Reverse time migration applied to structures imaging in SEG/EAGE salt dome model with acquisition parameters variation

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Abstract

This work aims to analyze the capacity of the conventional Reverse Time Migration related to structures imaging in complex geological models such as below salt bodies, which is one of the greatest challenges in the petroleum exploration. The velocity model used was a slice of the 3D SEG/EAGE salt dome, known as Salt-BB. Acoustic modeling was used to generate 2D seismic data. In order to enrich the study, this acoustic modeling was performed with the variation of two very important seismic data acquisition parameters: shot point interval and receiver interval. A technique for removing artifacts from migrated data, known as selective mute, was implemented to improve the outcome of the stacked section.

Introduction

It is practically unanimous among geoscientists that the easiest petroleum accumulations have already been discovered and it is necessary to work hard to find a new significant accumulation. The necessity of image structures beneath very complex geologies, like salt bodies for example, is increasing and because of this, the quality of the results of seismic processing has to be good enough to provide satisfactory sections for the interpreters. A good example of complicated geology is the SEG/EAGE salt dome model which will be described in more detail later. Acoustic modeling was performed to generate the synthetic seismograms and the algorithm used to migrate these seismograms was the pre-stack Reverse Time Migration (BAYSAL et al, 1983; WHITMORE, 1983; LEVIN, 1984). The shot point intervals and receiver intervals were varied during the modeling in order to test the migration algorithm power. A selective mute (SILVA, 2008; XAVIER et al, 2008) was used to remove artifacts from migrated data. After the application of the mute the seismograms were stacked.

2D Modeling and Reverse Time Migration

The 2D acoustic modeling was carried out according to the most common seismic investigation: an explosive source *f(t)* and the receivers were situated on the surface of the velocity model. The source used to simulate a seismic source was the second-derivate of a Gaussian (CUNHA, 1997). The shot point intervals used were 25, 50, 100 and 200 meters and the receiver intervals were the same. It is important to mention that while shot point intervals were varied the receiver interval stayed constant and was equal to 25 meters. The same happened to the shot point interval when the receiver intervals were varied. The acoustic wave equation with constant density was used to simulate the seismic wave propagation,

$$\frac{\partial^2 P(x,z,t)}{\partial x^2} + \frac{\partial^2 P(x,z,t)}{\partial z^2} - \frac{1}{c^2(x,z)}\frac{\partial^2 P(x,z,t)}{\partial t^2} = = f(t)\delta(x-x_f)\delta(z-z_f), \quad (1)$$

where $P(x,z,t)$ is the acoustic wave field, x and z are the spatial coordinates, t the temporal coordinate, $c(x,z)$ the velocity and x_f and z_f represent the source position. Due to the fact that reflections from model boundaries are problematic, boundary conditions (CERJAN et al, 1985; REYNOLDS, 1978) were used to avoid this. As a result of this modeling we have the seismograms which will be used to perform the Reverse Time Migration. This migration algorithm is very famous for producing very goods results and for its high computational expense, as shown in Yoon et al (2003, 2004). Basically, Reverse Time Migration can be treated as a problem related to a contour condition associated to an image condition. The seismogram *sis(x,t)*, provided from the 2D modeling, is the contour condition and a travel time matrix *TD(x,z)* is used to apply the image condition. This *TD(x,z)* matrix contains the travel times based, in this case, on the maximum amplitude wave that reaches each point of the velocity model (a smoothed model was used to generate them). In other words, these travel times are the time that the direct wave from the source spends to reach each point of the model. The image formation process is as follows: the seismogram is inversely propagated in time using the homogeneous and acoustic wave equation,

$$\frac{\partial^2 P(x,z,t)}{\partial x^2} + \frac{\partial^2 P(x,z,t)}{\partial z^2} - \frac{1}{c^2(x,z)}\frac{\partial^2 P(x,z,t)}{\partial t^2} = 0, \quad (2)$$

where, in this case, to carry out the inverse propagation we have,

$$P(x_n, z_{obs}, t) = sis(x_n, z_{obs}, t), \quad (3)$$

where z_{obs} is the observation surface where the n receivers are situated, x_n is the position of each receiver and $sis(x_n,z_{obs},t)$ is the recorded seismogram. Each time of the inverse propagation is compared to those in the *TD(x,z)* matrix. When a coincidence of two of these times happens, the image *mig(x,z)* of this *(x,z)* point is created,

$$mig(x,z) \equiv P(x,z,t=TD), \qquad (4)$$

this way, each point of the model is imaged and consequently, the model is rebuilt after the stack of the migrated shots (seismograms).

