THE SEISMIC STRATIGRAPHY AND FACIES OF A TRANSITIONAL CONTINENTAL RISE, OFFSHORE IRELAND

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ABSTRACT

The Miocene-Pleistocene sediments in the north-central portion of Porcupine Basin, southwest of Ireland, comprise a thick succession of sediments which record the transition from a basin plain through a continental rise to a present day lower slope environment. Seismically, the sequences show considerable variation, both vertically and laterally. Seismic sequence and facies analysis and interactive flattening and mapping of these sequences shows that the Miocene section was dominated by contourites in the east and distal turbidites, pelagites and overbanks deposits in the center and west. Younger sediments are dominated by axial transport, with submarine fans developing in the basin center. The younger sediments, now part of the lower slope, are in a transitional realm with aggradational features as channel-levee complexes alternating with erosional features as submarine canyons. Subsequent dewatering and gravity sliding has affected these sediments locally. If sand prone sediments are present in ancient analogs of the environments, many complex stratigraphic plays are present.

INTRODUCTION

The Porcupine Seabight, approximately 320 km long and 130 km wide, is a large reentrant in the continental shelf southwest of Ireland (Fig. 1). Porcupine Basin, which underlies it, was caused by rifting in the early Cretaceous (Masson and Miles, 1986). Its maximum fill approaches 7-8 km and the lateral extent is well defined by a gravity low east of the Porcupine Bank and north of the Goban Spur (Fig. 2). Several recent abstracts and articles have dealt with various aspects of its stratigraphy (Macurda, 1986; Crocker and Shannon, 1987; MacDonald, et. al., 1987; Naylor and Anstey, 1987; and Macurda and Nelson, 1987, 1988); part of this has been stimulated by exploration efforts by several oil companies. In 1981 Merlin Geophysical shot a speculative geophysical survey, part of which covered the full width of the basin at approximately 51° 30' N. Tapes for portions of ten of the lines were available to us. These were loaded onto a Landmark Interpreter Plus workstation and their location is shown in Figure 3. Water depths within this region range from 250 to 2,000 m (300 to 2400ms, Fig. 4). Bathymetrically, this is in the lower part of the continental slope and the upper part of the continental rise. The continental slope and rise are the complex zone of transition between the continental shelves and the ocean basin. These areas are still poorly understood on most continental margins as to the relative contributions of the three major vectors of transportation; mass debris flows and turbidity currents (the latter may be confined by channels or unconfined laterally), contour currents, and pelagic sedimentation. We have undertaken a seismic stratigraphic investigation of these environments in Porcupine Basin in an area which has been in the deep water realm since the Eocene. We have concentrated on the Miocene-Recent portion of the section in an effort to determine the relative contribution from each of these vectors of transportation and how their role varied with time.

PROCEDURES

The data which was utilized in this study was shot in April, 1981 with a 2950m cable and four 910 cu. in. air guns. A wide frequency range was recorded; data were sampled at 4 ms. The data were processed at 30 fold. It has been deconvolved both before and after stack; the data are probably minimum phase. The data has been migrated and a time-variant filter applied. A dip rejection filter was also applied. A short operator was used during the automatic gain control.

Macurda (1986) divided the Cretaceous and Tertiary fill into a series of megaunits or megasequences; i.e. a series of episodically-formed sequences, which, while separated by regional unconformities, are similar in the mode of formation and environmental setting. In all, there are 10 or 11 Cretaceous and Tertiary megaunits in this part of the basin; there are a total of approximately 55-60 seismic sequences. We have concentrated on the two uppermost megaunits (1 and 2); these were divided into six and three sequences respectively, by picking the termination of reflectors on paper record sections and tieing the sequence boundaries throughout the grid of data (six east-west and seven north-south lines), forming a swath approximately 33 km wide (N-S) and 65-70 km long (E-W). The sequence boundaries were transferred to the workstation. We have used the external geometry of the sequences, their external seismic facies characteristics, thickness, and directions of progradation to determine their environments. For each sequence, we have flattened on the top of the previous sequence (using Line 43) in order to determine the geometry of the succeeding sequence at the time it was deposited. We have also contoured the thickness (two-way travel time) in areas of mutual line crossing. The average velocity for the section we analyzed is probably about 2250 m/sec.

ENVIRONMENTS OF MEGAUNIT 2

Figure 5, an east-west line, and Figure 6, a north-south line, show the overall configuration of the reflectors from the seafloor downward. Megaunit 1 is characterized by the generally lower amplitude, and more continuous reflectors, which occupy the 800 ms as seen in basin center from the seafloor downward (approximately 900 m). Megaunit 2 has a very strong pattern of oblique prograding reflectors in the eastern part of the basin. Interval thickness is approximately 400 ms (450 m) in the east; the unit thins to the west (Fig. 7). We believe deposition of Megaunit 2 was due to contour currents in the eastern part of the basin. Since the critical north-south lines in the east were not part of the data on the workstation, we have excluded this part from our analysis and focused on the central and western portions of the basin. Megaunit 2 was divided into 3 sequences; 2, 2A, and 2B respectively. Each will be described in ascending order.

Sequence 2B

Megaunit 3 is interpreted as being a period of basin fill with relatively parallel internal reflectors. The middle of the interval contains an upper Oligocene unconformity traced in from a DSDP well on the southern margin of the basin. The boundary between Megaunit 3 and Sequence 2B was determined in the eastern part of the basin by recognizing the initiation of contourite deposition (Megaunit 2). Its external geometry is that of a sheet (Fig. 8); internally, its seismic facies are parallel or hummocky in the east-central portion of the basin, becoming more parallel to the west. When its thickness (approximately 150 ms; 170 m; all thicknesses are approximations) is contoured, no distinct trend is visible (Fig. 9). We interpret the topographic gradient to be very low; the environment was probably transitional to the basin plain and distal to the initial contourites to the east. Some limited sliding may have occurred to produce the hummocky reflectors in the east; pelagic sedimentation or sheet flow deposition of distal turbidites produced most of the deposits in the central and western portions of the basin.

Sequence 2A

This sequence comprises the lateral equivalent of many of the oblique, steeply dipping reflectors seen in the eastern portion of the basin on the regional east-west line (Fig. 5). Although relatively thin (100-150 ms; 115-170 m), it probably could be further subdivided into a series of sequences because many unconformities are present in the much thicker portion to the east. As with Sequence 2B, it is basically a sheet. Its seismic reflection character varies between parallel and hummocky-discontinuous in the central and western portion of the basin; the latter is more common in the east-central portion. There are subtle suggestions of a few channel-levee and channel complexes. Flattening on the sequence beneath (Fig. 10) and contouring (Fig. 11) reveals subtle thickening and thinning. We interpret the sequence to be a product of deposition by small scale channels and mass gravity transport in the east-central portion changing to sheet flow and pelagic sedimentation in the west. Topographic gradients were again low; we interpret it as being part of the continental rise.

Sequence 2

Sequence 2 is one of the more remarkable sequences in the upper portion of the sedimentary fill of the basin. It is basically a sheet (Fig. 12). It is not present in the eastern-most portion of the levee. In the east-central portion it forms a levee marginal to a large channel associated with the contourite drifts. Here it is slightly thicker and hummocky; westward it thins to 100 ms (100 m) and its seismic facies change to parallel, continuous reflectors which extend across the central and west-central portion of the data. In the west the sequence thickens slightly, particularly in the northwest (Fig. 13). There is local evidence of mounding and erosional truncation within the sequence, suggesting local unconformity surfaces. We interpret it as representing levee and overbank deposits; the continuity of the reflectors is quite evident, suggesting sheet flow as the predominant mechanism of sedimentation.

MEGAUNIT 1

The overall seismic reflection character of this Megaunit, the youngest in the basin, is quite different than that of Megaunit 2. The amplitude is lower (except in the central portion of the basin as shown in Fig. 14), the seismic faults are more variable, there is much more evidence of erosional truncation at sequence boundaries, and deposition seems to reflect transportation down the basin axis more than parallel to the contours (Fig. 15). Another very consistent character is a sense of concave faults in the east-central portion (Fig. 5). These are offset by about half a wavelength and many converge to common foci at the top of Megaunit 2. They are interpreted as being caused by dewatering. The absence of these in Megaunit 2 suggests a change in the lithofacies between Megaunits 1 and 2 and a time gap of greater duration than between sequences within the Megaunits. We have divided it into six sequences, 1, 1A, 1B, 1C, 1D, and 1E; the last is the oldest. One or two sequences (e.g. 1D) could probably have been divided into two sequences locally, but resolution is lost as the unconformities are traced laterally.

Sequence 1E

Flattening on the top of Megaunit 2 reveals that Sequence 1E is variable in its thickness (Fig. 16), as does the isochron map (Fig. 17 - 75-200 ms; 85-225 m; contours are locally distorted by the lack of north-south lines in the east). It is one of the most limited of the sequences, being present only from the east-central portion of the basin westward. In this regard it mimics Sequence 2, with onlap fill deposits at both the eastern and the western limits. (Fig. 18 shows a cross-section in the west and Fig. 19 shows the interpreted onlap fill environments posted in perspective on the top of Megaunit 3.) However, it shows mounding in the east-central part of the basin, becoming more sheet-like and thinning to the west. Its seismic facies are more subparallel, lower amplitude and higher frequency than Sequence 2. Locally there are hummocky facies. There is a suggestion of local erosion on its upper surface in the west-central portion of the basin. We interpreted the east-central portion of this sequence as being the distal portion of the lobe of a submarine fan, changing to outer fan or rise deposits to the west. The mechanisms of sedimentation probably included sheet flow (unconfined turbidites) and pelagic sedimentation. The variance in thickness implies localized source areas to the north.

In the far west, there is a listric fault which appears to sole out at the top of Megaunit 2. The far western part of Sequence 1E has been affected by downslope displacement along this listric fault.

Sequence 1D

Sequence 1D is one of the most variable of the sequences examined. This is evident when Sequence 1E is flattened (Fig. 20), and Sequence 1D is contoured (Fig. 21 - 100-250 ms; 115-280 m).

It has a large mound in the center of the basin; it thins eastward only to thicken again eastward before onlapping out against part of the contourite drift of Megaunit 2. Locally it infills the remnant channel on top of Megaunit 2. Internally its reflectors are fairly parallel and discontinuous in the east; in the center of the basin they are much less continuous, variable, and of higher amplitude in the mound. Locally, there is erosional truncation of the sequence in the east-central portion at its top and within it in the west-central portion. There is local evidence of channels. We interpret the mound in the center of the basin as the medial portion of a submarine fan with a large degree of local variability; the reflectors to the east represent deposition by sheet flow processes on an outer fan or continental rise environment. Sediment supply appears to have been principally from the north.

Sequence 1C

Sequence 1C is another complex sequence like 1D beneath it. It is variable in thickness, 100-300 ms (110-330 m), with a strong mounded profile in the cross section (Fig. 22) and there are local thicks and thins (Fig. 23). The seismic facies in the west-central portion are highly variable with channel-levee complexes and subparallel reflectors. They are discontinuous with variable amplitude to the west while to the east they become more parallel, onlapping farther up onto the contourite drift of Megaunit 2. There is a strong erosional submarine canyon present in the eastern portion of the sequence, producing a local unconformity surface. Rotational slumping can be observed along the canyon walls. We interpret the sequence to represent the proximal portion of a submarine fan in the west-central part of the data while outer fan to continental rise environments are present to the east. Local slumping has transported some of the sediments to a more basinward position. Deposition was affected by both channelized and unchannelized turbidity currents.

Sequence 1B

Sequence 1B is one of the thinnest units we attempted to discriminate. It is a sheet, as shown in cross-section (Fig. 24) and by its thickness (Fig. 25); it is usually 75 ms (85 m) thick, except where it infills residual lows on the top of Sequence 1C, where it increases to 170 m. The internal reflector character of this sequence is parallel. It is interpreted to be a low energy deposit resulting from distal turbidites or pelagic sediment. It infills erosional lows and submarine channels on top of Sequence 1C. The environment is in strong contrast to the proximal fan environment of Sequence 1C.

Sequence 1A

Sequence 1A is almost identical to Sequence 1B. It is a thin sheet (Fig. 26), varying from 75-120 ms (85-135 m; Fig. 27). It continues almost to the eastern margin of the basin in the northeast but ends against the wall of a submarine canyon in the southeast. Its internal reflection character is parallel and it has low seismic amplitude; there are suggestions of one or two small mounds and a channel. It represents another episode of low energy sedimentation by distal turbidites or pelagites.

Sequence 1

Sequence 1 represents the most recent episode of sedimentation in the basin's history. It extends downward from the seafloor for approximately 180 ms (200 m). Its geometry is that of a sheet (Fig. 28) and it has little variation in thickness (Fig. 29) except where incised by a large submarine canyon in the east and a smaller one in the center; it thickens as part of a channel levee complex in the west. Internally its seismic facies are high amplitude, subparallel in the west, changing to low amplitude, less continuous in the center of the basin and hummocky towards the east. We interpret the overall environment to be that of a lower slope on which base level has fluctuated, leading to an aggradational channel in the west and erosional canyons in the center and east. The parallel reflectors in the center and west are thought to be due to distal turbidites and overbanks deposit; local mass gravity transport is thought to have caused the hummocky reflectors in the east-central portion.

