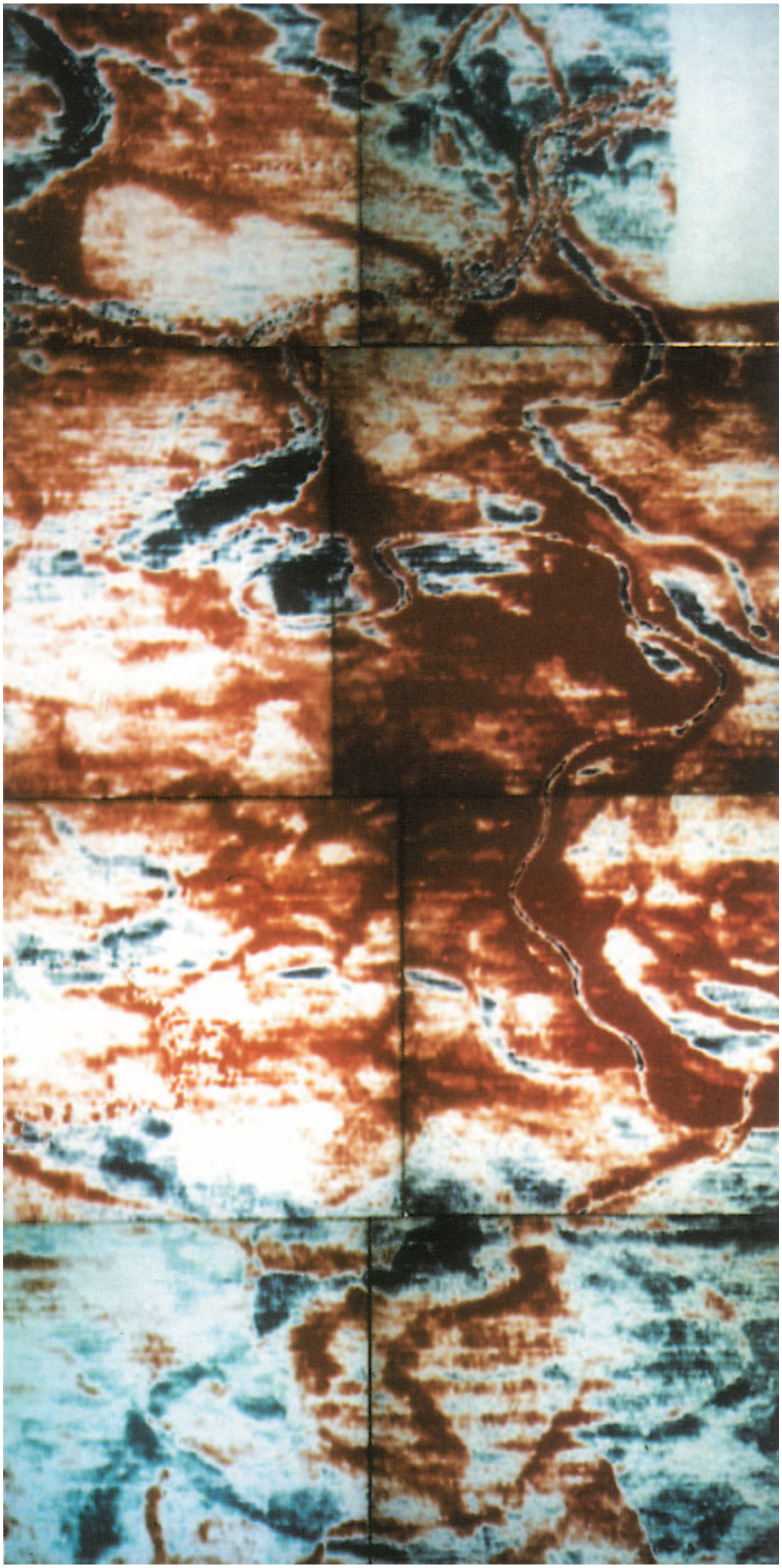
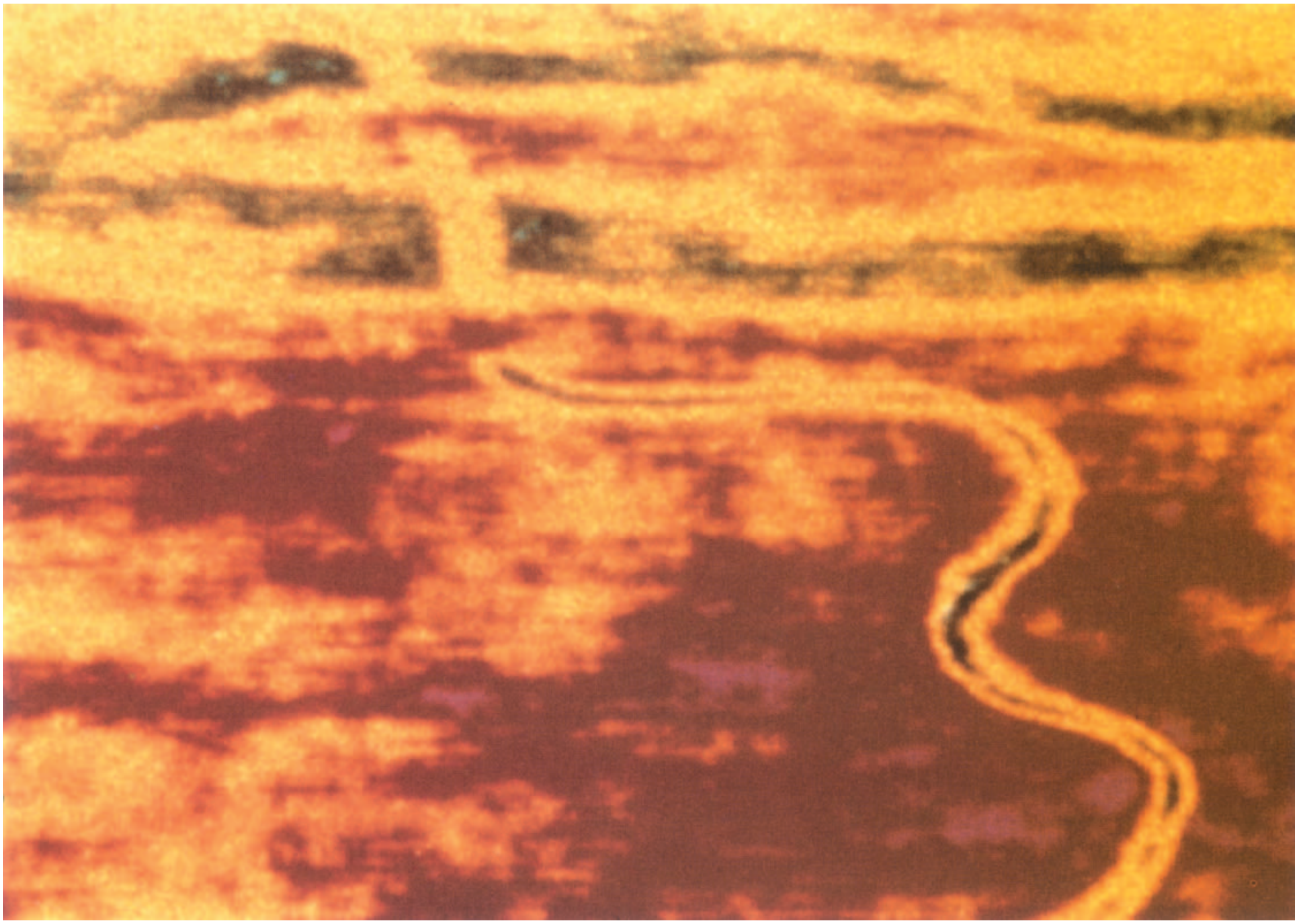


Fig. 4-20. Shallow horizontal section from Gulf of Thailand showing channels, point bars and crevasse splays. (Courtesy Unocal Thailand Ltd.)



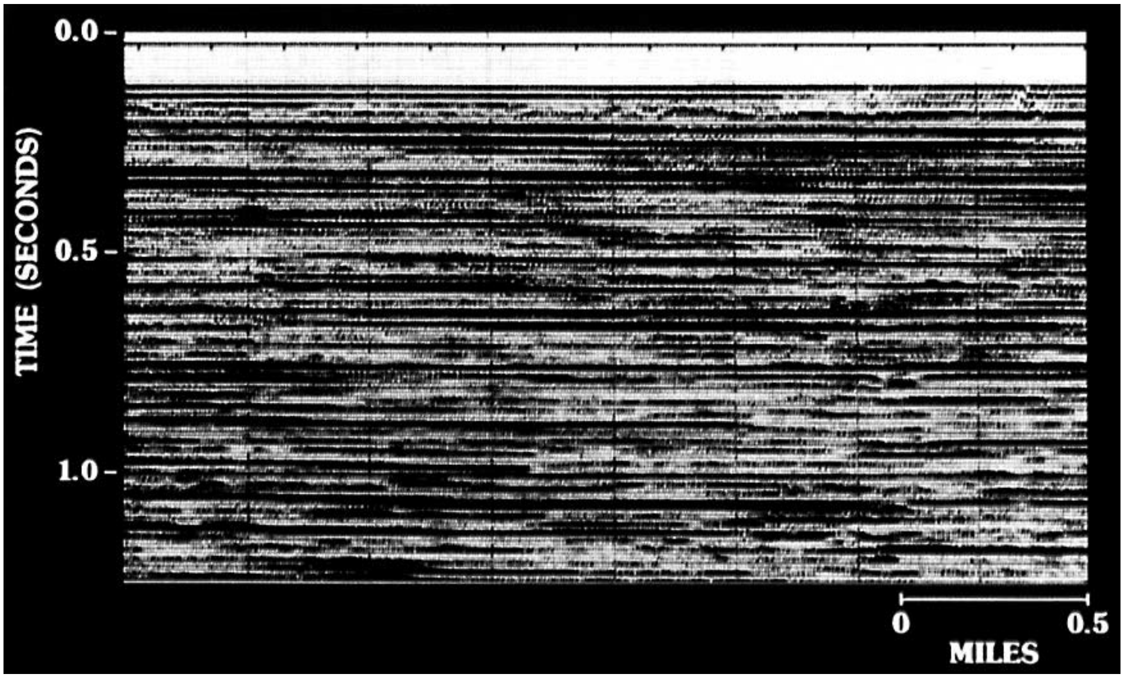


Fig. 4-21. Horizontal section from Matagorda Block 668, offshore Texas, showing prominent channel. It is a useful and interesting challenge to locate the channel intersection on the vertical section of Figure 4-22. (Courtesy ARCO Oil and Gas Company.)

