Straight to the Gathers for More Confident Amplitude Interpretation

Fast compute technologies and dramatic growth in data storage capacity are driving an exploding interest in pre-stack seismic interpretation. Bill Shea, CEO of Sharp Reflections, thinks the trend will only accelerate.

"When I started working with 3D seismic, migrated gathers were written to magnetic tapes, and usually wound up in an archive. Today, even the largest 3D gather datasets fit on a few usb disks. Sharp Reflections is making tools to put these data to work, so asset teams can use them to make better drill decisions.

"Sharp's Pre-Stack Pro software now integrates high-quality gather conditioning, rich 3D amplitude analysis, and pre-stack seismic inversion in a single application. This evolution has been fueled by an active, customer-supported R&D program with partner Fraunhofer ITWM. "Fast, high-quality AVO processing is our cornerstone", says Shea, "but we're building out a rich amplitude interpretation canvas. It's easy to QC many stacks or multiple versions of gather data sets in the same viewer, display any of them along arbitrary transects, and extract horizon attributes from any angle range or volume attribute. There's a lot of functionality overlap with traditional interpretation systems, but the analysis all flows from the migrated gathers."

> "When I started working with 3D seismic, migrated gathers were written to magnetic tapes, and usually wound up in an archive. Today, even the largest 3D gather datasets fit on a few usb disks."

Processing for Reliable Amplitudes Take Work

This approach makes it easy to calibrate amplitudes to rock property information immediately after the data are delivered from imaging contractors. "We compare real gathers to synthetic models, and tune post-migration processing flows to specific reservoir targets. With our parallel software architecture, we can remove additional noise and refine velocity picks on a terabyte of gathers in hours to days, depending on the speed of the computer. Our goal is to generate angle gathers and stacks with amplitudes that are consistent with reflection coefficients computed from wells. "Most processing contractors aren't asked to provide this specialized product, since it requires calibration. Our tools are so interactive that we can test in real time, with interpreters in the room. They decide which parameters to use, and learn the limitations of their data. This builds trust in the numbers, and fosters realistic expectations about what you can do with them. "

Reliable amplitudes are a requirement for confident amplitude interpretation, but not the real goal. "Our approach is very data-focused", continues Shea, "but our business is fundamentally about making predictions. We're building tools to interpret complex amplitude patterns, and relate them to rocks and fluids in the reservoir." AVO analysis focuses on amplitude changes across key boundaries, and can provide quick, reliable indications of hydrocarbons in certain reservoirs. Pre-stack inversion can be used to characterize spatial variation in rock

SEISMIC PROFILE SHARP REFLECTIONS

properties and reservoir thickness in more complex reservoirs, but often requires more calibration to geology and elastic properties. "Strategies and tools need to be flexible, since interface-based (AVO) and volume-based (inversion) methods each have their strengths and limitations," Shea concludes.

Pre-Stack Reservoir Delineation – A Practical Example

Sharp Reflections' industry development partners have played a key role in accelerating the company's development, by testing and providing feedback on new features before they are officially released. Det Norske oljeselskapet has been a key backer of Sharp's pre-stack focus for several years. They recently provided an excellent subsurface dataset from a decommissioned North Sea field for workflow development testing of Pre-Stack Pro's new amplitude analysis tools.

Setting

The study area is located in the Norwegian sector of the North Sea. Within the field and surrounding area, Lower Eocene Frigg Fm, sandstones are capped by upper Eocene shales, and the reservoir contains up to 80m of high-porosity sandstones (Figure 1). A time structure map of the top Frigg shows a clear four-way structural closure that appears to be defined by submarine-fan depositional topography enhanced by draping and differential compaction of sands (Figure 2).

Well log data (Figure 3) from the discovery well show a 50 meter hydrocarbon column (very light oils), with a hydrocarbon-water contact at approximately 2025m TVD-subsea. This occurs near the top of a transition to lower quality, inter-bedded sands and shales. Figure 4

