SPE-180412-MS

Analysis of SEAM Phase I Data and the Related Challenges

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This paper was prepared for presentation at the SPE Western Regional Meeting held in Anchorage, Alaska, USA, 23–26 May 2016.

Abstract

The salt related traps (sub-salt or slat flank) in the deep water of the Gulf of Mexico (GOM) has a pronounced impact on reservoir exploration and appraisal. It is, therefore, vital to do interpretation and attributes analysis on the seismic data to capture detailed reservoir structure and properties, as that is one of the core goals of the SEAM Phase I Project provided by the SEG. In this paper we will show how using Petrel and OpendTect is one of the keys to achieving that objective.

The strong seismic interpretation tools of OpendTect can help track seismic events and eventually guide us in selecting horizons. Furthermore, the novel approach of using the Supervised Neutral Networks can help us recognize the subsalt zone and faults structure. When the interpretation results, bolstered by additional measured information, are input to Petrel, it can offer the possibility of imaging the subsalt and increasing data analysis for this area.

Some interpretation and analysis results have been generated to represent our targeted area of the GOM. The stratigraphic variation and reservoir properties, as well as the feature of the salt domain, will be detailed in the results. Our analyses have revealed five major horizons in this area, three of which intersect with the salt body. The shape of the salt body is irregular, with a rugged top, and overhangs on both east and west sides. We will continue with confidence towards the end goal of imaging the area, lithology, and to distribute properties that include porosity, density, and fluid saturations (oil, water, and gas). This in turn will help us properly guide the reservoir development in that specific environment.

Our innovative methodology has rewarded us with an efficient way of combining two powerful commercial software programs to perform data analysis and ultimately enable us to image the complex structure of the salt body.

Introduction

SEG Advanced Modeling (SEAM) plans to create 3D subsurface models and synthetic datasets in order to establish an approach in which the model is continually updated as more data becomes available throughout the life of the field. The first SEAM Project (SEAM Phase I), which began in March 2007, was intended to address the challenges of Subsalt Imaging in Tertiary Basins. Given the growing emphasis on the deep water GOM, the project has become a resounding success, with the contributions of twenty four companies (Michael Fehler et al. 2011).

The Gulf of Mexico Basin is considered to be one of the world's great petroleum mega-provinces, wherein an abundance of untapped oil and gas remain. This ocean basin contains several geological layers, including Cretaceous, Oligocene-Paleocene, Miocene, Pliocene, and Pleistocene in decreasing chronological age. The reservoirs deposited in multiple rock types ranging from dolomite, limestone, highly cemented sandstone and mudstone to unconsolidated sand and mud (Galloway et al., 2009). It is well documented that the salt domes in the GOM cover a large area. However, despite having favorable conditions for accumulating and trapping oil and gas (Sayers and Herron, 2007), a salt body can inhibit seismic imaging. Significant challenges are presented during reservoir exploration and development operations (Close, F., et al., 2008). It is, therefore, essential to investigate salt body properties and use that information to guide future development.

Subsequent to the building of the famed 3D SEG/EAEG salt model (Aminzadeh et al., 1997), the research on salt interpretation and modelling increased. Various migration methods, including reverse time migration (Baysal et al., 1983) and 3D prestack depth migration (Ratcliff et al., 1992) were two of the traditional ways used to build salt modelling. However, those approaches were typically time-consuming and required much expertize to effectively manage all of the processes. More recently, the rapid development of computation capabilities has given rise to less complicated data analysis and to better performing modeling simulation (Sun, J., Schechter, 2015). Consequently, salt body analysis and 3D salt body imaging became more accessible to geophysicists with wide range of experiences.