Fig. 4-22. Vertical section from Matagorda Block 668, offshore Texas. (Courtesy ARCO Oil and Gas Company.)

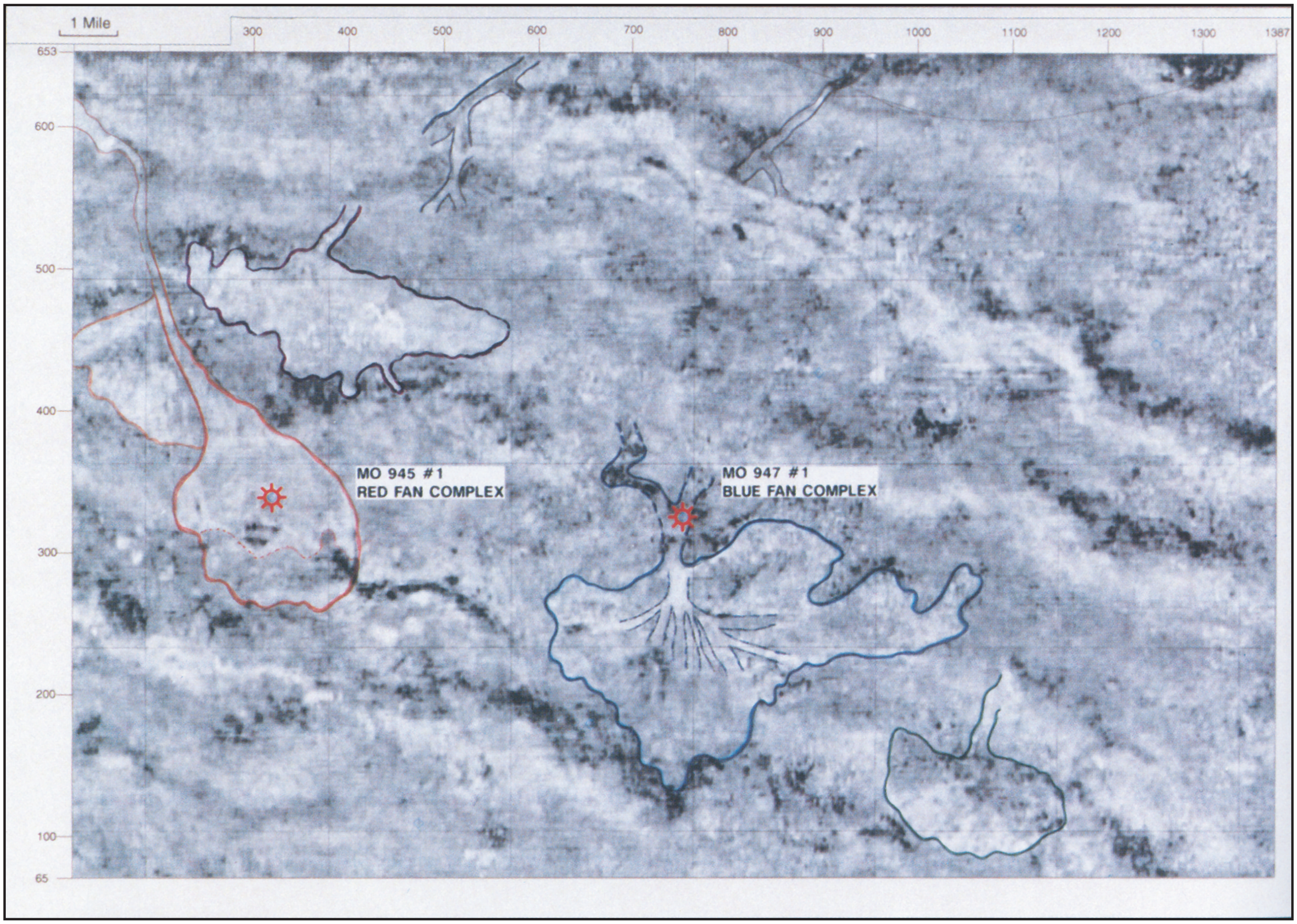


Fig. 4-23. Horizontal section at 936 ms from Mobile area, offshore Alabama, showing interpretation of numerous Miocene deltaic fans. (Courtesy Conoco Inc. and Digicon Geophysical Corp.)

Figure 4-25 illustrates schematically how a channel can be recognized and delineated in the presence of structure. In this example the interpreter has horizontal sections at 4 ms intervals from 1240 to 1260 ms. The selected event at 1240 ms for the horizon under study is traced to provide the contour as shown for 1240 ms. A high amplitude anomaly is recognized and marked at the position of the green blob. This procedure is repeated at 1244, 1248, 1252, 1256, and 1260 ms. At each of these levels the interpreter found an amplitude anomaly; together these arranged themselves into the curvilinear feature marked by the orange lines in Figure 4-25. This is manual amplitude mapping but the interactive workstation gives us several tools to do this in an efficient way.

Figure 4-26 shows a vertical section interpreted on three horizons. The Shallow Horizon, marked in blue, was selected on the basis of both structural and stratigraphic objectives. Figure 4-27 shows the structural contour map of the Shallow Horizon resulting from a full-scale structural interpretation of all the 3-D data. The desire then was to slice through the data volume along this structurally interpreted horizon in order to gather up all the seismic amplitudes associated with it. This is normally accomplished by the process of *amplitude extraction*, a menu-initiated search-and-gather operation on the interactive workstation. Alternatively, it is possible to flatten the data volume on the Shallow Horizon, as structurally interpreted in Figure 4-27, and then slice horizontally through the flattened volume at the level of the interpreted horizon.

The resultant section is known as a **horizon slice,** horizon amplitude map, or horizon Seiscrop section, where the critical word is **horizon**. This type of section, following one horizon, must be along bedding planes or it loses its value for stratigraphic

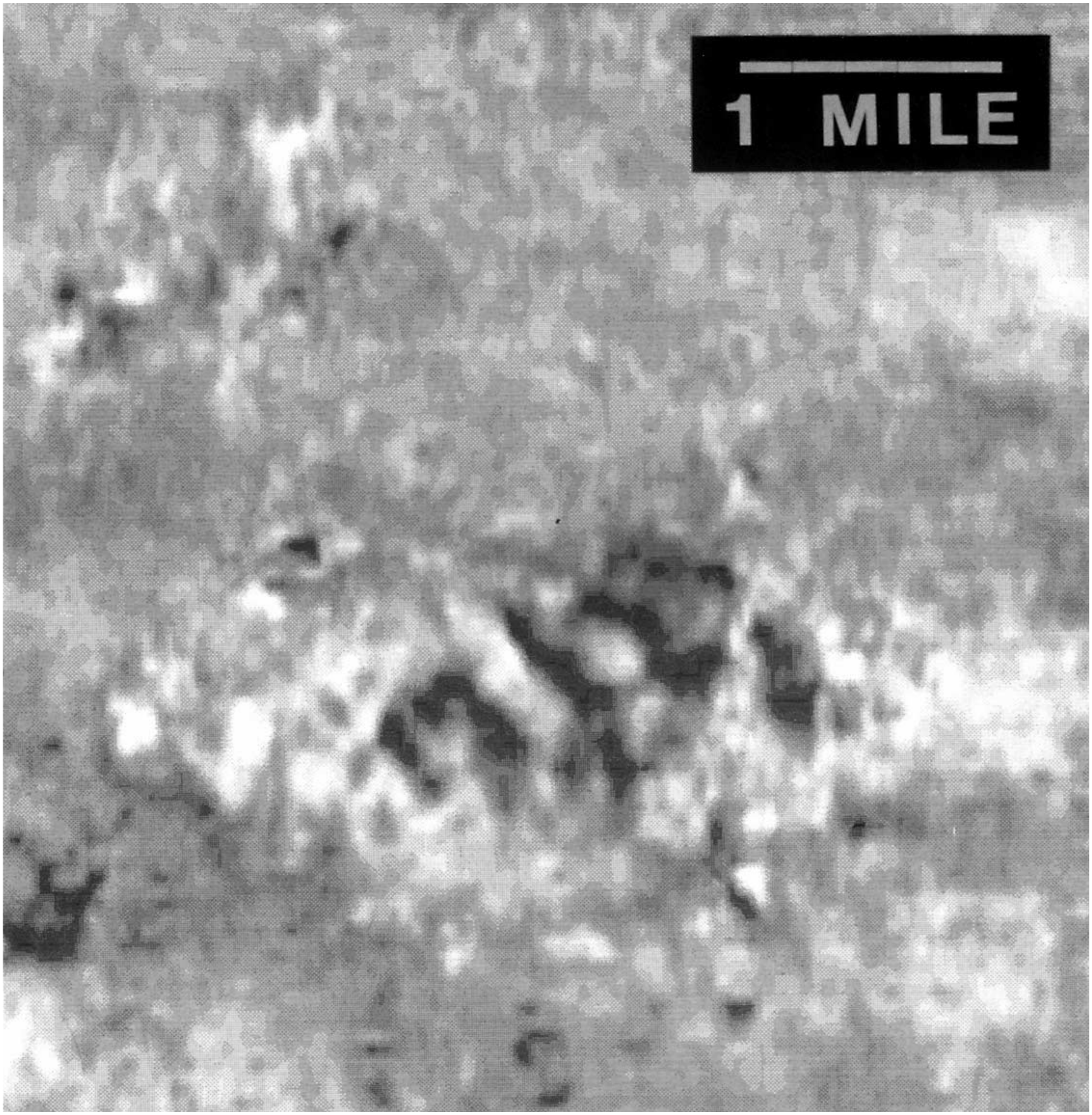


Fig. 4-24. Horizontal section at 1268 ms from Mobile area, offshore Alabama, showing one Miocene deltaic fan. Gas is being produced from one of the black channels. (Courtesy Conoco Inc. and Digicon Geophysical Corp.)

