3-D Can Provide Reservoir Data

The Geophysical Corner is a regular column in the EXPLORER, produced cooperatively by the AAPG Geophysical Integration and SEG Interpretation committees, and edited by M. Ray Thomasson. This month's column is titled "Predicting Reservoir Properties from 3-D Seismic Attributes With Little Well Control – Jurassic Smackover Formation."

By BRUCE S. HART

There is an increasing interest in the use of attributes derived from 3-D seismic data to define reservoir physical properties such as presence and amount of porosity and fluid content.

This seismic-guided property prediction approach was popularized only about five years ago, when it was demonstrated that log-derived reservoir properties sometimes could be relatively easily correlated to seismic attributes – and that the regression equations so derived could be used to make predictions about those properties away from existing wellbores.

Explosive growth in interest in this approach has led to a proliferation of methods for refining it. Multiple regression, geostatistics, neural networks and other approaches are being explored to help correlate log and seismic data, and then to distribute reservoir properties throughout the area of 3-D seismic surveys.

The predictions made by these methods are often appealing, especially when presented in color.

But how does one truly assess the likelihood that any given prediction truly represents the subsurface reality?

Various statistically based methods have been developed to help answer this question.

Using a procedure known as exclusion testing, the interpretation team will use only a subset of the well database during the project's correlation phase, then test the physical properties predictions against measurements from wells that were excluded from the calibration phase.

This procedure works well when abundant well information is available, but it is not practical when only a limited number of wells penetrate the target formation – such as when the field is either small or at an early stage of development.

A two-pronged methodology for assessing the results of a seismic-guided physical properties prediction can be used to reduce risk when only limited well control is available.

The methodology involves:

❒ Using seismic forward modeling to ensure that there should be a link between the reservoir properties and seismic attributes used in the correlation.

❒ Ensuring that the prediction results are geologically plausible.

This approach is illustrated herein with an example from the Jurassic Smackover Formation.

Testing the Model

The Appleton Field is a small field (840 aces, 13 wells, of which four were producing in 1997) in southwestern Alabama (Figure 1).

Unlike other Smackover fields, where high energy shoal carbonates are the primary productive intervals in the formation, here the best production is from a dolomitized algal buildup that developed over a paleo-basement high located landward of the Jurassic shelf margin.

True vertical depth to the top of the formation in the Appleton generally exceeds 3,800 meters (12,500 feet), and most wells are deviated, to variable extents.

The data set for this project consisted of wireline log information from 10 wells (deemed to be too few for exclusion testing), production data and a 3-D seismic survey.

The links between geology and seismic response were evaluated by creating simple 2-D seismic models. The modeling began with the construction of geologic models (e.g., Fig. 2a) that were convolved with a wavelet (chosen to match the frequency and phase characteristics of the data) to generate 2-D synthetic seismic transects (Fig. 2b).

The model results showed:

❒ That the reflection from the top of the Smackover would combine with that from the overlying Buckner Anhydrite to form a peak.

❒ That the porous part of the Smackover in this field would be represented by a trough.

❒ That the base of the Smackover would be a peak where the porous carbonates overlay basement rocks, but would change to a trough where non-porous carbonates overlay the siliciclastic Norphlet Formation on the ridge's flank.

Comparison of the model results to corresponding transects through the seismic data (Fig. 2c; note that the model result is noise free, whereas the data are somewhat noisy) allowed the horizons of importance to be identified and mapped in the 3-D volume.

Structure maps derived from the 3-D data showed undrilled structural culminations that were not apparent in previously published maps. If these structures are porous, they could be infill targets since existing wells would leave attic oil.

An empirical relationship was then sought between seismic attributes and log properties that could be used to predict the thickness of the porosity zone (defined by a 12 percent porosity cut off) away from existing wells.

Over 30 seismic attributes – a relatively small number compared to some studies – were derived and analyzed. Multiple regression techniques established a polynomial expression between the thickness of the porosity zone and three attributes:

✔ Average frequency of the Smackover interval.

✔ Average reflection strength for that interval.

✔ Isochron value between the porosity zone seismic pick and the base of the formation (e.g., Figure 2).

Values for these three attributes – for the entire 3-D survey area – were then input into the empirically derived

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Figure 1

Figures courtesy of Bruce S. Hart

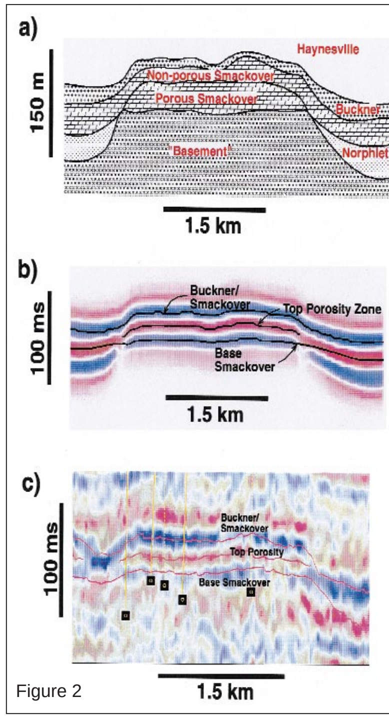

Figure 2

Figure 2. a) Geologic model (strike section) of the Smackover Formation at the Appleton Field. Porous bindstones and boundstones in the lower part of the Smackover developed preferentially over exposed basement ridges, whereas the upper part of the formation is essentially non-porous. The Smackover is typically non-porous throughout its entire thickness away from the ridges. The siliciclastic Norphlet Formation laps onto the flanks of the ridge beneath the Smackover. The Buckner Anhydrite overlies the Smackover, and thins over the ridge crest. A thick siliciclastic section of the Haynesville Formation caps the zone of interest.

b) Seismic model of the Appleton Field made by convolving the geologic model with a zero phase 25 Hz Ricker wavelet.

c) Arbitrary line through the 3-D seismic data that approximately corresponds to the geologic cross-section in 2a.