As previously mentioned, OpendTect has strong functionality and is used to perform seismic interpretation, and analyze well log and seismic data. Those interpretation results can then be transferred to Petrel in order to image the subsalt and do further analysis. The required steps for analysis and salt body imaging are shown below:

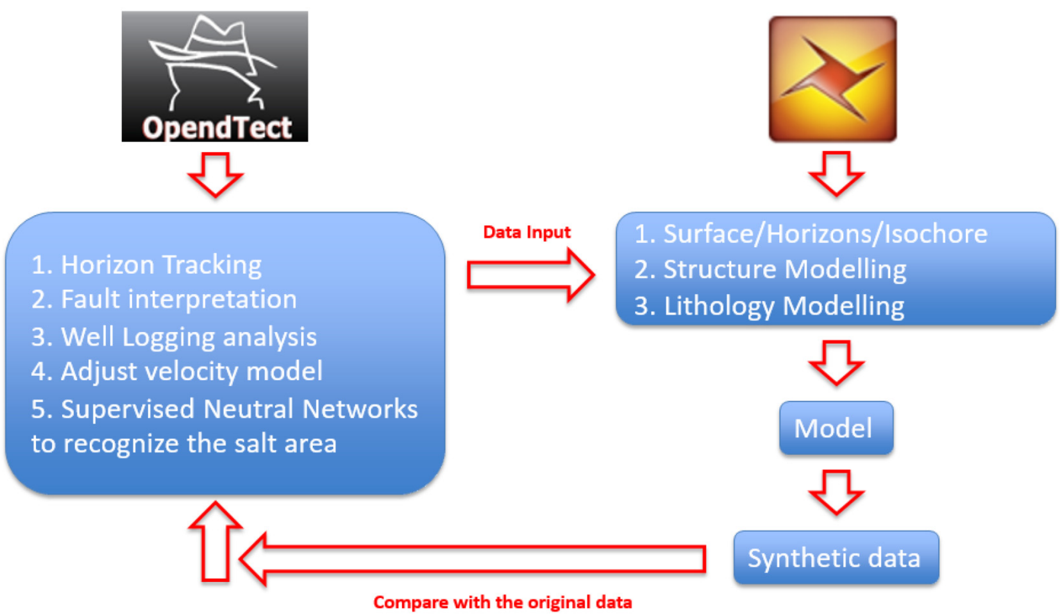

Figure 1—Anticipated procedures of this project

The overall procedure presents a viable, reliable and systematic way to analyze and image a salt body. However, the issues of weak seismic response and its negative effect on tracking horizons and interpreting faults will need to be addressed.

Generated Analysis

The definitive objective of this project is to analyze all the available data, then glean as much property information as possible about the salt body, and finally to use those results to effectively image the salt zone. Given the size of the project, it will require ongoing effort before reaching the final goal. At this juncture, the work contains well log analysis, seismic attribute analysis, and partial horizon tracking work.

Well Log Analysis

The elastic properties of velocity, density, P-wave and S-wave impedance, and Vp/Vs ratio are a good representation of reservoir attributes such as water saturation, porosity, and shale volume. Therefore it is important to analyze the elastic properties before we actually look into seismic data. Herein we analyze the well logs to better understand the lithology and reservoir rock.

SEAM I Data provides five synthetic well log data within the area of interest. Although the only available data in this part is synthetic, we are still able to do the analysis as an illustration exercise. The same procedures can be applied once we get the real log data.

Figure 2 shows the correlation of the Vp log across five wells. This can provide an overall picture of the number of layers in the reservoir. Compared with the 2D section of seismic data, we know that the pink zone represents the salt area (the velocity in salt zone is very high). Furthermore, the thorough analysis of the well log data suggests that there are five distinct geological formations. In addition to the main salt body, there is a salt layer covering the entire deep part of this area. Using this information, we performed further cross-plot analysis.

