

Integration Aids Reservoir Effort

(Editor's note: The Geophysical Corner is a regular column in the EXPLORER and is produced by the AAPG Geophysical Committee.)

By BOB A. HARDAGE

This article is part one of a two-part series that summarizes a study of the Stratton Field, a large, Frio gas-producing property in Kleberg and Nueces counties in South Texas.

The stratigraphic interval involved was the Oligocene Frio Formation – a thick, fluvially deposited sand-shale sequence that has been a prolific gas producer in Stratton Field and in several other fields along the FR-4 depositional trend (figure 1).

This reservoir characterization effort is an example of integrating geophysics, geology and reservoir engineering technologies to detect thin-bed compartmented reservoirs in a fluvially deposited reservoir system.

The Study Site

The study covered a 7.6-square-mile area (figure 2) where 3-D seismic data were acquired, and where a large number of wells were used in making a geologic analyses of the Frio reservoirs.

Additional data (the circled dots) were used to supplement the historic well log, production and reservoir pressure data bases, and consisted of modern well logs, cores and various pressure tests.

Vertical seismic profile (VSP) data were recorded in two closely spaced wells inside the triangle shown near the center of the 3-D grid.

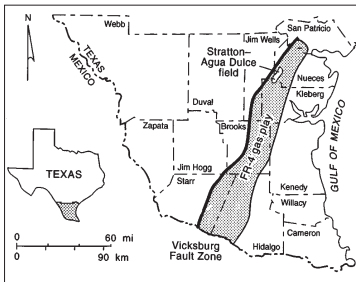


Figure 1

Thin-Bed Interpretation Procedure

The seismic interpretation at Stratton Field was particularly challenging because most of the Frio reservoirs were thin (<15 feet, or five meters), and they were closely stacked, in some areas separated only 10-15 feet (3-5 meters) vertically. These conditions required precise calibration of stratigraphic depth-versus-seismic travel-time to extract a depositional stratal surface from the 3-D data volume that would reliably depict the areal distribution of a particular Frio thin-bed reservoir.

Zero-offset VSP data recorded in one of the wells shown in figure 2 were used to establish the precise depth-versus-time control needed for the thin-bed interpretation. Figure 3 (page 12) shows the zero-offset image spliced into a north-south vertical slice from the 3-D data volume passing through the VSP well. Also

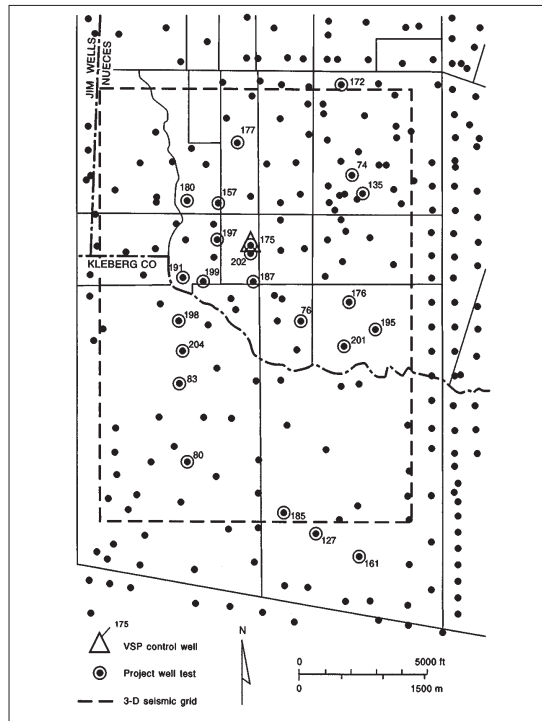


Figure 2

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shown in the figure is a graphic representation of the stratigraphic column penetrated by the VSP well.

Only producing or potentially-producing Frio reservoirs are shown in this diagram, and not all of the reservoirs are labeled by name. The top and base of each reservoir are accurately positioned in terms of two-way VSP travel-time, and since there is no difference in the VSP and 3-D time datum in this instance, the reservoirs are also correctly positioned vertically inside the 3-D seismic data volume at the VSP well.