Selective mute: an improvement of the sections

If we look at the migrated shot (Figure 10) we can see that the region of the interest signal is in the middle of the shot (or the region immediately below the shot position). In the other areas there are some undesirable artifacts that decrease the signal to noise ratio when the data is stacked. The solution is literally to cut these artifacts out (Figure 11) from the migrated shot. This technique is called selective mute and it was applied to all of the shots migrated automatically using a programming routine. After the mute application all of the migrated shots were summed to generate the stacked section. In Figures 12 and 13 are the results of a stacked section before and after the application of the selective mute. The improvement of the sections is very clear.

Results

The 3D SEG/EAGE Salt Dome model was built with similar characteristics as the geology of Gulf of Mexico Basin (AMINZADEH et al, 1994, 1996). Here one of its slices was used, called Salt-BB (Figure 1), with 801 points in the horizontal and 201 points in the vertical and its range velocity is from 1500 m/s to 4480 m/s. A high contrast velocity salt body is situated in the middle of the model and below it there are some interesting structures to be imaged, as some fault planes, for example.

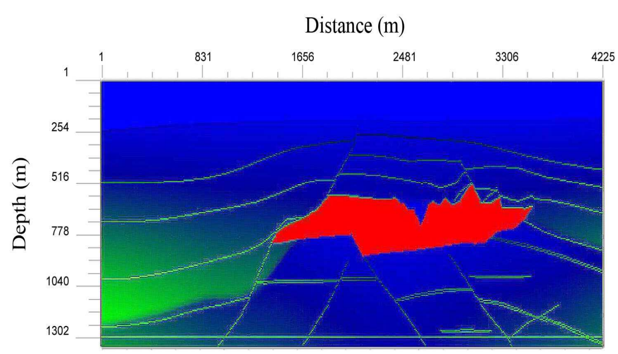

Figure 1: A slice of the 3D SEG/EAGE Salt Dome, known as Salt-BB. The dimensions are 4225 meters (horizontal) and 1312 meters (vertical).

The seismic sections resulted from the application of Reverse Time Migration are shown in the Figures 2 to 9. First, those related to the receiver interval variation are in Figures 2 to 5. The structures above the salt body in figures 2, 3 and 4 are well interpretable (receiver intervals equal to 25 m, 50 m and 100 m, respectively) but in figure 5 (receiver interval equal to 200 m) the interpretation is difficult. The top and base of the salt body is well identified in all of them. Some structures below the salt body are also reasonably interpretable in the figures 2, 3 and 4 but again in figure 5, it does not happen, the image is confusing and the interpretation is extremely difficult.

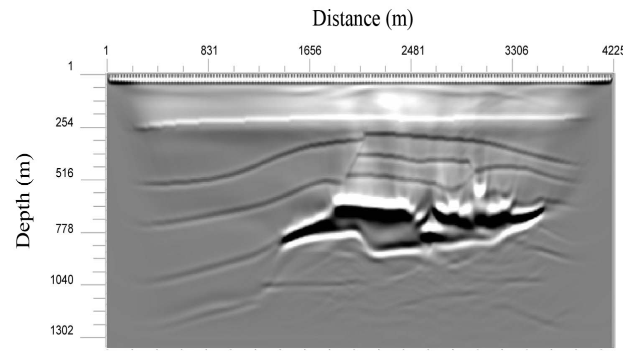

Figure 2: Receiver interval equal to 25 meters.

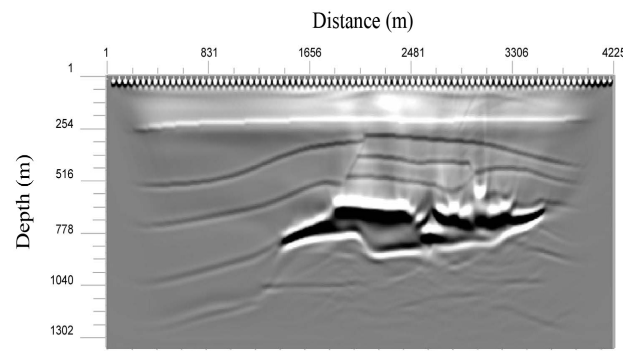

Figure 3: Receiver interval equal to 50 meters.

