Velocity model building for seismic modeling and depth imaging applied to carbonate reservoirs in presence of karst

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Abstract

Carbonate reservoirs are increasingly being one of the most important hydrocarbon sources for the oil companies and, consequently, they have a giant value for the entire petroleum industry. Because of this, it is very important to have the best possible comprehension of their geological characteristics and internal processes. Karst zones are very complex geological environments, frequently formed by the dissolution of carbonate rocks in presence of meteoric water or subsurface upward flows heated fluids, in combination with faults, fractures and stratigraphic surfaces, giving origin to complex geometries such as vugs and caves. When karstified morphologies are present in the carbonate reservoirs, they may represent additional uncertainty to the petroleum production process if their presence and characteristics are not well described and analyzed. Results from depth imaging, for example, can help to better understand the reservoir scenario but it is necessary to have an accurate and reliable velocity model. This work attempts to show the possibility to insert a karst model, generated by stochastic simulation, in a velocity model in a pre-salt reservoir scenario and study the visibility of such features in a synthetic seismic, generated by seismic modeling. Conventional RTM migration was carried out to perform the depth imaging. As the current available methods were not satisfactory, a new strategy based on computational development had to be applied to insert the karst model into velocity model using a plugin for karst modeling and simulation developed in another research and development cooperation term. The final generated velocity model presents a satisfactory representation of the karst model, and the result of seismic imaging shows that these geological objects can be well identified in the seismic volumes.

Introduction

Karst features are geological structures that sometimes can be very complex and difficult to map and to understand their geometry. Often, such type of geology plays a very important role in the petroleum industry (CAZARIN et al., 2013). Commonly formed by, for example, a combination of fractures, caves, vugs and dolines, the karstified zones in subsurface can represent a big challenge for reservoir characterization and, consequently, for petroleum production.

Karstified zones are largely present in pre-salt reservoirs (OLIVEIRA et al., 2019), so, in order to avoid negative impacts in production, it is mandatory to have a good knowledge and understanding of their localization and characteristics. In terms of velocity model building, it is very important to have an accurate representation of the karstified features because such models can be used to help, or even to guide, several types of studies as, for example, generation of new seismic data from seismic modeling and pre-stack depth migration (EBUNA et al., 2017) or new seismic survey design for exploration, illumination studies, or even consider what can be detected, etc.

The quality of depth migration image is totally related to the quality of the velocity model (XAVIER et al., 2009). So, it is mandatory that the velocity model building process must be done in such a way that the geological details are respected and well represented. Complex geological environments, with carbonate geo-bodies or salt domes, for example, are commonly inserted into velocity models during the end of seismic processing workflow, using very specific techniques as, for example, full waveform inversion (FWI) (VIRIEUX et al., 2014) or seismic tomography (MENG et al., 2004).

Nevertheless, if, for some reason, some new relevant information related to the geological structures of the studying area arises and if it needs to be inserted as soon as possible into the velocity model, depending on the stage of the reservoir study, there is not enough time to go back to seismic processing or seismic imaging environment to perform this modification. And, this way, this process of velocity model update can be done in the seismic interpretation environment.

The objective of this work is to show how very complex geological structures related to karstified regions can be represented in a velocity model. Given an input velocity model, how could we insert karst related objects into this model, in a seismic interpretation environment? After building the velocity model, a seismic acquisition simulation was performed to create synthetic seismic data. Then, pre-stack depth migration was applied to the synthetic data to generate the seismic volume and, this way, it was possible to confirm if the karst geological features could be well identified or not in the depth imaging result. To carry out this study, a region which belongs to a pre-salt zone (SPINOLA et al., 2018) was chosen.

Method

Firstly, an initial velocity model, called original velocity model, without karst features, was built (Figure 1). The minimum velocity was about 1500 meters per second and the maximum velocity was 5300 meters per second. Then, next step was to generate and import the karst features geological model.