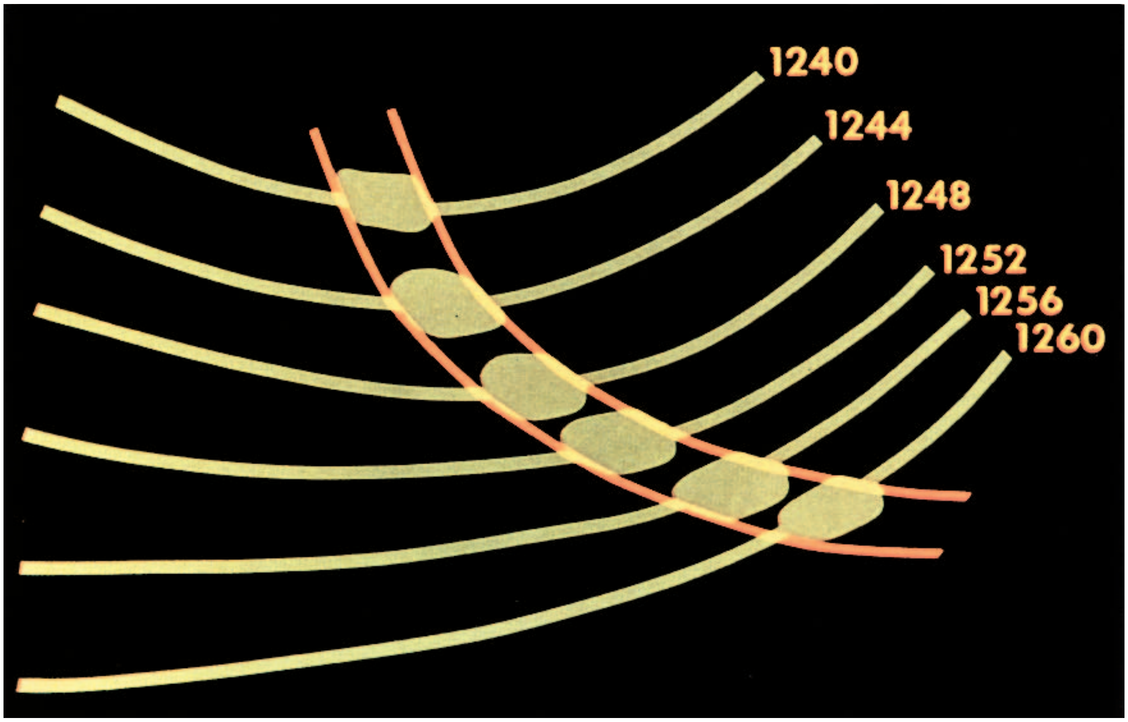


Fig. 4-25. How to follow an anomalous amplitude feature in the presence of structure on a sequence of horizontal sections.

interpretation. The importance of this approach was first stressed by Brown, Dahm, and Graebner (1981).

Figures 4-28 and 4-29 are horizon slices through adjacent conformable horizons both following the structural configuration of Figure 4-27. Both were sliced through peaks and hence all amplitudes are positive and show as varying intensities of blue; the darker blues indicate the higher amplitudes. The approximately north-south light-colored streaks are the faults; the width of a streak gives an indication of fault heave.

Figure 4-28 shows a broad high amplitude trending northwest-southeast toward the left of the section. This is interpreted as a sand bar. It is evident that this inferred bar has been dissected by several faults. The process of constructing the horizon slice has put the bar back together. Hence the construction of a horizon slice amounts to the reconstitution of a depositional surface.

Figure 4-29 shows more spatial consistency of the darker blues, indicating that this horizon follows a sheet sand. There is a curvilinear feature, somewhat the shape of a shepherd's crook, which runs northwest-southeast just to the west of well 5X. This is interpreted as an erosion channel in the sheet sand. The fact that this inferred channel is continuous across the fault just west of well 5X lends support that this horizon slice has correctly reconstituted the depositional surface into which the channel was cut.

Figure 4-30 indicates by two black arrows the two seismic horizons followed in the construction of the horizon slices of Figure 4-31. The high amplitude feature shaped somewhat like a hockey stick appears very similar on the two sections. It is invisible on other adjacent horizon slices (not shown). Hence the seismic signature of this inferred channel is trough-over-peak, which implies high velocity material, given the polarity convention implicit in these data. After inverting the whole data volume to seismic logs, a horizon slice through this velocity volume positioned between the horizon slices of Figure 4-31 generated the velocity horizon slice of Figure 4-32. The darker colors indicate the high velocity channel fill.

Methods of Making Horizon Slices

Automatic horizon tracking, now commonplace in interactive interpretation systems, has greatly facilitated the generation of horizon slices. When a horizon is tracked, the extreme amplitude as well as its time is stored in the digital database. Mapping of the times produces a structure map; mapping of the amplitudes produces a horizon slice. More commonly, only the time is stored as a result of horizon tracking and later the amplitudes are extracted from the data. In addition, it is possible to extract the amplitudes not coincident with the tracked horizon but parallel to it and shifted by a chosen number of milliseconds.

Figure 4-33 shows two lines from a Gulf of Mexico 3-D prospect, where a horizon is tracked one-and-a-half periods above a red blob considered to be of stratigraphic interest. The structural continuity is better for the horizon being tracked than for the blob, so the structure was defined at this level and the horizon slice made parallel to it through the blob at a fixed time increment deeper.

The resulting horizon slice is shown in Figure 4-34 and the interpreter can readily infer the existence of another channel. The black horizontal lines indicate the positions of the two vertical sections of Figure 4-33. The amplitude of the channel reflection is greater to the northeast; a discussion of this relative to implied gas content appears in Chapter 5.

A horizon slice is by definition a slice along a bedding plane, but the methods by which an interpreter may make such a slice are many and varied (Figure 4-35). If the slice is made at the tracking level, following automatic horizon tracking, the horizon slice is made up of truly crestal amplitudes and should thus be accurately along the bedding plane. However, if the structure is defined by tracking at one level where the continuity is clear but the slice is made parallel to that at another level, then the slicing and tracking levels must be sufficiently conformable for the horizon slice to adequately follow the bedding plane. This approach beneficially segregates the stratigraphic and structural components of an interpretation. Minor irregularities at the tracking level may not be paralleled at the slicing level, so spatial smoothing of the tracked times may be desirable before displacing the horizon down or up to the slicing level.

When a tracked horizon is displaced down by a constant time shift, the option exists to snap the displaced horizon to the exact crestal amplitude of the new reflection. Sometimes this will be the right course of action and sometimes it will be wrong. Figure 4-36 illustrates diagrammatically a situation where it would be wrong. Good reflections exist at the sand/shale interface and the shale/limestone interface. However, at the latter patches of porosity form the exploration objective and also introduce character changes along the limestone reflection. The shale is of uniform thickness. The structure is followed on the sand/shale reflection, which is stratigraphically uncomplicated, and displaced down by a constant time shift to the top of the limestone. The amplitudes are then extracted *without snapping* to yield a horizon slice on which the porosity should show as low amplitude patches. Snapping would move the horizon down to the top of the unporous limestone and the low amplitude patches would be lost!

Slicing through a zone of poor reflection continuity (where tracking would have been impossible) parallel to a good reflection at the top or the base of the zone has in several cases yielded meaningful and interpretable stratigraphic patterns. This demonstrates that data that may appear poor and uninterpretable on vertical sections may in fact reveal significant stratigraphic information when viewed spatially over bedding plane surfaces. In the case of a poor continuity interval of nonuniform thickness it can be useful to track a reflection at the top and one at the base (Figure 4-37). Then the slice is made within that interval using a surface whose shape is based partly on the upper tracked surface and partly on the lower tracked surface, the proportions of each depending on where within the interval the slice is desired. This method yields **proportional slices**.

