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## Exploration '84: New Technology Is Emerging

*Part III*

# Seismic stratigraphy moves towards interactive analysis

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**20-second summary**

Seismic stratigraphy aids interpretation of complex geology, particularly by helping effectively identify the right geologic environment for potential hydrocarbon traps. This, the third article in a series, reviews advanced geophysical techniques, including direct hydrocarbon indicators, shear waves and seismic modeling (the fourth key seismic stratigraphy approach).

AS THE SCIENCE of exploration seismology has matured, there have been tremendous advances in extracting information from seismic wiggles. Since geophysicists are very pragmatic, if a technique seemed to help in one exploration play, it is often used in other environments where the conditions might not produce the same results. This, in fact, has happened several times.

When applying any of the techniques discussed in this series, scientists should be aware that the more information that can be input into an exploration effort the better, and that no **one** technique works in all cases. This includes the application of direct hydrocarbon indicators, shear wave methods or seismic modeling, as discussed herein, or other non-seismic exploration methods such as gravity, magnetics, electrical, geochemical, remote imaging, etc.

## Direct hydrocarbon indicators

There is no **single** attribute that provides a reliable, direct indication of hydrocarbons. While seismic brightspots indicate large velocity differences which are sometimes indicative of hydrocarbons, large acoustic impedances could also be from a porous, carbon dioxide gas-filled reservoir or a coal layer. The dry Destin Dome prospect offshore Florida in the Gulf of Mexico is an expensive example of brightspot application gone awry.

Amplitude blooms are often treated as direct hydrocarbon indicators, but they can just as easily be a result of amplitude tuning due to thinning. However, complex seismic trace analysis provides several attributes that, used in conjunction, provide strong evidence of hydrocarbons. Table 1 summarizes these attributes.[1]

Direct hydrocarbon indicators often are subtle, and need to be closely worked into structural, stratigraphic and lithologic interpretations. For example, limestone usually has a higher velocity than overlying rocks, which implies a strong reflection. However, if a portion of a limestone reservoir happens to be gas filled, there can be a dim spot where the gas is located due to reduced acoustic impedance. Such a porous zone, as interpreted from a 3-D survey, would be an ideal horizon from which to extract amplitudes. The spatial extent of the dim spot would be related to the areal extent of the porous zone. Of course, this dim spot should be evaluated relative to a structure contour map. Fig. 1 illustrates a similar example from some physical model data.[2]

Similarly, a flat spot reflection can be generated from a gas/liquid interface. This interface could be tilted due to secondary cementing of the pore space before tectonic forces set the structural framework. Tilting of a flat spot can also be due to velocity pushdown, where thickening of a slow velocity gas sand slows down the seismic travel time to the gas/water contact.

## Shear waves

The geologic complexity of the earth is so great that for scientific experimentation and analysis a very simple model must be utilized in order to achieve any degree of understanding. In general, this requires that seismic methods are

**TABLE 1—Summary of hydrocarbon indicators[1]**

(1) **Amplitude change**—a brightening or dimming of the reflection amplitude; amplitude also affects the generation of multiples because of the change in the reflection coefficient

(2) **Frequency change**—generally involving a lowering of frequency immediately below the reservoir

(3) **Velocity change**—almost always involving a lowering of velocity, where the reservoir is sufficiently thick, it may produce a velocity anomaly in reflections beneath it. Polarity reversal can indicate a velocity change

(4) **Change in wave shape**—sometimes shows up as a reversal of polarity and sometimes by other phase changes

(5) **Flat spot**—can result when a reservoir is sufficiently thick

(6) **Miscellaneous**—a. association with a trapping mechanism (reservoir being located on an anticline crest or at a fault), b. a presence of associated accumulations, c. indications of gas leaking out of a reservoir, etc.