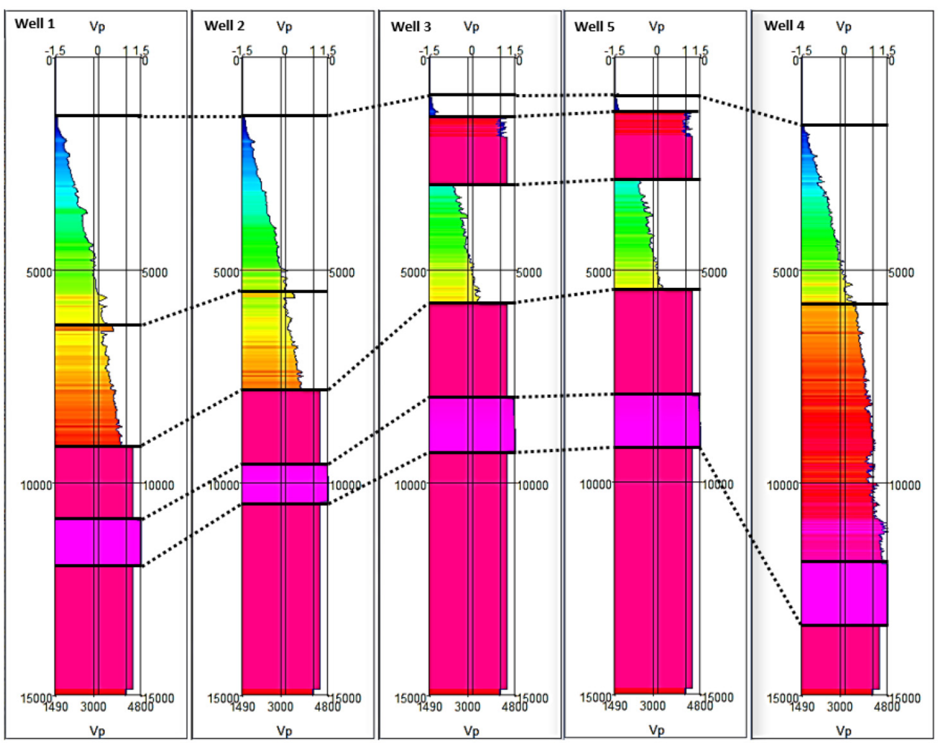

Figure 2—P-wave velocity Vp curve for the 5 wells

Figure 3 shows the cross-plot analysis by using the well log data. Here we only show the analysis of Well #1, but similar analysis was performed at the other four wells. Given the well spacing in this study, we recommend analyzing the wells separately. Figure 3(a) is a cross-plot of P-wave impedance with respect to S-wave impedance; Figure 3(b) is a cross-plot of Vp/Vs ratio and P-wave impedance; and

Figure 3(c) is the 3D cross-plot of P-wave impedance, S-wave impedance and porosity. In order to better differentiate other layers, we introduce the Clustering Analysis which gives us an overall lithological distribution. The clustering method we chose is based on Fuzzy C-means algorithm (Bezdek, J. C et al., 1984, Lashgari, 1991). For other applications of fuzzy in the petroleum industry see Aminzadeh and de Groot, 2006.