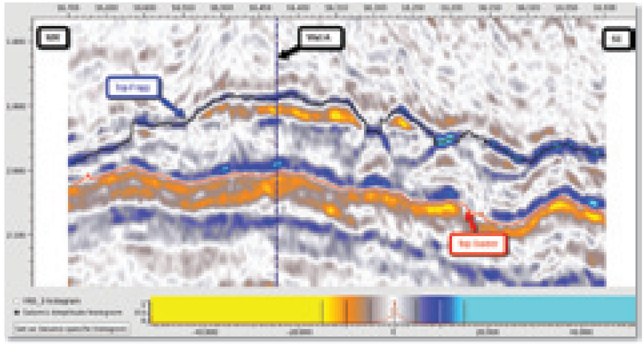

FIG. 1

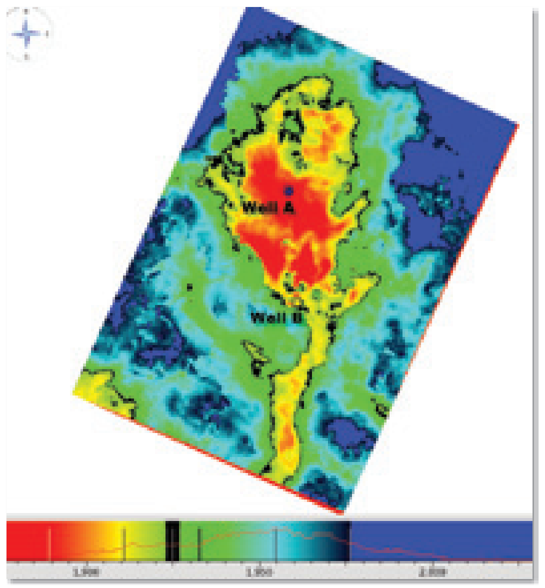

FIG. 2

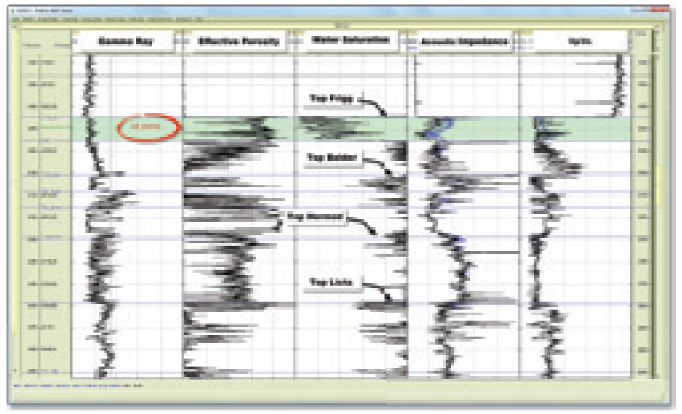

FIG. 3

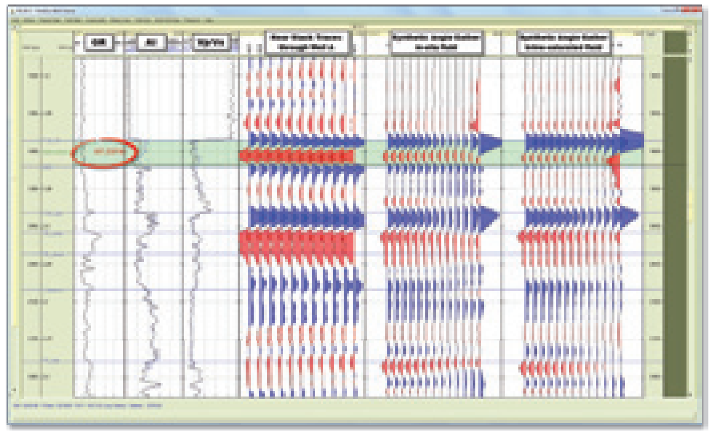

FIG. 4

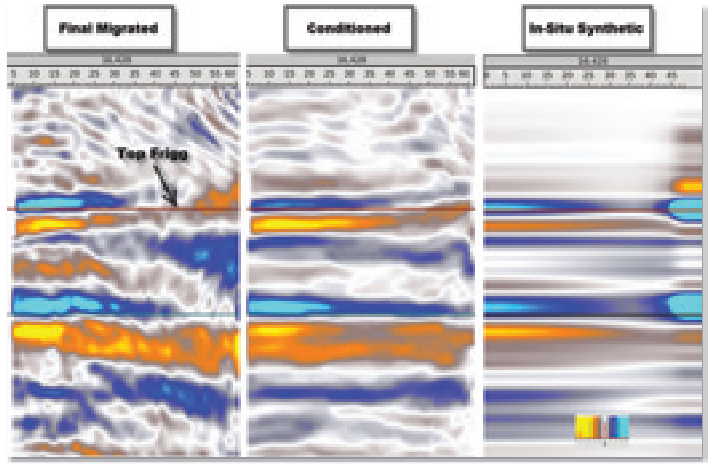

FIG. 5

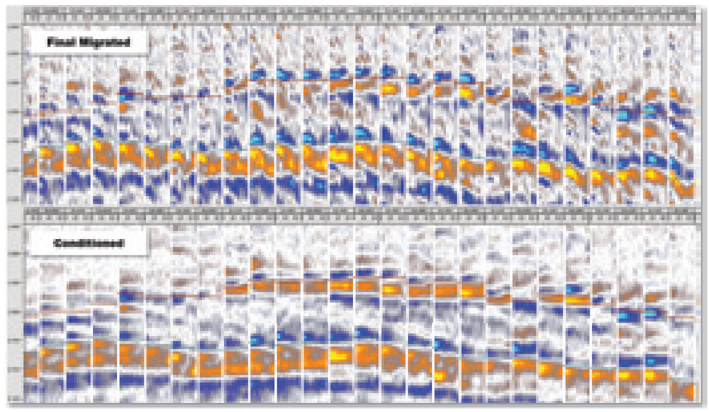

FIG. 6

shows the seismic-to-well calibration, which compares elastic property logs, stacked near-angle traces, and synthetic CDP gathers at the well location.

Gather Conditioning

Amplitudes on a migrated CDP gather show a qualitative match to the in-situ synthetic, but are clearly contaminated to some extent by coherent and random noise. Key reflections also show as much as 20 ms of moveout, which is detrimental to both AVO and pre-stack inversion results. However, after Pre-Stack Pro conditioning, amplitudes show an improved match to synthetics, and a good AVO tie (Figure 5). Conditioned gathers extracted from an inline through the discovery well show a very consistent amplitude response within the hydrocarbon zone, in contrast to the pre-conditioned gathers (Figure 6). All amplitude interpretation work was subsequently carried out on partial angle stacks generated from the conditioned data

Reflectivity Analysis and Rock Property Cross-plots

Acoustic impedance and Vp/Vs logs for the in-situ fluid and a "brine-substituted" pore fill case in the sands show clear contrast with the overlying shale. Impedances in the overburden are much lower than either brine or hydrocarbon sands in the Frigg Formation, leading to a strong positive response at the top Frigg. The pre-stack synthetics match the near-offset seismic at low angles, and predict an AVO Class I reflection at the top of the sand for both fluids. On this interface, the near-angle amplitudes in the gas leg are expected to be dimmer than for brine sands. Brine sands have a very flat AVO gradient, while gas sands are expected to dim significantly with offset. This modeling predicts that

Far-angle amplitudes should be a good fluid indicator, and instantaneous amplitude mapping on Top Frigg confirm the prediction (Figure 7).