Using these VSP travel-time control data, each thin-bed reservoir can be placed in the correct reflection phase position in the 3-D seismic reflection wavefield at the VSP well. This thin-bed calibration was extended away from the VSP well and across the entire 7.6-square-mile area imagined by the 3-D data using the interpretation principles of seismic stratigraphy.

Defining Chronostratigraphic Depositional Surfaces

The fundamental assumption made in the seismic interpretation was that seismic reflections follow chronostratigraphic depositional surfaces (Vail and Mitchum, 1977). Thus, a continuous seismic reflection even imaged over the entire 7.6-square-mile area by the 3-D seismic data defines a geologic surface that corresponds to a fixed, constant

Figure 3 shows the zero-offset image spliced into a north-south vertical slice from the 3-D data volume passing through the VSP well from figure 2 (page 10). Also shown is a graphic representation of the stratigraphic column penetrated by the VSP well. Figure 4 shows a continuous seismic reflection event imaged over the entire area by 3-D seismic data, defining a geologic surface that corresponds to a fixed, constant depositional time.

depositional time.

Two such areally continuous reflection events were found in the Frio interval. These two surfaces are shown on the east-west vertical section crossing the VSP well (figure 4).

At the VSP control well, the apex of the peak associated with the shallower stratal surface (the orange surface in figure 4) corresponded to the thick C38 reservoir (figure 3), and the apex of the peak at the deeper stratal surface (the green surface in figure 4) correlated with the F11 reservoir.

Thus, the seismic time surface following the apexes of all of the peaks of the orange event is assumed to define the ancient topographic Frio surface at the time when the C38 reservoir sediments were deposited. Similarly the seismic time surface following the apexes of the peaks of the deeper green event define the ancient depositional surface associated with the F11 reservoir.

Once the 3-D data volume was flattened relative to one of these two reference stratal surfaces, it follows that any horizontal time slice in this flattened data volume also followed an ancient

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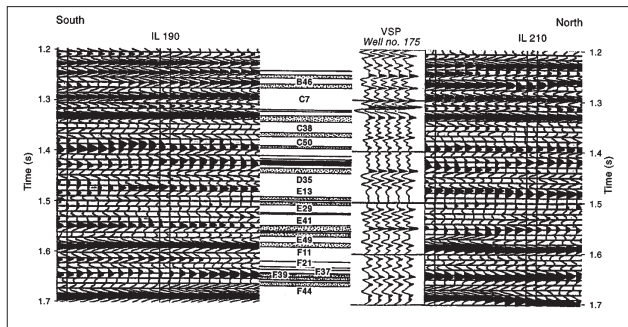


Figure 3

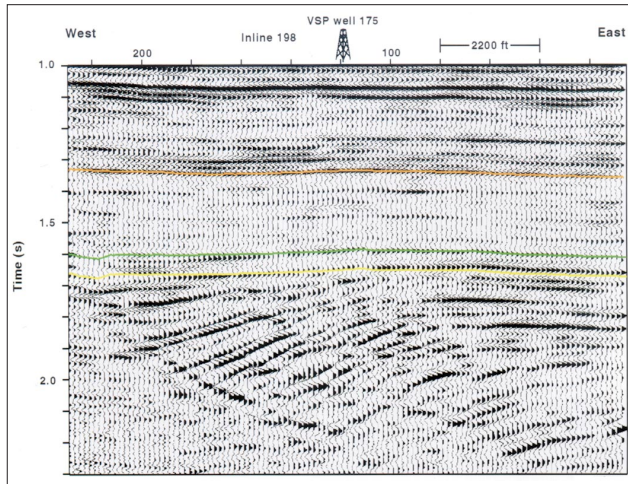


Figure 4

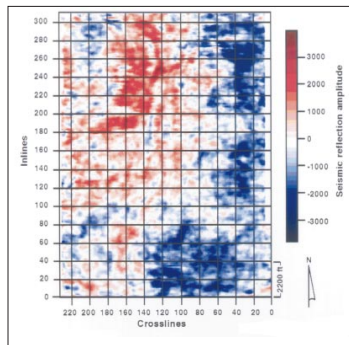


Figure 5

Figure 5 shows the reflection amplitude behavior on the F39 depositional surface shown in figure 4; figure 6 is a magnified view of this F39 surface in the vicinity of four key wells; and figure 7 shows the F39 reservoir pressure measurements that were acquired in all four wells. The differences in these static pressures indicated that each well was in a different F39 compartment.

