Drilling closer to salt

Ahmed Ammar[1], Ross Saunders[1], Chuck Henry[2*], Tim Wilkinson[3], Mike Frismanis[4], Mike Bradshaw[4], Jeff Codd[4] and David Kessler[4] present the use of improved model building and prestack depth imaging technology and workflows that led to identification of multiple new opportunities in the Gulf of Mexico.

Drilling up-dip wells, in close proximity to salt bodies is common practice in exploration for oil and gas. Imaging of sand layers close to salt however is difficult in many cases owing to the complex geometrical shape of the salt body as well as the rapid change in material properties between the sedimentary section and the salt body. In many cases this results in either drilling into the salt body by mistake, or too low in the target formations. This difficulty is very well known in the Gulf of Mexico shelf which has been a prolific oil and gas producing region for more than 70 years. Over the years, seismic data used for interpretation and prospect generation in this area has been sub-optimal in many cases. Many of the producing fields in the Gulf of Mexico shelf consist of steeply dipping hydrocarbon-bearing sands truncated against salt domes. Unfortunately, in many cases the salt bodies defining the reservoir edges are not well imaged on associated seismic data, making the accurate mapping of the producing reservoir very difficult (Foley et. al., 1991).

One solution to the seismic imaging problem can be achieved by design and acquisition of new seismic data. In the past few years, more effort has taken place to acquire new data on the Gulf of Mexico shelf, but dense spacing of surface platforms makes acquiring new surface streamer data difficult. The newer data is mainly acquired using ocean bottom node technology which results in wide azimuth seismic data. The new data has the potential to have much better seismic resolution than the older narrow azimuth streamer data used by the industry for many years. In addition, nodes can be placed much closer to surface installations creating better illumination in these areas. However, because of the complexity of the geology in close proximity to salt bodies, the clear imaging of sedimentary layers near salt remains challenging even when the newest seismic data is used.

In parallel to the development and deployment of new acquisition technology, much progress has been made in the past few years in processing and imaging technology. The main advancements include (a) the ability to construct more detailed anisotropic earth models with much more complex salt bodies and (b) the use of more accurate prestack depth migration algorithms.

In general, processing and imaging results will only be as good as the quality of the input seismic data and the velocity model. However, the use of more accurate models and depth imaging algorithms and workflows can result in much more

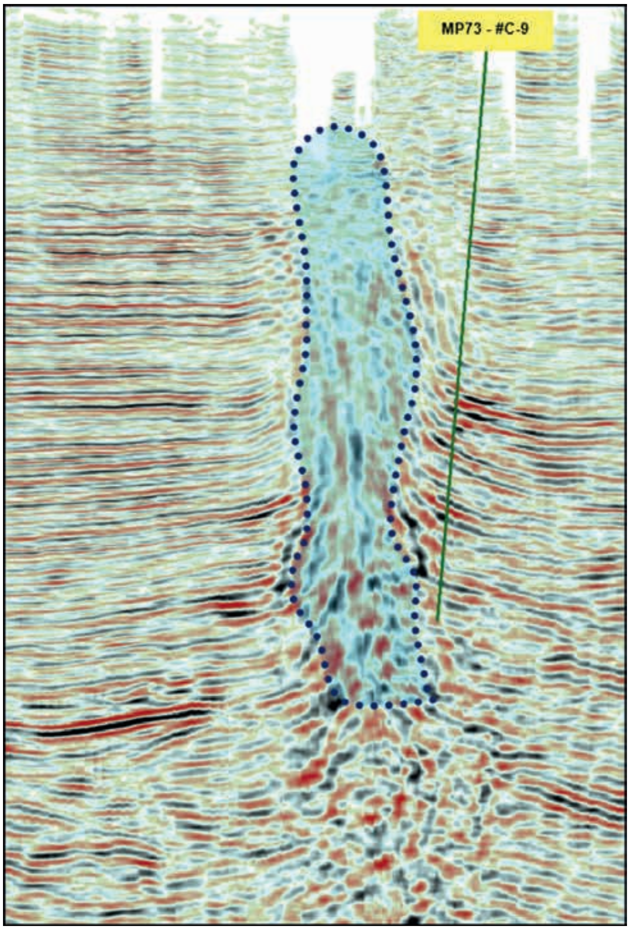

***Figure 1** Main Pass 73 historical salt model. The historical model consists of a steeply dipping salt dome surrounded by hydrocarbon bearing sands. The well path displayed was drilled through the producing zones.*

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interpretable data, even when we are limited to the use of older seismic data.