The strong Top Frigg reflection is close to tuning with the fluid contact. Where the logs have had fluid substitution performed, the fluid contact vanishes and the "brine filled" synthetics do not show any reflection near the base of the high porosity upper Frigg sands. More detailed amplitude-versus-angle variations should be useful for differentiating sands with different fluid fill in the inversion.

A cross-plot of the well data (Figure 8) shows clear discrimination between hydrocarbon sands, overburden shales, and all other facies. The hydrocarbon sands are slightly softer than the brine, and have lower Vp/Vs. However, the elastic properties of the brine sand are closer to those of the intra-Frigg and deeper shales, leading to considerable overlap in the point clouds for these facies. The cross plot also shows that amplitude-versus-angle variations on reservoir reflections (which drive Vp/Vs estimation at high angles) should be useful for differentiating sands with different fluid fill in the inversion.

We conclude from the rock physics and synthetics that the reservoir is thick enough to be resolvable, and that we have a reasonable possibility of discriminating hydrocarbon sands from shales or brine sands. However, discrimination of brine sands and intra-Frigg shales is unlikely.

PCube Inversion

PCube is a Bayesian inversion technique, developed by Statoil, and based on the publications of Buland and Omre. It is a two-step process, which first uses a Bayesian scheme to obtain elastic properties from the pre-stack seismic data, and then derives facies probabilities via rock physics models. The scheme requires good quality angle gathers or several angle stacks over different angle ranges, as with most AVO inversions. It also requires a wavelet for each angle, which is usually obtained by well-ties. The prior model is calculated by defining facies probabilities for each different facies between interpreted horizons, and these are interpolated across the survey volume (Figure 9).