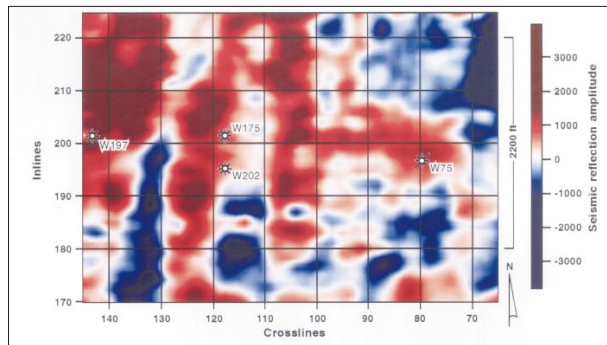


Figure 6

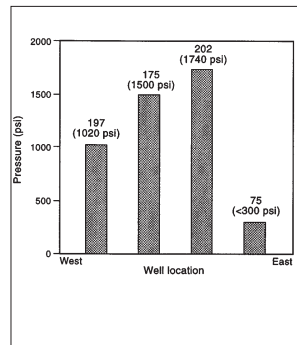


Figure 7

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Frio depositional surface – as long as the seismic reflection character in the immediate neighborhood of the time slice was time-conformable with the reflection character in the immediate vicinity of the reference surface used to flatten the data volume.

This interpretation is based on the assumption that the entire Frio section inside the 7.6-square-mile grid was seismically conformable to one of the two seismic reference surfaces.

In this specific interpretation problem, with many closely spaced (vertically) thin-beds, the VSP-defined position of a particular thin-bed reservoir was rarely at the apex of a reflection peak or trough. Invariably, each thin-bed of interest was positioned at some intermediate, often non-

descript phase point in the reflection waveform at the VSP control well.

To create a seismic image that emphasized the internal complex architecture of a given thin-bed reservoir system, the migrated 3-D data volume was:

- First time shifted so the proper pre-defined reference stratal surface was flat.

- Then a horizontal time slice was made through this flattened data volume at the exact VSP-defined time for the targeted thin-bed, regardless of where that time slice was positioned in the reflection waveform at the VSP control well.

By prior assumption, the seismic time surface contained in this horizontal slice was the fixed depositional stratal surface where that thin-bed unit was deposited, and any seismic anomalies

seen on this surface would be related directly to stratigraphic heterogeneities within the targeted thin-bed and, to a lesser degree, would be related to stratigraphic variations in thin-beds positioned immediately above and below the target thin-bed.

The F39 reservoir was the deepest Frio reservoir studied. (The depositional surface for the F39 reservoir is shown by the yellow horizon in figure 4; the reflection amplitude behavior on the F39 depositional surface is shown in figure 5.)

The linear north-south trends near the image's center are assumed to be residual effects from the deeper Vicksburg faults (a magnified view of this F39 surface in the vicinity of four key wells is shown in figure 6).

F39 reservoir pressure measurements were acquired in all four

wells (figure 7), and the differences in these static pressures indicated that each well was in a different F39 compartment. The 3-D seismic image and the available geologic control gave clues as to where the boundaries were that segregated the F39 reservoir into these distinct compartments.

Figure 8 (page 14) displays the available geologic control. The log curves infer that the F39 reservoir in each well was deposited in a channel environment that showed some evidence of splay deposition.