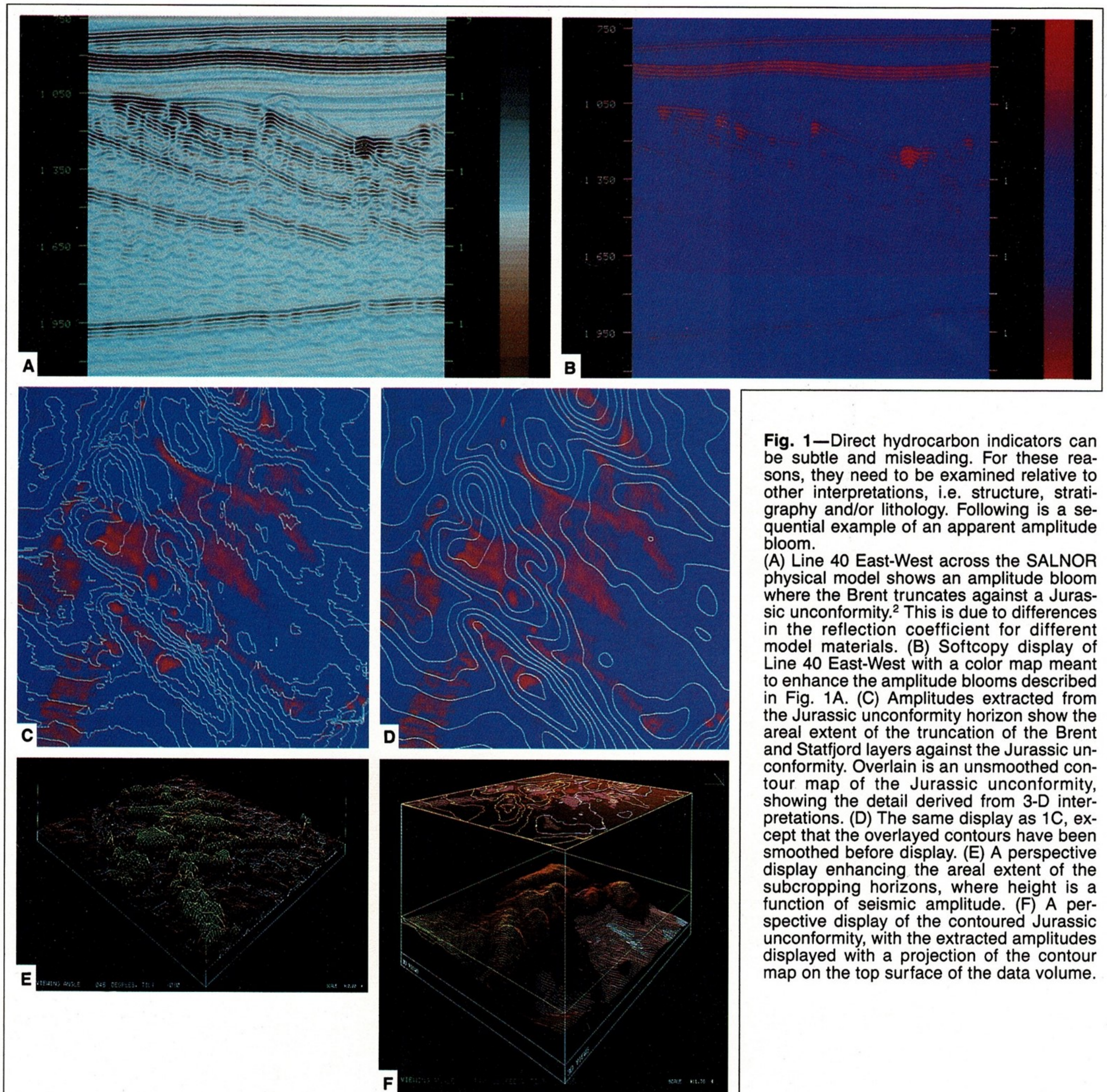

**Fig. 1**—Direct hydrocarbon indicators can be subtle and misleading. For these reasons, they need to be examined relative to other interpretations, i.e. structure, stratigraphy and/or lithology. Following is a sequential example of an apparent amplitude bloom.
(A) Line 40 East-West across the SALNOR physical model shows an amplitude bloom where the Brent truncates against a Jurassic unconformity.[2] This is due to differences in the reflection coefficient for different model materials. (B) Softcopy display of Line 40 East-West with a color map meant to enhance the amplitude blooms described in Fig. 1A. (C) Amplitudes extracted from the Jurassic unconformity horizon show the areal extent of the truncation of the Brent and Statfjord layers against the Jurassic unconformity. Overlain is an unsmoothed contour map of the Jurassic unconformity, showing the detail derived from 3-D interpretations. (D) The same display as 1C, except that the overlayed contours have been smoothed before display. (E) A perspective display enhancing the areal extent of the subcropping horizons, where height is a function of seismic amplitude. (F) A perspective display of the contoured Jurassic unconformity, with the extracted amplitudes displayed with a projection of the contour map on the top surface of the data volume.

concentrated on deriving a velocity/depth model that illustrates the **major** geologic boundaries within the earth. To this end, the first step in seismic surveying is to discard the majority of the generated energy, and concentrate on the most simple transmission mode—compressional or P-waves.