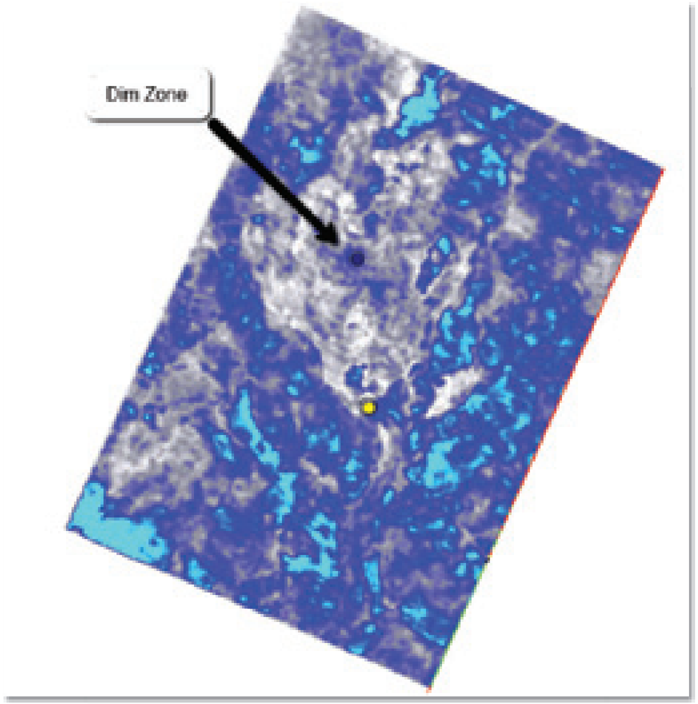

FIG. 7

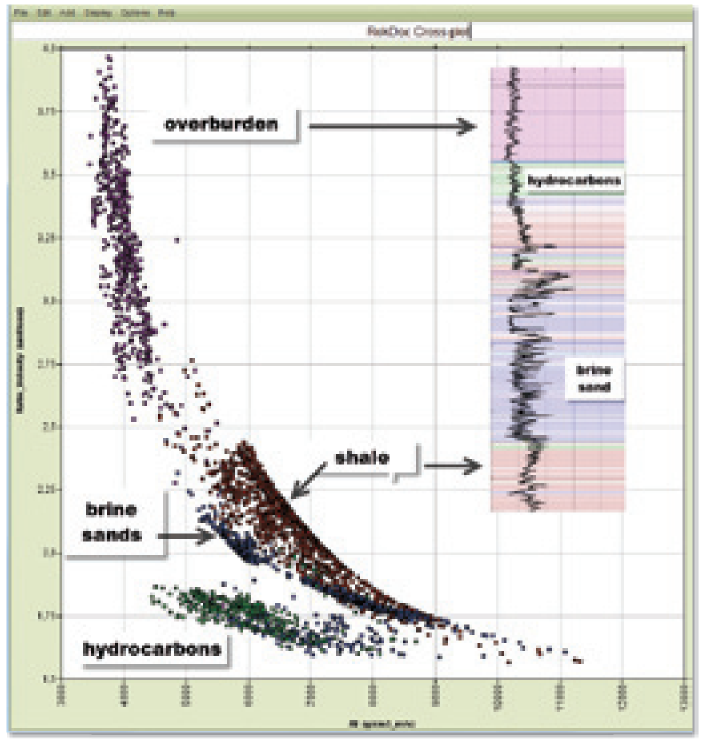

FIG. 8

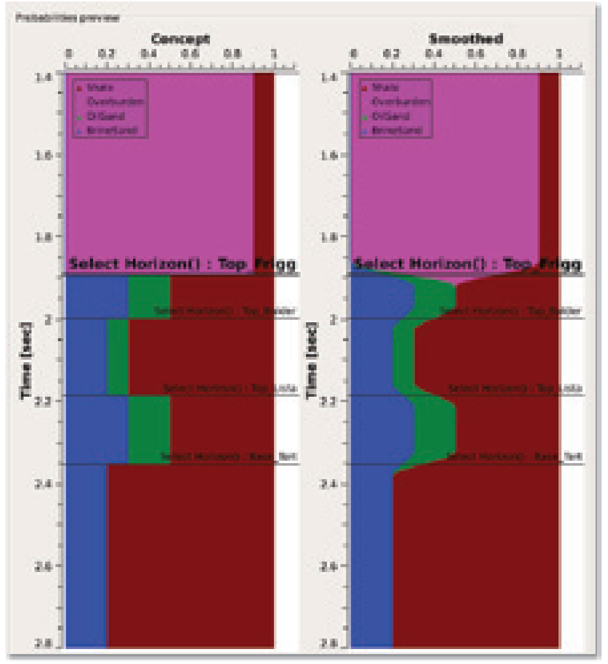

FIG. 9

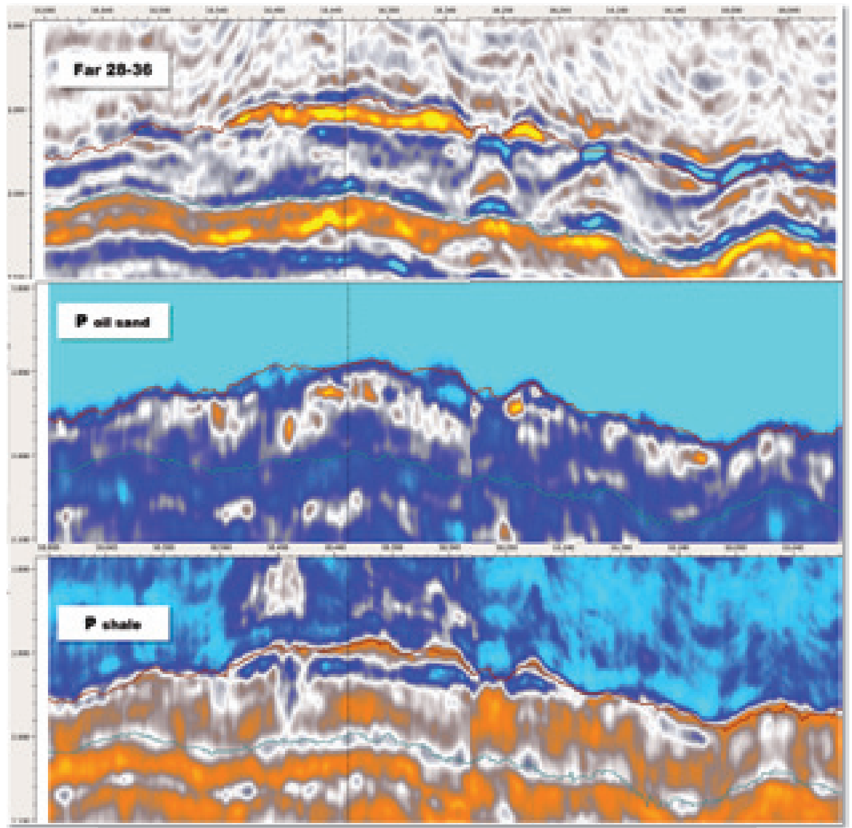

FIG. 10

Our example uses a simple rock physics model with four classes, labelled overburden, shale, brine sand and oil sand. Four main horizons were used to build the prior model. Only one well contained a sufficiently long logged interval, and this was used to perform a well-tie and wavelet extraction. The tie was good at all angles and the resulting wavelets were close to zero phase and had consistent bandwidth.

Once data are prepared, Pre-Stack Pro runs the entire two-stage process extremely quickly; our inversion took less than two minutes on a modern dual-core workstation for the entire map area shown in Figure 2. Peter Harris, geophysical advisor in Sharp Reflections, sees clear benefits with faster computations. "This high speed facilitates sensitivity testing of the inversion. Interpretation teams can re-run the initial result using different facies classes and inversion parameters, to obtain results which are geologically and geophysically consistent."

Results

Figure 10 shows an inline through well A. The tuning response between top Frigg reservoir and the hydrocarbon contact is very clear in the far angle stack, and sets up a strong trough amplitude between. High values of the oil sand probability tend to correlate with the presence of the base reservoir reflection, rather than the actual interval of hydrocarbon sand. However, low values of the shale probability match the reservoir geometry fairly well.

