Seismic Gymnastics Provide View

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Massive salt bodies in the deepwater Gulf of Mexico can be both a blessing and a curse for oil companies exploring the depths.

Yes, large salt-related structures can hold huge accumulations of oil -- but the same salt makes finding those big fields a complicated and risky enterprise.

Consequently, the lure of big finds has prompted companies to develop new techniques to reduce risk and improve seismic imaging beneath and around salt bodies.

Pre-stack, depth migrated seismic data is a crucial tool for today's deepwater explorers -- and advancements in computing technology and power has made it possible for seismic experts to glean more and more information from data.

This is a story of how advanced depth imaging technology helped one Gulf sub-salt operation.

"Sub-salt reservoirs are the ultimate goal of Gulf of Mexico deepwater exploration," said David Kessler, president of Houston-based Seismic City Corp., "and in the last few years several new, large deepwater fields have been discovered using new developments in imaging technology."

Kessler and his team recently worked with geologists and geophysicists at another Houston firm, EEX Corp., to demonstrate how advanced depth imaging technology can enhance the accurate and successful definition of a new exploration prospect.

EEX acquired Mississippi Canyon blocks 975 and 976 and Atwater Valley block 8 in 1999 when Shell relinquished the acreage. The firm believed the blocks had potential based on the Atwater Valley 8 #1 well Shell Offshore drilled in 1997 to 20,700 feet.

Although the Cyclops well was deemed unsuccessful, it encountered several reservoir quality sands in the Lower Pliocene section.

"Based on 3-D data we had, we felt we could get as much as 2,000 feet up-dip to those sands in Mississippi Canyon block 976 just to the north," said Marshall Thomsen, senior exploration geophysicist with EEX.

The deepwater channel-sands and sheet-sands encountered in the well were deposited in a lower-slope, fan depositional environment. Eighty feet of gas pay was logged at about 14,400 feet, and other sands had significant oil shows.

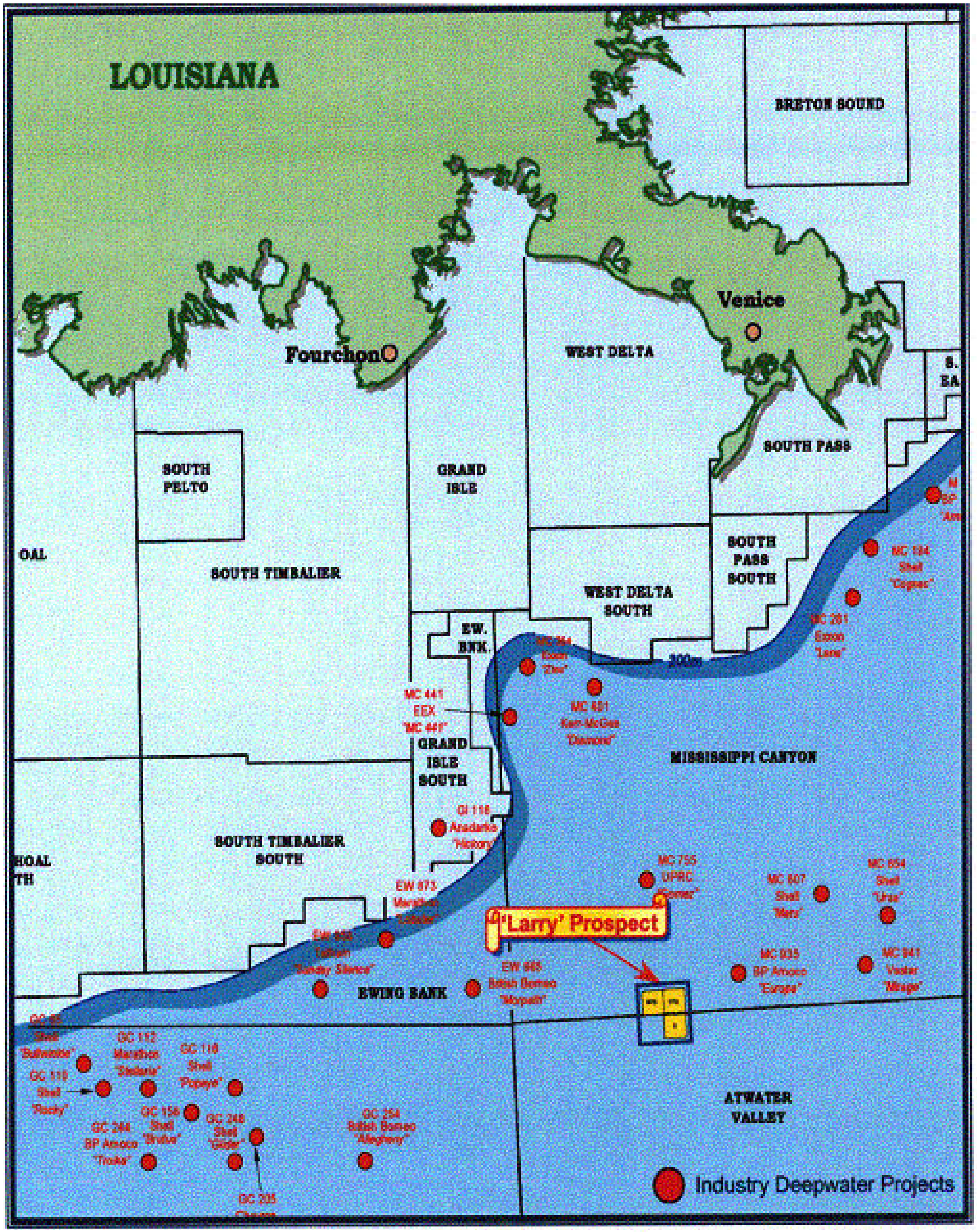

Figure 1 -- EEX "Larry" Prospect is located at Mississippi Canyon blocks 975, 976 and Atwater Valley block 8.