After amplitude has been extracted on the objective horizon corrections are sometimes required (Figure 4-35). Consider, for example, that a high amplitude bright spot on a deeper horizon slice is shadowed over part of its area by a shallower high amplitude anomaly. This is commonly referred to as transmission effect, and an example of this is discussed in Chapter 5. Some fraction of the amplitude extracted on the shallower horizon can be added to the amplitude on the deeper horizon to compensate for the shadowing effect. The fraction to use must be established empirically but the

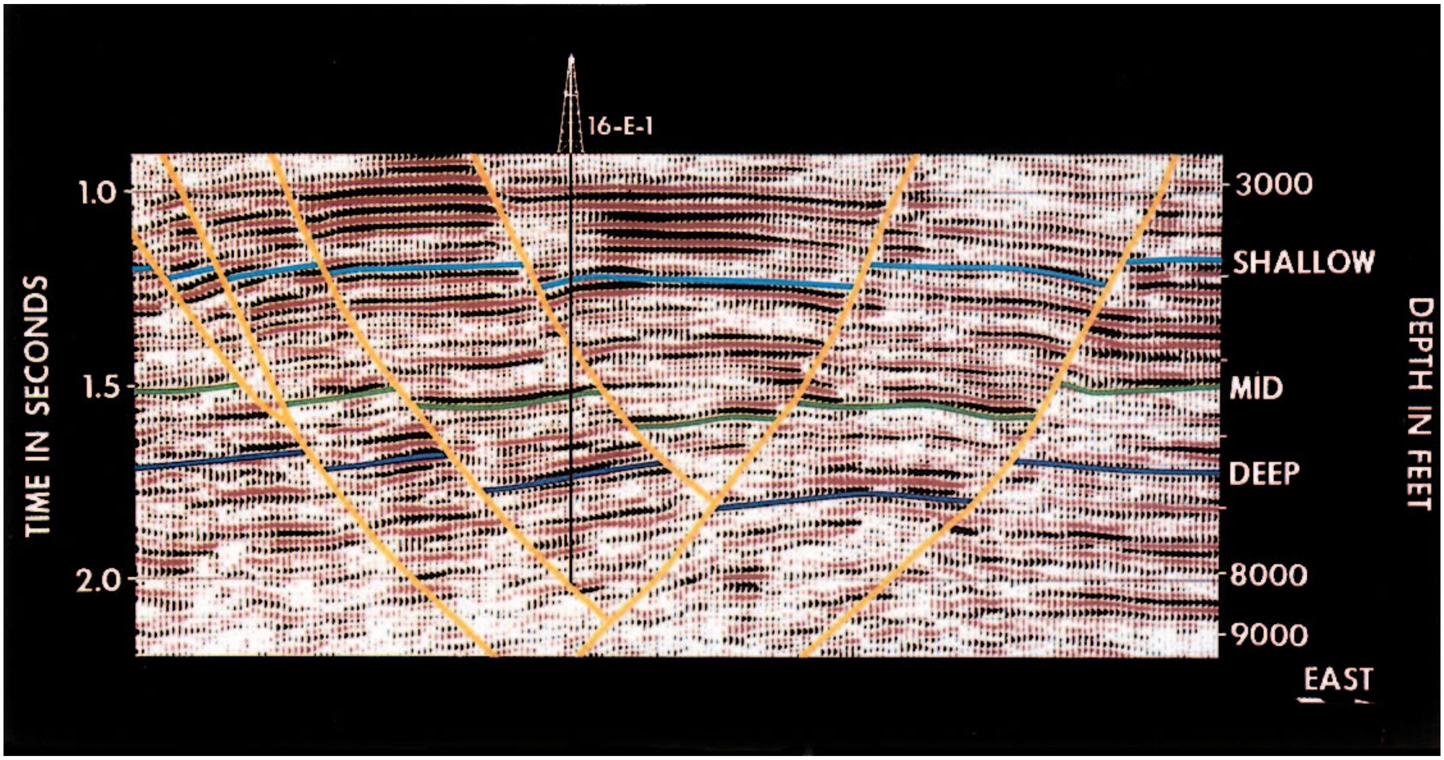


Fig. 4-26. Line 55 interpreted showing structure of Shallow Horizon. (Courtesy Texas Pacific Oil Company Inc.)

author has often used one-quarter. Lateral variations in amplitude caused by surface conditions or acquisition footprint can sometimes be removed successfully by normalization. The amplitude of a shallower horizon is assumed to be constant and then the amplitude ratio of the objective horizon to the shallow reference should remove the effect.

Horizon Slice Examples

Figure 4-38 shows a sequence of faults affecting one horizon interpreted on a vertical section from a 3-D survey in the Gulf of Thailand. Figure 4-39 shows the time structure map resulting from the complete structural interpretation of the same horizon. The faults trending north-northwest to south-southeast divide the area into seven fault blocks. The corresponding horizon slice is shown in Figure 4-40. A meandering stream channel is evident and gas production from the channel has been established in two of the fault blocks.

The continuity of the channel confirms that the depositional surface has been correctly reconstituted. Clearly the value of such a horizon slice for stratigraphic purposes is critically dependent on the accuracy of the structural interpretation that was involved in its derivation. Here the stratigraphic and structural interpretation actually impacted each other iteratively. The first horizon slice generated for this level did not show the channel continuity of Figure 4-40 in one of the fault blocks. This suggested miscorrelation into that block. After re-examining the correlation and retracking the data in that block, the horizon slice shown as Figure 4-40 was obtained. The improved channel continuity indicated the relative correctness of the updated structural interpretation.

Figures 4-41 and 4-42 show the time structure map and horizon slice for one interpreted horizon in a Gulf of Mexico shallow water prospect. Two channels are evident, one of them intersected by a fault. The deeper channel lies between 2100 and 2200 ms which converts to depths around 2500 m (8,200 ft).

Figure 4-43 shows a Gulf of Mexico horizon slice with overlain structural contours. This is a particularly valuable form of display (compare Figure 5-30) because it permits interpretation of stratigraphic/reservoir patterns in their present-day structural

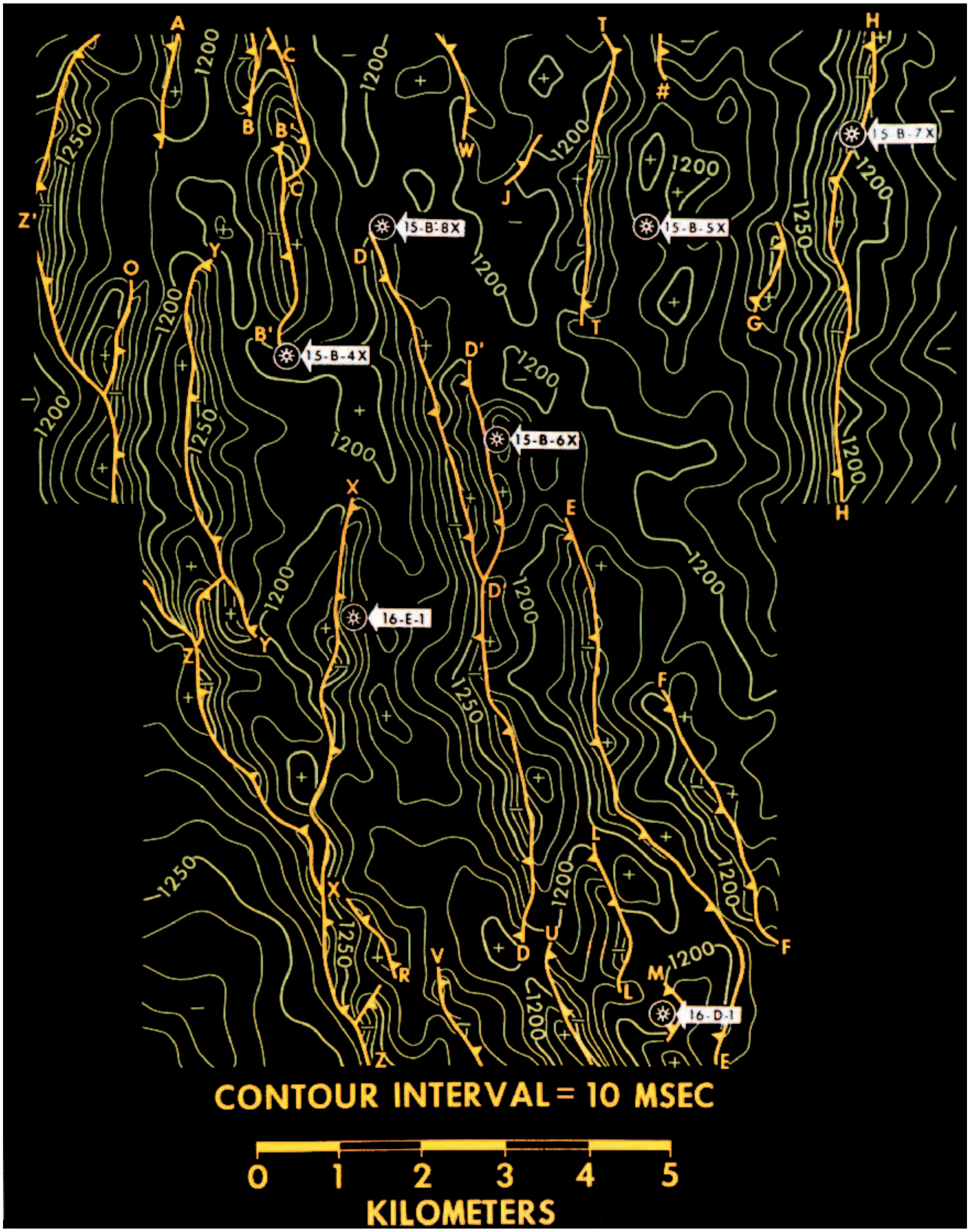


Fig. 4-27. Time structure map of Shallow Horizon. (Courtesy Texas Pacific Oil Company Inc.)

context. Here the high amplitudes (reds and oranges) are caused by gas in several sand bodies. Note the sharp amplitude terminations toward the south (downdip), indicating the position of the gas-water contacts.

Figure 4-44 is an arbitrary line through three wells from a 3-D survey in southern Canada. The structure was defined at the Base Bow Island reflection. A slice parallel to this through the Glauconite zone yielded the horizon slice of Figure 4-45. This approach was used in order to help distinguish stratigraphic variations from structural variations at the objective level. Even then the stratigraphic patterns were not clearly apparent, but a further interpretation tied to well intersections yielded the superimposed stratigraphic descriptions.

Fig. 4-28. Horizon slice 180 feet (60 m) below Shallow Horizon showing northwest- southeast-trending high amplitude interpreted as a sand bar. (Courtesy Texas Pacific Oil Company Inc.)

