A REPRINT FROM
OIL&GAS JOURNAL

EXPLORATION

Interactive fault interpretation and seismic amplitudes

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In December 1985 various contractors were approached with an exploration problem by Dr. Don F. Beaumont.

Don was an exploration coordinator at Texaco's Bellaire, Tex., office before voluntary retirement in 1986. Dr. Serpell Edwards at Texaco's Houston Research Center was then assigned as project coordinator. Landmark Graphics was one of the companies chosen to evaluate the exploration problem of juxtaposition of seismic events along nonvertical fault surfaces.

A Gulf of Mexico 3D survey from the New Orleans division of Texas U.S.A. and partners Unocal, Pogo, and Tricentrol was loaned to the contractors for this study. Standard seismic interpretation and mapping software tools were used in this project, with the exception of a test utility to translate the fault plane in x and y. The workstation used was standalone, with two screens and an optical disk (Mouton, 1986).

Background. The data consist of a 190 line, 178 traces per line 3D seismic survey. The data were 3D migrated. Well control and post stack processing are not discussed since the objective was to study the relationship between fault planes and seismic amplitudes.

The structure of the survey area is dominated by a deep-seated anticline and it's relationship with a regional fault system. Production is from expanded Lower Miocene sands, downthrown to the regional faulting. The Miocene sands have produced about 281 bcf of gas and 14 million bbl of condensate from depths of 11,000-17,000 ft in the general area of the study.

The interpretation process

Fault and horizon picking. The first interpretation step was to pick the faults.

Fig. 1 shows a typical seismic line. Line 60 crosses the crest of a downthrown structure. Trace 15 is to the south. The blue line on Fig. 1 highlights a regional down to the south growth fault parallel and south of the major regional fault. All of the faults that could be identified were picked on every fifth line through the survey. Picking all of the obvious faults on these 40 sections over the entire survey took 2 hr, 50 min. Faults were recognized, as they are on paper seismic sections, by thin linear areas of no data and terminations of reflector continuity.

There are several bright events that terminate adjacent to the faults. The yellow pick, Horizon A, just above 2.8 sec on the right-hand side of Fig. 1, shows that locally the bright events appear to continue across the fault. The orange pick, Horizon B, was modified from a depth map of the Robulus L horizon. The Robulus L is shown in Fig. 2 on the type log of the prospective interval. A large interpreted Rob L paper map was digitized on a 60 × 54 in. digitizing table connected to the workstation. Next the digitized contours were gridded using HMAP (Nelson and Hildebrand, CSEG, 1986), and transferred to a horizon file. Using a constant velocity of 8,000 ft/sec, the depth horizon was converted to a time horizon. The picks were then adjusted to the nearest trough (white reflectors on Fig. 1).

The standard manual, delete and automatic picking options were used to make the slight travel-time adjustments that were required because of the simplified velocity assumption and linear in-fill between digitized contours. The horizons were left one pixel wide on Fig. 1 so that variations in the amplitude could be evaluated. Later Horizon B was repicked from scratch over the western 40% (lines 1 to 75) of the survey.

Fault correlation. Before horizons A and B were picked, the fault picks from every fifth line were assigned to a fault plane.

This is accomplished with the FMAP (Nelson and Hildebrand, EAEG, 1986) interpretation tool. Fig. 3 is a snapshot of this process after the first set of fault picks were assigned to the burgundy fault plane, triangulated, and contoured. The white lines highlight the location of every fifth line, or the picked control. The color bar indicates that the shallowest part of the fault plane is displayed white, with a gradual darkening of the colors with depth. The colors can be changed at the users discretion.

For instance, they may be altered to blocks of specific colors. The map view (MV) shows the initial contours for the Burgundy fault. The arrows show dip on unassigned fault segments and are used to spatially correlate fault planes. It took about 5 min to assign the 17 unassigned fault segments to the burgundy fault plane and generate this contour map. Note that because of mispicked faults, the contours do not all make geometric sense. Problem points can be deleted, or new control added to geometrically alter or extend the fault plane spatially beyond map control.

The cross sections at the top of Fig. 3 allow the interpreter to instantly study fault picks or fault planes on any picked or arbitrary section. The cross sections shown are all along picked section lines (SL). In the interactive world the location of these windows is available by pressing a button and having the location flash on all map displays. These four cross sections are evenly spaced across the Burgundy fault, and north is on the right. The Burgundy fault was not assigned in the second window.