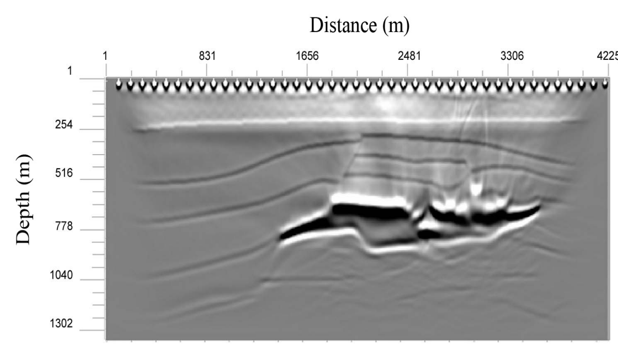

Figure 4: Receiver interval equal to 100 meters.

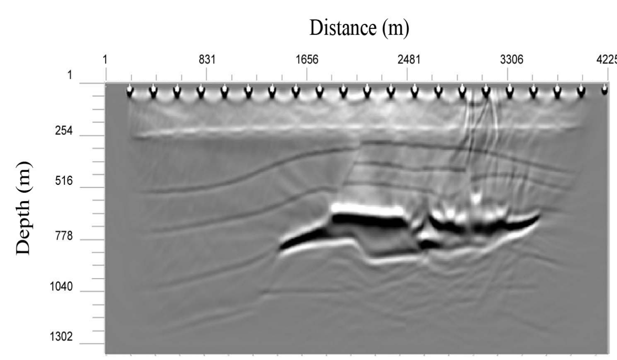

Figure 5: Receiver interval equal to 200 meters.

The seismic sections related to the shot interval variation are in the Figures 6 to 9.

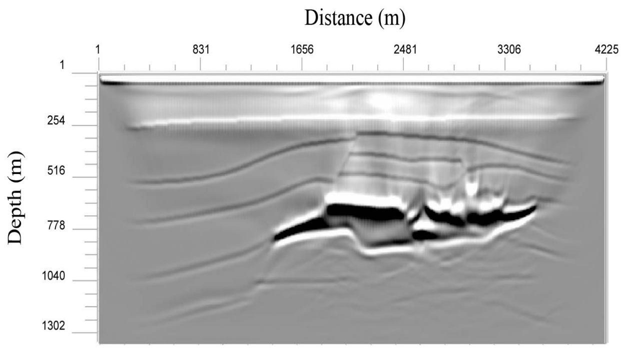

Figure 6: Shot point interval equal to 25 meters.

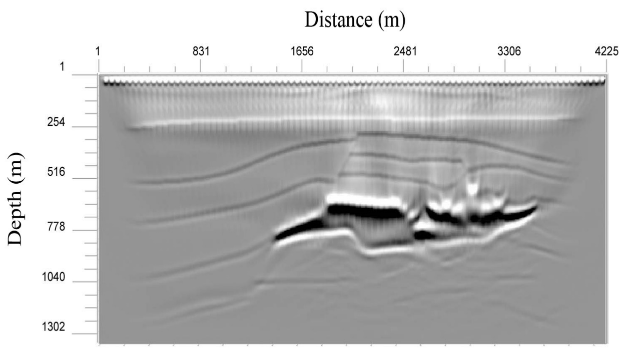

Figure 7: Shot point interval equal to 50 meters.

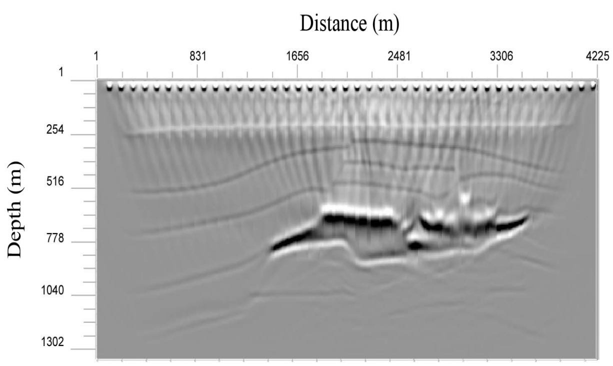

Figure 8: Shot point interval equal to 100 meters.

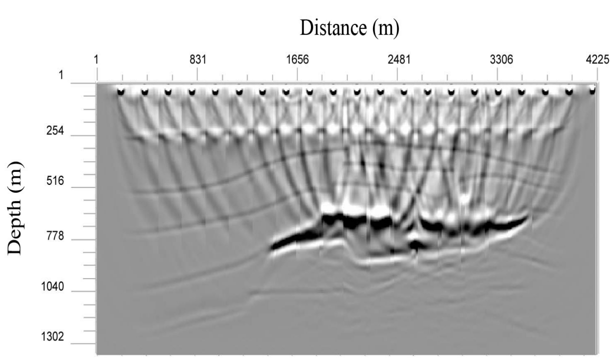

Figure 9: Shot point interval equal to 200 meters.