CONCLUSIONS

Detailed examination of the seismic stratigraphy and facies of the Miocene and younger sediments in Porcupine Basin at 51° 30' N, in present water depths of 500-1500 m, has determined that a variety of sedimentary processes have formed the continental rise and lower slope in this region. Many of the sequences are quite thin, recording frequent changes of base level. The lower portion of Megaunit 2 records the transition from basin plain to the continental rise where deposition by contour currents was dominant in the east and distal turbidites, pelagites, and overbank deposits were predominant in the central and western part of the basin. At the beginning of Megaunit 1, deposition was localized in the central and western part of the area; the contourite drift itself was not overstepped until the middle of Megaunit 1. Transportation was axially oriented; the outer portion of submarine fans built into the area, culminating in the proximal part of a fan in the west-center. This was followed by more quiescent conditions, where pelagites and distal turbidites predominate. The present environment in the lower slope is a transitional realm where aggradational features alternate with erosional submarine canyons. Thus, the slope and rise are a product of many processes which varied in time and space. Detailed seismic stratigraphic and facies analysis of other similar environments will help to understand the genesis of the sediments and what potential hydrocarbon plays may exist.

ACKNOWLEDGEMENTS

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FIGURES

FIGURES

Figure 1 - Location map, showing position of Porcupine Basin

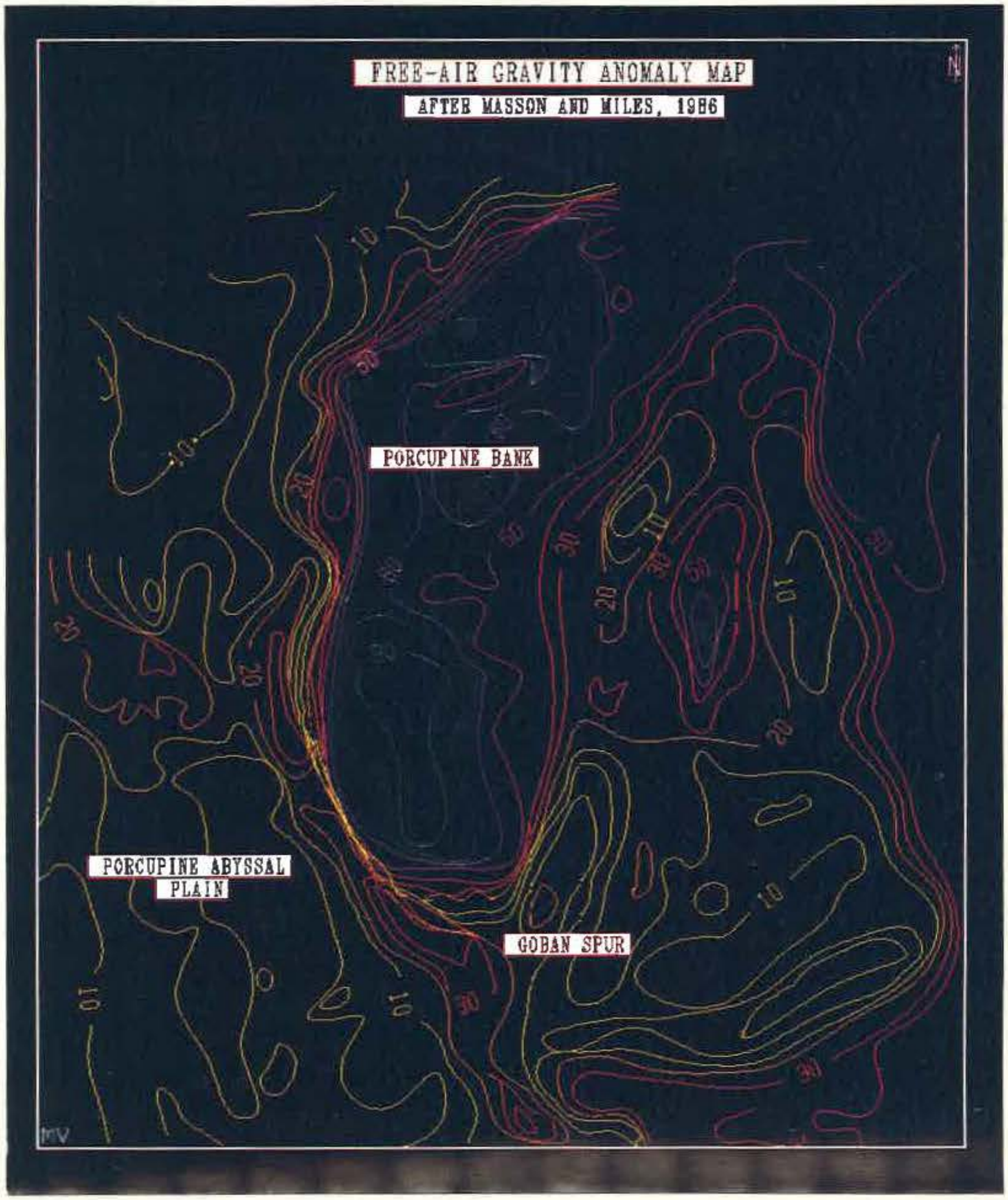

Figure 2 - Gravity Map (after Masson and Miles)