Perspective views allow fault picks or fault planes to be dynamically rotated until a spatial correlation of the fault picks is observed. In this case, a large perspective view was displayed on the right hand screen but is not included as a figure because of space considerations. When an unassigned fault segment is assigned from a cross section or map window, it is flashed in all of the windows to help the interpreter visualize spatial relationships. Once it is assigned it is changed to the specified fault color, which was burgundy in this case.

This fault correlation process was continued until all of the major faults were defined. Fig. 4 is a picture of these fault planes after an hour of correlating faults and geometrically editing the fault planes. To show separation between the fault planes, contours were displayed over the 400 ms window from 2.6 to 3 sec. The Blue fault is to the north (top) and the Burgundy fault to the south of the map section. Note the large transverse fault between the Burgundy and Blue fault planes on the right side of the map.

This shows as an orange fault in the arbitrary cross sections (AS) at the top of Fig. 4. These arbitrary sections are perpendicular to the regional strike of the faults, and go left-to-right from northwest to southeast. Remember with the interactive system, a simple button push will flash a specified cross-section location on the map display(s).

The spatial relationship between these faults is shown better in Fig. 5. Note that the faults can be colored in the uniquely assigned fault color or instantly changed to time-varying colors to highlight contours on the fault planes. This perspective display has been rotated so that north is towards the right, and the view is along the strike of the Blue fault.

An interesting fallout of this display is the corrugation along the Blue fault. Initially it was thought that this was an artifact due to picking faults on every fifth seismic line. However, this was shown not to be true by returning to A3DI and displaying several in-lines and arbitrary lines that crossed the fault plane in both dip and strike directions.

To check this phenomenon in detail, the Blue fault and Horizon B were repicked on each line over lines 1 to 75. This process took 3 hr and 20 min. Fig. 6 shows that the fault plane is indeed corrugated. The Blue fault was projected onto the sections not previously picked and used as a guide to repick the fault in detail on each section. Care was taken to locate the fault as accurately as possible on each of the lines picked.

As the picking progressed the contour map of the Blue fault was updated on the right hand screen. When the projected fault picks or the fault contours didn't make geometric sense, having both the map and seismic data simultaneously displayed allowed instant returning to a previously picked line to repick the fault. The blocks of color at the south end of the map are due to interpolation of the display map. The color map used to display the fault plane map is designed to enhance the perception of depth in the viewers mind. The fault plane dips from north to south or from light to dark.

Transverse faults. The Blue fault was used for this initial study of the juxtaposition of seismic events along nonvertical fault surfaces. This is the major fault through the survey and parallels a more regional fault just to the north. Since the fault strike trends northeast, the first step was to move the fault laterally in one grid increments to the northwest (−110 ft west and +110 ft north). This fault plane shifting was repeated up to 10 grid increments in this direction. Later the fault plane was moved to the north and to the south in one grid increments.

The objective was to find spatial or map relationships between the seismic amplitudes that could be related to the limits of closure against the fault. By extracting amplitudes at each of these offsets, a map was generated that showed the areal distribution of amplitudes along this parallel fault plane. This is like projecting amplitudes on, or parallel to, fault planes to the top of the 3D cube. It has been shown in numerous time-slice interpretations that a logical way to study small faults is in map projections (Blake, et al, 1982; Horvath, 1985; Cole and Nelson, 1984). Stepping through a sequence of these fault plane amplitude maps, or making a composite picture with fault plane amplitude maps at several locations, pointed out relationships of the various amplitudes.