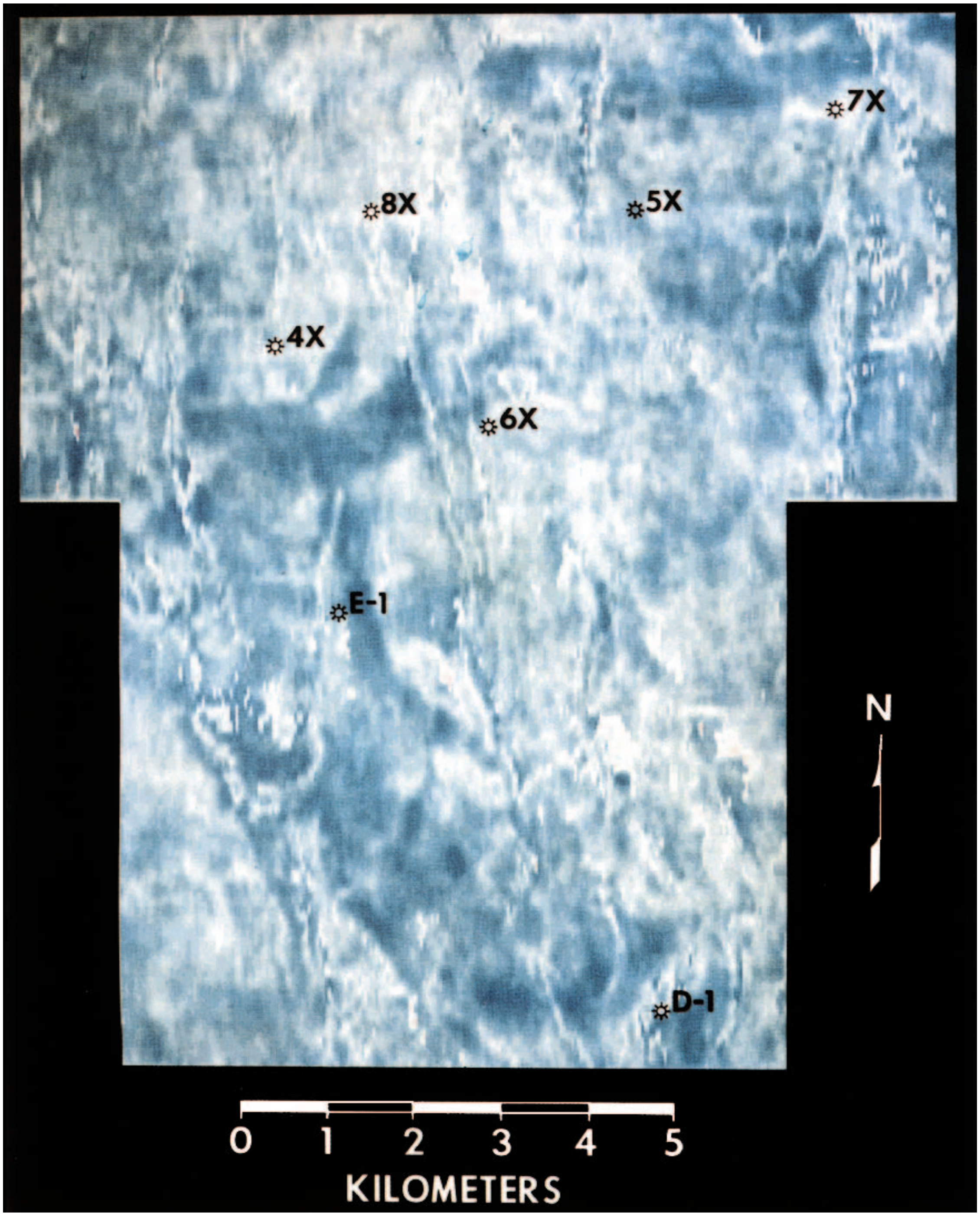


Figure 4-46 is a mosaic of amplitudes from 3-D and 2-D data from Argentina and demonstrates the increased stratigraphic detail available from 3-D data (Gerster, 1995). Three 3-D surveys are shown; seven others exist in the immediate area.

Figure 4-47 is a horizon slice from offshore eastern Canada between 2.4 and 2.8 seconds showing many channels and their levees, an old shore line and an abandoned lake (Enachescu, 1993).

Figure 4-48 is a horizon slice from the Norwegian North Sea. The interesting fan-shaped feature is interpreted as a mass flow in the Danian (basal Tertiary) chalk.

The majority of the horizon slices presented in this chapter display seismic amplitude, and this also reflects the author's usage. However, it is possible to make horizon slices in other attributes. Figure 4-32, for example, displays inversion velocity.

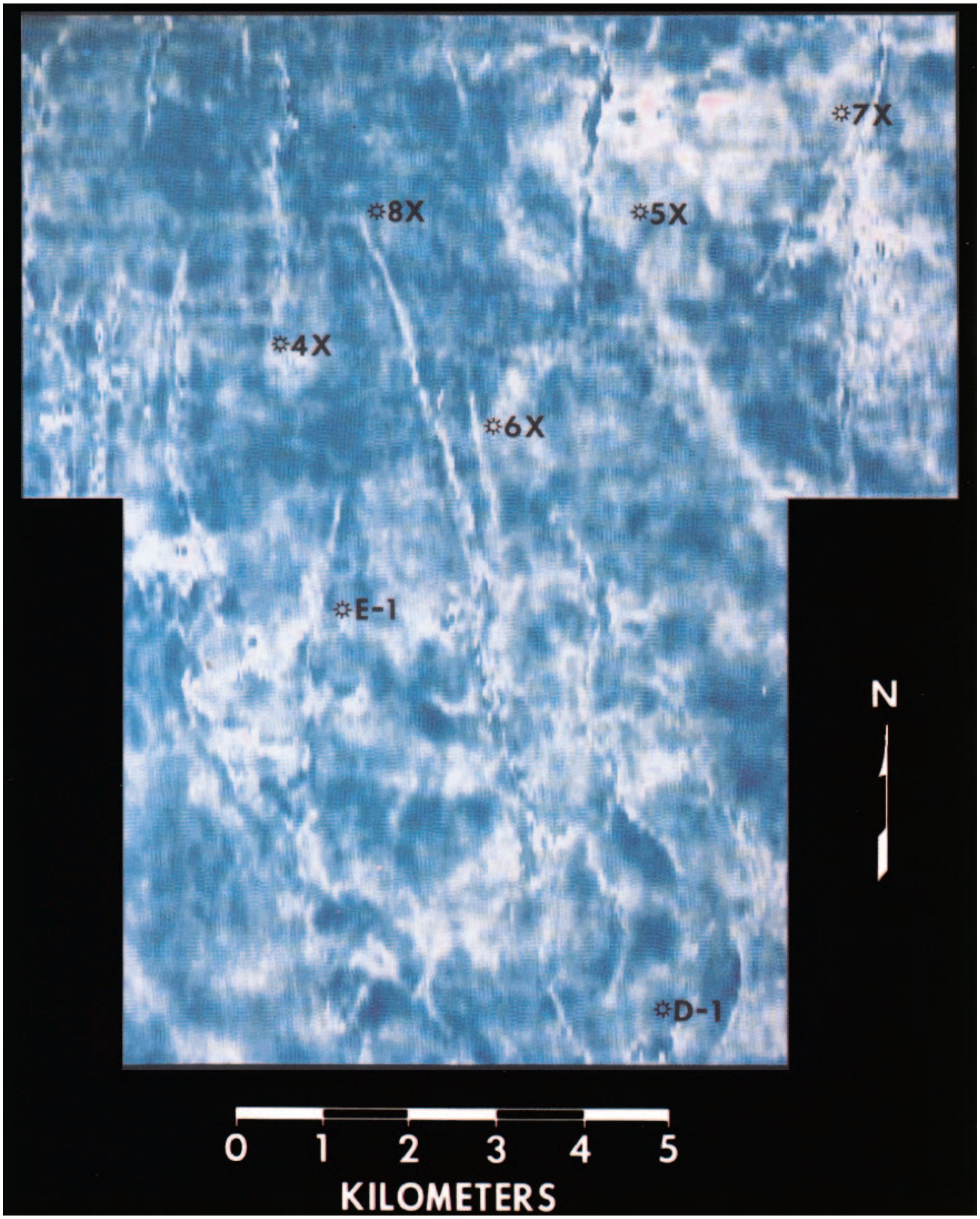


Fig. 4-29. Horizon slice through Shallow Horizon showing a partly eroded sheet sand. (Courtesy Texas Pacific Oil Company Inc.)

Unconformity Horizon Slices

Figure 4-49 shows a horizon slice from another Gulf of Mexico prospect. The amplitudes are in shades of blue and the time structure is superimposed as contour lines with an interval of 100 ms. Several amplitude lineations are apparent. The ones running approximately east-west are faults as evidenced by the displacement of the contours. The major lineation running north-northwest–south-southeast is apparently unrelated to the faulting. It is interpreted as the truncation of a sand dipping up from the east. It is probably a depositional edge but the erosional truncation of a sand at an unconformity would show in exactly the same manner. It is this lineation on the horizon slice which caught the interpreter's eye and thus begged for an explanation.