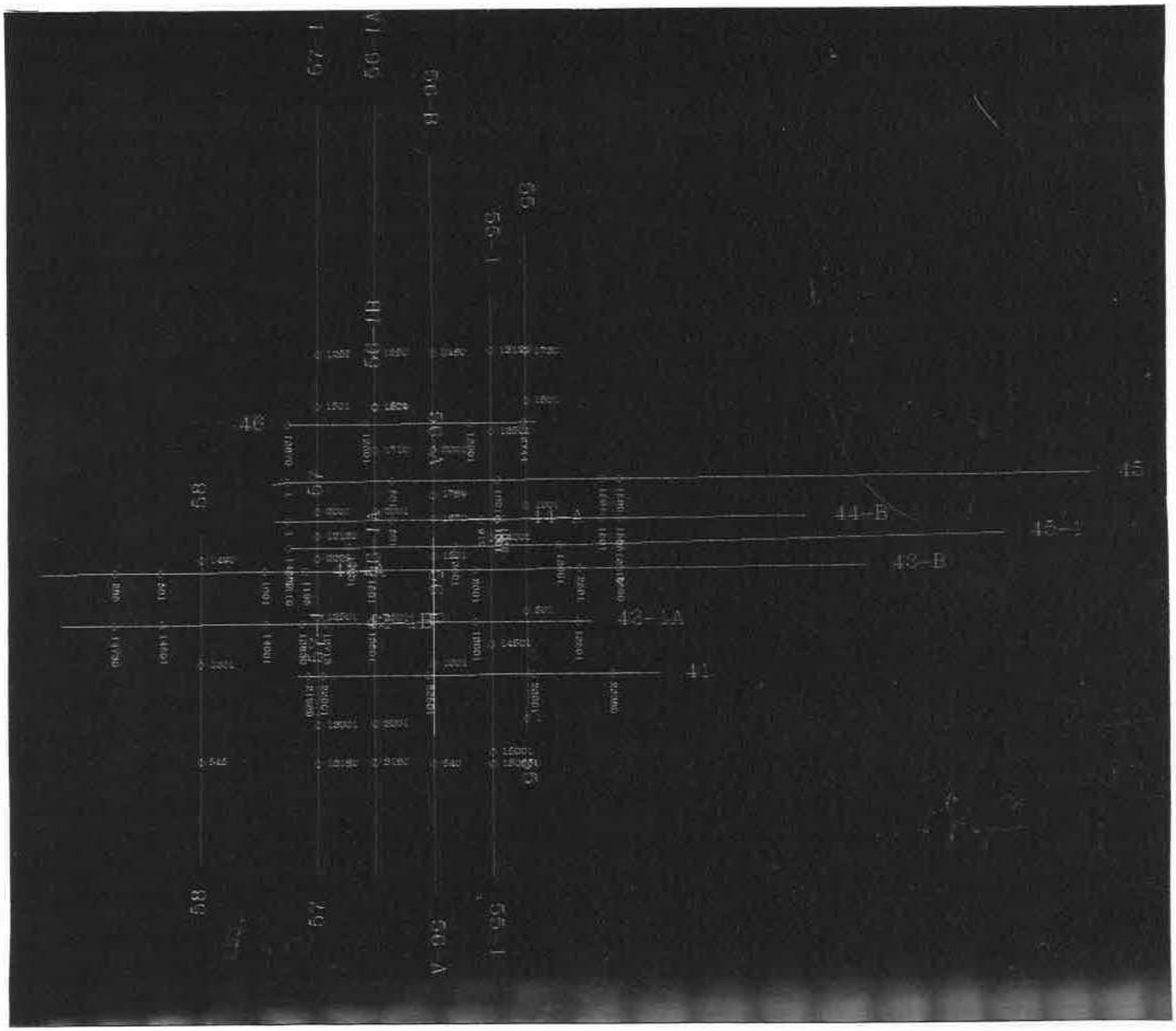

Figure 3 - Base map showing line locations and numbers

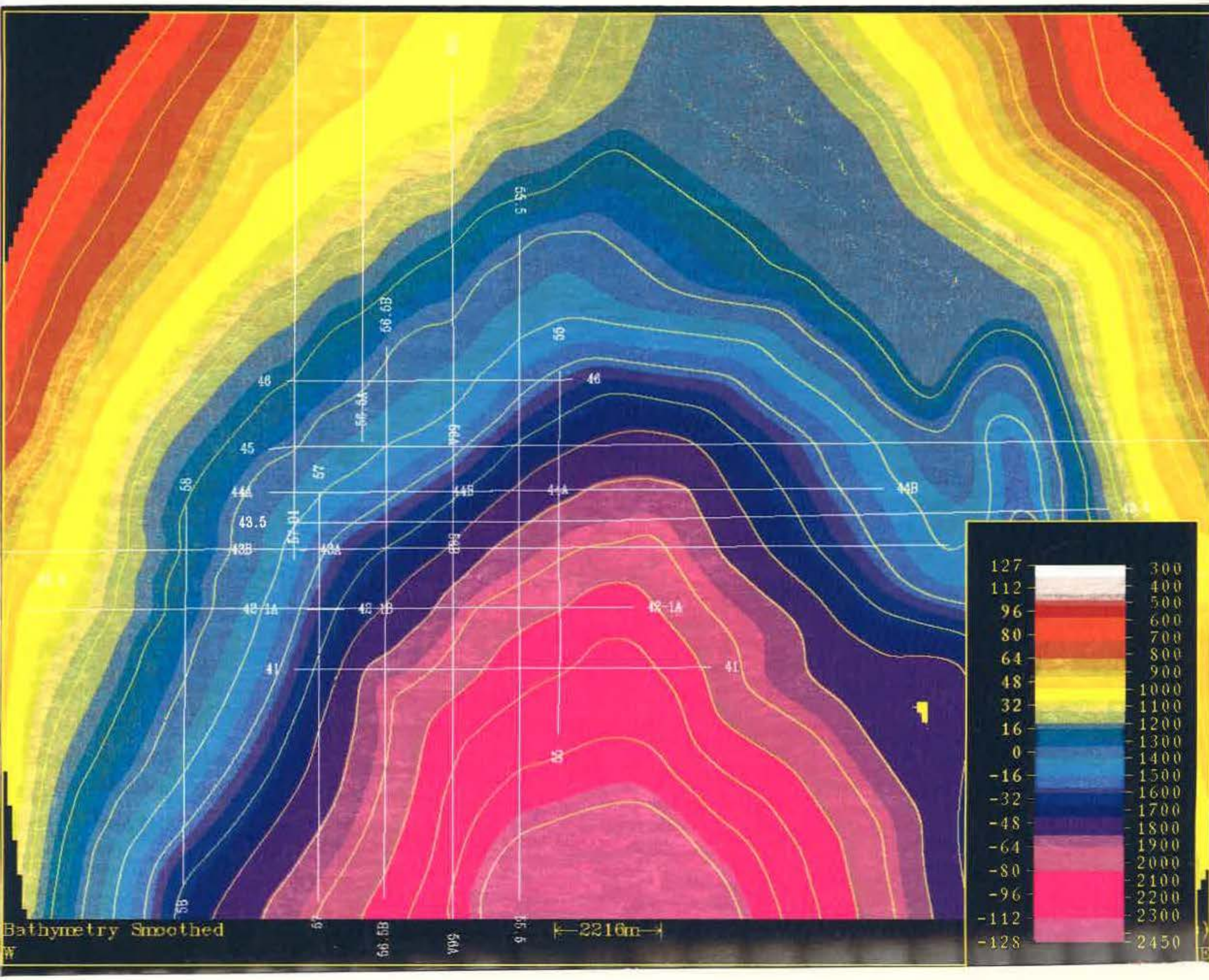

Figure 4 - Bathymetry map with line locations overlaid

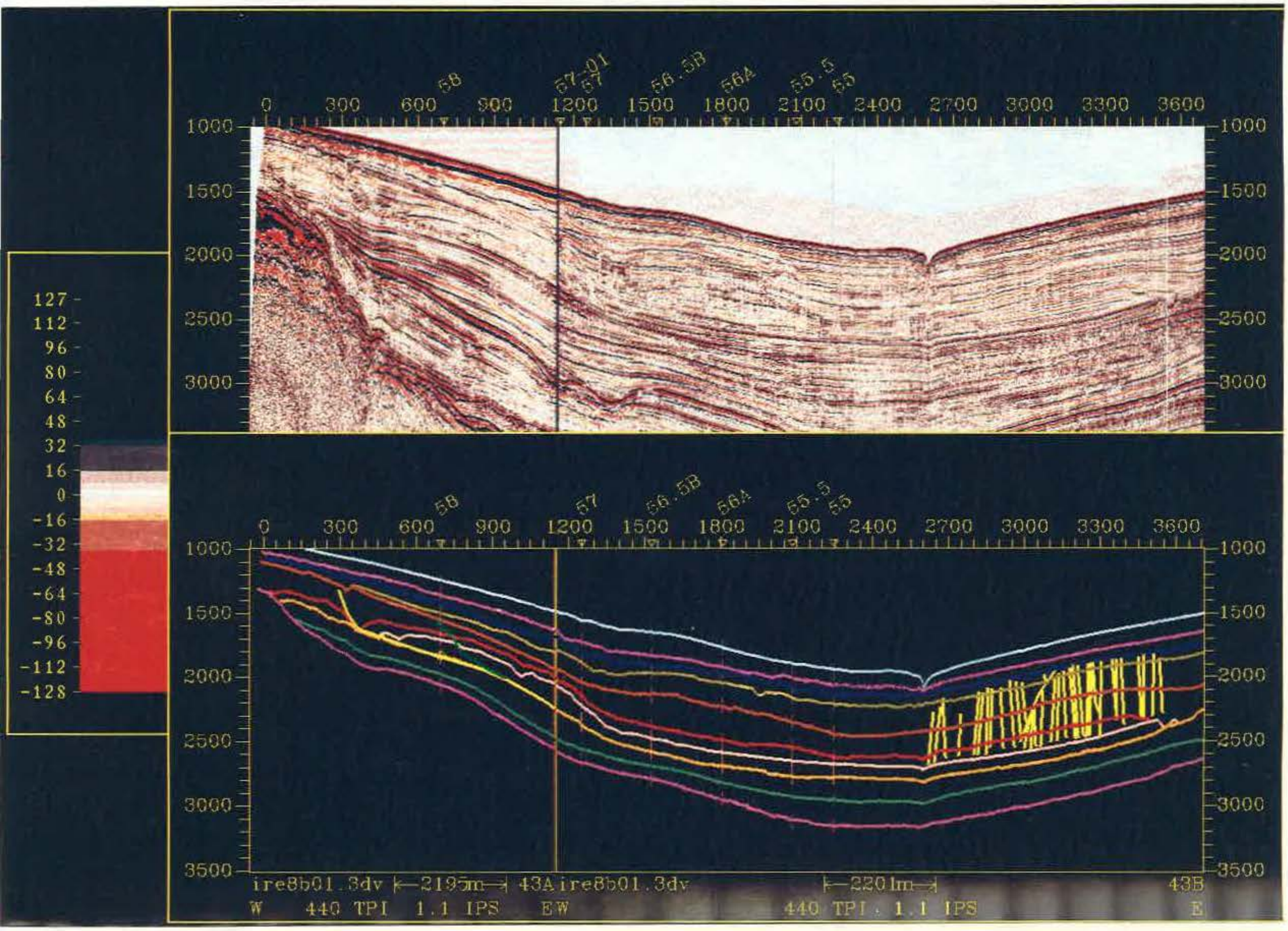

Figure 5 - Regional east-west lines 43A and 43B, showing stratigraphic and structural confirmation of Porcupine Basin

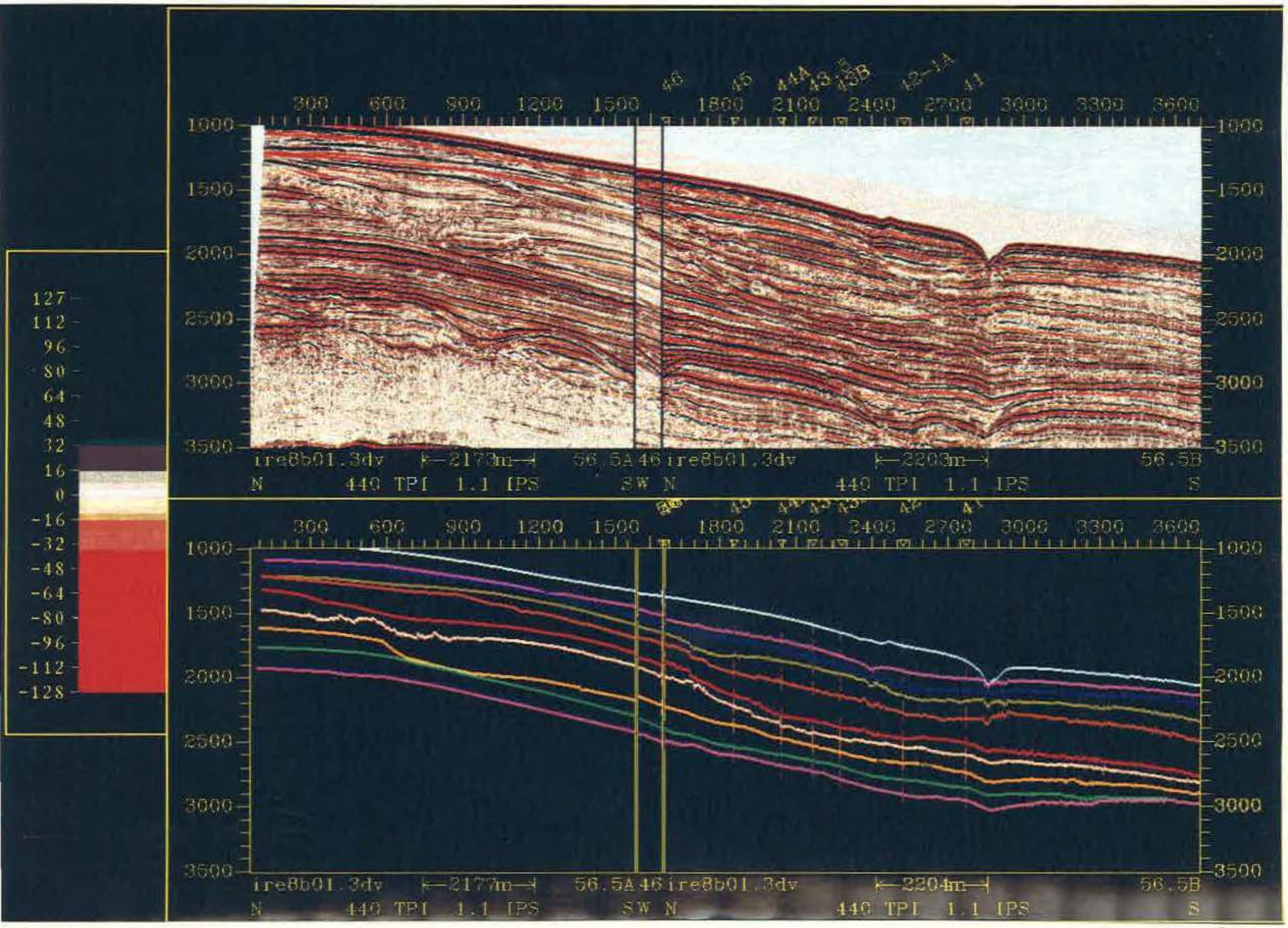

Figure 6 - Regional north-south lines 56.5A and 56.5B, showing stratigraphic and structural configuration of Porcupine Basin

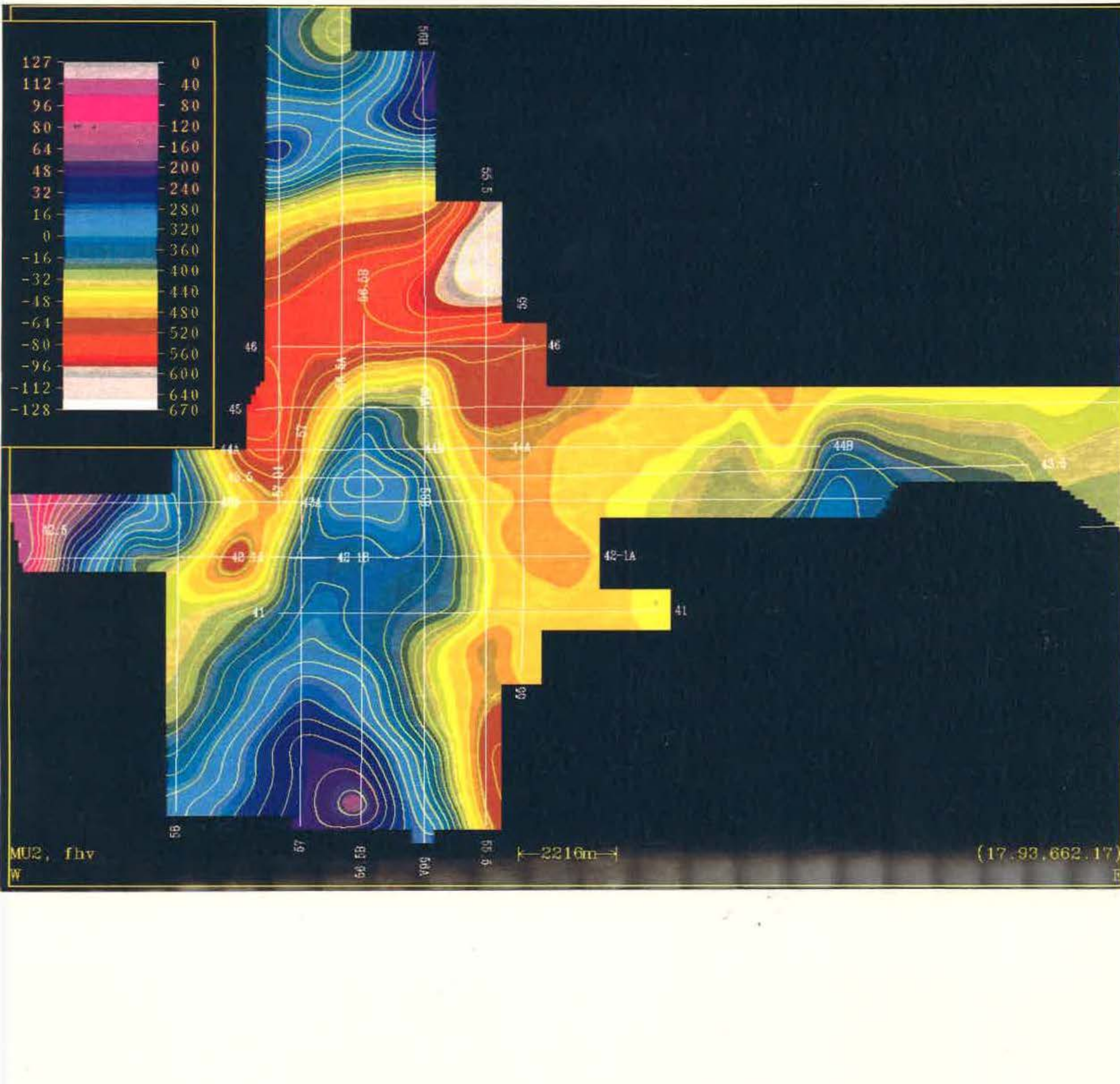

Figure 7 - Isochron map of Megaunit 2

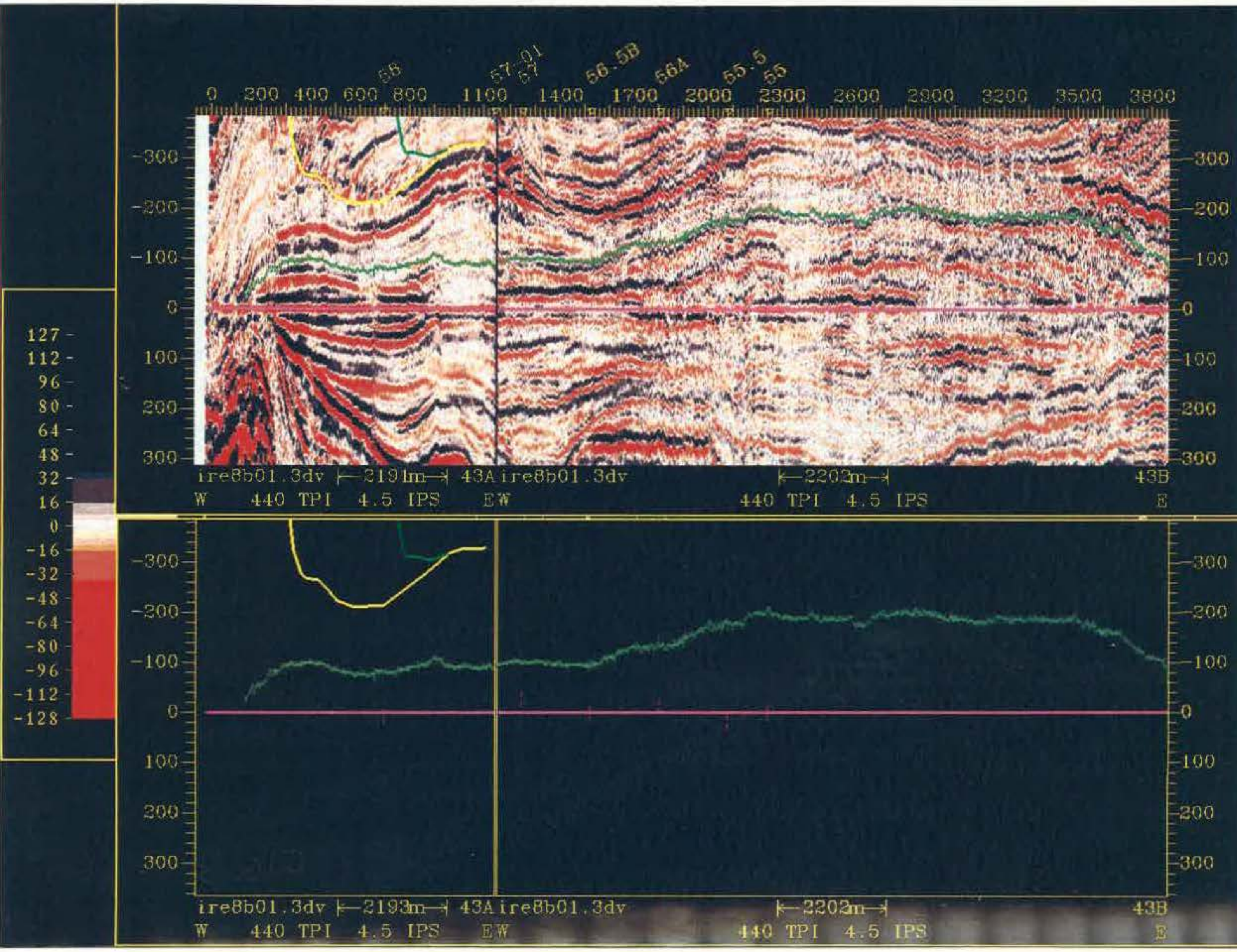

Figure 8 - Cross section of Sequence 2B, with flattening on Megaunit 3 (Line 43)