The above difficulties were discovered when we were assigned with the task of increasing the productivity of an old oil and gas field in the shelf known as Main Pass 73 (MP73) field. Having only older and sub-optimal seismic data in hand, the decision was made to rely on seismic processing technology to produce better seismic data that will enable us to more accurately interpret the sand layers around the field main salt dome and define new up-dip, closer to salt drilling locations.

The use of improved model building and prestack depth imaging technology and workflows resulted in a change in the interpretation of the salt model for the MP73 field, and led to identification of multiple new opportunities. This was followed by a drilling programme targeting the Lower Pliocene and Upper Miocene sands that resulted in significant new discoveries of up dip oil and gas reservoirs.

Historical background – MP73 Field

MP73 Field was discovered in 1974 by Mobil. The seismic data that was used in the discovery of the field was 2D data that was available at the time. Based on 2D seismic data and well control, a salt model was developed. The model consisted of a salt dome with steeply dipping flanks and hydrocarbon-bearing sands around the dome (Figure 1). First production of the field was established in 1979. The field has been producing ever since, and over the years has been operated by several companies. From 1979 to 2015 the field has produced 46 MMBO and 255 BCF. Production has been from about 30 sands ranging from Lower Pliocene to Upper Miocene (Figure 2).

In 1992 a 3D dataset was acquired over the field. The 3D dataset did not add a clear image of the salt dome, and therefore the historical model did not change. One of the reasons for the poor data quality was the low seismic fold over and in close proximity to the salt, as streamer data could not be acquired around the producing rigs. Moreover, mud slide zones in the area resulted in noisy seismic data.

In 2007 Energy XXI acquired the field with the objective to locate attic oil and gas around the field salt dome. Working with all available data, discrepancies between well data and seismic data were found. In order to resolve these discrepancies a decision was made in 2008 to reprocess