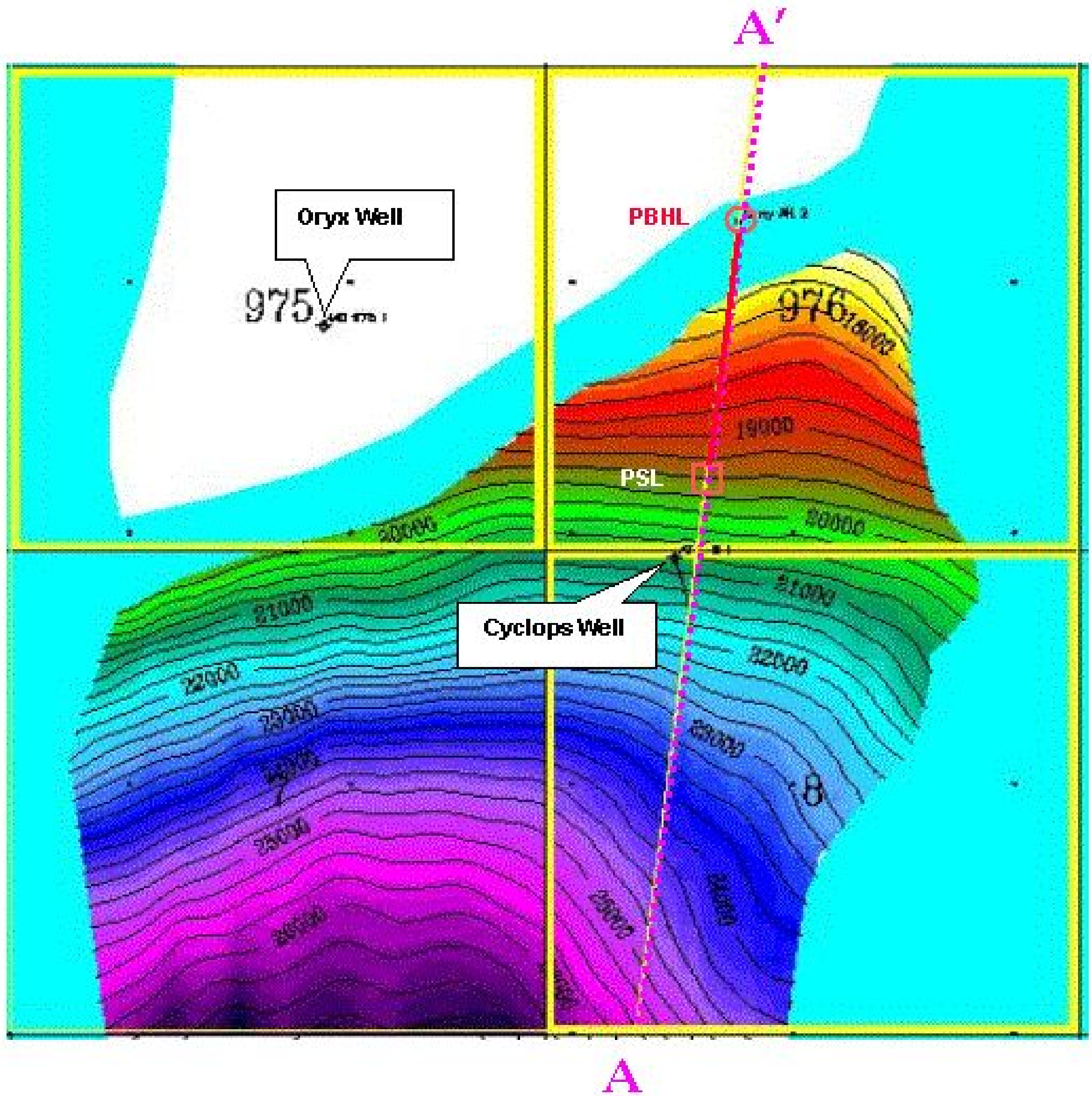

Figure 2 -- Depth structure of the Larry 6 horizon resulting from interpretation of the 3-D prestack depth migrated seismic volume.

After acquiring the leases, EEX licensed 1998 vintage pre-stack and post-stack time migrated seismic over the area from Diamond Geophysical. Structural interpretation of this data was EEX's first indication that the same sands at the Cyclops well could be tapped updip at Mississippi Canyon block 976.

According to Thomsen, the prospect is a structural trap below a salt/shale overhang. Massive salt walls form the trap on the east and west flanks, while a rafted shale section -- having a remnant salt at its base -- creates the trap to the north. Structural dip is to the southwest.

Seismic data quality is quite good for mapping the up-dip truncation of Pliocene-age sand found in the Cyclops well against the rafted shale/salt weld, he added.

"The Larry prospect, as we call it, has potential for multiple, stacked pays of Pliocene age with seismic amplitudes increasing up-dip from the Cyclops well," Thomsen said. "Miocene reflections seen on the seismic also subcrop up-dip against the rafted shale section -- (and) Miocene age sands produce at Shell's Europa Field nine miles to the northeast."