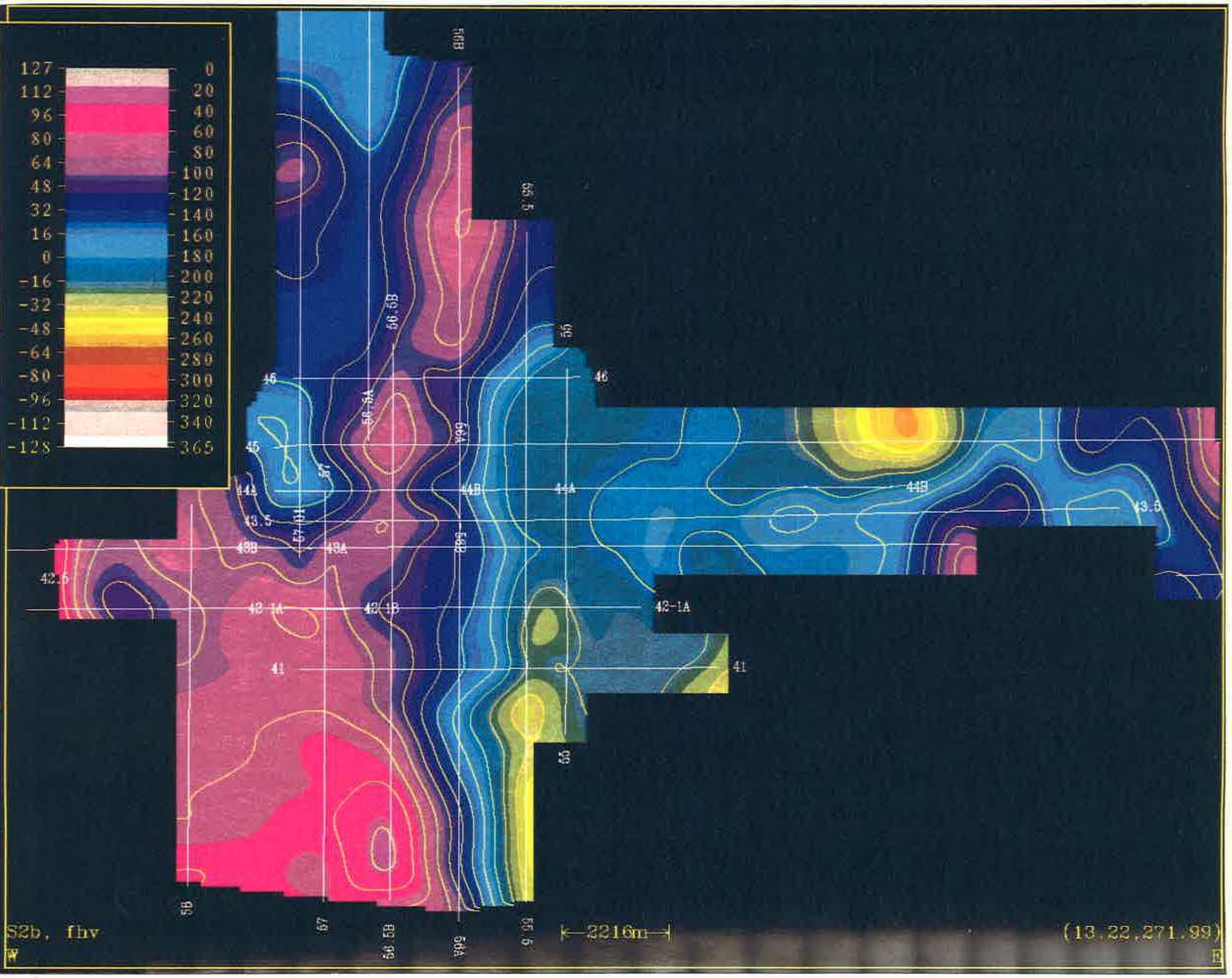

Figure 9 - Interval contour map (two-way travel time) of Sequence 2B

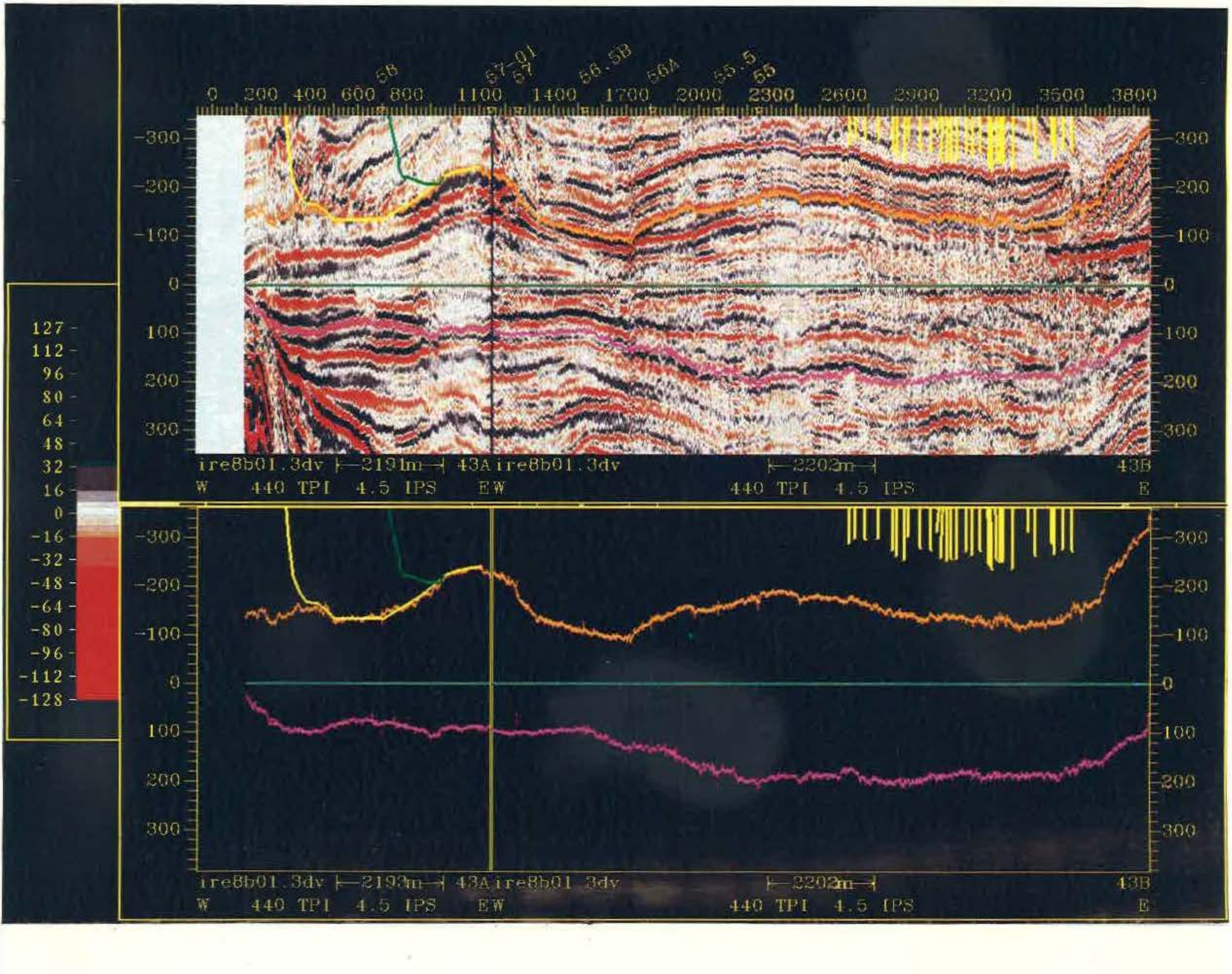

Figure 10 - Cross section of Sequence 2A, with flattening on Sequence 2B (Line 43)