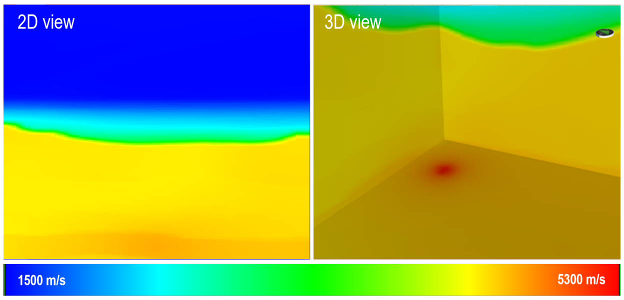

Figure 1: *Original velocity model in a bidimensional view (left) and in a tridimensional view (right).*

Basically, the karstic geological models were created from stochastic simulation, using a combination of well data and literature information from karst modeling and simulation plugin developed in cooperation term with Petrobras. The final karstic geological model, which was selected to be inserted in the velocity model, contained sets of complex structures like caves and dolines. Once with the karst geological model, the next step was to insert it in the velocity model.

The first strategy to insert the karst model was to use the same conventional approach applied to salt bodies, i.e., to perform the interpretation of the karst structures, top and base, and then create closed bodies (ZHANG et al., 2009). After that, theoretically, it was possible to insert these closed bodies in the velocity model. But, because of the different sizes and complex geometric shapes of the structures present in the karst geological model, a second strategy had to be adopted.

Thus, it was necessary to develop a special computational object, using a very specific technique based on TINTI et al. (2008), to represent and to insert the karst geological model in the velocity model. In order to highlight the karst related structures and produce enough contrast in the velocity model, a constant velocity as arbitrarily to value equal to 6000 m/s was attributed to the karst model. Further studies on velocity contrast could be done but it was not the scope of this work.

In order to verify if the karstified objects could be identified in a depth imaging process, synthetic seismic data was generated and then a migration algorithm was applied to it. The synthetic seismic data was generated by tridimensional acoustic modeling. For this marine seismic acquisition simulation, the shot interval was around 180 meters, the receiver interval was 25 meters, and the number of streamers was equal to ten. The depth imaging was performed by pre-stack depth migration of the synthetic seismic data using the isotropic RTM technique (BAYSAL et al, 1983).

Results

The generated karst structural model with caves and dolines, created after stochastic simulation, is shown in Figure 2. As can be seen, caves and dolines were very well represented in the models. The results clearly show the degree of complexity related to karstified environments and as mentioned before, the very different sizes and shapes of the karst features make their insertion in a velocity model a challenging task.

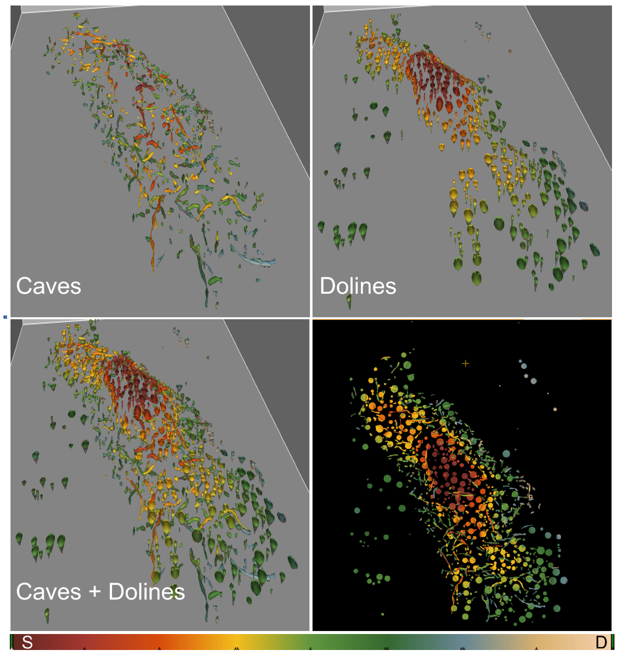

Figure 2: *Karst structural model. In the top, a tridimensional view of generated caves (left) and dolines (right). In the bottom, caves and dolines combined to form the Karst model (left) and a depth slice view of the Karst model. In the color bar, S means shallower objects and D means deeper objects.*

Once the karst model with different parameters configurations was successfully created, it was inserted into the original velocity model (Figure 3). It is easy to see that the caves and dolines, which belonged to the karst model, had a satisfactory representation after being inserted into the velocity model.