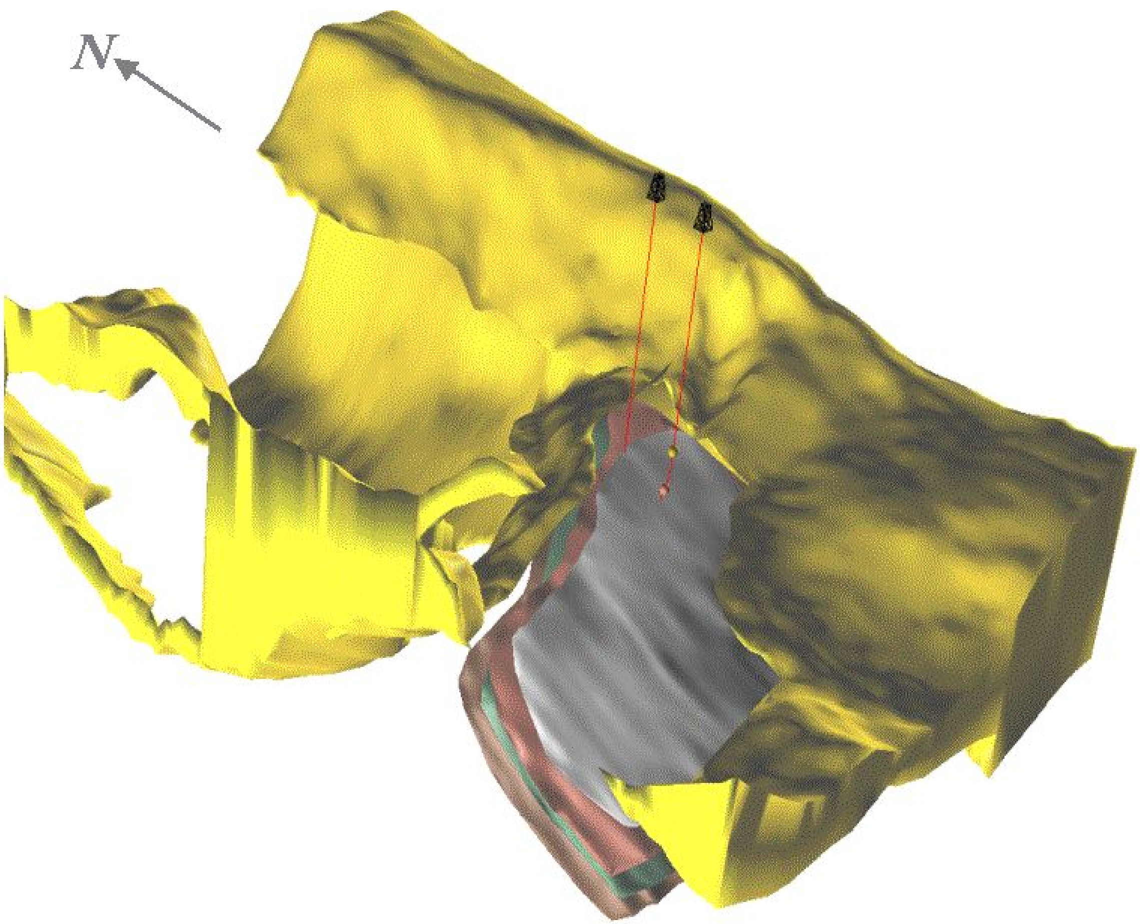

Figure 3 -- "Larry" salt body and target layers. The salt body is constructed in steps during the depth imaging process and is a key to successful implementation of 3-D prestack depth migration imaging.

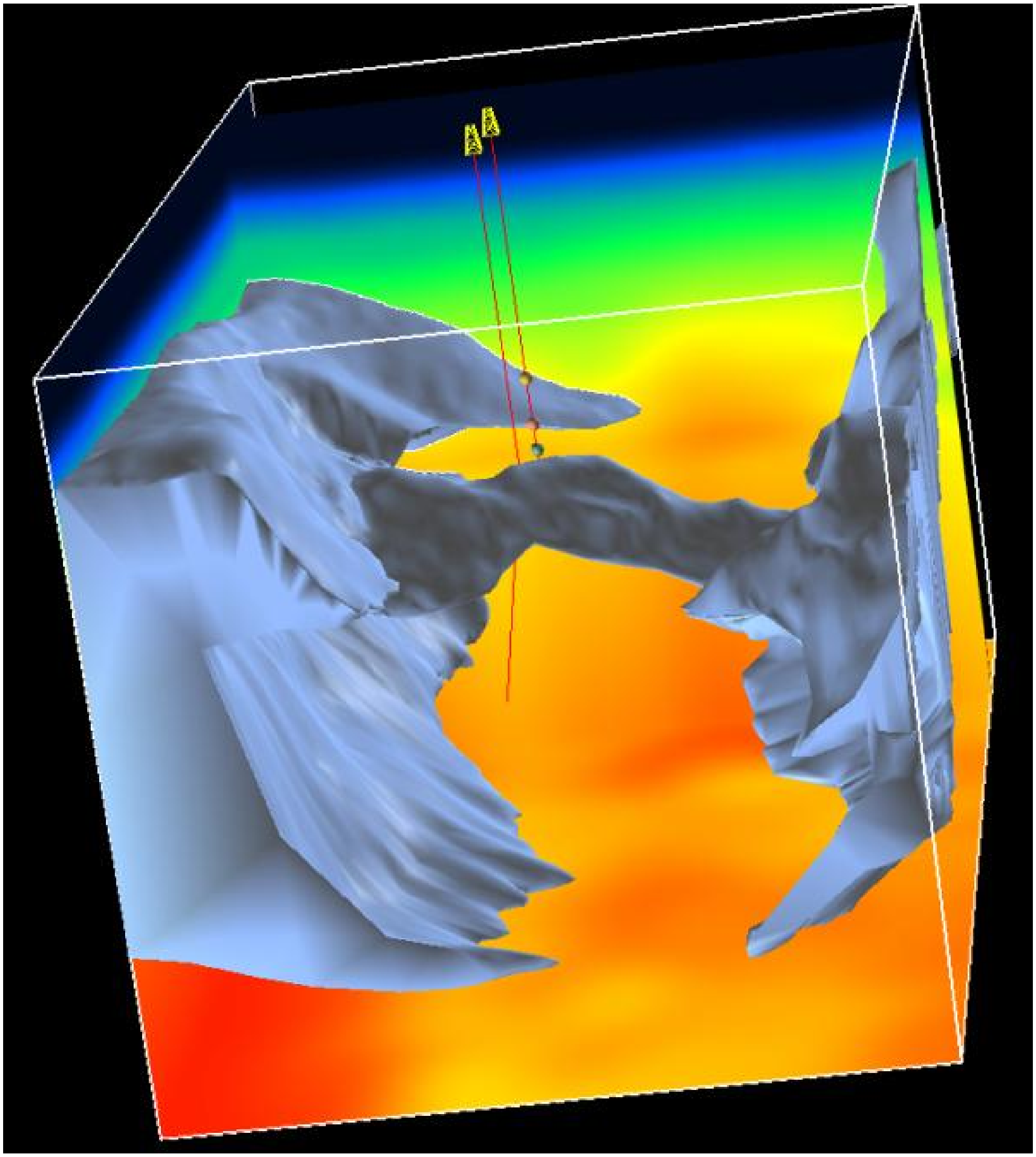

Figure 4 -- Three-D velocity model input to 3-D prestack depth migration.
An accurate model is necessary for construction of a reliable depth image.