The seismic image defines some possible compartment boundaries. For example, the most likely cause of the compartment boundary that separates well 197 from the other wells is the depositional variation that created the

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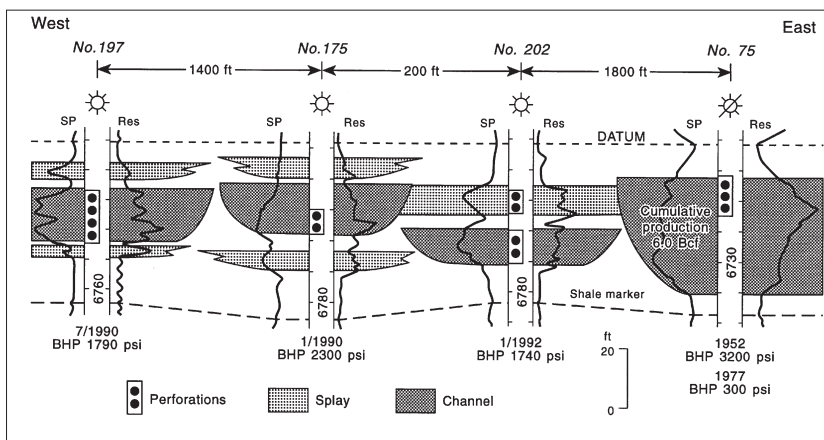


Figure 8

This graphic displays the available geologic control. The log curves infer that the F39 reservoir in each well was deposited in a channel environment that showed some evidence of splay deposition.

Graphics courtesy of Bob Hardage

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red/blue (positive/negative) amplitude changes, which trend north-south between crossline coordinates 130 and 140 (figure 6).

Similarly, a probable seismic indication of the compartment boundary that segregates well 75 from the other wells is the positive-to-negative (red-to-blue) amplitude variations trending north-south between crossline coordinates 110 and 120.

By analyzing the seismic, geologic and engineering data associated with the F39 reservoir it is possible to seismically detect F39 reservoir compartments – at least in the vicinity of wells 75, 175 and 197.

To create this reservoir compartment model, it is essential that the seismic image be interpreted with the assistance of reservoir pressure data to infer which of the many stratigraphic changes revealed in the seismic image are most likely to be the compartment boundaries.

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Combining Data Aids Interpretation

(Editor's note: The Geophysical Corner is a regular column in the EXPLORER, produced by the AAPG Geophysical Committee. This month's article is part two of a two-part series on reservoir characterization and results from the integration of geology, geophysics and reservoir engineering.)

techniques used in thin-bed interpretations and examples of reservoir heterogeneity. This month, an integrated interpretation of a complex reservoir system is made using 3-D seismic, well log and bottom-hole pressure data.

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By BOB A. HARDAGE
Last month we discussed the

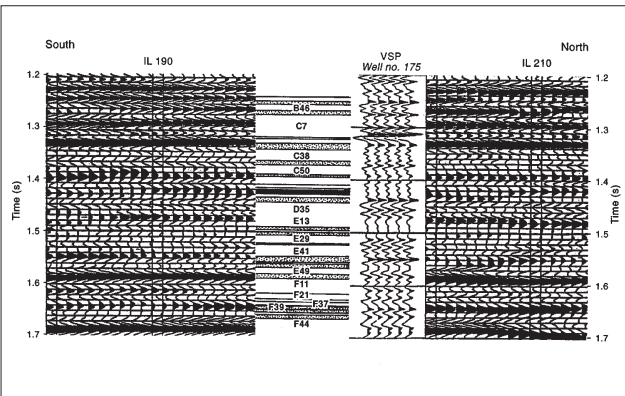


Figure 1 – The F37 reservoir is about 20 feet above the F39 reservoir.

The F37 reservoir is approximately 20 feet (6 meters) above the F39 reservoir in the VSP calibration well (figure 1). The two-way travel-time difference between F37 and F39 is only four milliseconds (4 ms).

Using the thin-bed interpretation procedure described last month, a time slice was made through the flattened 3-D data volume 4ms above the F39 stratal surface. This F37 surface is displayed in figure 2.