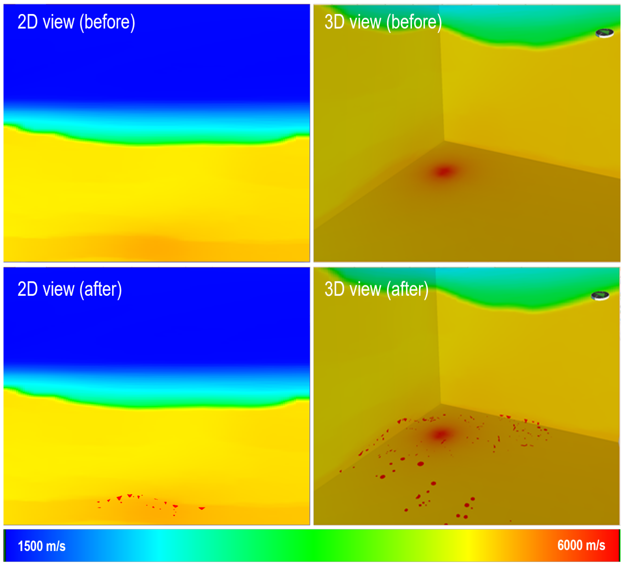

Figure 3: *A comparison between before (top) and after (bottom) the insertion of the karst model into the velocity model.*

The next step was to carry out the 3D marine seismic acquisition simulation to create the synthetic seismic data. In Figure 4, it is possible to see the acquisition direction relative to the structural karst model.

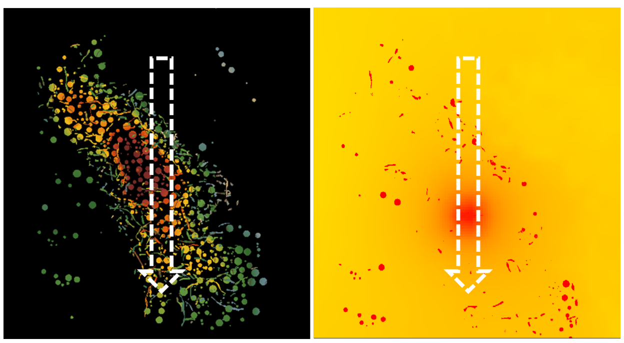

Figure 4: *Depth slice view of the direction of seismic acquisition simulation. In the left, it overlays the karst structural model and, in the right, overlays the velocity model that contains the karst model.*

In Figure 5, it is possible to see few examples of the generated synthetic seismograms and their respective results of the isotropic Reverse Time Migration.

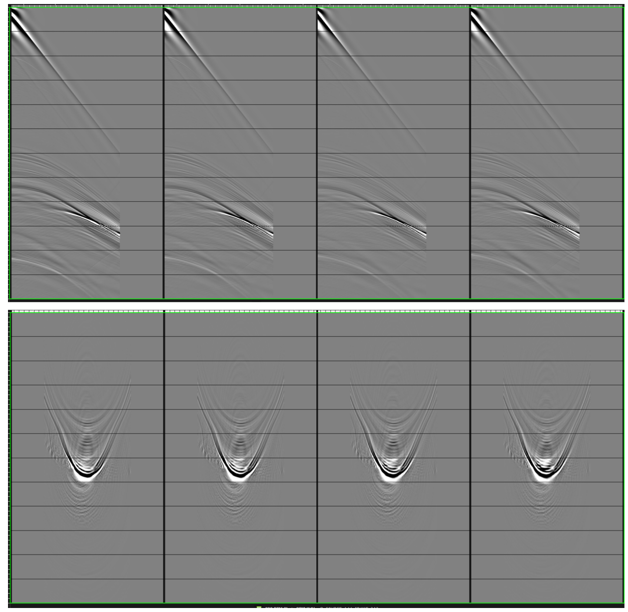

Figure 5*: Examples of the generated synthetic seismograms (top) and of the common image gathers generated by RTM migration.*

To generate the seismic volume, or stacked volume, all the common image gathers (CIGs) were summed. In Figures 6 and Figure 7, which have strong zoom applied, it is possible to perform a comparison, in a bidimensional view, between the stacked volume and the velocity model.

It is clear that the karst model present in the velocity model can be very easily interpreted in the seismic section. Although there are some migration artifacts, which sometimes can make seismic interpretation very difficult, the karst model is relatively well identified.