An excellent example of the variation in reflection character and amplitude across an angular unconformity comes from the Lisburne 3-D survey. The following

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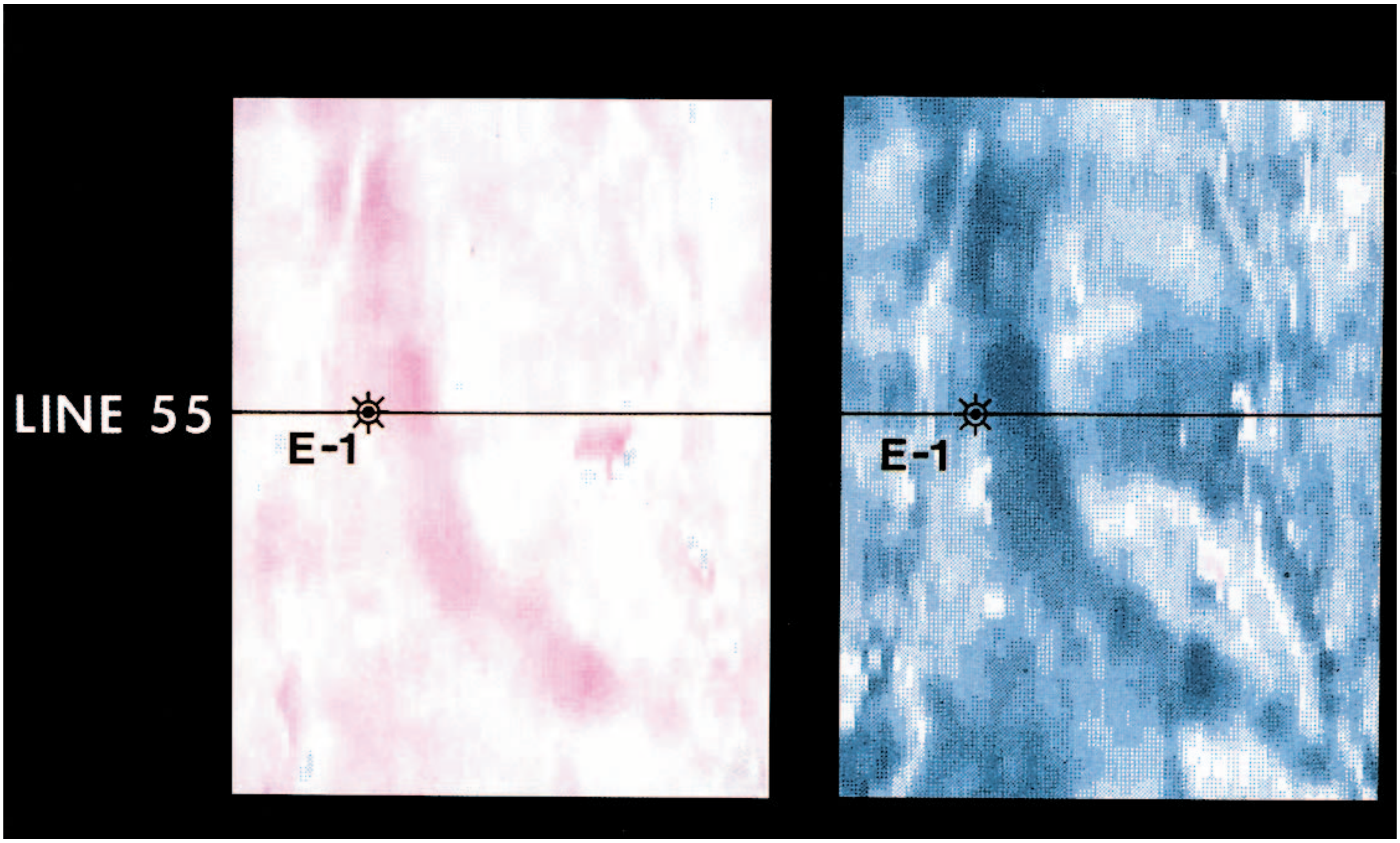


Fig. 4-31. Horizon slices through the two events marked with black arrows on Figure 4-30. The curvilinear features are interpreted as the reflections from the top and base of a channel. (Courtesy Texas Pacific Oil Company Inc.)

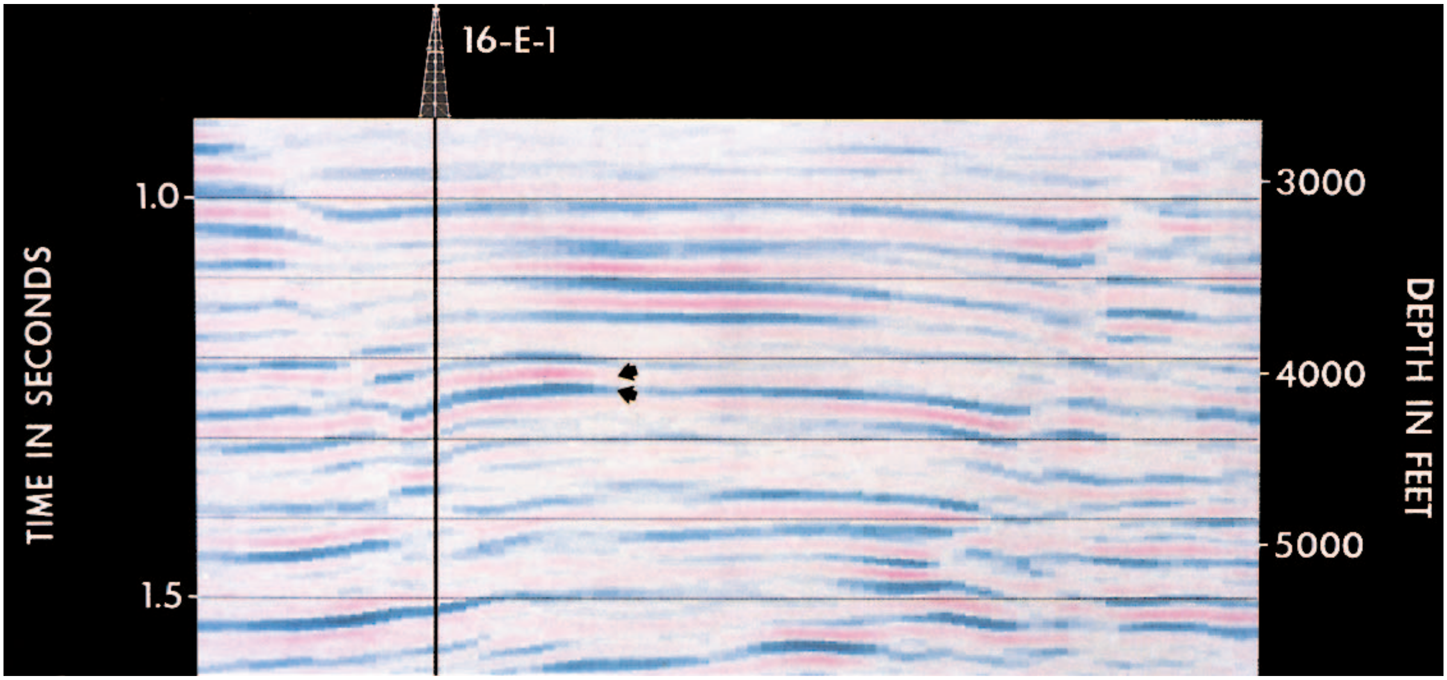


Fig. 4-30. A portion of Line 55 through the central graben of the 3-D prospect. (Courtesy Texas Pacific Oil Company Inc.)

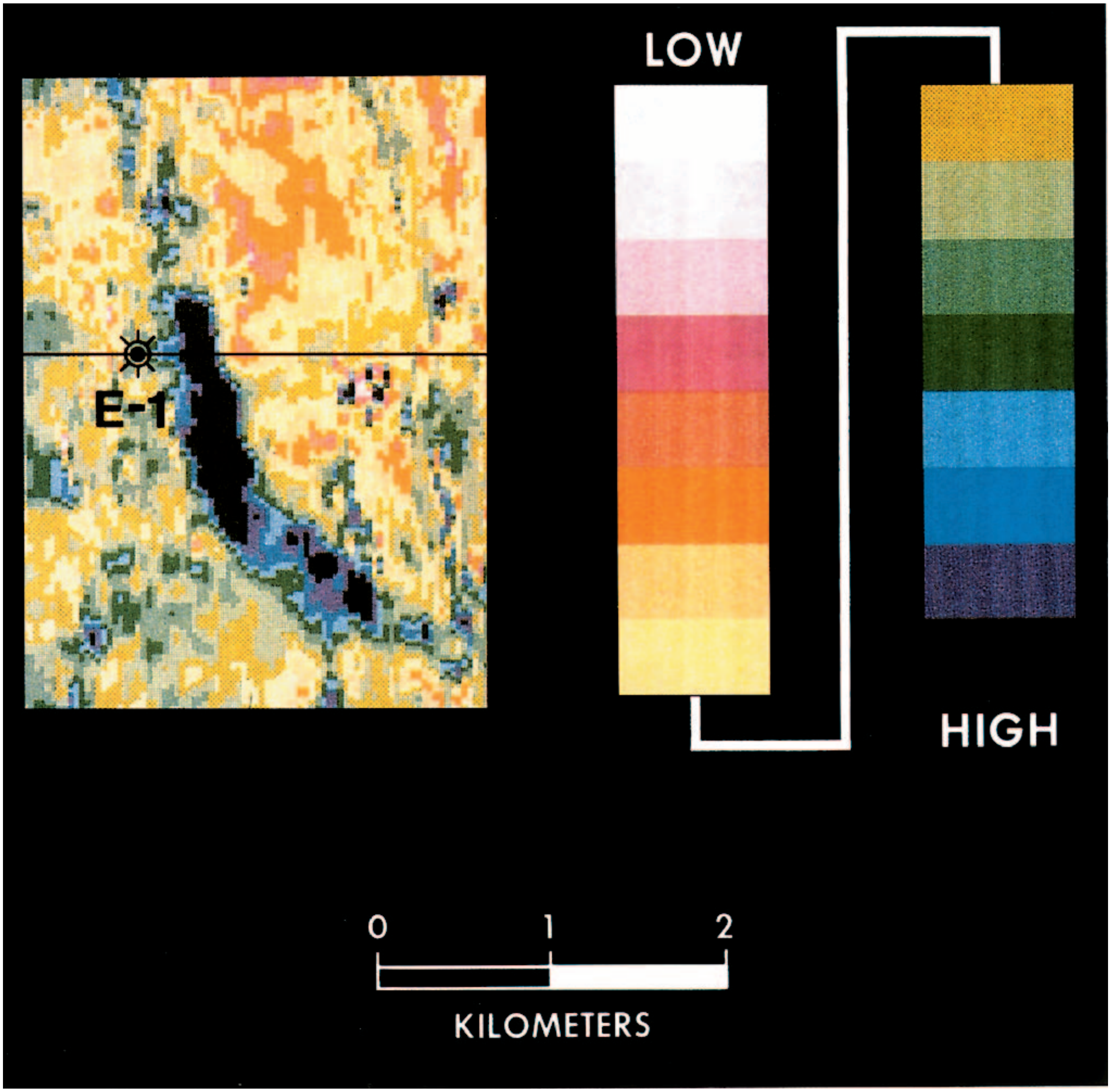


Fig. 4-32. Horizon slice in velocity positioned between the sections of Figure 4-31 and showing the extent of the high velocity channel fill. (Courtesy Texas Pacific Oil Company Inc.)