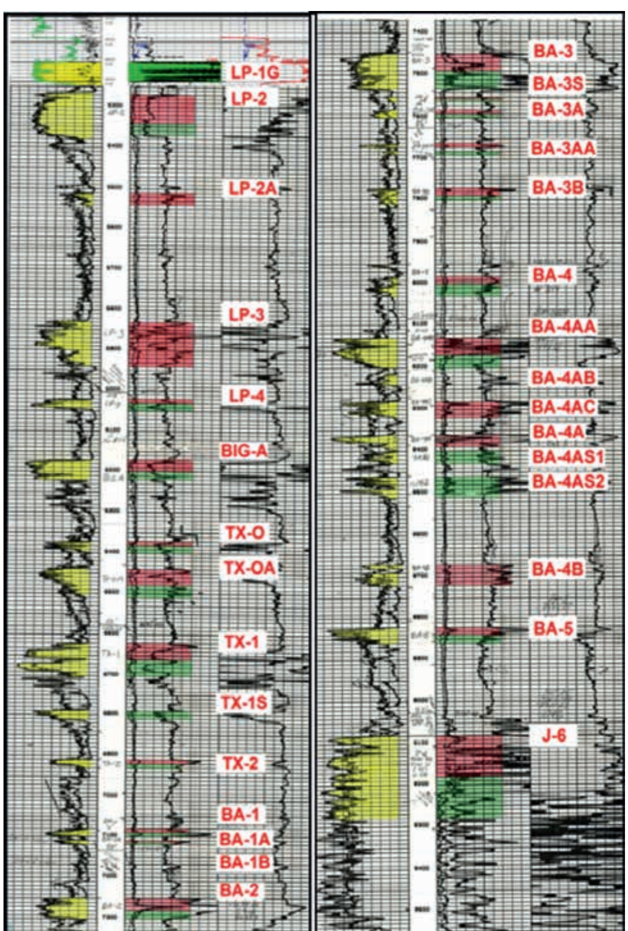

Figure 2 *Type log. Main Pass 73 field.*

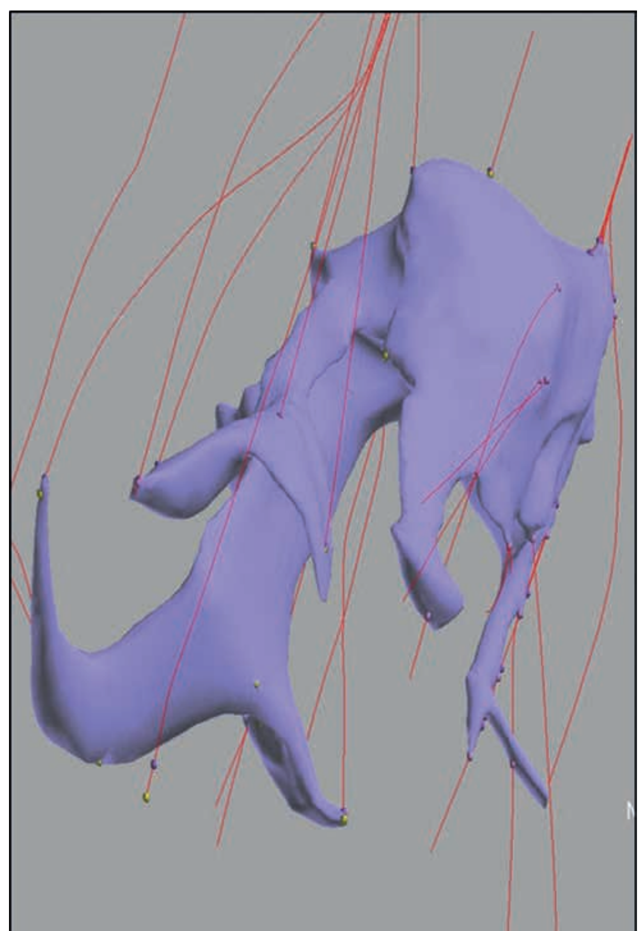

Figure 3 *(a) Newly developed salt model.*

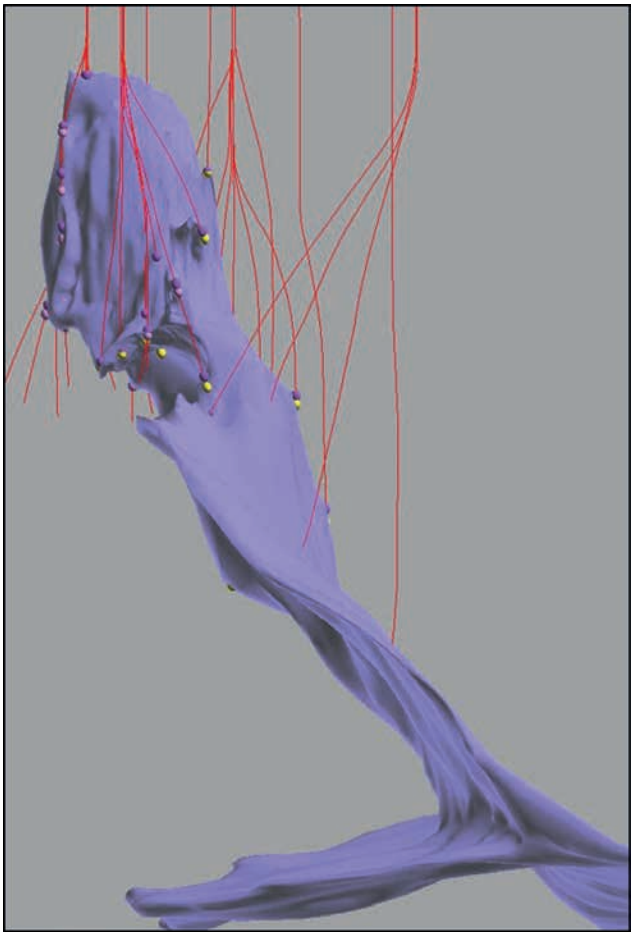

Figure 3 (b) Newly developed salt model.

Figure 3 (c) Newly developed salt model.

the existing seismic data. SeismicCity was given the task of developing an anisotropic model and applying prestack depth migration with the objective of clarifying the image and interpretation around the salt dome. This will enable identification of up-dip drilling opportunities closer to the salt. The full scope of technical objectives that were set by application of depth imaging and reinterpreting the seismic and well data was the following:

- Image the salt/sediment interface and delineate the reservoir to understand its extent, geometry and architecture.
- Increase the resolution of the current seismic data, and enable detailed stratigraphic interpretation.
- Discriminate between the various lithologies and facies, and improve the geological interpretation.
- Quantify thickness, lithology, porosity, and other reservoir properties.
- Calculate volumetrics for the reservoir to understand reserve estimates.