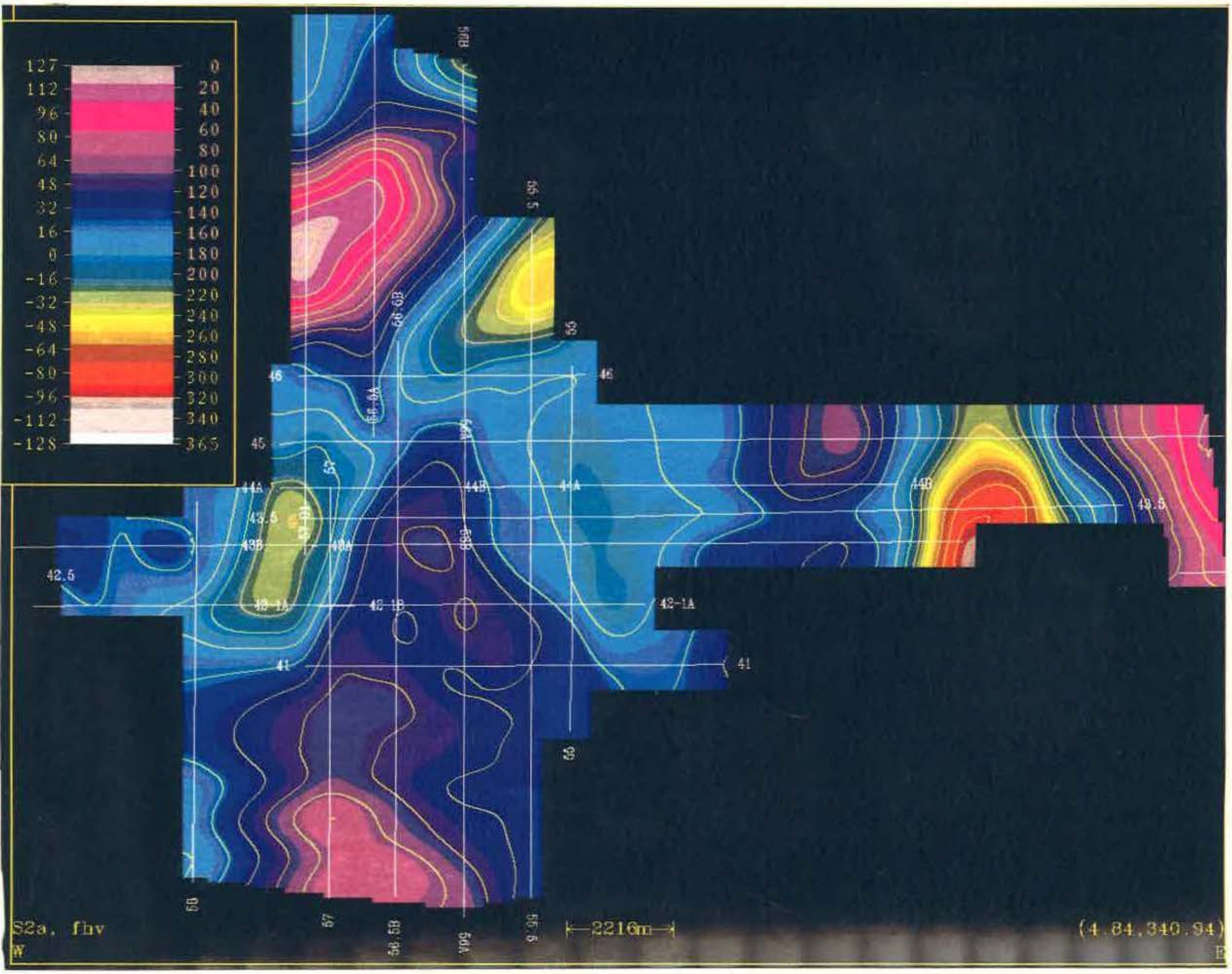

Figure 11 - Interval contour map (two-way travel time) of Sequence 2A

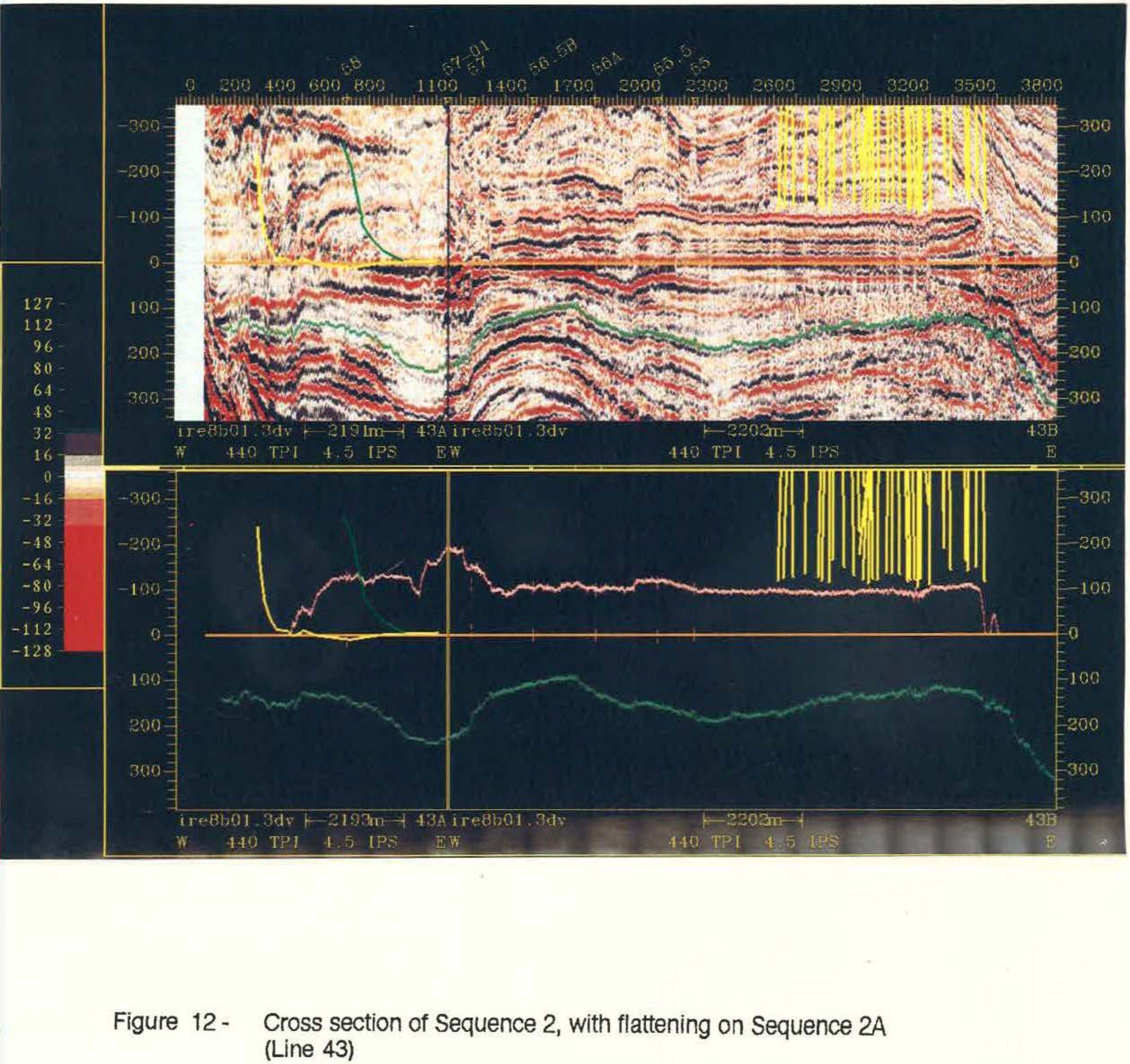

Figure 12 - Cross section of Sequence 2, with flattening on Sequence 2A (Line 43)

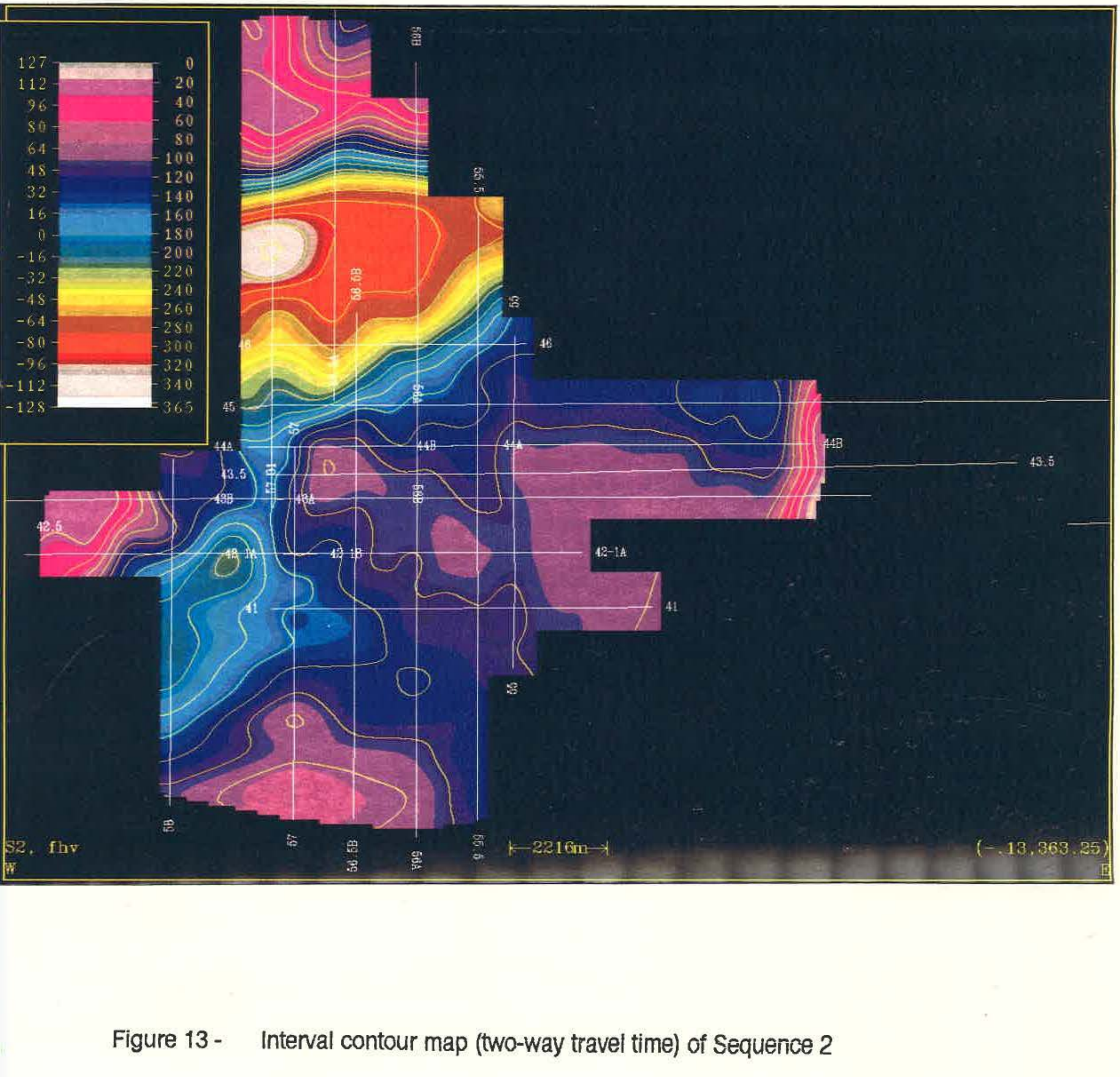

Figure 13 - Interval contour map (two-way travel time) of Sequence 2

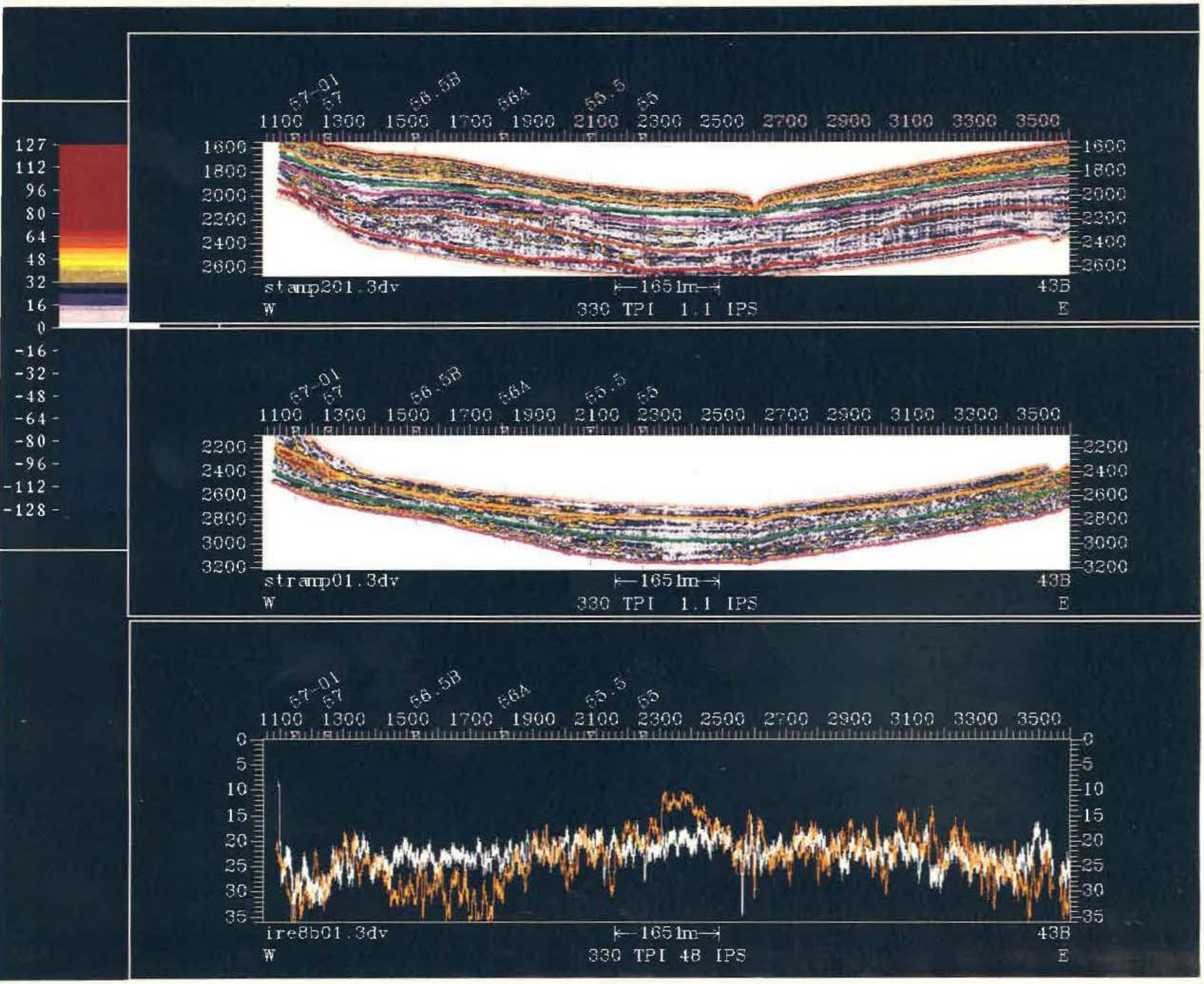

Figure 14 - Cross section showing seismic reflection strength within Megaunit 1 (top window), within Megaunit 2 (middle window), and the normalized average amplitude (bottom window) within Megaunit 1 (white) and within Megaunit 2 (orange)