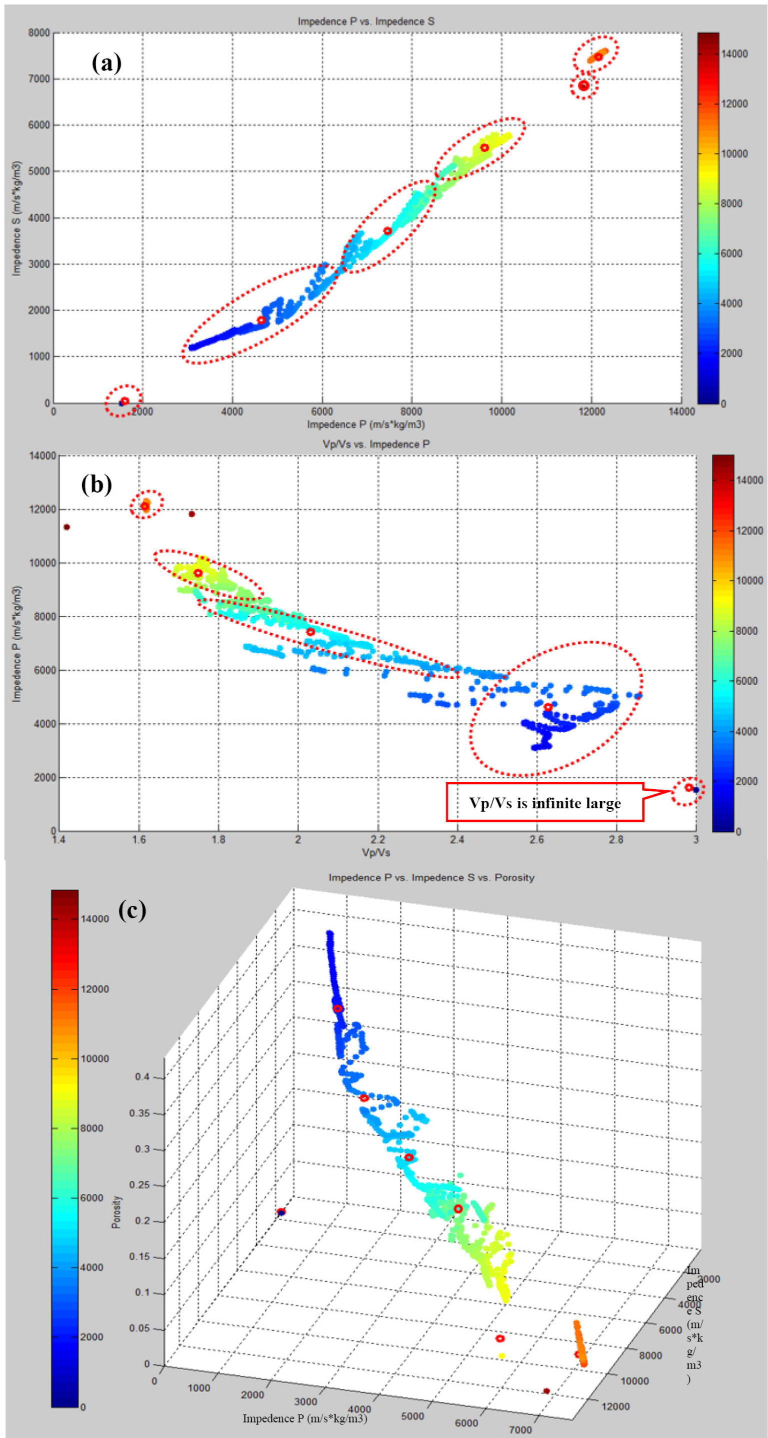

Figure 3—The rock physics template posted in the cross-plot. a) P-wave impedance vs S-wave impedance (b) Vp/Vs ratio vs P-wave impedance (c) 3D cross-plot among P-wave impedance, S-wave impedance and porosity. The color bar represents depth. Red circles in the figures are cluster centers. The red dot lines are drawn according to the 90% possibility that the data in the circle belongs to that cluster.

The basis of Fuzzy C-means algorithm is the minimization of the following equation:

$$J(X;U,V) = \sum_{i=1}^{c}\sum_{k=1}^{N}(\mu_{ik})^m \|x_k - \mathrm{v}_i\|^2{}_A \quad (1)$$

Where $\mathbf{v}_i$ is a vector of cluster center, c is the number of clusters, N is the number of samples, μ_{jk} is the membership function that measures the degree to which the j-th data belongs to the k-th cluster; the parameter m is known as fuzziness parameter, which controls the degree of fuzziness of the resulting membership functions -- the bigger m we have, the more overlaps among different clusters. In equation (2), the distance norm is defined as:

$$D_{ikA}{}^2 = \|x_k - \mathrm{v}_i\|^2{}_A = (x_k - \mathrm{v}_i)^T A (x_k - \mathrm{v}_i) \quad (2)$$