Changing a historical model and interpretation

Model building and depth imaging started in 2008. Several salt model building workflows are used in the industry with the most common being a 'salt flood'. The 'salt flood' workflow became industry practice in use of 2D seismic data, and will work correctly in many cases, but not always. In cases of tabular shape salt, the base of salt reflection can be correctly imaged by creating a trial model consisting of vertical salt walls 'hung' from the top salt which is the basis of the 'salt flood' technique. In cases of more complicated salt shape, and especially in cases where several salt bodies fall within the aperture zone, use of the 'salt flood' technique may result in the imaging base of salt and salt flanks in the wrong spatial location. In the case of MP73, owing to the lack of salt flank image, model building and depth imaging was done using a model-building technique called the 'salt expansion technique'. This workflow is based on the generation of multiple prestack depth migration (PSDM) volumes where a trial salt model is used at each iteration. Because of the absence of salt flank reflections, analysis of the noise patterns around and inside the salt body are used as a guide for the construction of the salt body model during the salt model building work.

When applying the 'salt expansion' technique for model building, we discovered that primary reflection seismic

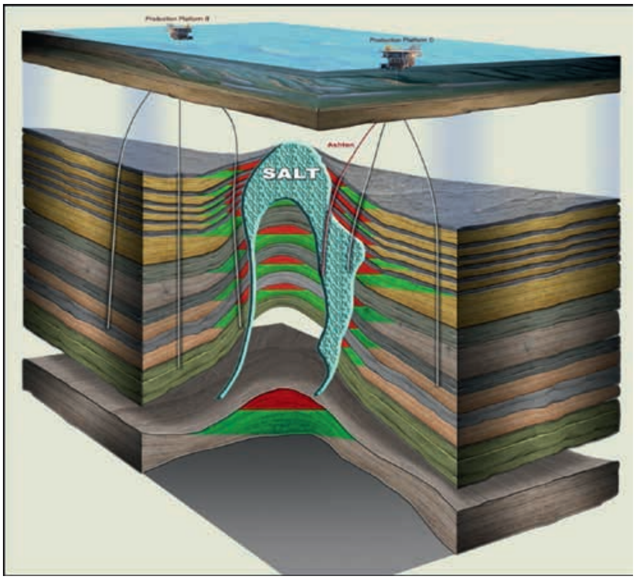

Figure 4 *Schematic model representation of the updated MP 73 salt body and surrounding oil and gas bearing sands. Two new possible well paths are displayed, which were planned to be drilled into the older salt model.*

events were imaged inside the historical boundaries of the salt body. The only way to preserve these seismic reflections was to develop an alternative salt model consisting not of a single dome type salt body, but several smaller detached salt bodies with sedimentary sections between the salt bodies. This seismic processing observation leads to a dramatic change in the historical salt model. In 2009 35 years after the discovery of MP73 Field, a new salt model, consisting of several smaller and detached salt bodies, was developed.

This new model replaced the historical diapiric shaped salt dome leading to a new and optimistic interpretation of the producing sands. In many cases there are only a few to no wells that can be used to constrain the model building process. In the case of MP 73 many wells penetrated the salt over the years resulting in a well dataset that can be used to greatly help in the model building process. After careful analysis of all the existing well data, and using additional geological considerations utilizing all subsurface salt markers from all older wells drilled in the area of the producing field, the salt model was further modified during 2010. Additional analysis of the depth migrated data revealed the presence of welds (i.e. evacuated salt) connecting the smaller salt bodies. This additional 2010 model building effort resulted in model modifications where the smaller salt bodies were connected through a series of thin salt welds leaving a sedimentary cavity inside the salt body (Figure 3).

To complete the geologic model, an anisotropic field was developed for the sedimentary section around the salt, and application of the final anisotropic PSDM was done in late 2010. Interpretation of the depth migrated data using the new salt model followed the model building and PSDM work. This resulted in a complete new programme for drilling new prospects. All these new prospects are located both up-dip to older well penetrations, and inside the historical boundaries of the salt dome model (Figure 4).