In the Figures 6 and 7 (shot point intervals equal to 25 meters and 50 meters, respectively) the reflectors above the salt body are well interpretable and below it, some structures are reasonably interpretable. The top and base of the salt body is well identified in all of them, except for Figure 9.

Conclusions

The power of the Reverse Time Migration algorithm is proved one more time. It could generate good sections even with the complexity of the SEG/EAGE Salt Dome velocity model. The usage of the silent mute was very important to improve the results. Comparing the imaging results between the generated sections with variation of shot point interval and variation of receiver interval we conclude that the best ones are in the latter. The good section generated from the receiver interval equal to 100 meters is very interesting because even with a small amount of data the result was satisfactory. In other words, a good result using big receiver intervals shows that we can do faster analyzes in the modeling because of the smaller amount of data and even use less equipment in a seismic investigation.

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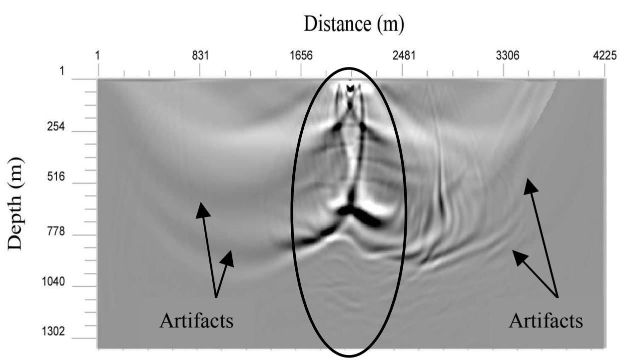

Figure 10: Migrated shot. The interest signal is in the center of the shot and the other areas present some artifacts.

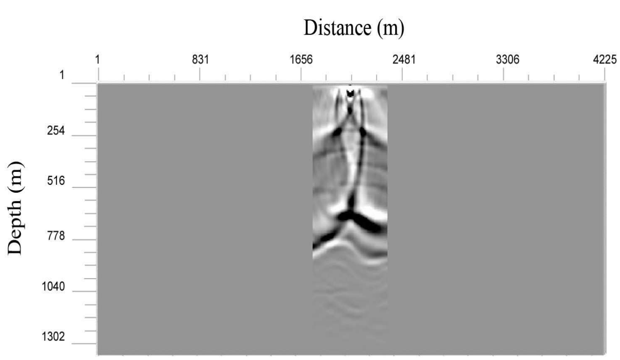

Figure 11: The same migrated shot of the Figure 10 but now with the silent mute applied.

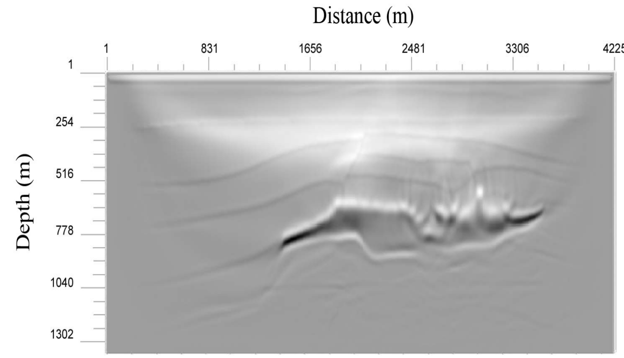

Figure 12: Section generated by the stack of migrated shots without mute.

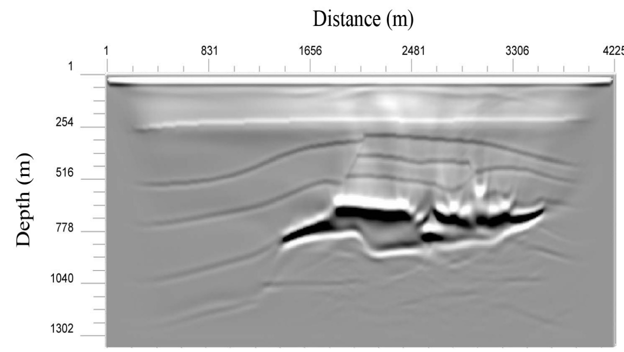

Figure 13: Section generated by the stack of migrated shots with the silent mute applied. The interpretation became easier than in the Figure 12.