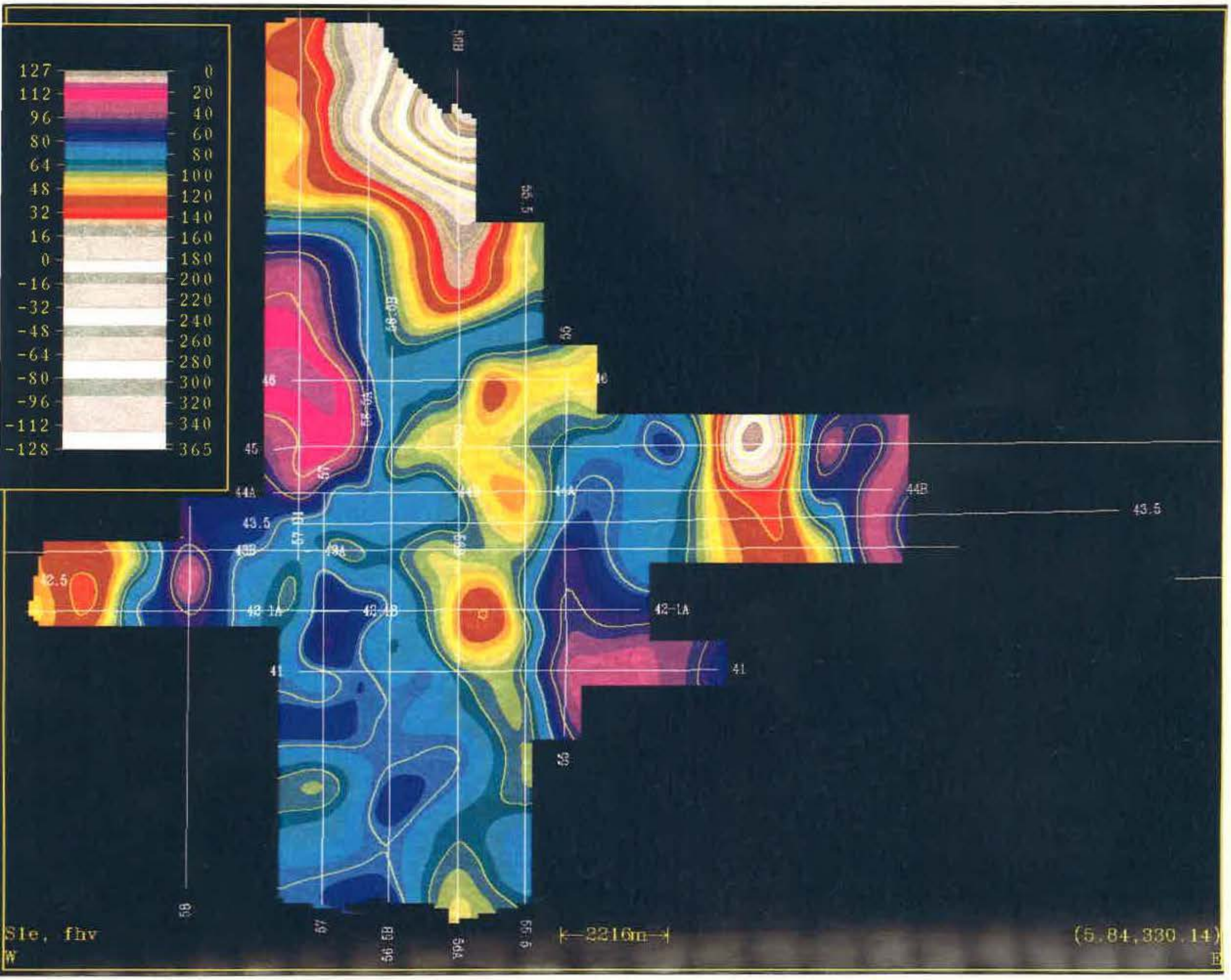

Figure 17 - Interval contour map (two-way travel time) of Sequence 1E

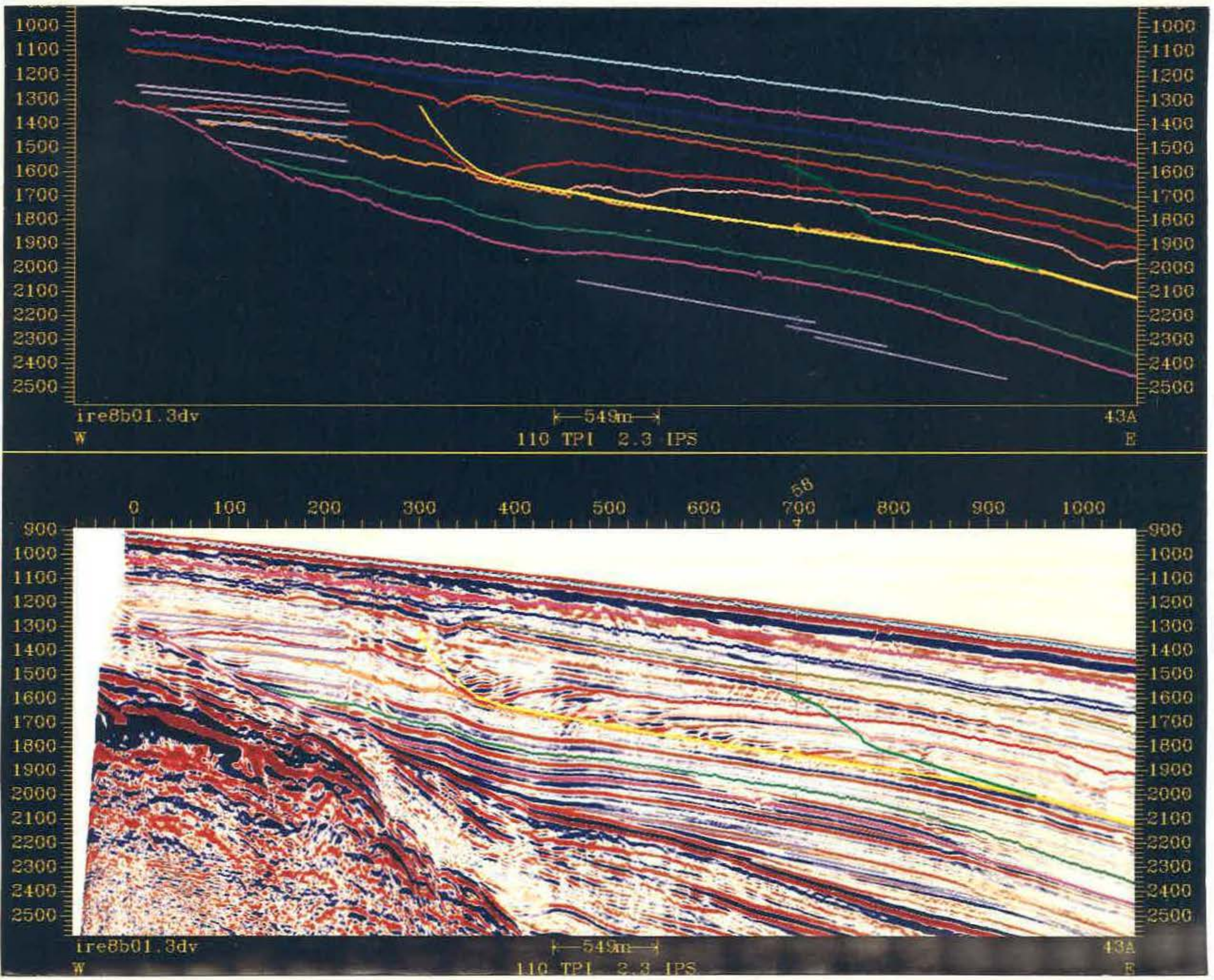

Figure 18 - Cross section showing Onlap Fill in Sequence 1D, as well as in and beneath Megaunit 2

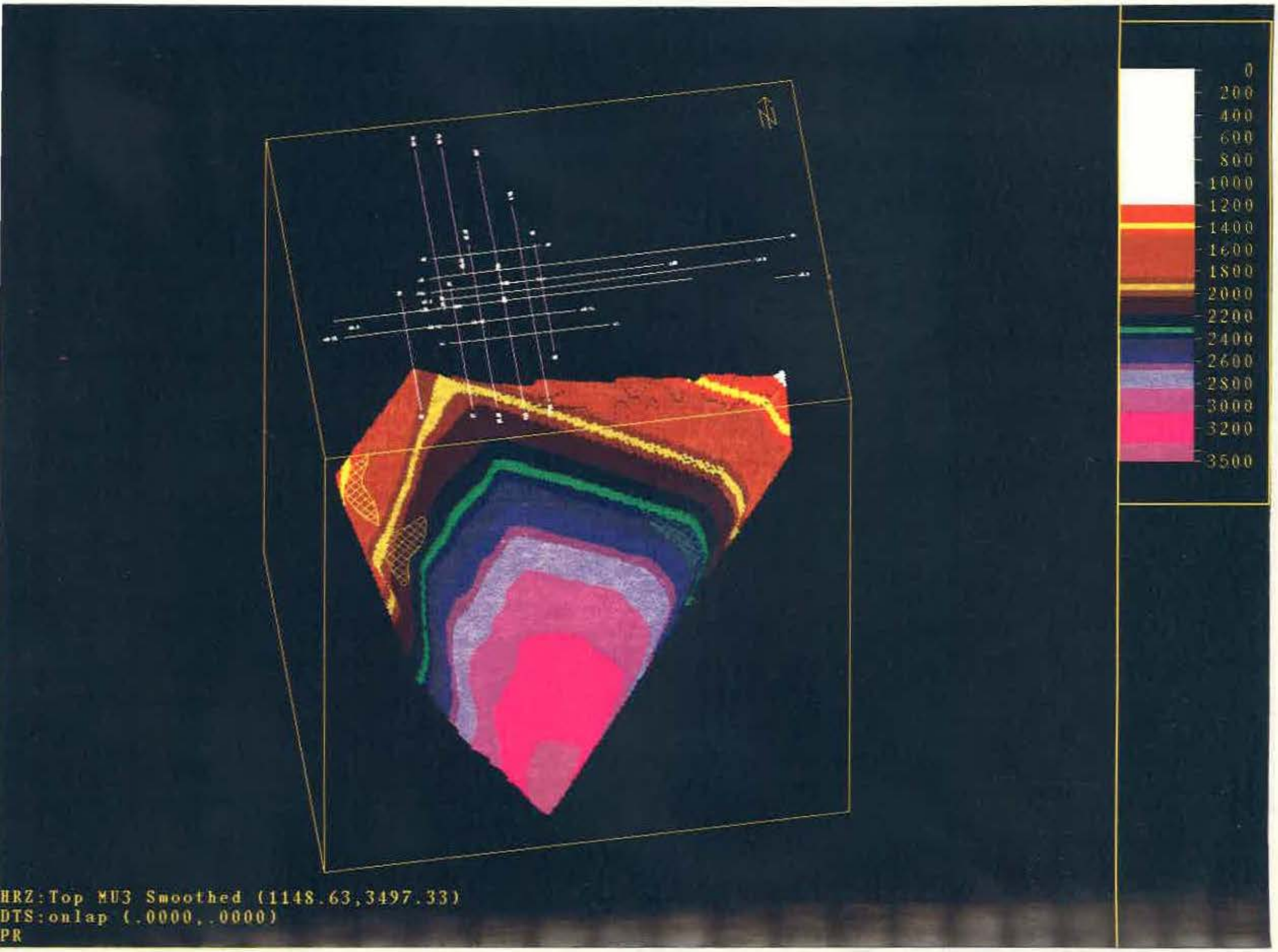

Figure 19 - Perspective display showing lateral extent of interpreted Onlap Fill deposits coming up against the top of Megaunit 3