Defining the Parameters

While the time domain seismic data EEX acquired revealed a new prospect opportunity, the data was not imaged correctly in areas associated with the thick salt on the east and west flanks and the overhanging rafted salt/shale section.

Pre-stack depth migration modeling and imaging, applied to better image the target structure, resulted in a more accurate prospect definition and better well planning.

"One of the most important steps of the interpretation process is to define the prospect area by extracting amplitude from the seismic volume," Thomsen said. "In areas of complex geology, the seismic image might contain both primary signal as well as seismic noise. In areas where lithology is rapidly changing, 3-D pre-stack depth migration is needed to correctly image target sands terminating against a salt weld."

To help the technique to properly migrate the seismic data in areas of strong lateral velocity variations, the team used a modeling tool that predicts the wave patterns of the seismic energy recorded during the acquisition phase, explained Jeff Codd, vice president seismic technology for Seismic City.

A new modeling algorithm -- called wave-front reconstruction -- simulated complex wave propagation from the surface to the sub-salt target area. Due to the accuracy of the method, the resulting seismic image had very little numerical artifacts.

Three-D pre-stack depth migration was applied in such a way that the relative amplitude of the seismic data was preserved. "This enabled us to successfully extract seismic amplitude directly from the depth migrated volume," he said, "resulting in a very clear definition of the up-dip limit of the prospect."

Stretching for an Answer

The reservoir quality sands at the Cyclops well ranged in thickness from 50 to 200 feet, and a check-shot corrected synthetic seismogram was generated from the sonic and density logs acquired in the well.

This synthetic correlates with the seismic data and, for mapping purposes, was used to identify reflections associated with the thicker sands -- many of which have an increase in amplitude, updip from the Cyclops well, to their termination at the overhanging salt/shale section.

At the Larry prospect, paleo markers identified in the Cyclops well were input to the seismic time data and tied to it using a velocity function derived from a check-shot corrected synthetic. Stretching and squeezing was done to tie the synthetic to the seismic using a log editing software.

A map generated from the seismic volume described the prospective target, but the map had to be converted from time to depth after imaging.

"Depth migration accuracy depends on the velocity field input to the migration process," Kessler said. "This velocity field is a detailed model of the subsurface geology that describes the main geological units -- in this case, a complex salt body embedded in a sedimentary section."

Inputting an accurate velocity field to the imaging process will produce a depth section that positions seismic events close to their true depth.

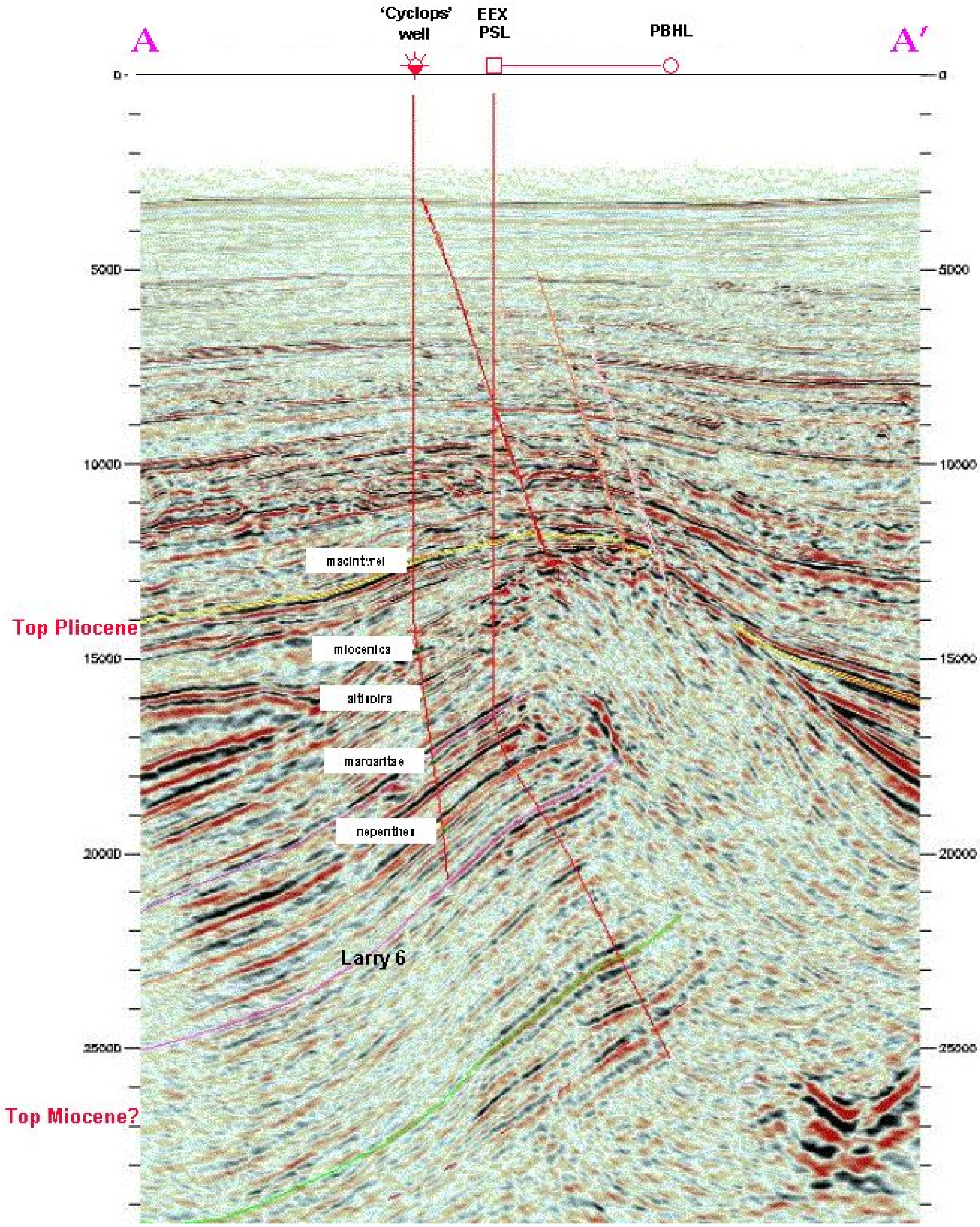

Figure 5 -- The depth section resulting from 3-D prestack depth migration closely matches well formation tops in the Cyclops well. This leads to more accurate mapping of the target sand layers. Original time data courtesy of Diamond Geophysical.