Figure 11 shows a "max trough" amplitude attribute computed in a short window below the Top Frigg horizon. The amplitude map identifies areas where hydrocarbon-relating tuning effects are strong. This reflectivity pattern is consistently identified as "low shale probability" by the inversion (Figures 12, 13). However, we also see that the model predicts high shale probabilities in the uppermost part of the Frigg. This matches impedance data in well A, where the uppermost Frigg has higher impedance than the lower part of the hydrocarbon zone. Thus it seems that the inversion is resolving about 25 m thicknesses. A map of minimum shale probability, extracted in a short window below the top Frigg (Figure 14), shows that this attribute conforms very well with the structural detail, albeit with a slight tilt from west to east.

The ambiguity in the oil sand identification may have a number of causes, both in the rock physics or in the seismic data. The benefit of our integrated approach is that we can easily compare real gathers to synthetics generated by the inversion to improve understanding of and confidence in the results. The fast run time allows testing and rerunning of the entire volume, condensing project cycle times and increasing value to the interpreter.

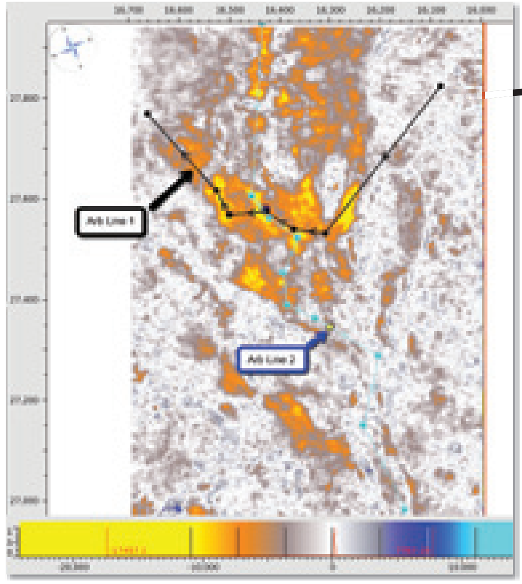

FIG. 11

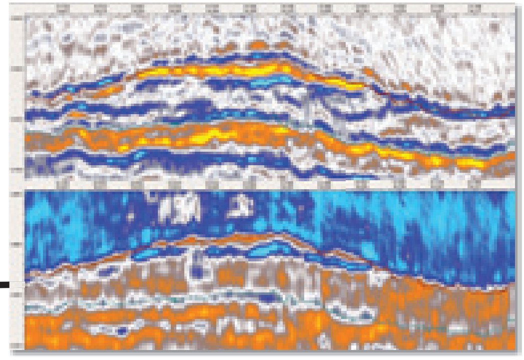

FIG. 12

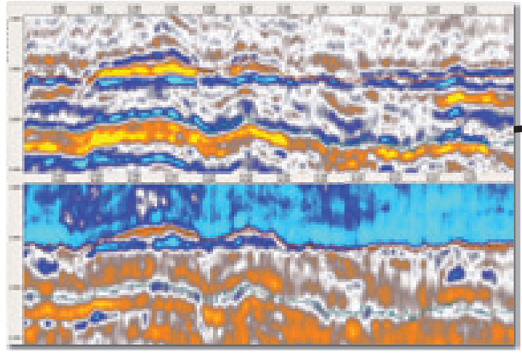

FIG. 13

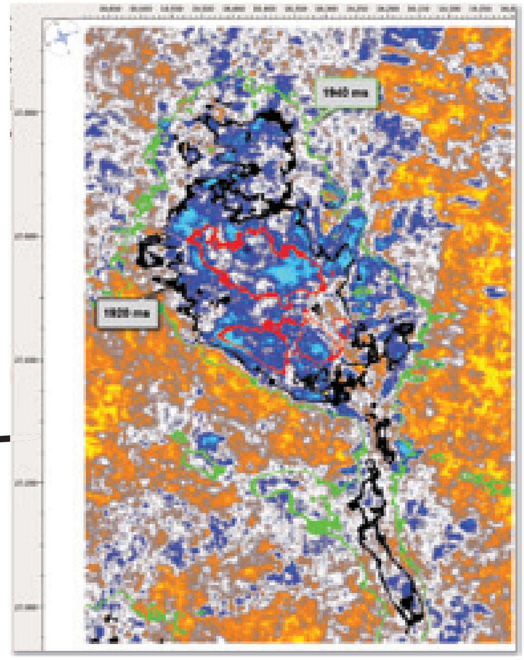

FIG. 14