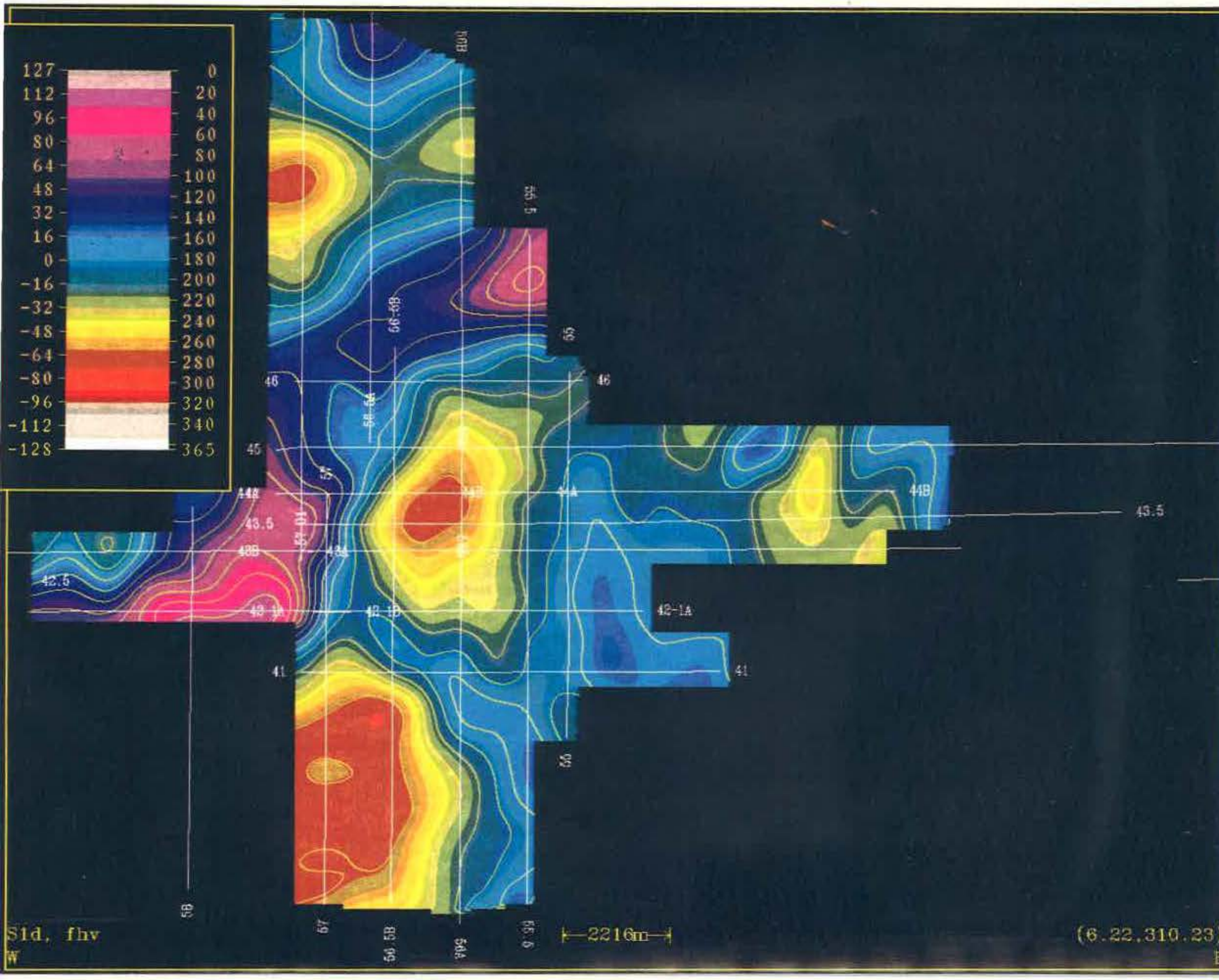

Figure 21 - Interval contour map (two-way travel time) of Sequence 1D

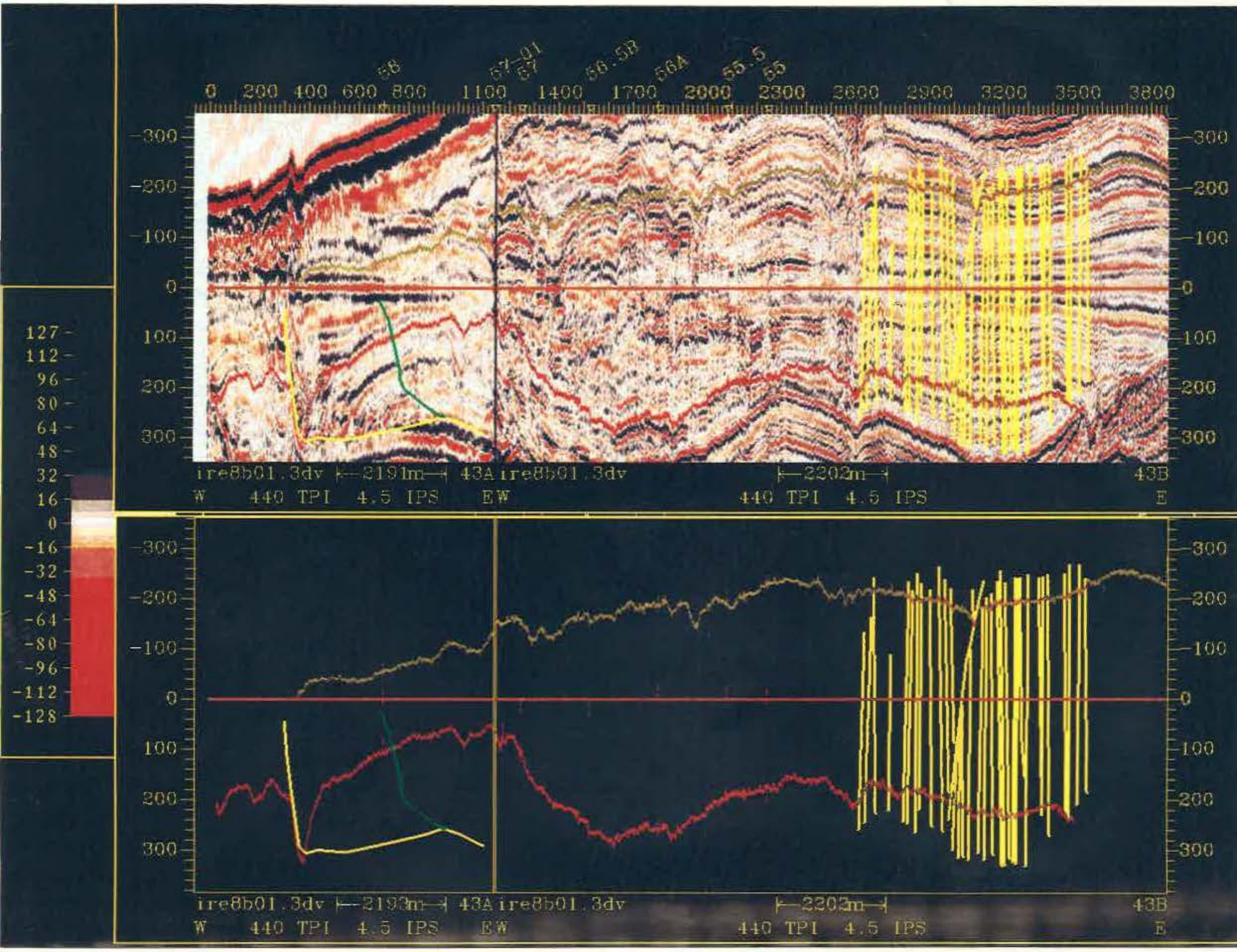

Figure 22 - Cross section of Section 1C, with horizon flattening on Sequence 1D (Line 43)

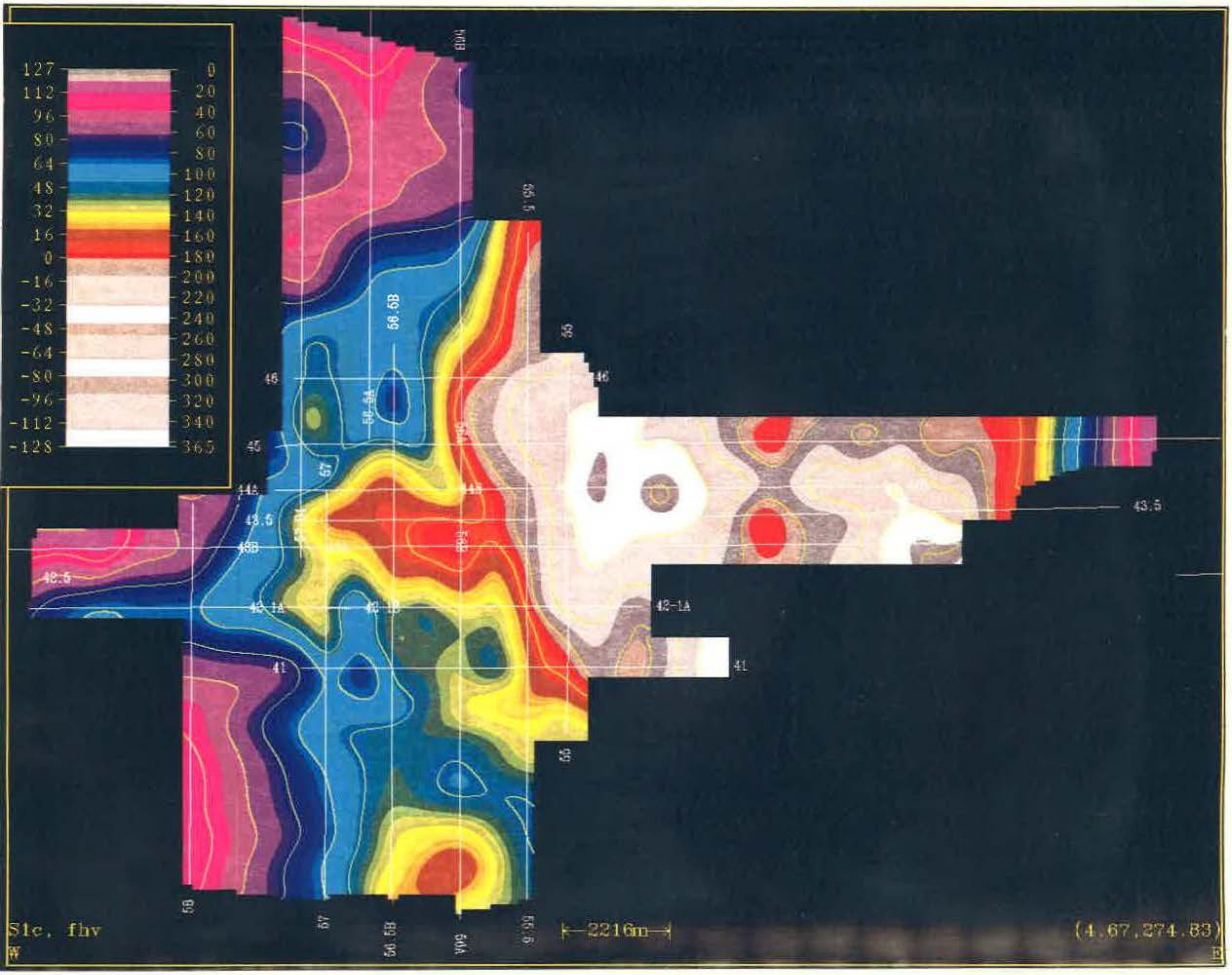

Figure 23 - Interval contours map (two-way travel time) of Sequence 1C

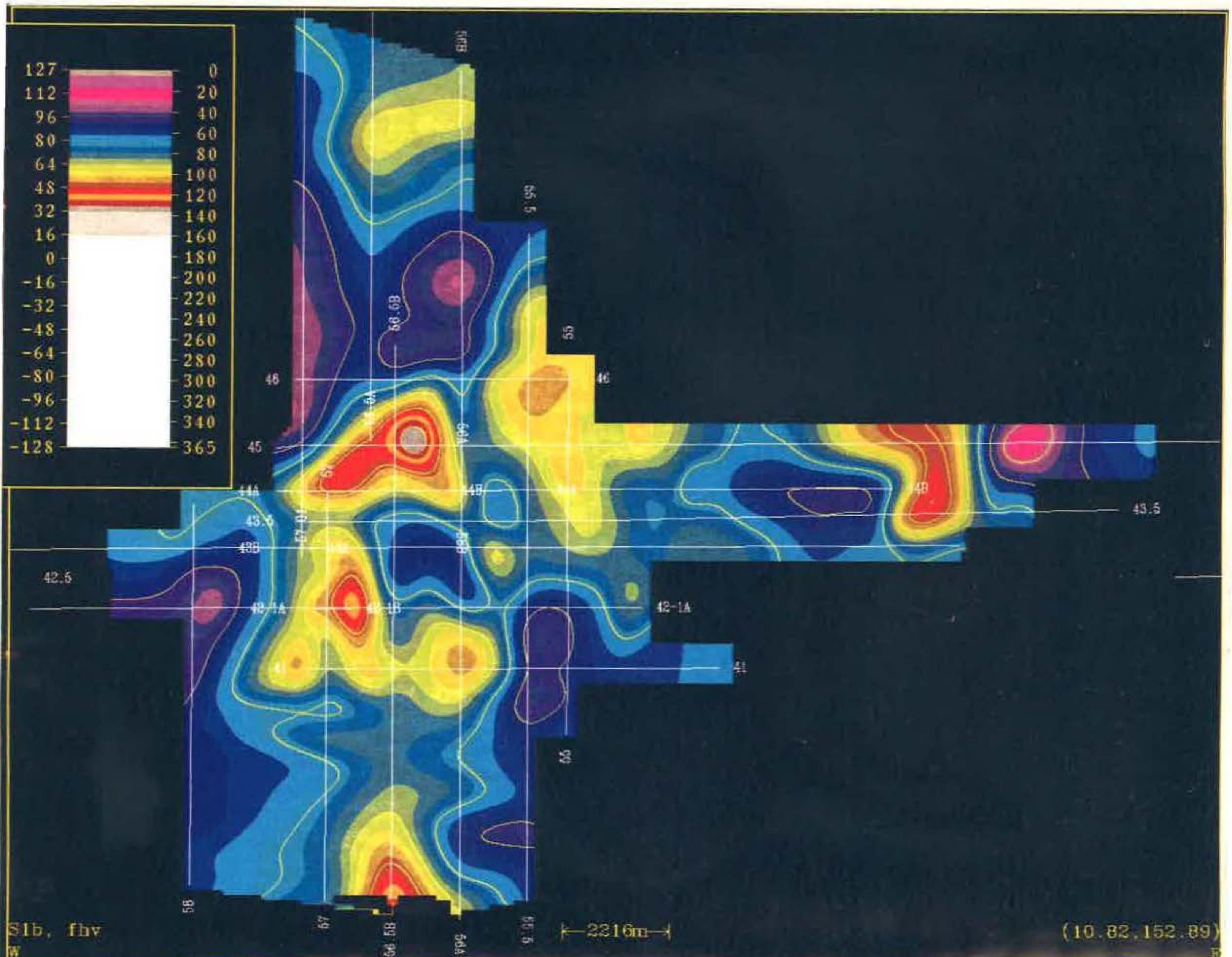

Figure 25 - Interval contour map (two-way travel time) of Sequence 1B

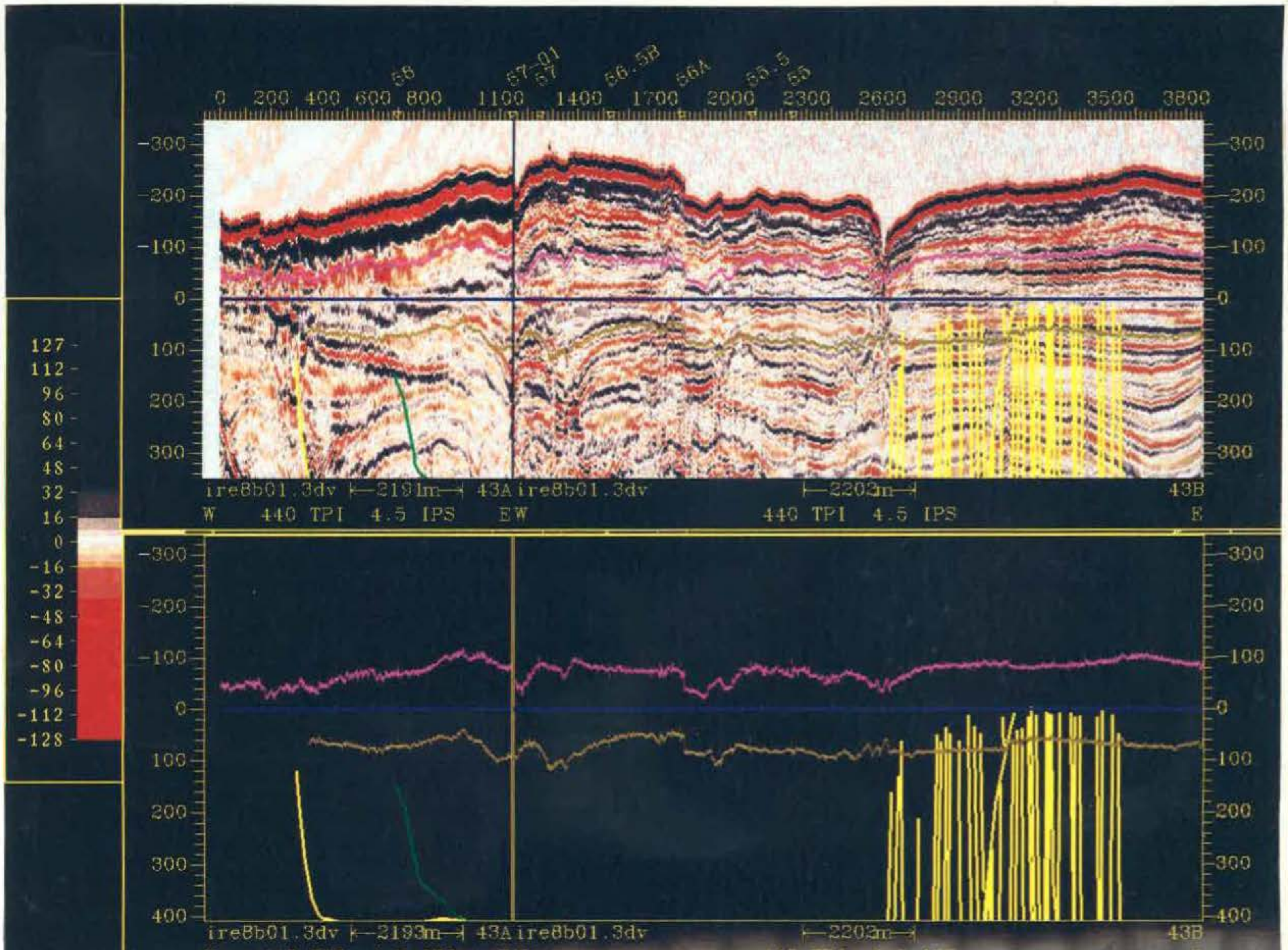

Figure 26 - Cross section of Sequence 1A, with horizon flattening on Sequence 1B (Lines 43)