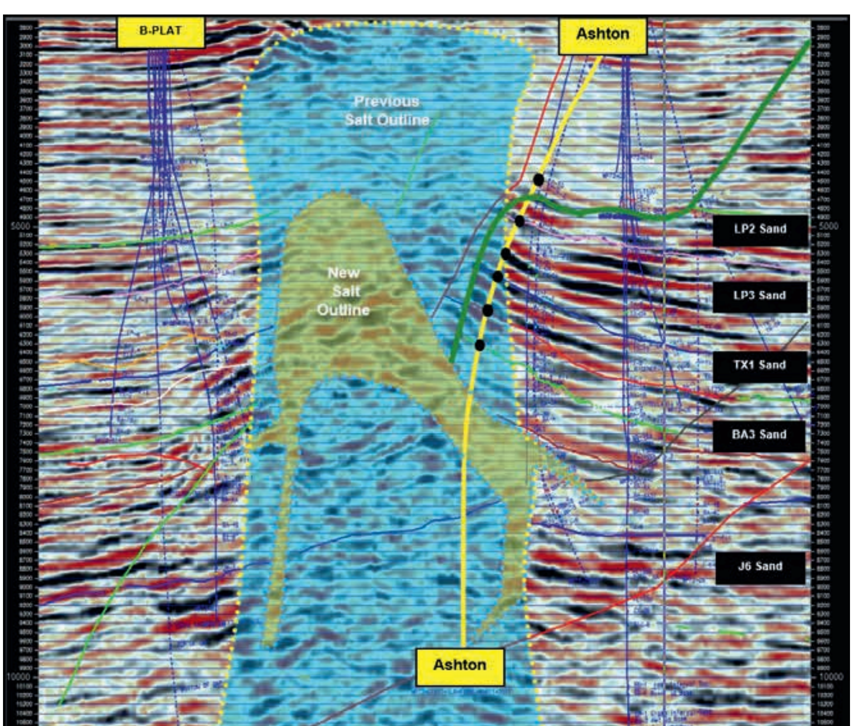

Figure 5 *Ashton well. It was the first well that was drilled into the older salt model and outside the newly developed salt model.*

Drilling campaign

The interpretation of the anisotropic depth migrated data was done in 2011 as soon as model building and PSDM were completed. The interpretation work resulted in several new drilling locations. Two wells were approved in 2011, moving the focus from interpretation to well path design.

The first well, named Ashton (C15-ST1), was drilled in 2011. It targeted a series of seismic amplitudes located inside the historical salt body boundaries and outside the new model (Figure 5). The well encountered multiple hydrocarbon sands (Figure 6), and was completed in 2011.

Oil-based mud (OBM) was selected as the drilling fluid since the well has targeted sand layers located inside the old salt model. The well encountered six pay sands located inside the old salt model and tagged salt at 6500 ft measured depth. During drilling the well became unstable and therefore production casing was set for the first three pays. Shortly after, production started from Big A and LP-2 sands. This indicated connection to the down dip reservoir, confirming the seismic interpretation that amplitude imaged in the new processing inside the old salt model are an up-dip continuation of the down dip sands.

The second well, named Onyx (C17-ST1), was drilled in 2011 into a series of sand layers that were not imaged on any previous prestack time migrated data (Figure 7). As in the case of Ashton well, OBM was selected as the drilling fluid as we expected to encounter salt. The well encountered two significant shallow pays, LP-1G sand and LP-2 sand. LP-1G sand was never produced in MP 73 field. LP-2 sand is producing in an adjacent fault block. Drilling deeper, the well head encountered a limestone section, and then salt. Our interpretation was that we might be crossing a thin segment of salt. Taking a more conservative approach, a decision was made to complete the well and start producing from the two shallow sands.

The well was completed, and production started soon after from the two sands, LP-1G and LP-2.

LP1-G sand was found to be very productive with initial production rate (IP) reaching 5500 BOPD. This made Onyx the highest-producing oil well on the Gulf of Mexico shelf at the time (Figure 8). LP-1G sand has 36% porosity and 3 Darcy permeability, making the sand the best reservoir rock ever seen in the field.

After the first well, two down dip wells were completed within the pay and connected to production. This resulted in peak production of more than 9000 BOPD. From start of production later in 2011 through to early 2015, the three wells drilled into the LP-1G sand have produced 1500 MBO and 580 MMCF.