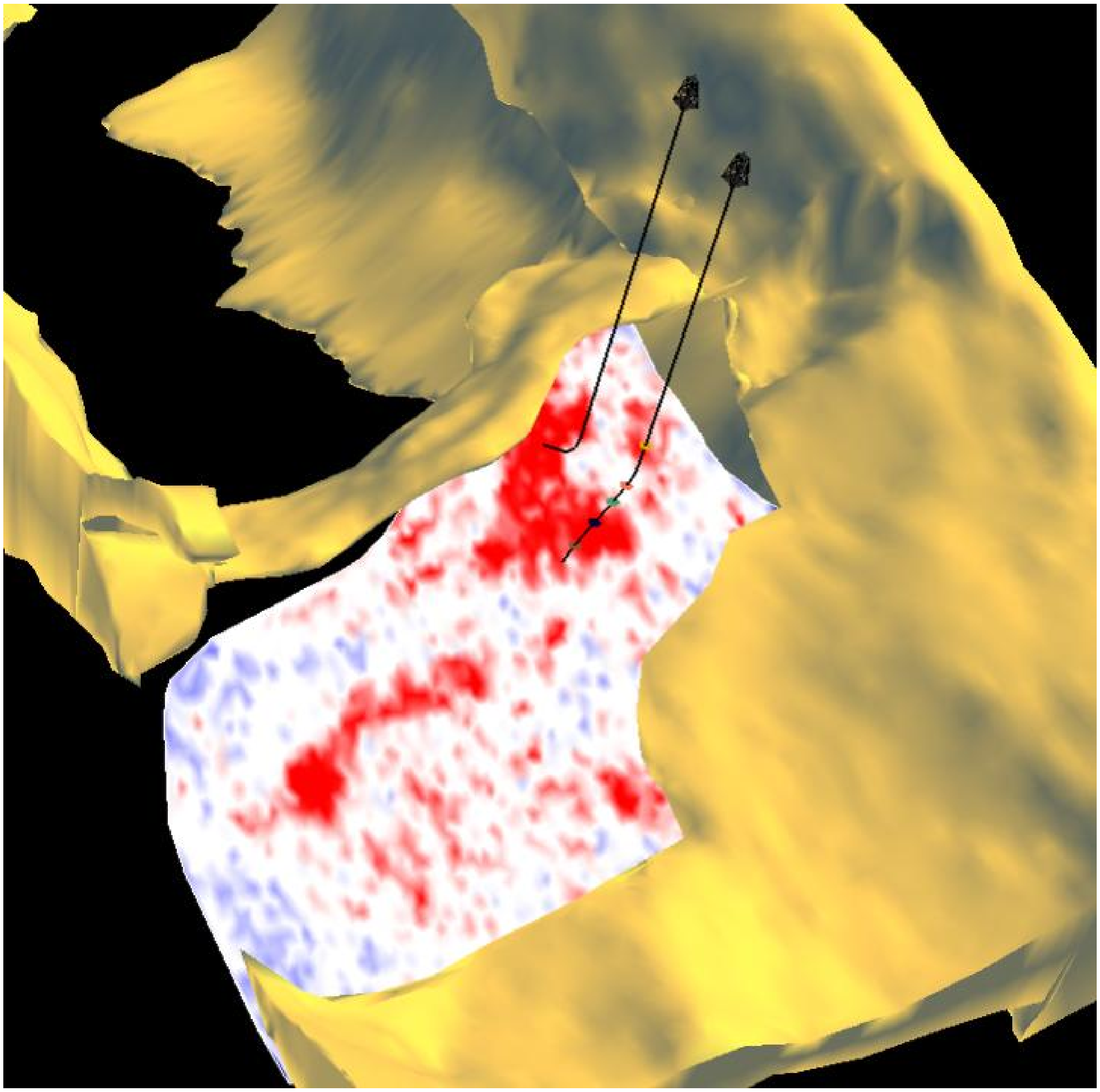

Figure 6 -- Seismic amplitude extracted from the 3-D prestack depth migrated volume along one of the target horizons. The down-dip well is the Cyclops well. The up-dip well is the new proposed well.

"In cases of velocity anisotropy, the imaging algorithms can use anisotropic parameters to more accurately model seismic wave propagation in the subsurface," Kessler continued, "and therefore, more accurately position seismic events in depth."

The advantage of direct mapping depth seismic volumes, according to Kessler, is that no simplifications of the earth model are done in order to tie the seismic data to known well data. The resulting structure map constructed directly from the depth volume is more accurate than the classic workflow of mapping in time domain and then stretching the map to depth.

The synthetic log was converted to depth and correlated to the pre-stack depth migrated data to determine any depth misties, Kessler said.

This procedure also was used to tie in an Oryx well drilled in Mississippi Canyon block 975, where depth misties ranged from 20 feet at the water bottom to 200 feet at a depth of 20,400 feet.

Is It Salt or Shale?

In many cases of Gulf of Mexico seismic data interpretation, scientists analyze high amplitude markers and determine if they are related to salt or shale, according to Peter Harth, senior geophysicist, and Glen Denyer, depth migration specialist, both with EEX.

At the Larry prospect it was imperative to differentiate between a salt body with a distinctive base and a rafted shale body on top of a salt weld.

"For the purpose of detailed well planning, it was important to determine if the overhanging section is salt or shale since the proposed well is designed to penetrate about 1,500 feet of formation overhang," Denyer said.

A shale raft and any drilling problems associated with it, including basal shear zones, must be isolated in a single hole section, he added, and directional work in the raft and any basal shear zone should be avoided due to potential instability in pre-failed material.

"Determination of the raft, possible basal shear zones underneath the raft and location of remnant salt section are all partial constraints to determine where to set casing," he said.

The salt or shale question was resolved during the depth imaging process: Two main operations completed during the model-building phase -- the construction of the salt body, and the construction of the velocity field around the salt -- produced "interval velocities" directly related to lithology, according to the EEX scientists.