And the membership function and vector of cluster center can be derived as:

$$\mu_{ik} = \frac{1}{\sum_{j=1}^{c}\left(\frac{D_{ikA}}{D_{jkA}}\right)^{\frac{2}{m-1}}} \qquad 1 \le i \le c, 1 \le k \le N. \quad (3)$$

$$\mathrm{v}_i = \frac{\sum_{k=1}^{N}\mu_{ik}^m x_k}{\sum_{k=1}^{N}\mu_{i,k}^m}, \;\; 1 \le i \le c. \quad (4)$$

The norm inducing matrix A can be I, or can be the inverse of the covariance matrix F:

$$\boldsymbol{F} = \frac{1}{N}\sum_{k=1}^{N}(x_k - \bar{x})(x_k - \bar{x})^T \quad (5)$$

When the l-th cluster result $\mathbf{U}^{(l)}$ satisfies $\left\|\mathrm{U}^{(l)} - \mathrm{U}^{(l-1)}\right\| < \varepsilon$, we can stop iteration and get the final results. In this paper, we use the FuzzyClusteringToolbox for matlab (Balasko, B et al., 2005) to do the clustering analysis and give a rough distribution of different lithological layers.

In Figure 3, the data is colored in such a way as to represent the depth; the red circles are the cluster centers calculated by the Fuzzy C-means algorithm, and the red dotted circles in Figure 3(a) and Figure 3(b) are determined according to the membership function equaling 90%. The red circles highlight the data points that fall within each cluster with a high degree of certainty.

In Figure 3 we can clearly observe different layers and their respective positions. Within a depth range between 2,000 – 9,000 m, this clustering method works well, can guide the horizon tracking work, and help us delineate the lithology. The clustering method seems to be helpful in this case. However, in the zones that have similar characters but are located at different depths (such as the main salt body and the salt area below the mother salt horizon) the clustering method is less effective and cannot differentiate among them. Based on this study, the cross-plot can truly provide useful information about the lithology, and with the implementation of the clustering algorithm we can identify the depth of different rock types. Furthermore, we plan to incorporate this analysis into the seismic interpretation by overlaying the formations extracted from the cross-plots with the seismic reflectors.

Seismic Attribute Analysis

Seismic attribute is defined by Sheriff (1991) as a ″measurement derived from seismic data″. It is a powerful tool to both quantitative and qualitative seismic interpretation, which can help us interpret faults and other geological bodies, as well as recognize the depositional environment. OpendTect has provided various seismic attribute calculations that can be easily accessed. In this part, we chose several representative attributes to do the seismic analysis. Figure 4 and Figure 5 show the Dip Steering Median Filter, phase and amplitude attributes in inline section and depth slice.