LP-2 sand was completed as well, targeting preserved porosity in the middle of the sand. The well confirmed a thick sand, but significant diagenesis and cementation. From start of production in later 2011 through to early 2015, the well drilled into the LP-2 sand has produced 430 MBO and 150 MMCF.

Based on these results, several future wells are currently being planned to target the attic reservoir up dip to the Onyx well. These planned wells are even farther inside the old salt boundary, targeting amplitudes imaged well on the new PSDM data.

The new salt dome model reinterpretation, confirmed through the drilling results of the Ashton and Onyx wells, proved that the salt body was indeed smaller than the old dome model. This has allowed the exploration team to derisk several other new prospects around the field. Drilling these new prospects will be an ongoing process. Each additional

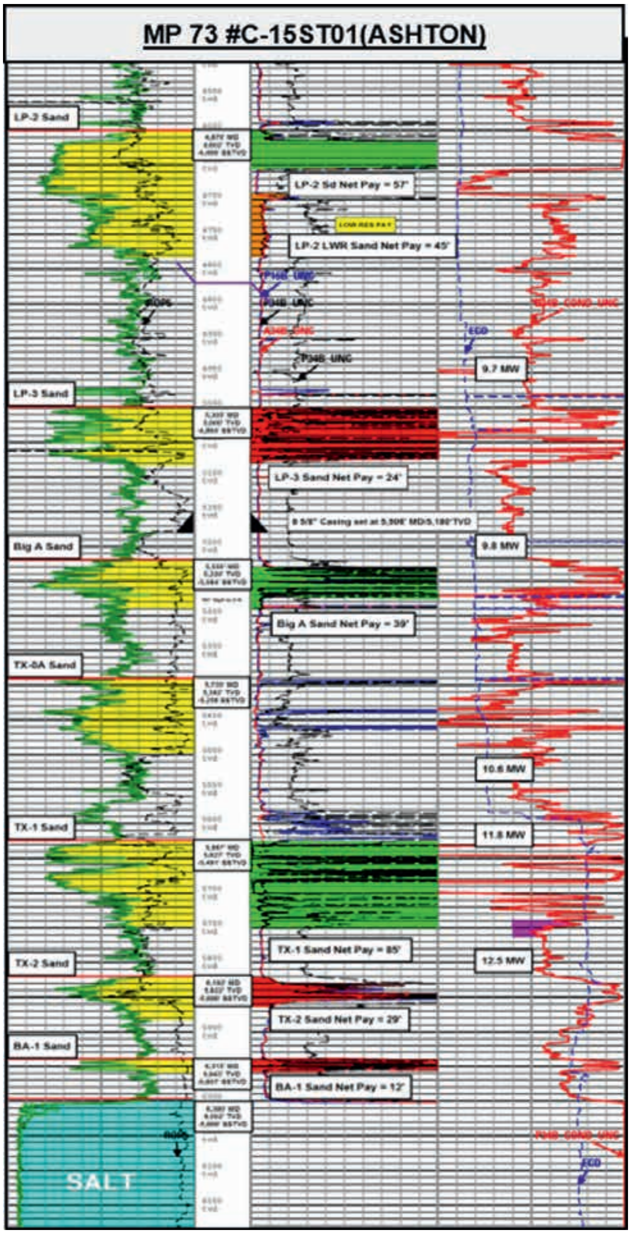

Figure 6 *Ashton (C-15ST01) well log.*

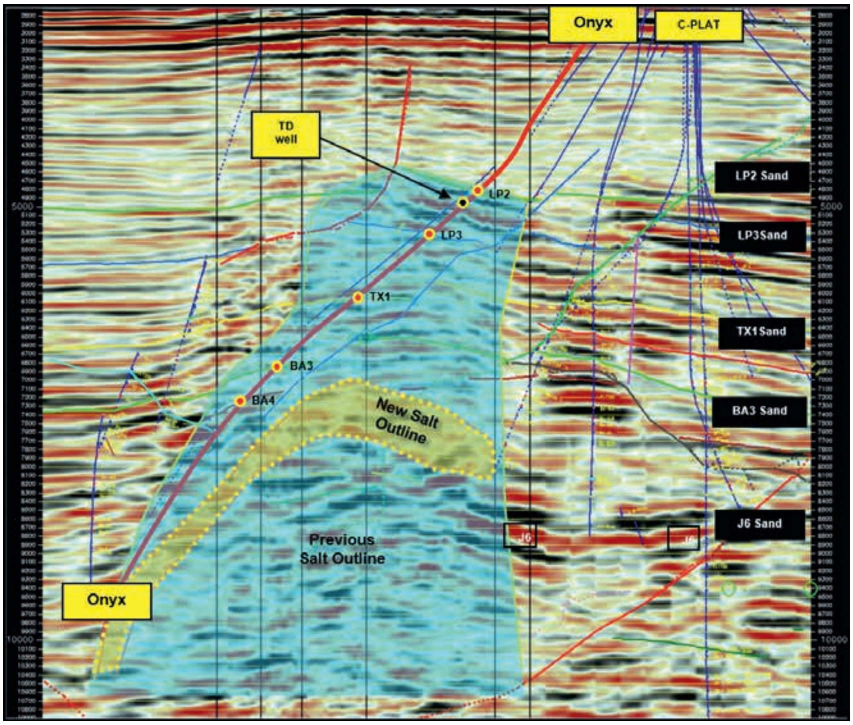

***Figure 7** Onyx well plan. The plan was to drill into a series of sand layers that were not imaged on any previous prestack time migrated data.*

drilled well will provide much more information about the true shape of the dome. We hope that together with new and improved seismic data we will be able to improve the interpretation of the salt and construct even a more accurate model of the salt body.