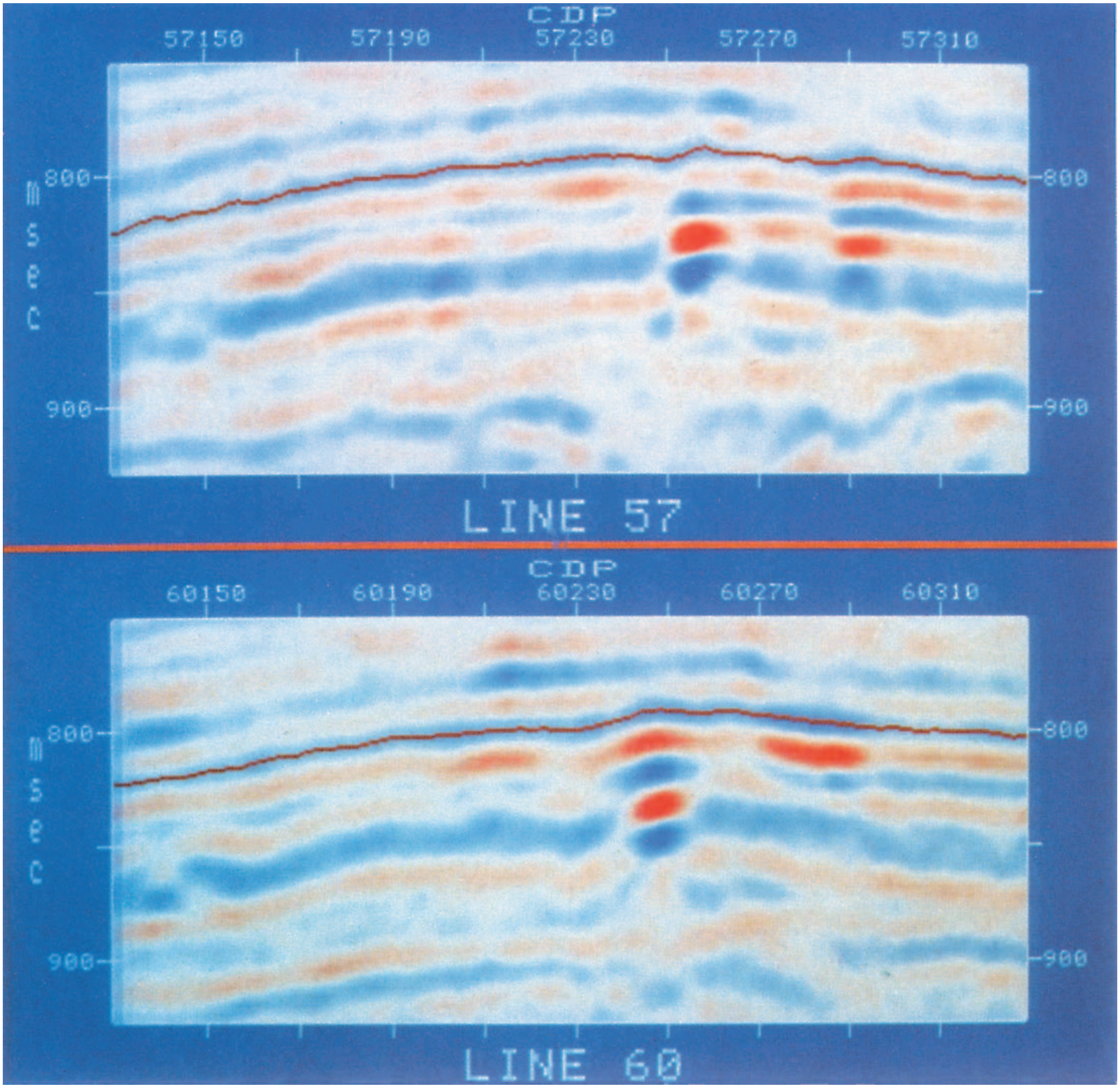


Fig. 4-33. Lines 57 and 60 from a 3-D survey in the Gulf of Mexico showing a tracked horizon above bright events indicating channel intersections. (Courtesy Chevron U.S.A. Inc.)

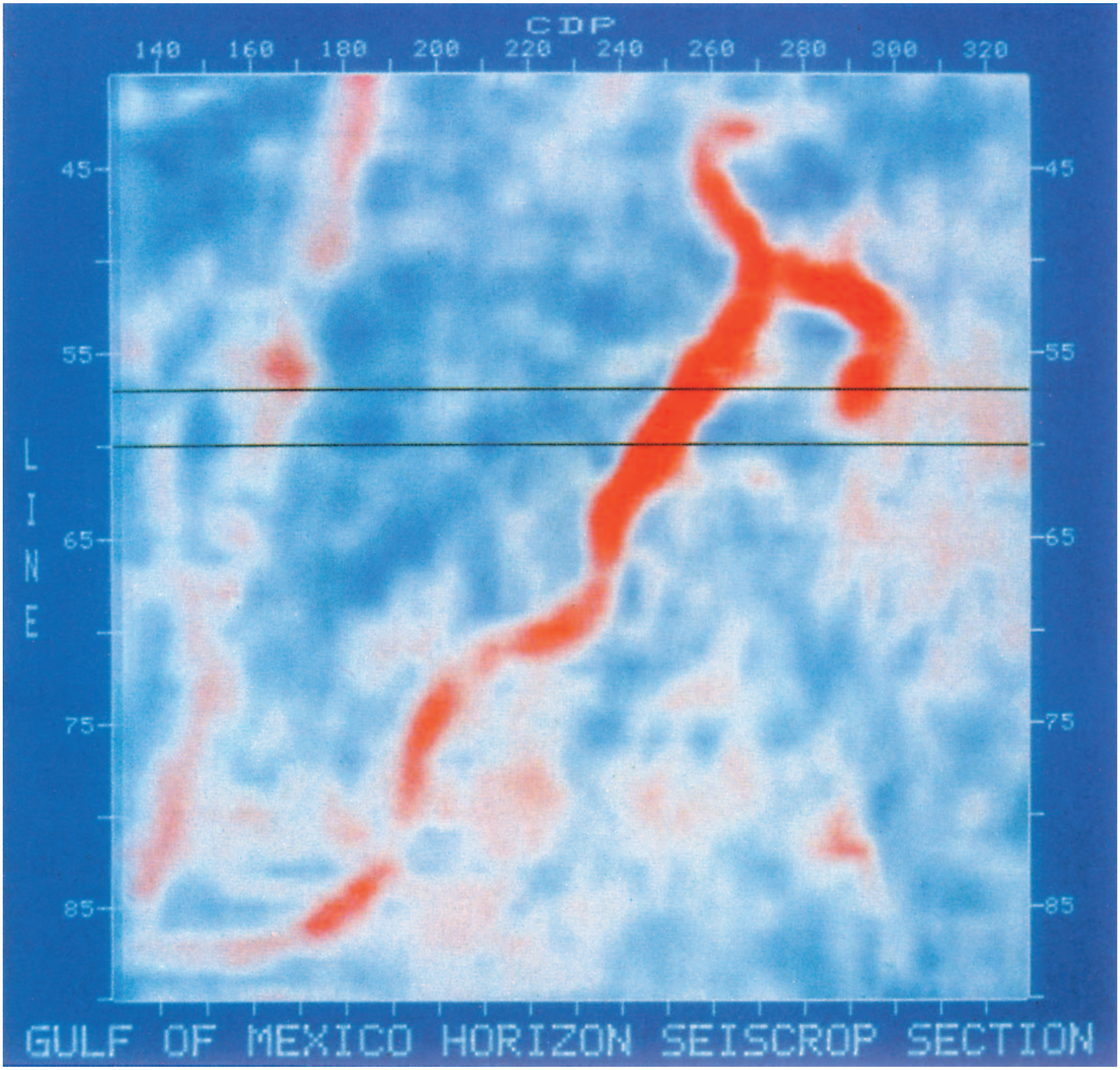


Fig. 4-34. Horizon slice showing channel intersected in Figure 4-33. (Courtesy Chevron U.S.A. Inc.)