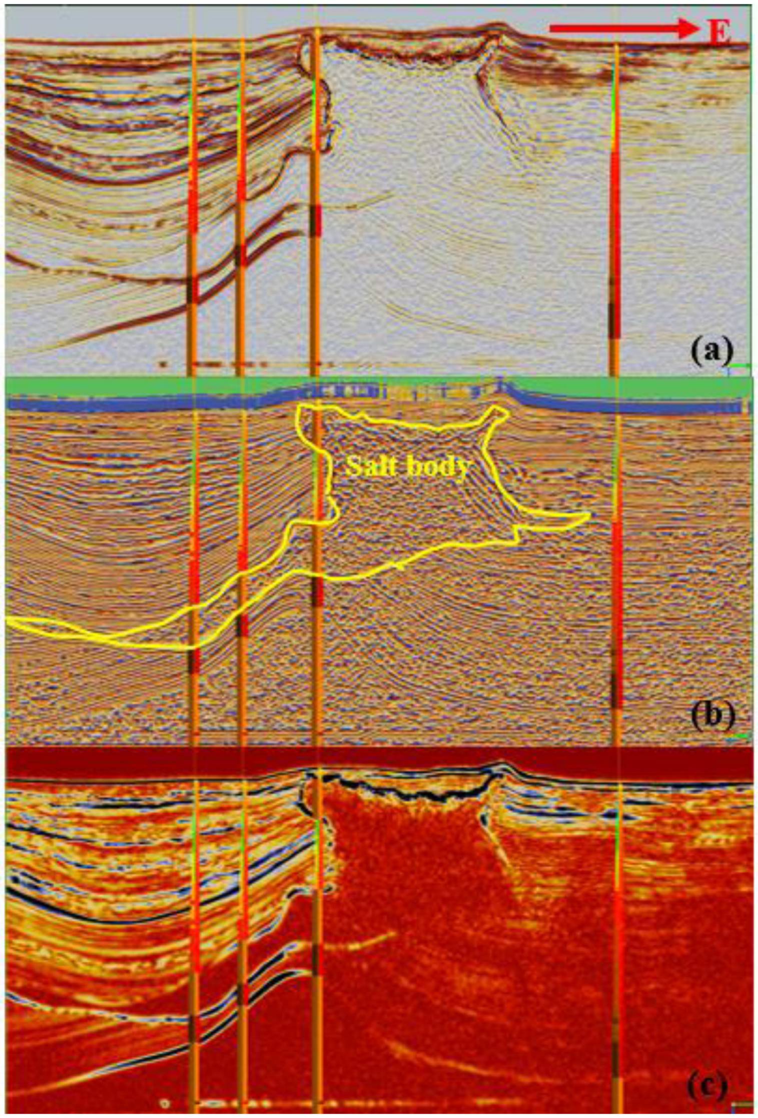

Figure 4—Seismic Attributes of inline 5783. The logs from left to right are well 1, 2, 3, 4 (Left is Vp Log and right is Density Log) (a) Dip Steering Median Filter (b) Phase (c) Amplitude

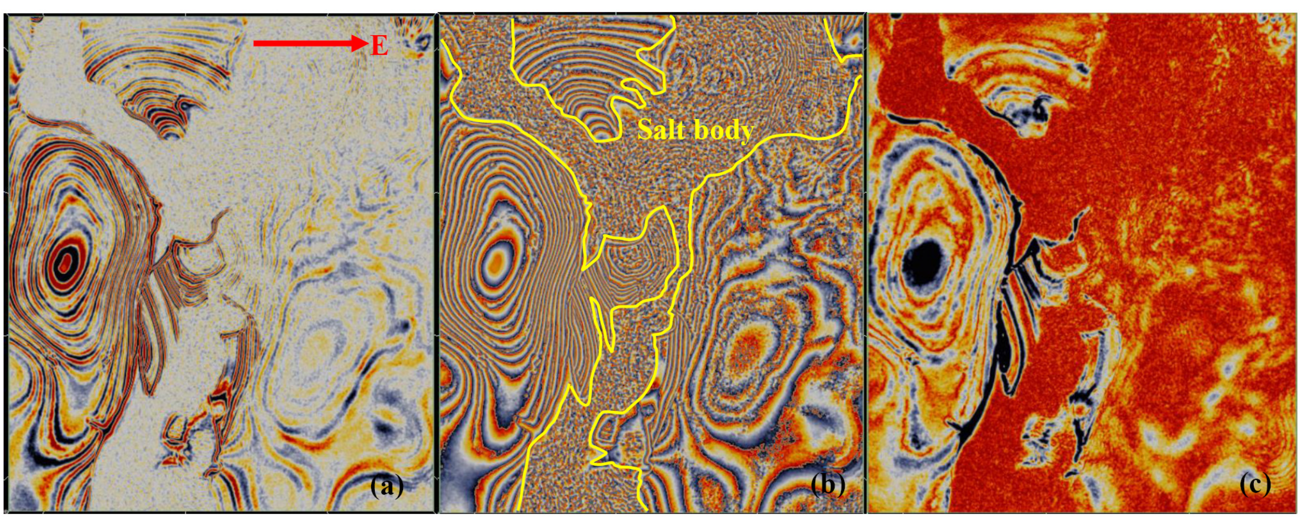

Figure 5—Seismic Attributes of depth slice at 7500m. (a) Dip Steering Median Filter (b) Phase (c) Amplitude

From the above we notice that the western part in this area has better seismic response, while in the eastern part the seismic response is very blurred because of the negative effect of the salt body. This was quite troublesome when we attempted to track horizons. But we can still distinguish some layers from the above attributes, especially from the phase attribute. In the salt body zone, the seismic response is relatively weak, therefore the phase attribute shows great distortion in the seismic signature compared to the other area. From this analysis we can easily differentiate the salt body from any rock type. We concluded that the phase attribute is best able to discern different geological features.