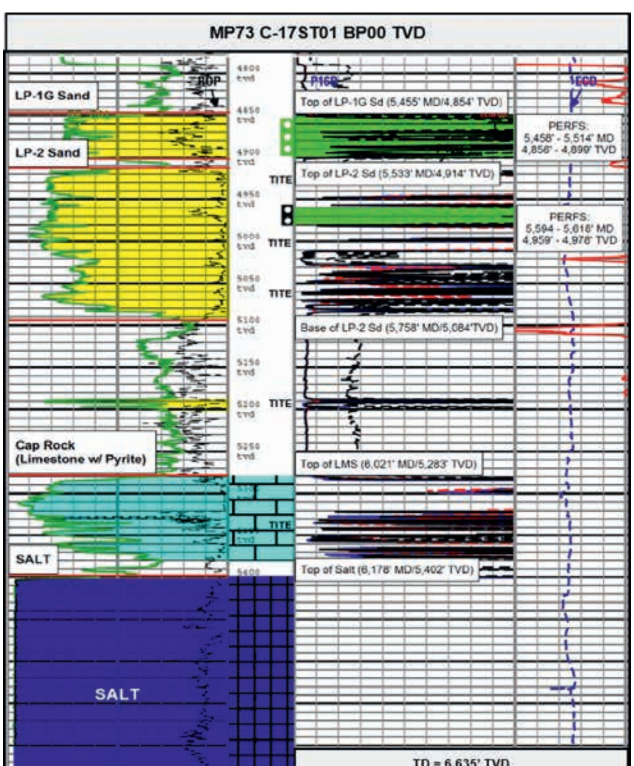

***Figure 8** Onyx (C-17ST01) well log.*

Summary

In the study presented in this paper, model building, depth imaging, and new interpretation were applied using legacy streamer 3D dataset acquired over MP73 field on the Gulf of Mexico shelf. Successful drilling that has been executed using new PSDM data resulting in significant new finds of additional oil and gas reserves in MP73 field. These finds validate the viability of the model building and depth imaging techniques that were used in this project.

This work started with a model that was established in this area about 35 years ago, and has been dramatically changed. The initial salt model consisted of a dome-shaped salt body. The new model consists of a much more complicated shape salt body that includes salt cavities, welds, and overhangs. We are not sure that the newly developed model is the exact salt model, but we do know that (a) the historical dome type salt model is not correct, (b) we believe that the new model is a closer representation of the true salt geometry, and (c) there is a great potential for much more up-dip, closer to salt drilling opportunities than what we expected before starting our work in this area.