This technique -- a new velocity analysis based on a depth migration algorithm -- gives processors the ability to define velocity variations within geologic formations with a one percent margin of error.

At the Larry prospect shale units were differentiated from the salt body by careful analysis of 3-D pre-stack depth migration image gathers. Special effort was made to carefully analyze the velocity above the high amplitude marker, resulting in a very slow velocity field in this area.

"The resulting interpretation of the velocity field, together with the seismic image, concluded that the geology is of a rafted shale section located on top of a salt evacuation weld," Denyer said, "with a remnant salt of about 1,200 feet thick at its base."

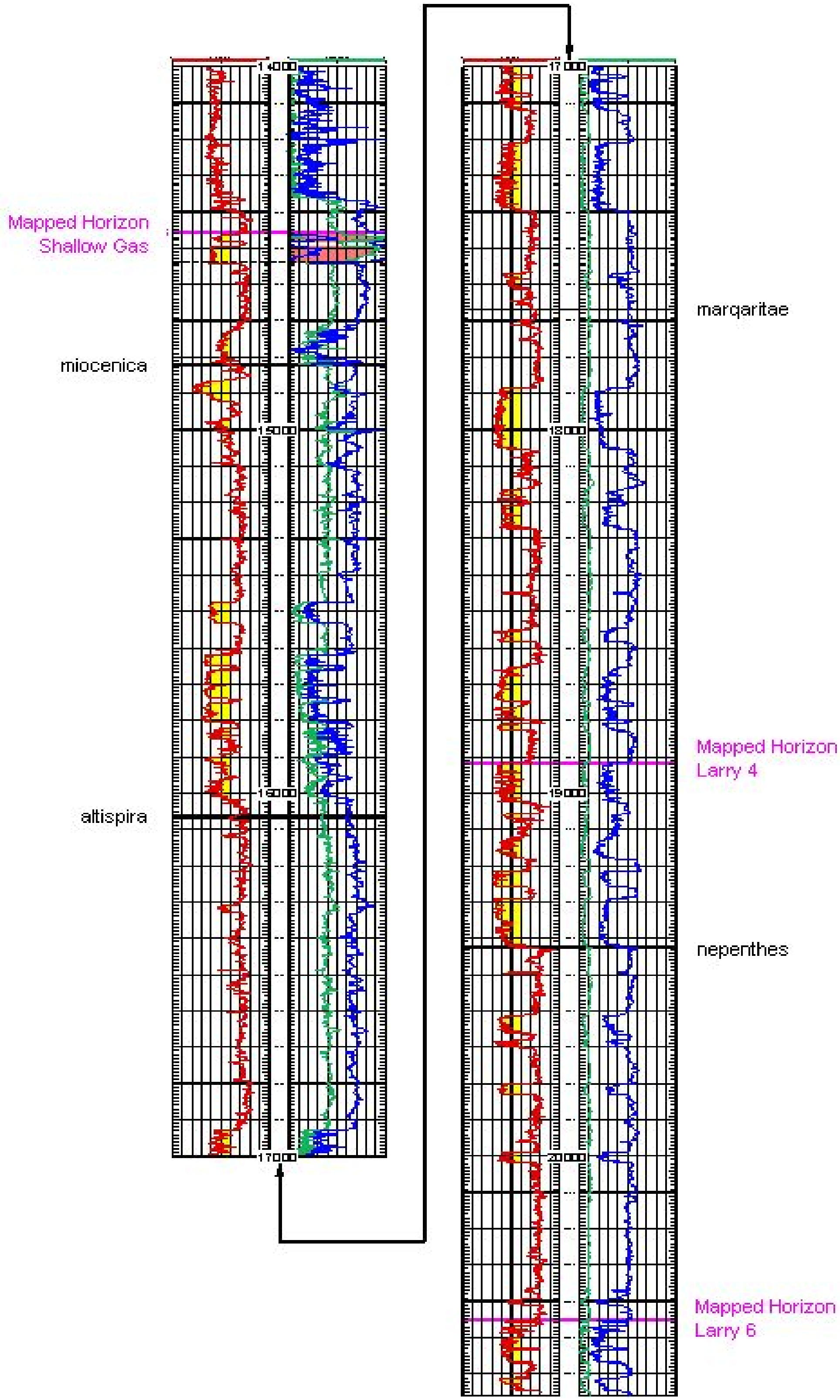

Figure 7 -- Type Log of Cyclops well at Atwater Valley block 8.