Comparing this image with the F39 surface (figure 3), red, linear north-south apparent channels in the central part of the F37 image are similar to those observed in the F39 image, implying that Vicksburg faulting was still controlling sedimentation in this part of the field.

However, there is a significant difference in the southeast quadrant of the F39 and F37 images. Specifically, meander channel features occur at the F37 level but are not present at the deeper F39 surface. (An enlarged plot of the meander features in figure 2 is shown on figure 4.)

A log-based stratigraphic cross-section of the F37 reservoir across the meander features and extending southward beyond the seismic grid was constructed (figure 5, page 32). The depositional environment (either channel or splay) at each well is an interpretation based on log curve shape and was made before the 3-D seismic data were recorded.

This geologically-based interpretation of the F37 depositional environments indicates that the meander feature seen in the F37 seismic surface is indeed a depositional channel. Specifically, the log interpretation (figure 5), implies the F37 reservoirs found in wells 189 and 185 were deposited as channel fill, and the seismic image shows these wells to be directly on top of a meander feature.

The depositional interpretation for the extremely thin F37 reservoir in well 211 was that this wellbore could have penetrated a splay (figure 5). The 211 wellhead is approximately 300 feet (91 meters) north of the meander feature (figure 4).

The log-based interpretation of the F37 depositional environment at the 211 well is thus supported by seismic evidence.

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Pressure histories recorded in several F37 reservoirs near these seismic meander features were analyzed to determine if reservoir compartmentalization existed. These pressure histories (figure 6, page 32) show there are at least three, and

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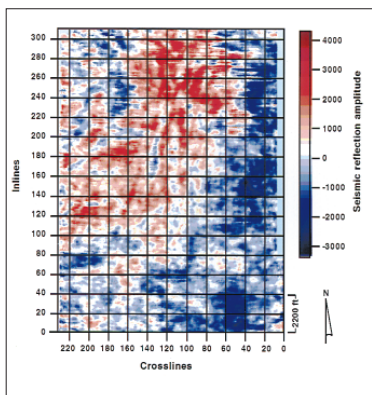


Figure 2 – The F37 surface.

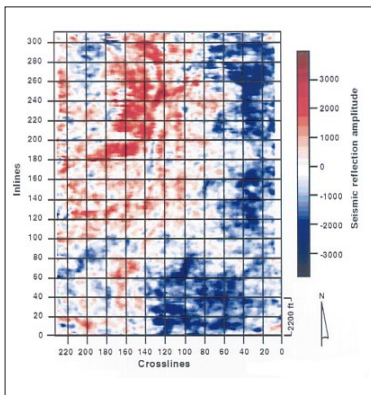


Figure 3 – The F39 surface

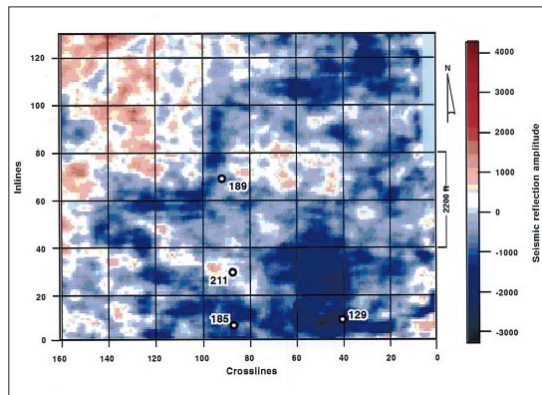


Figure 4 – An enlarged look at the meander features of F37.

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perhaps four, individual F37 reservoir compartments that occur in this area of the field.

A reservoir model that honors all three data bases – the seismic, the geological and the reservoir engineering – is proposed in figure 7 (page 32). This model assumes that the F37 reservoir in the southeast quadrant of the 3-D grid is composed of three intermeshed channels, labeled A, B and C, and a grid overlay of seismic inline and crossline coordinates is provided so these channels can be correlated with features in the 3-D seismic image.