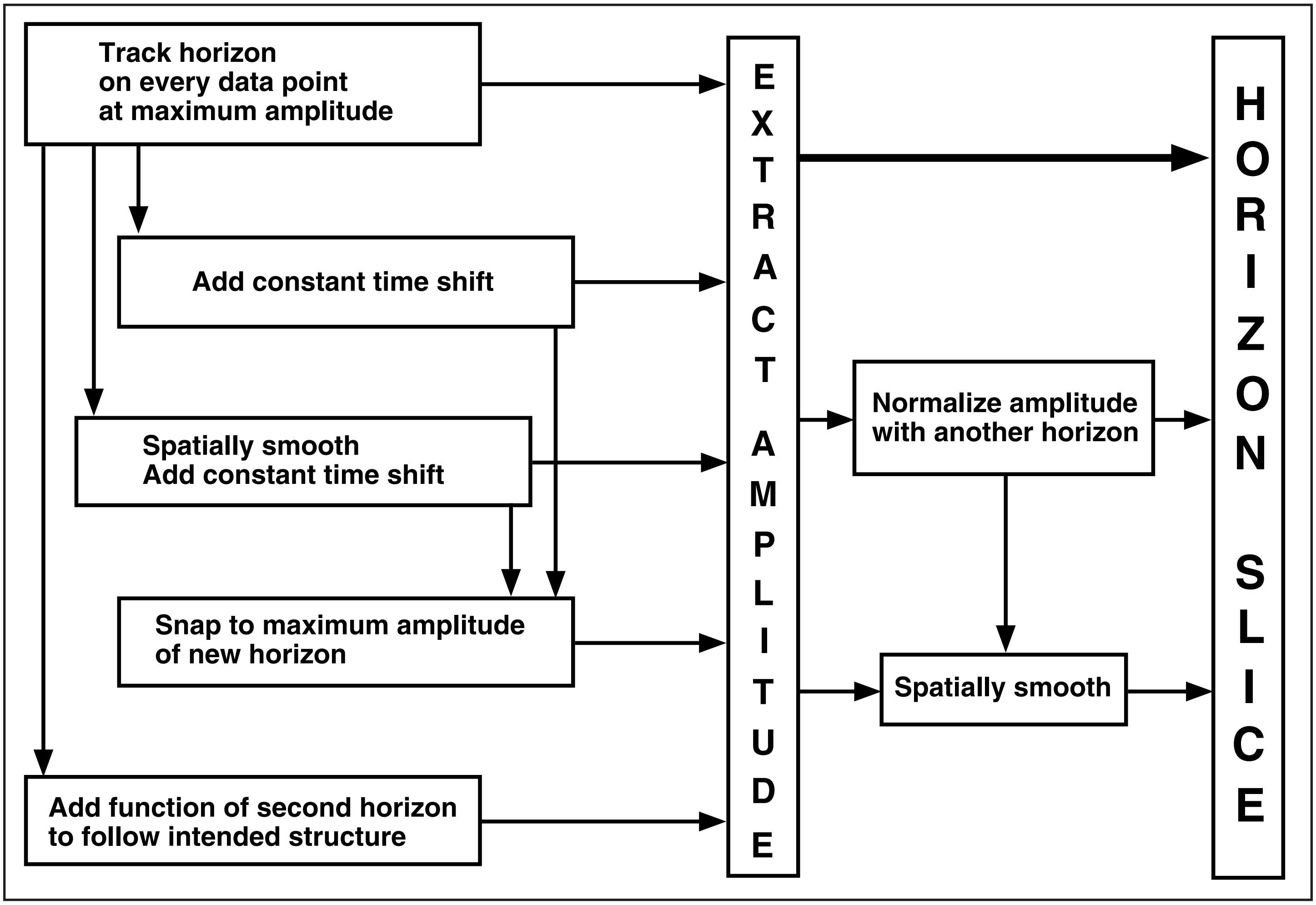


Fig. 4-35. Methods of making horizon slices. The tracking level and the slicing level need not be the same. Amplitude corrections may be necessary to compensate for shallower effects.

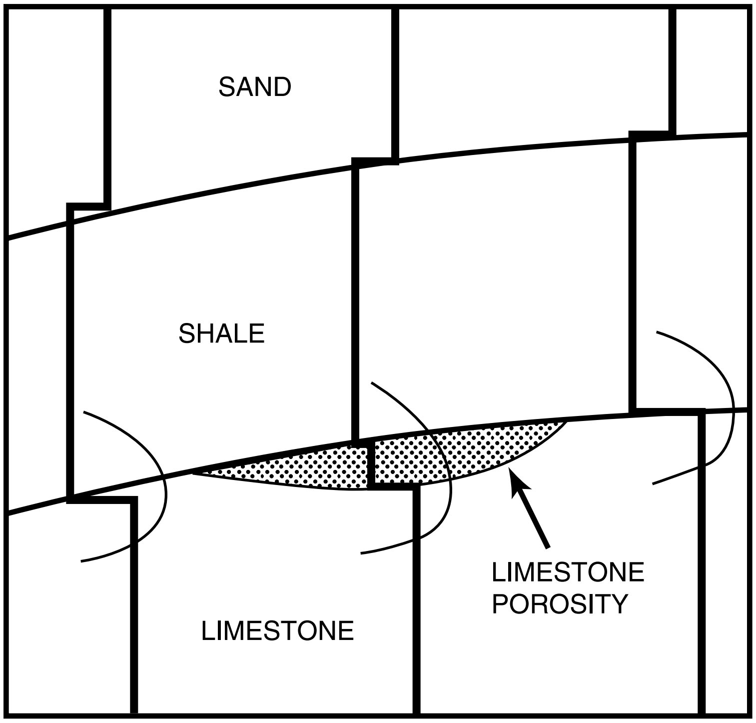
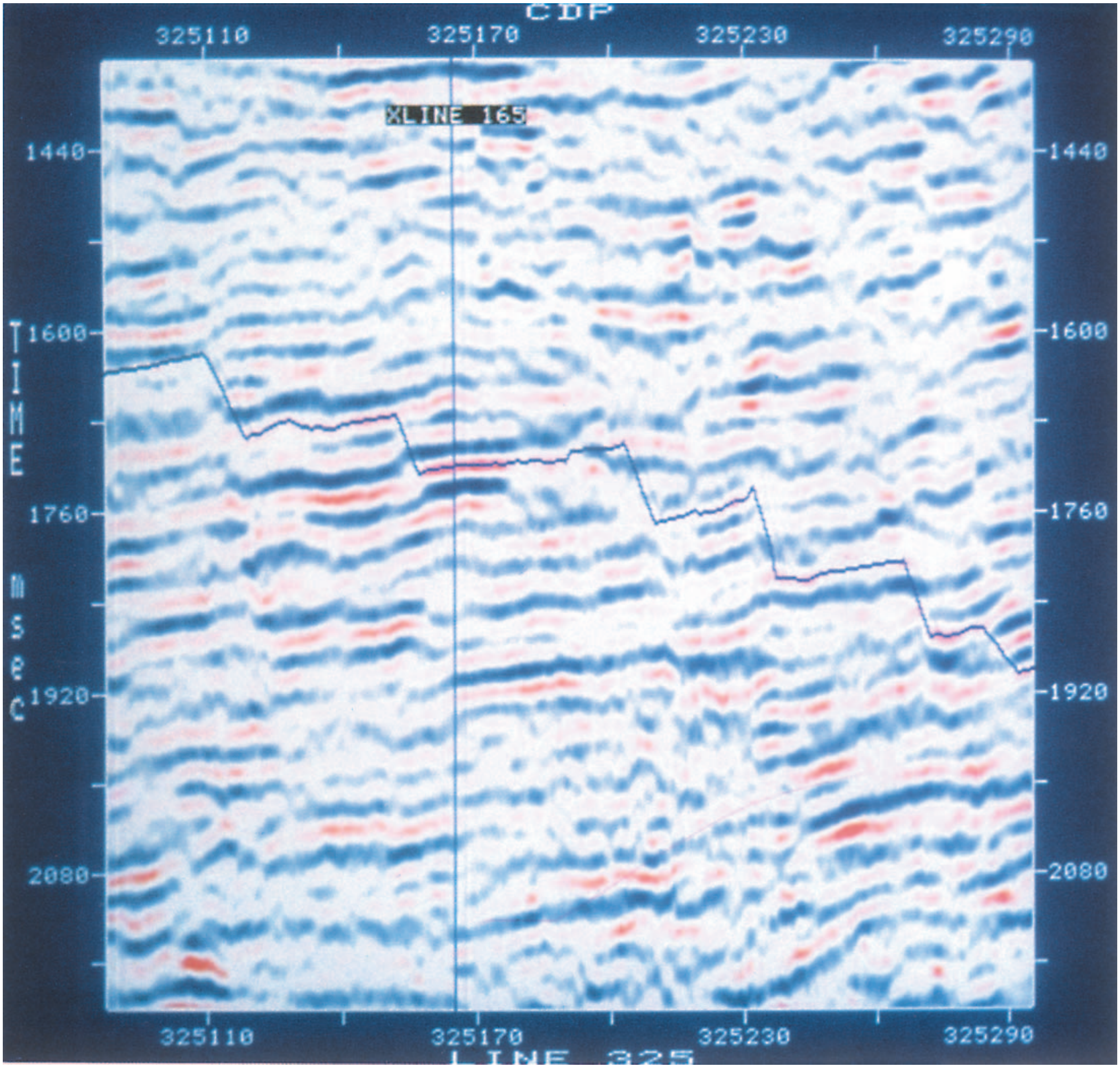


Fig. 4-36. Should a vertically-shifted horizon be snapped to the local amplitude maximum? In this situation the answer is 'no'. The heavy black vertical profiles are acoustic impedance and the exploration objective is the porosity patch at the top of the limestone layer.



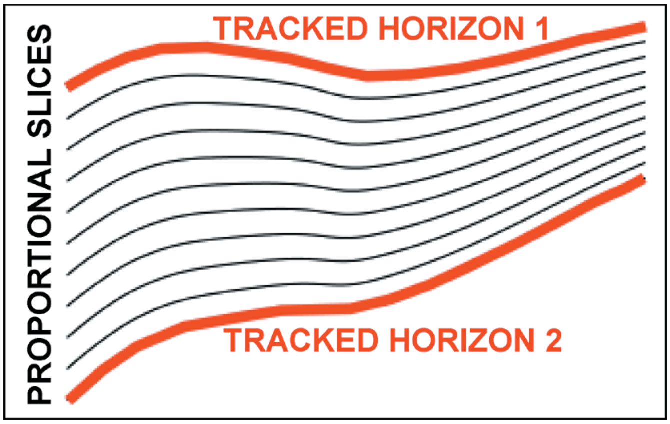


Fig. 4-37. Proportional slices are akin to horizon slices. The interval between two tracked horizons is divided proportionately into multiple increments in an attempt to slice along bedding planes when there is no horizon to follow at the level of interest.

Fig. 4-38. Line 325 from 3-D survey in the Gulf of Thailand showing interpreted horizon through many fault blocks. (Courtesy Unocal Thailand Ltd.)

Fig. 4-39. Time structure map of horizon tracked in Figure 4-38. (Courtesy Unocal Thailand Ltd.)