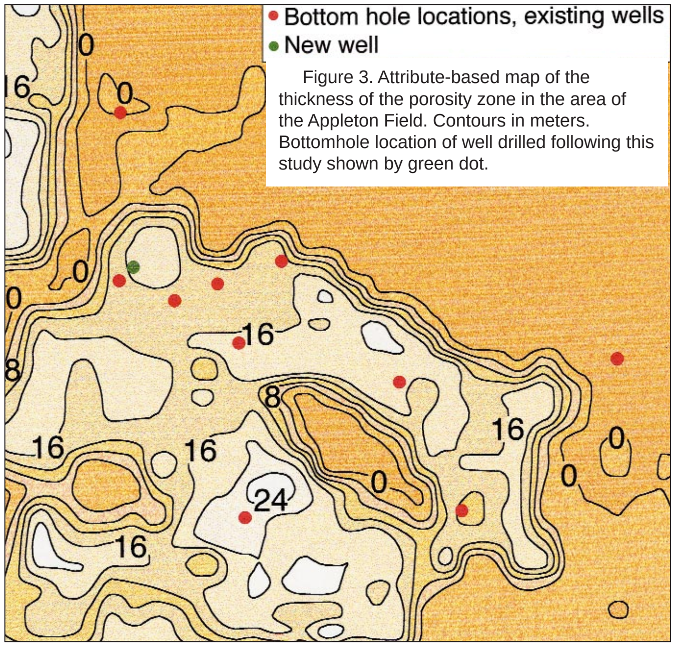

Figure 3. Attribute-based map of the thickness of the porosity zone in the area of the Appleton Field. Contours in meters. Bottomhole location of well drilled following this study shown by green dot.

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regression expression to generate a map of the thickness of the porosity zone at the Appleton Field (Figure 3).

The results suggested that porosity is well developed beneath the structural culminations.

Results

To help assess the validity of this prediction, one of the initial 2-D seismic models was refined and the results were exported to a seismic interpretation package. From the model results, it was possible to derive the same seismic attributes that had been used in the physical properties calibration.

The same general trends seen in the 3-D data were visible in the model results (Figure 4), suggesting that the attributes selected for regression analyses were responding to stratigraphic geometries.

Next, the porosity zone thickness map was compared to what is known about the field's geology.

The best – and thickest – porosity zones in the Appleton Field are considered to be developed in algal boundstones on the crest of the paleostructure, where our seismic predictions indicated. Other porosity predicted to be present on the seaward flank of the buildups might be explained as reef-front talus accumulations.

Despite the porosity in the reef-front areas, they are located below the oil water contact (as derived from well control), and apparently lack updip closure.

A well drilled following this study (Figure 3) encountered 21 meters (69 feet) of porosity > 12 percent at a location where the predicted thickness of this zone was 19 meters (62 feet). The well tested 136 BOPD.

This result is considered to be a successful test of the physical properties prediction, although the structural culmination was not as well developed as predicted. Ideally, the new log information would be used to help update the existing structure map and attribute correlation parameters.

Neither the seismic modeling component nor the geologic "reality check" of this program is intrinsically new. The potential exists, however, for these methods to be underutilized during field development, since so much effort is focused on the process' mathematical (statistical) aspects.

Although ideally all components of the process (statistics, geology and geophysics) will be satisfied during an attribute-based characterization program, risk can be reduced (not eliminated) where limited well control exists through forward modeling and integration of the geology.

No matter how mathematically rigorous a physical properties prediction might be – and no matter how many wells are available for the study – it should be rejected if it is not both geologically and geophysically plausible.

(Editor's note: Bruce Hart is with the New Mexico Bureau of Mines, a research division of the New Mexico Institute of Mining and Technology, Socorro, N.M. His co-author is Bob Balch, currently with the Petroleum Recovery Research Center.) ❏

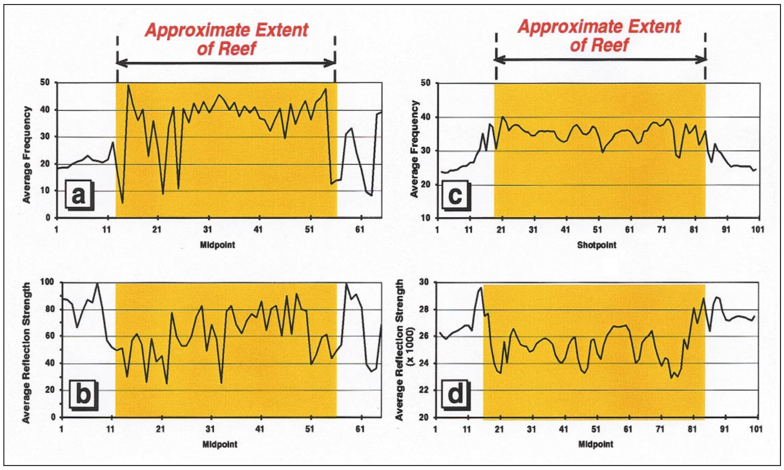

Figure 4. Comparison of seismic attributes derived from data shown in Figure 2c with seismic attributes derived from model results shown in Figure 2b.

a) Average frequency between the top and base of the Smackover from the data. b) Average reflection strength between those same two markers from the data. c) Average frequency between the top and base of the Smackover from the model results. d) Average reflection strength between those same two markers from the model results. In both cases, average frequency for the Smackover is higher and average reflection strength is lower where the porosity zone is present beneath the reef crest.