Looking down onto the top of the area enables us to observe the shape and the geometry of the salt body. Due to the that body's inhibition to seismic resolution, we are only able to exact the salt geometry of the western part. For this we used both Dip Steering Median Filter and Amplitude attributes. In Figure 5(b), the phase attribute provides an awareness about the distribution of the salt body at a depth of 7500m. Combining Figures 4 and 5, the shape of the salt body can be delineated; as earlier stated, the main salt body in this area has a rugged top (from Figure 4), irregular shape, and overhangs on both of the east and west sides (from Figure 5).

Horizon Tracking

With both well log analysis and seismic attributes, we can ensure not only the distribution of the salt body, but also distinguish the main horizons and their relative positions. Armed with such information, we can follow the seismic signals at the corresponding positions and track the horizons, which is essential input for the interpretation in Petrel. Figure 6 is the horizon tracking results using OpendTect.

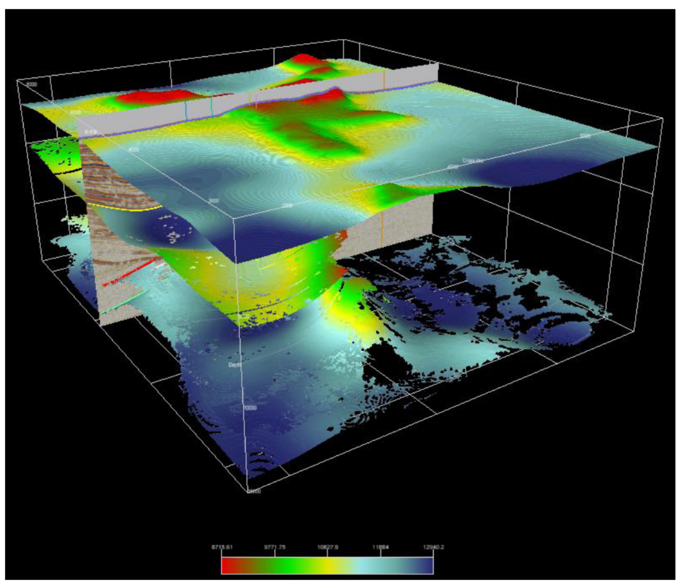

Figure 6—Five main horizon tracking results (Layers from top to bottom: water bottom, Miocene, Oligocene, Cretaceous, Mother salt layer)

The horizon tracking part is not fully satisfactory at this time, as we cannot track the entirety of a layer in all cases. Tracking seismic events in the eastern part of the area was also challenging because of the weak seismic signature. That is one of the issues we have faced with SEAM dataset.

Challenges and Future Work

Our studies so far have primarily relied on OpendTect for both the well log analysis and seismic attribute analysis, which are the initial steps in our project. The main challenge at the moment is that the weak seismic response zone has a negative effect on our seismic interpretation work (horizon tracking and faults interpretation), which is crucial information in building a comprehensive model.

After resolving those issues, we will move forward to the next stage, which contains salt body imaging and populating model with properties including porosity and permeability. Such work will be reliant upon using a combination of tools from OpendTect and Petrel. As Figure 7 shows, their software can share and exchange most of the data and interpretation results. Those conclusions will then be loaded into Petrel for the salt imaging and properties analysis.