The fault plane was, in effect, translated in x and y in order to study the relationship of seismic amplitudes and the fault plane. Since translation is an associative operation, the moved fault planes could later be translated in time. Making a "time-slice" animation file at specified offsets from the fault plane proved particularly useful. Rapidly viewing in one time-step (4 ms) intervals "time-slice" fault plane amplitude maps showed the consistency of blocks of similarly trending

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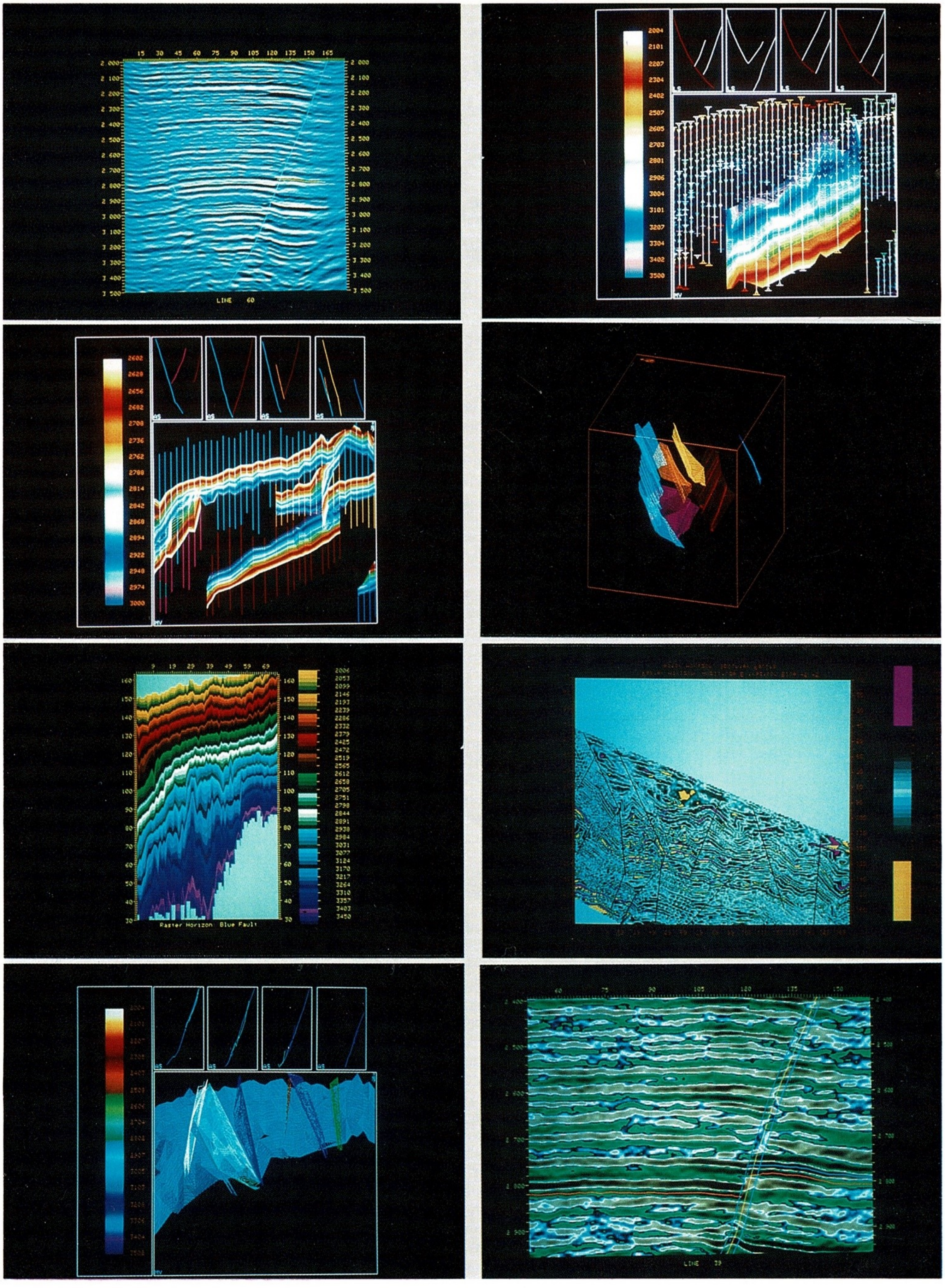
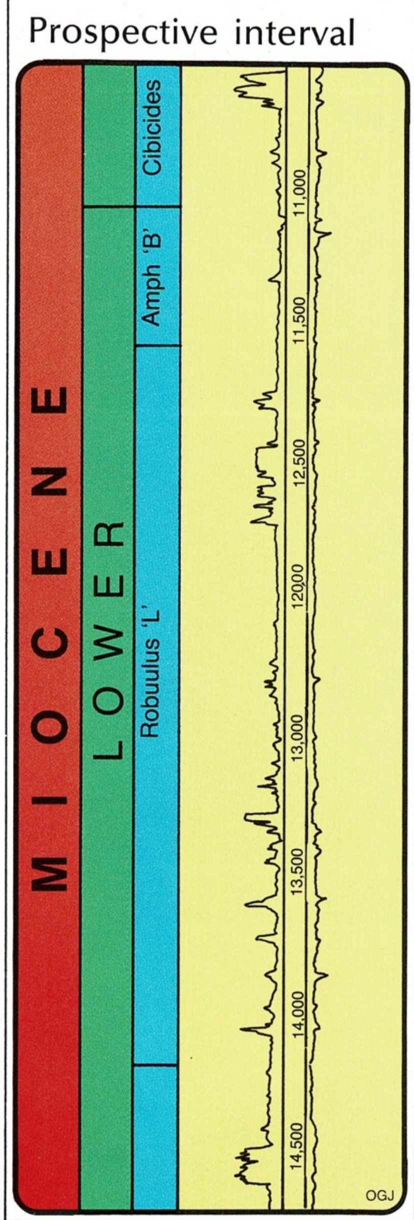