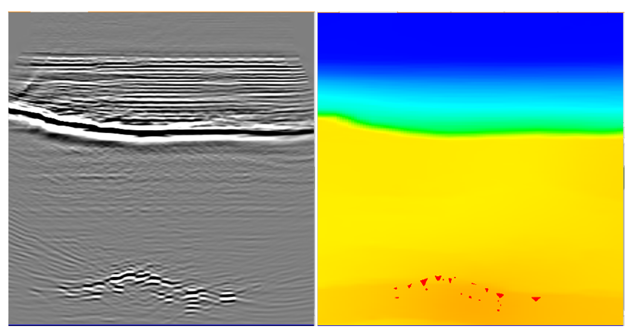

Figure 6: *The migrated seismic volume (left) and the velocity model (right), in a bidimensional view.*

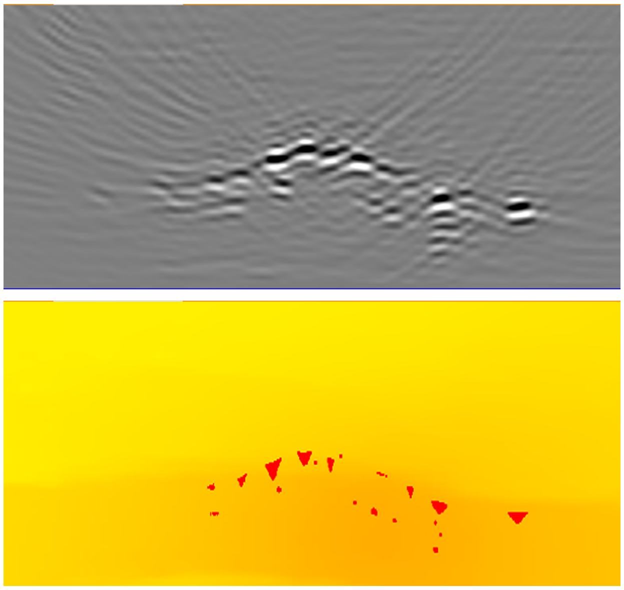

Figure 7: *Comparison, in a bidimensional view with a zoom applied to the karst region, between the synthetic seismic volume (top) and the velocity model (bottom).*

Another very interesting comparison is to put side by side, in a slice view, the karst structural model and the stacked volume (Figure 8). One more time, it is relatively easy to see that karst model could be satisfactorily identified given the velocity model contrast.

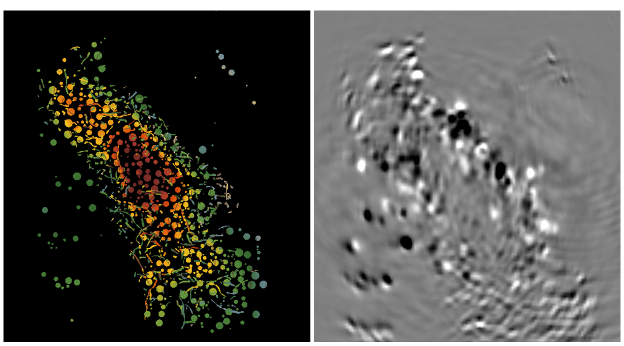

Figure 8: *Slice view of the karst structural model (left), which was inserted in the velocity model, and the result of the seismic imaging time slice (right).*

Conclusions

Velocity model building can be a challenging task, depending on the degree of complexity related to the geological bodies one wants to represent. Karst features have complicated shapes and geometry and, due to this, it can be a big challenge to represent it in a velocity model. As the current available methods didn't work, a different strategy was applied to insert the karst model in the velocity model. Such strategy included the developed plugin with new computer object inserted into velocity model representing kastified regions.

Once the karst model was well represented in the velocity model, the next step was to investigate if it could be identified or detected in a synthetic survey. Tridimensional marine seismic modeling was carried out to generated synthetic data and isotropic RTM migration was applied to it in order to perform depth imaging to generate seismic volume. The quality of the seismic was relatively good and the karst model could be easily identified in one azimuth. Further study was carried out for the multi-azimuths acquisition after completion of this work.

Although to perform the inclusion of complex geological bodies into velocity models during the end of seismic processing workflow is a very standard process, using FWI and tomography, for example, is not a very common task during the seismic interpretation stage and even for further stages during the reservoir study. Thus, it is important to have a tool or a workflow which can help to perform such task during the seismic interpretation flow, even though the technique is less accurate than those used in the seismic processing flow.

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