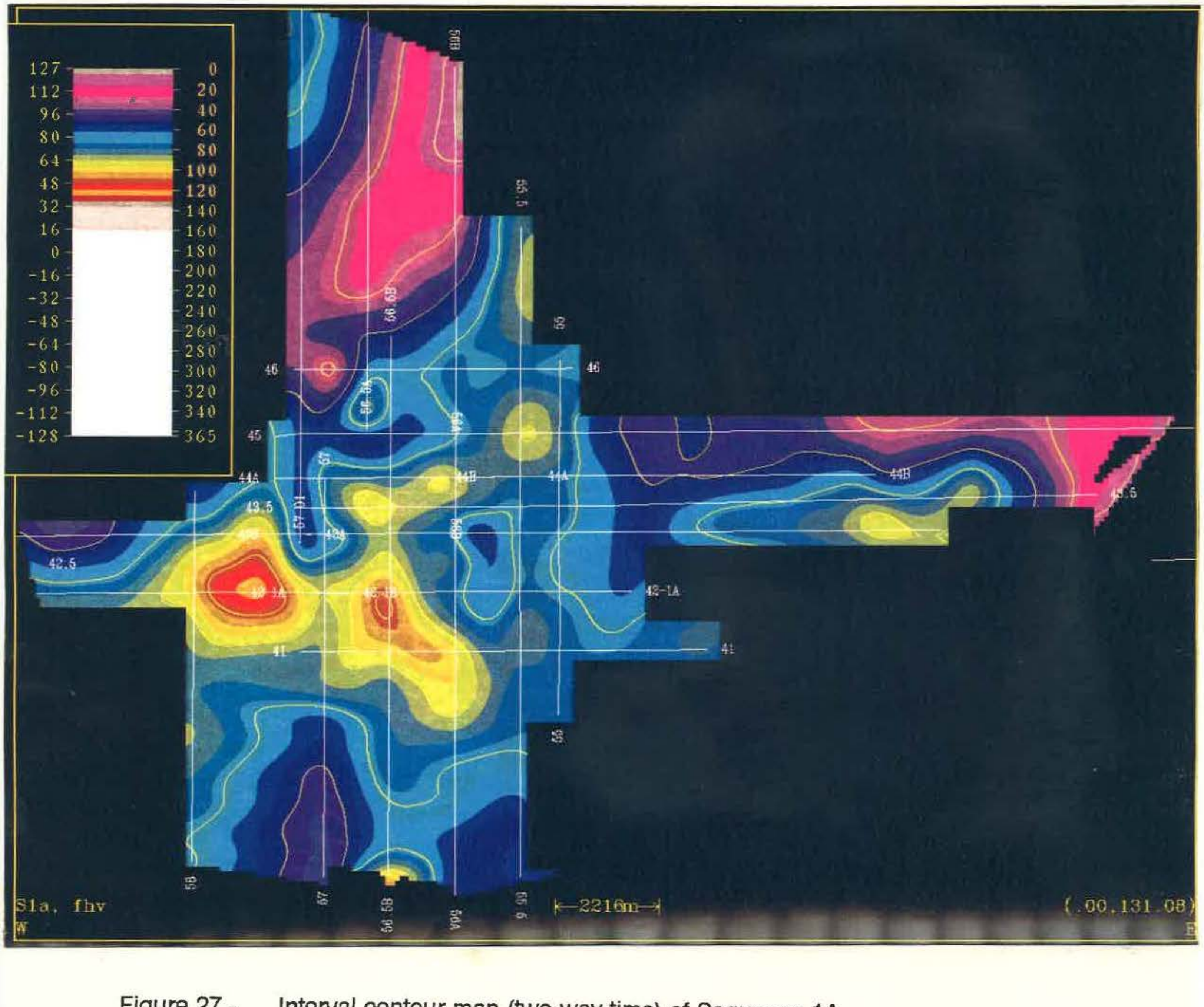

Figure 27 - Interval contour map (two-way time) of Sequence 1A

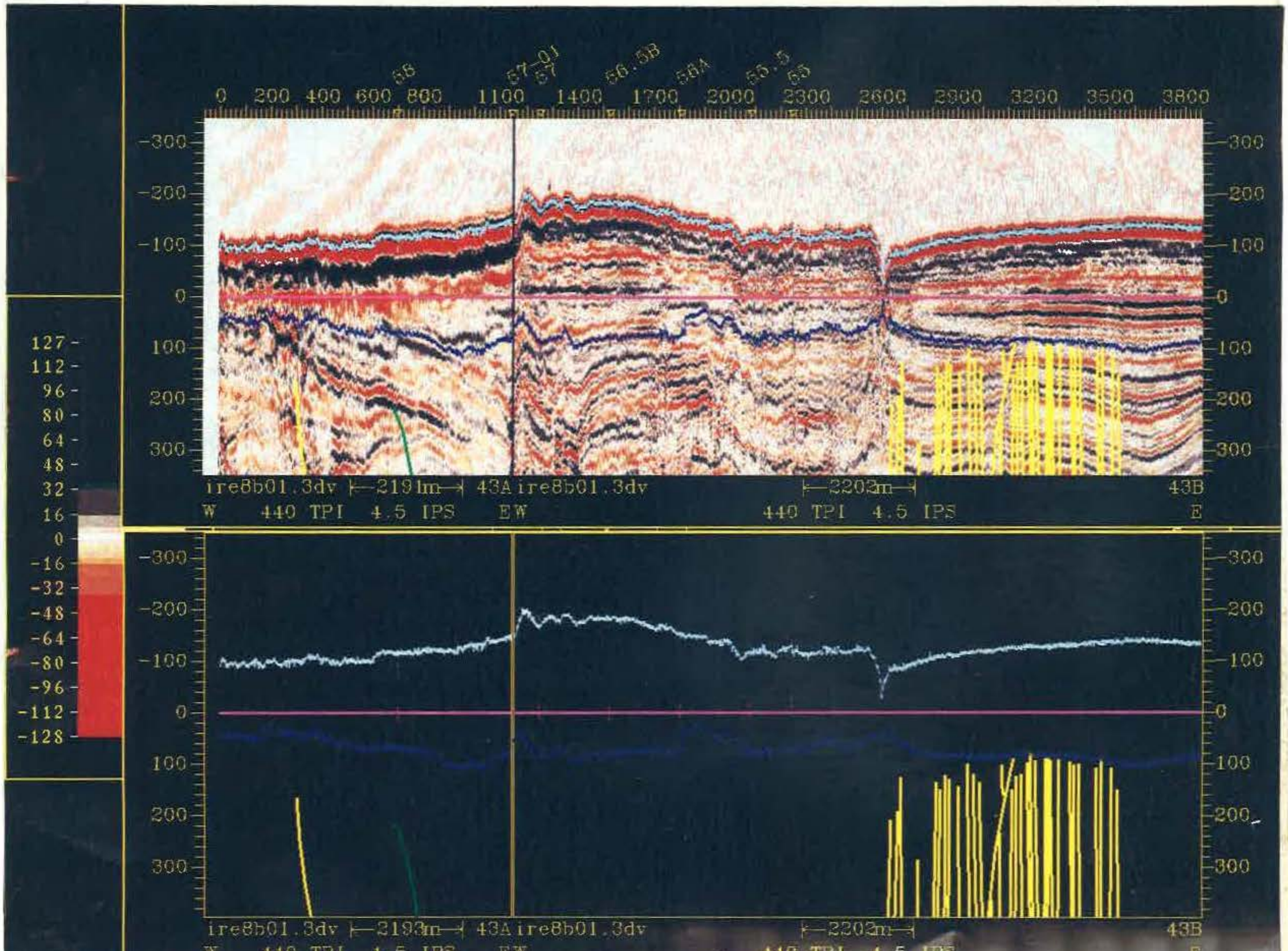

Figure 28 - Cross section of Sequence 1, with horizon flattening on Sequence 1A (Line 43)

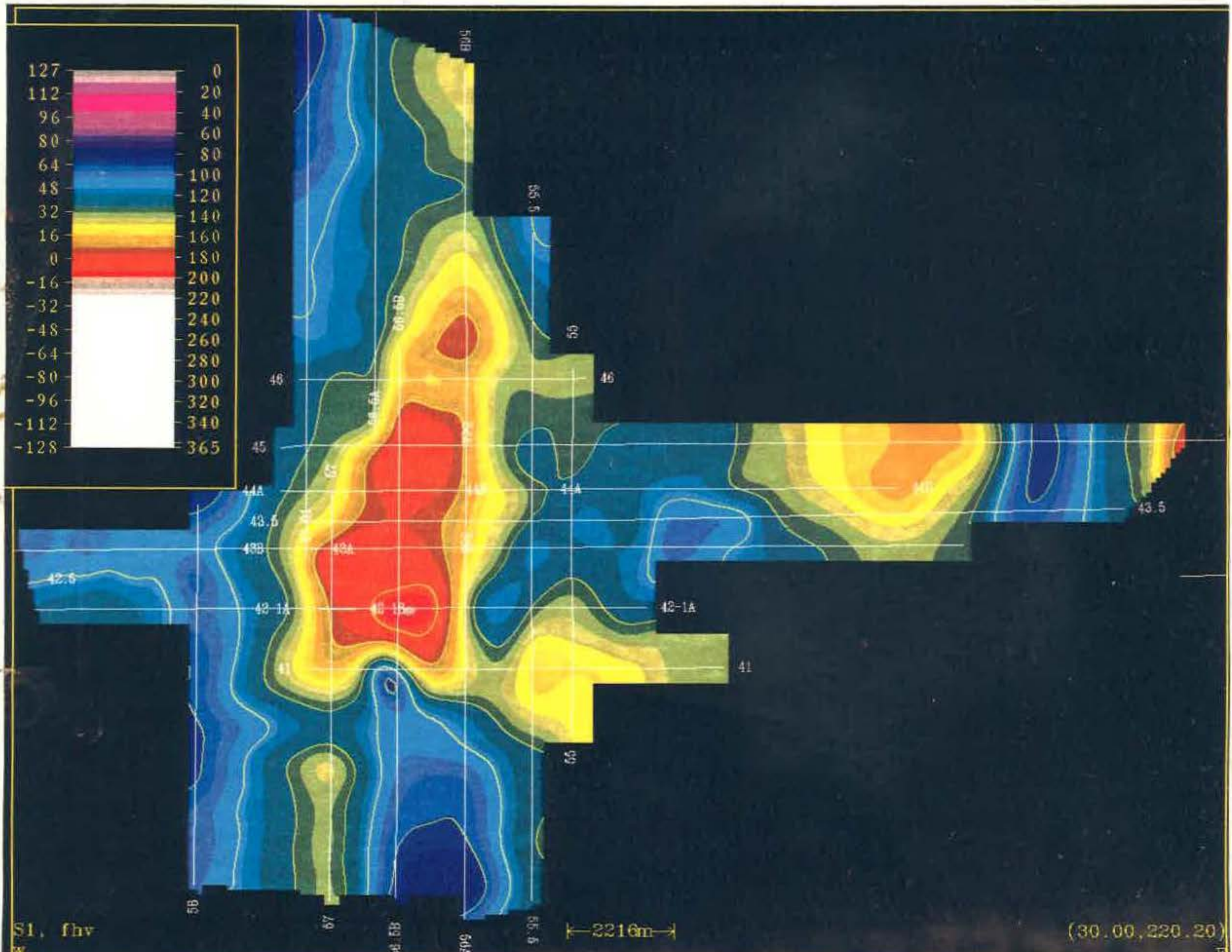

Figure 29 - Interval contour map (two-way travel time) of Sequence 1