For seismic stratigraphy, this approach is rarely adequate. Much of the detailed information vital for rock property estimation has been lost. Hence, one technique that offers the potential to record the full seismic waveform is shear-wave (S-wave) analysis.

Using complex 3-component geophones and special sources, it is possible to recover data (especially S-waves) that allow estimates of Poisson's ratio, lithology, fluid content, and more. Poisson's ratio, a measure of the geometric change in the shape of a rock, is a function of the ratio of P and S-wave seismic velocities.[3] Recognizing the difference in Poisson's ratio for sandstones, dolomites and limestones, lithologies can be estimated from P and S-wave data over a prospect. These techniques are in an experimental stage and have not yet proven cost effective on a large scale.

However, an alternative approach, which offers wider application of these general principles, is the study of ampli-

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tude as a function of offset. P-wave energy incident on an acoustic interface undergoes various physical processes. In addition to reflection of P-wave energy (the signal detected at the surface), there are several other energy modes generated. The degree of mode conversion increases with the angle of incidence, until in the limit the critical angle is reached and refraction occurs. In addition to angular dependence, mode-conversion is controlled by the rock properties across the interface (particularly the contrast in P-wave/S-wave velocity ratio).

The source/receiver offset variation of a Common-Mid-Point gather provides angular-dependent measurements of the reflected P-wave amplitude, from which the P-wave/S-wave velocities can be modeled. It is then possible to estimate lithology, fluid content, etc., with much more confidence than from traditional seismic sections.

## Modeling

Modeling techniques are probably the most advanced of the four basic approaches to interpreting seismic data as discussed in this three-part overview. Each geophysical contractor and major oil company have their own modeling algorithms, and preferred procedures. These might be simple 1-D synthetic traces, 2-D or 3-D convolutional modeling, ray trace modeling, inversion schemes, regressive optimization, acoustic modeling or even elastic modeling algorithms.

Typically, interpreters will create a depth model based on the seismic reflection form and use this as input to a forward modeling algorithm to create a synthetic time section. This synthetic section is then compared back to the raw data, variations are noted and modifications are made to the depth model. A new synthetic is thus generated. The goal of this loop of (1) model design, (2) computation and (3) comparison, is to gain confidence in the interpretation. In addition, some algorithms do an automatic regressive optimization to fit the model to the field data. Obviously, good velocity control is critical if these models are to mean anything.

An alternate modeling approach is to take **time** horizon picks and, using the best available velocity model, convert the horizon(s) to **depth**. This velocity model can also be used to create a depth section, which may look more like true geology than a time section. However, if formation tops from well data are plotted on the seismic depth section, they most likely will not overlay. It is important to note that without extremely accurate velocity information, depths can not be accurately calculated from seismic; dips are unknown also. However, if model results fit field data, confidence in a stratigraphic interpretation increases.

## Summary

After all the expense and effort of shooting a seismic survey, processing the data and interpreting it, what are the chances of success? Many wells drilled on seismic alone are dry. Recent examples are the Jabiru-2 and 3 wells drilled in the Timor Sea offshore northwestern Australia. Well 1A showed a 187-ft gross oil column; however, the second and third wells were drilled (both dry) and the fourth well located (which recently flowed minimal amounts of crude) before a 3-D survey was even processed. It will be interesting to watch the success of future wells as sites are picked using an interactive workstation to do interactive stratigraphic analysis of the 3-D survey.

Wells are **so** expensive that no one wants dry holes. Even after applying the best of science, prospects are never sure bets. However, techniques like seismic stratigraphy are improving the odds.

## Series topics

The introductory article of this three-part series on seismic stratigraphy discussed phase effects, resolution and color softcopy. The second article reviewed three of the four key approaches to interpreting stratigraphy from seismic, namely seismic sequence analysis, seismic facies analysis and reflection character analysis. This, the third article in the series, reviewed advanced geophysical techniques, including direct hydrocarbon indicators, shear waves and seismic modeling (the fourth key seismic stratigraphy approach).


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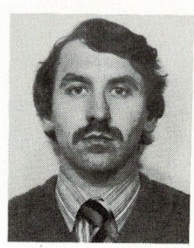
### The authors

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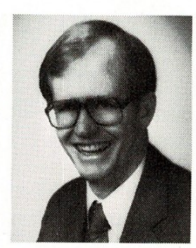


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