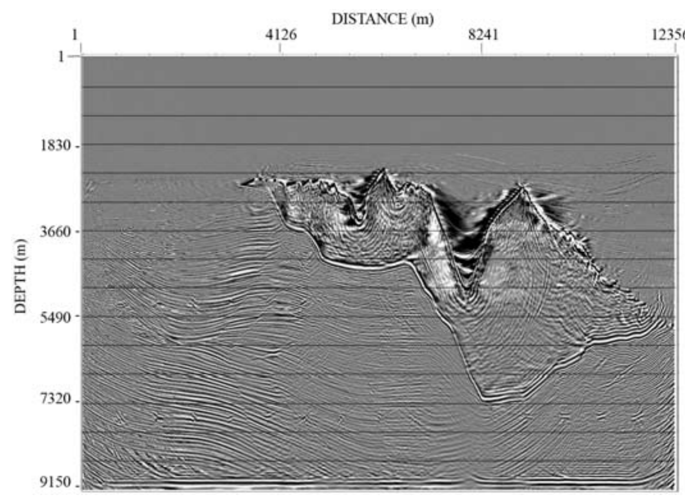

Figure 7: Difference between section generated with the original migration velocity model (cdp increment: 11,5 m) (Figure 2) and section in Figure 3 (cdp increment: 92 m).

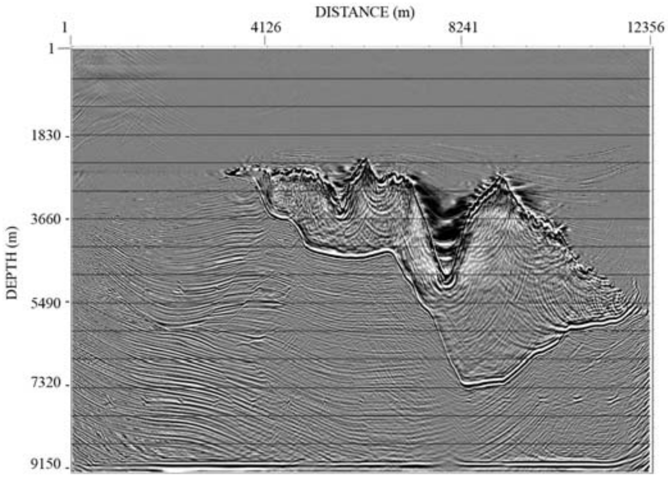

Figure 8: Difference between section generated with the original migration velocity model (cdp increment: 11,5 m) (Figure 2) and section in Figure 4 (cdp increment: 184 m).

This dataset was migrated on a single node with 8 processors (3.0GHz and 6Mb cache) and 32 GB of RAM. Table 1 shows the computational time in minutes.

Table 1: Migration Times

Cdp increment (m)	Migration time (minutes)
11,5	107
92	103
184	91

Conclusions

The wave equation migrations are highly dependant on the velocity field density. To this synthetic example simulating subsalt prospects, an interval of 184 meters was the maximum distance for velocity analysis to get an interpretable image result. Grid spacing coarser than this will degrade the signals below salt dome. In conclusion, in face of the high dependence on the spatial density of velocity field, an automatic process is mandatory to get WEM on production. On regions far from the salt layer and lower geological complexity, larger interval can be accepted. It was proved one more time that the quality of the seismic image is directly related to the degree of precision of the velocity model.

Acknowledgments

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