The location of the F37 stratigraphic cross-section (figure 5) is shown, but this geologic information defines channel locations along only a single 2-D profile of the model.

The important information is the reservoir pressure data, because without this engineering data there would be no reason to conclude that a three-channel model would be appropriate.

Thus, the reservoir compartment model places well 129 in Channel A and well 185 in Channel B, which allows these two wells to be in different F37 pressure regimes; i.e., in different compartments (channels).

Wells 127 and 161 are proposed to be in channel C, south of the 3-D seismic coverage. Only one meander loop of this hypothesized channel C extends into the 3-D seismic grid. The rapid F37 pressure decay observed in well 189 (figure 6) implies that this well is not in pressure communication with well 185, even though both wells are in channel B. There may be an intrachannel compartment boundary in channel B.

The reservoir model in figure 7 is hypothetical and may not yet be the correct picture of the compartmentalized nature of these F37 reservoirs. However, the F37 reservoir in this portion of Stratton Field is segregated into distinct compartments, and this compartmentalization must be caused by the fluvial deposition, because the seismic data show no evidence of faulting in these particular reservoirs. The proposed reservoir model honors all existing data that provide any information about the F37 reservoir system.

The figure 4 seismic image revealed not just one meander channel system but at least three intermeshed thin-bed channels. By using pressure histories it was possible to use 3-D seismic images to define where compartment

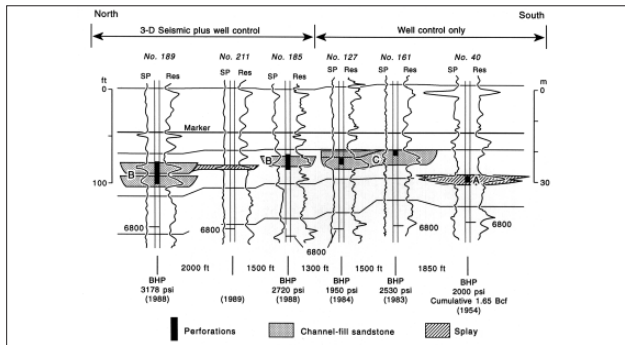
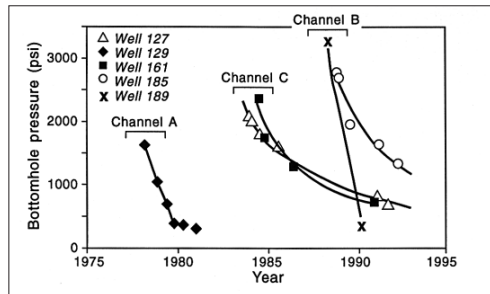


Figure 5 (left), a log-based stratigraphic cross-section of the F37 reservoir; Figure 6 (right) shows the rapid F37 pressure decay in well 189; Figure 7 (below) is a multi-discipline reservoir model.



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boundaries most likely existed in the interwell space.

Two examples of seismic thin-bed interpretation in a fluvially deposited gas reservoir are shown, and these interpretations are supported with geologic and reservoir engineering data.

In these examples, the 3-D seismic data reveal stratigraphic variations where reservoir pressure information implies that a compartment boundary should exist.

These examples illustrate that, although fluvial deposition creates numerous compartment boundaries, determining which seismically imaged stratigraphic changes are compartment boundaries requires that geologic and

reservoir engineering data (particularly reservoir pressure data) be incorporated into the seismic interpretation.

In this study it was particularly important to have an accurate and reliable way to translate thin-bed stratigraphy (known in depth) into precisely defined seismic time windows.

VSP data, when properly recorded and processed, are the best information to establish the detailed depth-versus-time calibration required to seismically distinguish closely spaced thin-beds.

The VSP calibration procedure used was able to seismically distinguish thin-beds that were vertically separated by as little as 4 ms.

(Bob Hardage is senior research scientists with the Bureau of Economic Geology at the University of Texas at Austin. Raymond A. Levey, Virginia Pendleton, James Simmons and Rick Edson, all also of the Bureau of Economic Geology at the time this work was done, assisted in the writing.)