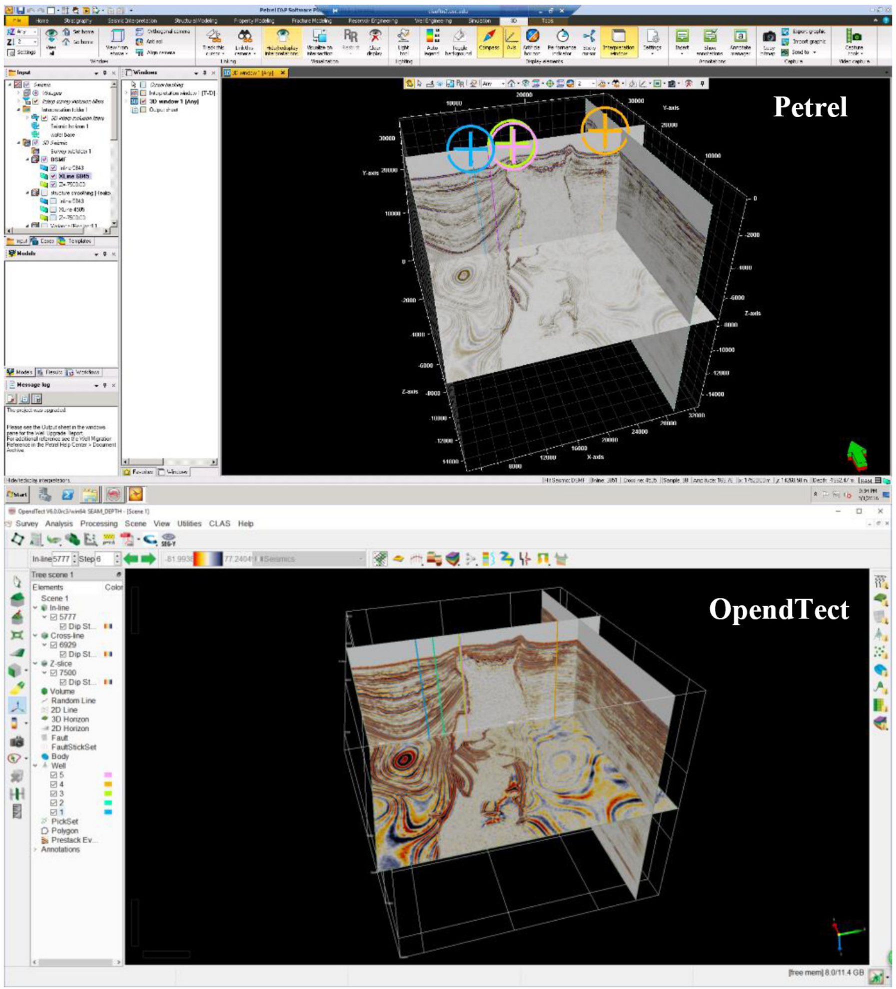

Figure 7—Data and interpretation results share between OpendTect and Petrel

To reach our ultimate goal, some of the following are under consideration for future work:

- Inverse the P-wave impedance, S-wave impedance and Vp/Vs ratio among the whole area.
- Rock physics template analysis to the seismic data.
- Use such as Neutral Network Method to predict rock properties such as porosity and permeability.
- Complete the horizon tracking and faults interpretation work.
- Combine OpendTect and Petrel to image this salt body area.

Conclusion

Our work presents a reliable and rapid way of combining two powerful software programs on data analysis for reservoir characterization on a complex salt body from the Gulf of Mexico. The current results have shown the basic characters of the SEAM I survey area (the geological layers, the shape and distribution of the main salt body etc.) and built a fundamental understanding of the well log data. This is an ongoing project and further analysis will be required in order to achieve the ultimate goal of the SEAM Project. The presence of complicated geometrical salt bodies had previously led to poor illumination and consequently a more puzzling interpretive task. The available data may not contain all information needed about the subsurface. To overcome these challenges, seismic data using Full-azimuth and long-offset acquisition configurations are recommended for imaging the subsalt structure (Li, Y et al., 2014). The completion of the entire project can help us more fully understand the complex structure of Gulf of Mexico and thus guide the reservoir appraisal, and provide solutions to the difficulties we may meet while developing this area.

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