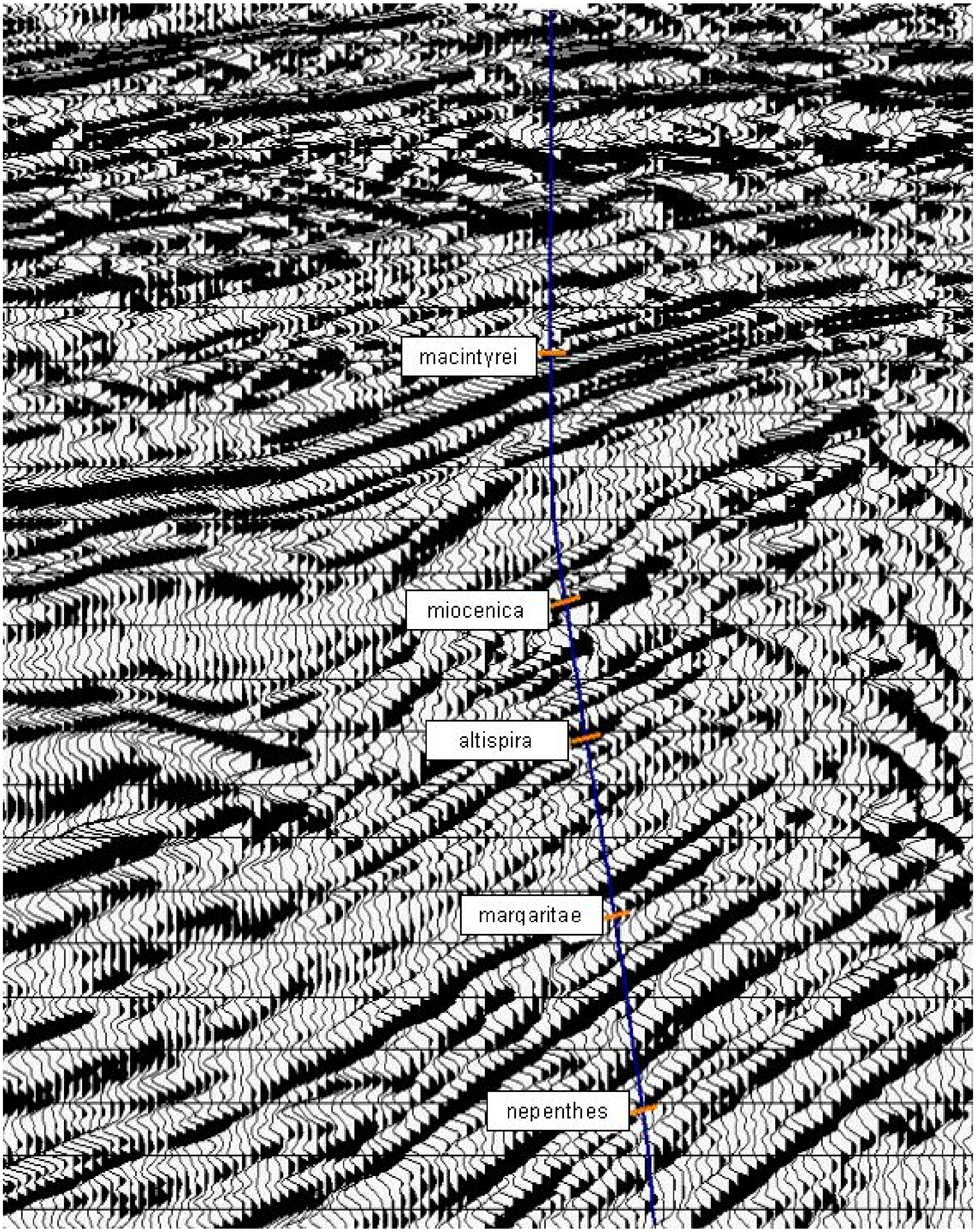

Figure 8 -- Seismic depth section generated by relative amplitude preserved wave-front reconstruction 3-D prestack depth migration. Original time data courtesy of Diamond Geophysical.

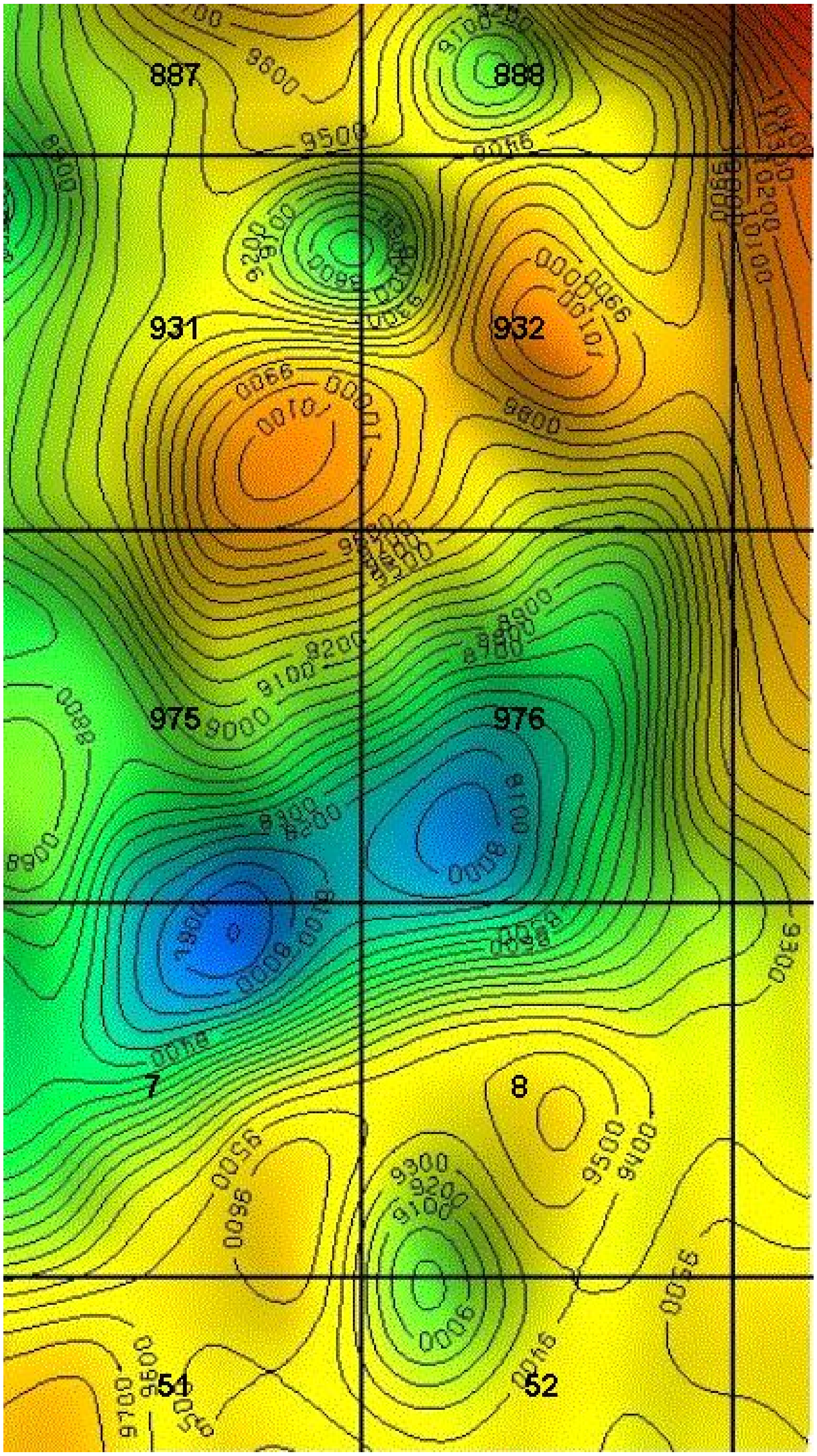

Figure 9 -- Interval velocity field above the target sands. The blue area relates to slow velocity rafted shale. Contour values are interval velocities in ft/sec. OCS block numbers and block boundaries are displayed in bold.