We frequently work in salt-related prospects where the salt image is far from being optimal. We hope that newly acquired seismic data will result in better seismic imaging and more precise interpretation, but new seismic data is not always available. When new data is available there is no guarantee that we will be able 'to see' complete salt bodies. This is is a closer representation

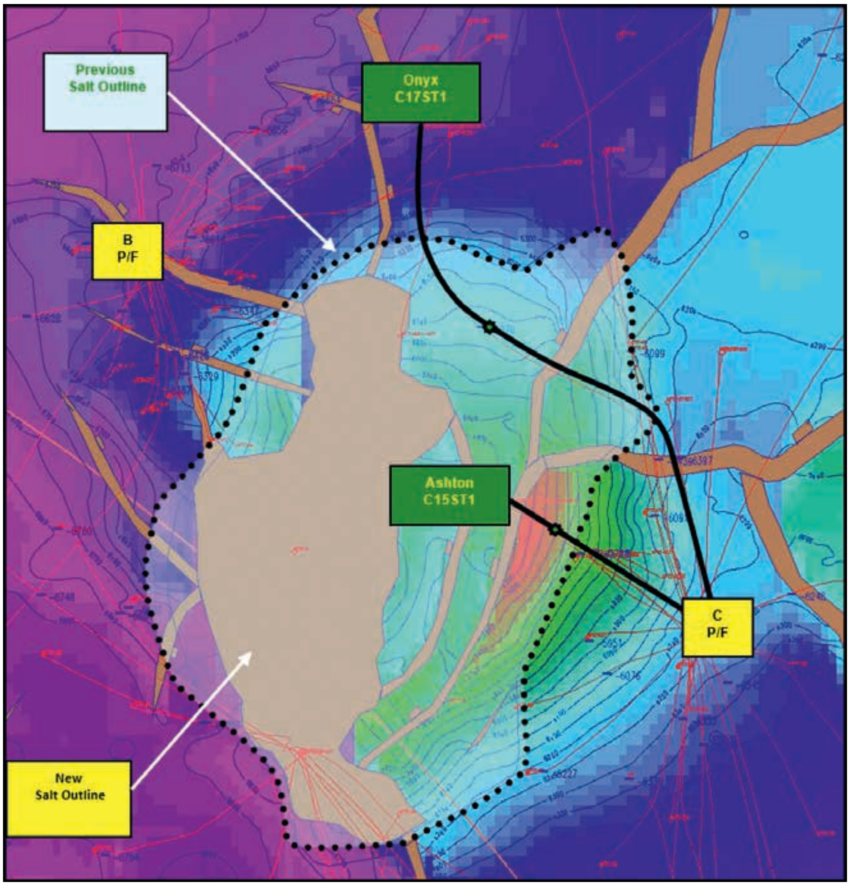

Figure 9 *MP73 depth structure map. The dotted line shows the old salt model's edges. The grey coloured polygon shows the edges of the new salt model. The area between the old salt model and new salt model presents new exploration opportunities.*

of to sub-surface illumination difficulties, complex lithological settings, and coherent seismic noise normally generated around salt bodies. The work presented in this paper demonstrates that with the application of more advanced model-building workflows, such as the 'salt expansion technique', the construction of more accurate anisotropic models, and incorporating all available subsurface information, better PSDM data can be produced even when old seismic data is used.

The results of the work over the MP73 field demonstrate a radical change in the understanding of the field, the salt body, and the surrounding sands (Figure 9). This led to the start of a completely new exploration programme around one salt dome that has been in production for more than 35 years. There are many other dome-related fields in the Gulf of Mexico shelf that can probably be opened again for exploration if they, as with the MP73 field, have only sub-optimal seismic data. There are as well similar geological setting fields and prospects in other mature basins over the world.

Besides the increased potential around the salt body, we can easily identify multiple deeper potential prospects. In the case of the Gulf of Mexico shelf, only 4% of the wells were drilled to a depth greater than 15,000 ft. Accurate models that include reliable salt bodies in the shallow part of the section will result in much more reliable images in the deeper section, opening new exploration opportunities in areas that have been producing for several decades.

Newly developed technology is introduced to the industry every day. In recent years further improvements have been achieved in the area of prestack depth imaging technology. Wide azimuth node data has become more and more available in areas where streamer seismic data cannot be acquired (Walker and McIntosh, 2011), enabling use of wide azimuth (WAZ) data where streamer WAZ data cannot be acquired.

Future use of the better WAZ data coupled with advanced depth imaging technology are expected to further improve the interpretation and geological model building of additional salt bodies in this area, and in other basins around the world. This will lead to successful exploration programmes in areas that have been thought to be too mature for new exploration.

References

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