From left to right, each row: Line 60, Fig. 1; first fault plane, Fig. 3; fault plane map, Fig. 4; fault planes perspective, Fig. 5; blue fault map, Fig. 6; transverse faults, Fig. 7; FMAP transverse faults, Fig. 8; Line 39, Fig. 9.

Fig. 2



seismic events. The animation files showed that the spatial relationship between the changes in dip on the amplitude events were related to small compensation or transverse faults. Brown, et al. (1986) make a similar observation about small faults near a fault plane.

An example of one of these fault plane amplitude maps is shown in Fig. 7. Some of the transverse faults have been highlighted in red. The name transverse faults is chosen because they strike perpendicularly or diagonally to the strike of the regional fault. In addition, a transverse fault is normally associated with detached normal fault extension or compensating faults, and not with thrust faulting. At this fault plane offset (775 ft to the northwest), the amplitudes of Horizon B and yellow events starting at trace 95 on the west and trending to the northeast. There are obvious changes in the amplitudes at the transverse fault boundaries.

As a test of the spatial relationship of the transverse faults, fault picks from several plane amplitude maps were correlated using FMAP. These fault planes are displayed in map view with the Blue fault in Fig. 8. The transverse faults parallel the Blue fault, as shown in the four cross sections at the top of the figure. These faults have little spatial expression and so are hard to visualize from dip cross sections.

However, the transverse fault relationships show up well in perspective or map views. It is interesting that the transverse faults seem to follow the same map trends as the corrugations described above.

The transverse faults were then projected onto various in-line and arbitrary line seismic sections to see how they are related to a normal seismic display. Fig. 9 shows line 39 with these data overlaid. The seismic is colored brown for the peaks, a white to black gradation around the zero crossing, and greens for the troughs. Horizon A is blue, Horizon B is orange and both are displayed with picks three pixels thick. The Blue fault is colored yellow (active horizon color), and the fault plane projected to the north 440 ft is light blue, and to the south a darker blue. The Burgundy fault was not picked on this section and is projected as a set of red dashes ending at the top of the section at trace 80. The transverse faults also are projected gray, brown, and pink dashes near the Blue fault. As expected, there is little seismic expression of the transverse faults on this in-line seismic section.

Conclusions. If there is access to seismic data, especially a 3D survey, it makes sense to take a closer look at the data before drilling a well or placing a platform. Much more information than the normal structural interpretation can be gleaned from the data. Doing a detailed evaluation of subtle features, such as the fault corrugations and transverse faults discussed in this article, can make a significant impact on the economics of a prospect.

Optimal production of a reservoir will vary depending on how the small transverse faults are associated with a major controlling fault and segment the reservoir. It is expected that accurate mapping of these small transverse faults will be of great benefit to production geologists. In addition, it is easy to use a small workstation with flexible interpretation tools to accurately and efficiently study details of a large seismic data set.

Acknowledgments

The authors would like to thank Texaco Inc. and Landmark Graphics Corp. for permission to publish this work.

We also would like to thank those who reviewed and commented on the paper, especially T.L. Smith at Landmark, who "in his own spare time" wrote the utility to spatially translate the fault plane.

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