Mission Accomplished

Four different seismic volumes were used during the interpretation of the Larry prospect: The original 3-D post-stack time migrated data; a 3-D post-stack depth migrated volume; a 3-D pre-stack time migrated volume; the 3-D pre-stack depth migrated data.

The pre-stack depth migrated volume definitely provided superior formation correlation, discontinuity resolution and deep amplitude preservation when compared to the previous processing, according to both Thomsen and Michael Padgett, EEX's vice president of Gulf of Mexico exploration.

"Again, the issues for the Larry prospect are target placement and hazard avoidance," Thomsen said. "With the 3-D pre-stack depth migrated data, the location and thickness of the rafted shale section are well constrained, which allows for casing-setting above and below this interval."

In drilling down from and along the basal salt, he continued, the pre-stack depth migrated image allows well placement to be significantly up-dip of the Cyclops well, while minimizing the probability of crossing into salt.

"The vertical error for target placement is expected to be plus or minus 200 feet," Thomsen said. "Also, as a well is drilled, the pre-stack depth migrated volume can be continuously tied and depth-updated, which decreases the uncertainty during the drilling process."

As Padgett pointed out, the two primary goals of any seismic project are to unravel the geology and help reduce the drilling risks.

"Today nobody is going to drill around these shale or salt masses without 3-D pre-stack depth migrated seismic," Padgett said, "especially in the deepwater Gulf of Mexico, where a drilling disaster on a planned $20 million well ends up costing $50 to $80 million. Wells of that magnitude demand the best possible imaging technology."

Three-D pre-stack depth migration technology was originally developed to image seismic data in areas where time domain imaging failed, according to Denyer and Harth. Today's depth processing technology can produce seismic depth volumes that bring many advantages to deepwater exploration.

"We foresee that further development in depth imaging and modeling technology will improve our ability to interpret seismic images and understand seismic amplitude," Denyer said, "and will help in lowering the risk of deepwater exploration."

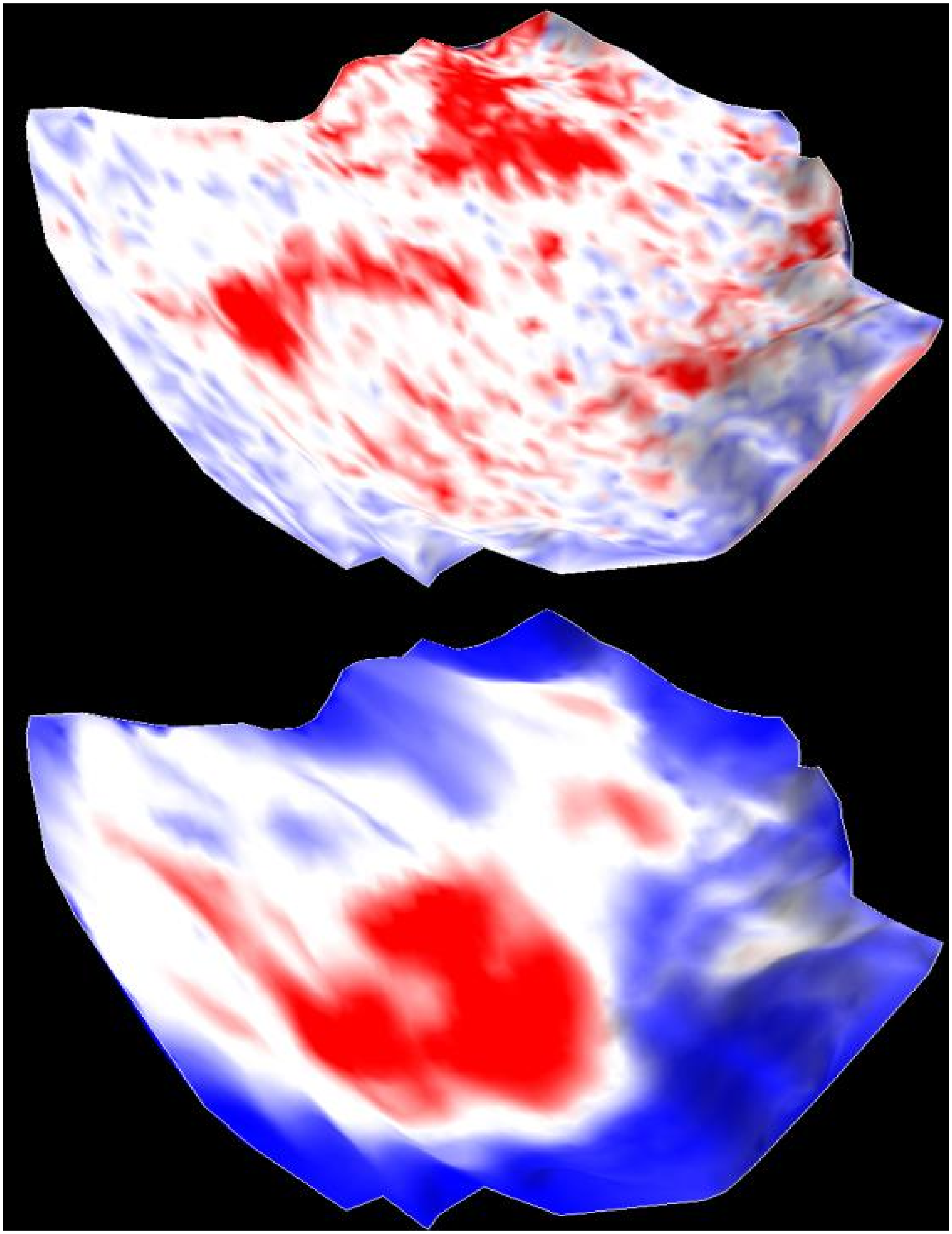

Figure 10 -- Seismic amplitude (top) and illumination amplitude (bottom). High seismic amplitude can result from either high reflection coefficient or from focusing of energy. The illumination amplitude surface reveals areas of high illumination during seismic acquisition. The correlation between the two surfaces will produce an amplitude surface that is crucial for correct well placement.