THE STRATIGRAPHY OF A MIO-PLIOCENE CONTOURITE DRIFT

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Abstract

The Miocene-Pliocene sediments in the northeastern section of the Porcupine Basin, offshore Ireland, contain large prograding clinoforms with up to 450 m of relief. The bedforms are up to 12 km in width and over 50 km in north-south extent. Seismic stratigraphic and facies analysis delineated seven sequences internally. Each successively younger sequence is offset to the southwest; the clinoforms have toplap in the northeast and downlap to the southwest. A channel sequence corresponds with the prograding clinoforms of the sequence. Reconstruction of the flow directions suggests the clinoforms are a result of episodic current flow from north and north-northwest to south-south east; this flow is parallel to the contours. The interpretation of the deposits as being due to contour currents raises interesting questions about Miocene-Pliocene paleo-oceanography of the northeastern Atlantic.

SEISMIC FACIES PATTERNS

The sequences within Megaunit 2 were labeled A to G from the bottom up in order of their development. The sequences were named according to the color used to pick the top of the sequence. Sequence E or the Orange Sequence was one of those with the greatest variety of seismic facies and will be discussed as illustrative of the data we interpreted. Figures 3 and 4 illustrate some of the seismic data from this interval. Note that in the northeastern part of the data set the sequence terminates by onlap against the eastern margin of the basin. The reflectors are shingled (to the west), show toplap, and form a band 3-6 km in width which trends NNW-SSE. To the west of this, the next seismic facies belt is a zone approximately 12 km wide of parallel reflectors with the same orientation. The next three facies belts, which also trend NNW-SSE, are comprised of three different patterns of prograding clinoforms. The first of these, proceeding westward, is a slightly sinuous band of oblique reflectors 6-9 km in width. The second band is narrower, 1.5-3 km, and is comprised of hummocky clinoforms. The third band is broader in the north, approximately 6 km, narrowing to the south to 3 km; its reflection character is shingled. All three bands show the resultant direction of progradation to be SW to WSW, with toplap to the northeast and downlap to the southwest. To the west, the sequence has basically parallel reflectors with occasional ovoid areas of hummocky reflectors.

It is instructive to compare the seismic facies with the isochron thickness map (Figure 5). The shingled zone at the eastern edge is thin as expected. The belt of parallel reflectors to the west are seen as the blue zone (gradual thickening to the west as shown in Figure 6). The zone of prominent red colors track the axis of the oblique reflectors; this is the thickest part of the sequence. It thins to its minimum along the dark blue zone which is the shingled reflectors; the thickness values of the hummocky clinoforms lie between those of the oblique and shingled reflectors. The light purple colors show that the sequence again becomes thicker in the west in the region of the parallel reflectors.

What are the dimensions of the prograding clinoforms? The width of the prograding facies measured perpendicular to the strike is an average of 12 km. If one measures the difference in two-way travel time between the top and base of an individual clinoform in this sequence, it is as much as 400 ms. Given an interval velocity of 2,250 m/s, this would imply a bathymetric relief of up to 450 m. on the prograding surface. The feature is not small; from basin and sequence analysis and from well data from older sequences we know it was deposited in a bathyal environment.

COMPARATIVE FACIES OF OTHER SEQUENCES

Sequence A (Blue)

The seismic facies of the oldest sequence do not show the variety seen in the Orange Sequence. Those in the east are parallel; there is a zone of prograding facies in the north. To the south there is an incised area which suggests a channel; to the west the reflectors are in belts of either parallel or hummocky reflectors which trend north-south (Figure 7). The sequence is thin; its maximum thickness is in the northeast (Figure 8).

Sequence B (Green)

This sequence is not as extensive in its southward extent as the Blue Sequence. There is a zone of broad parallel reflectors in the east and a zone of north-northwest-south-southwest prograding or channelized facies in the east-center. A zone of parallel reflectors some 12 km wide succeeds these to the west, followed by a zone of hummocky reflectors. The center and west of the map area are parallel or hummocky (Figure 9). Again, the sequence is thin; the maximum thickness is in the north, but displaced towards the west (Figure 10).

Sequence C (Vermillion)

The seismic facies of the third sequence have a more integrated appearance to them than the two older sequences. A belt of parallel facies occurs at the eastern limit; this tapers from 18 to 9 km from north to south. The next north-south facies is a meandering belt of prograding facies in the south and center of the eastern portion; this is succeeded to the north by a channelized facies (Figure 11). It varies from 3 to 12 km in width. Parallel reflectors occur to the west of the prograding or channelized facies. The center of the map area is occupied by an oval (25 km) north-south zone of hummocky reflectors; parallel reflectors occur to the west. The isochron thickness map clearly shows the thickest interval corresponds to the prograding-channelized facies (Figure 12).

Sequence D (Light Blue)

The Light Blue Sequence is not as clearly differentiated internally as Vermillion below or Orange above. The eastern portion of the map area has a zone of marginal onlapping reflectors in the northeast, a broad zone of parallel reflectors in the eastern center, succeeded to the west by a belt of prograding facies in the center and south; a channel occurs to the north (Figure 13). Hummocky and parallel reflectors occur in the center and west respectively. The maximum thickness occurs in the center of the eastern portion of the map area and is slightly offset to the east of the prograding facies (Figure 14).

Sequence F (Rose)

The facies of the Rose Sequence are well organized. It does not extend as far north as the Orange Sequence. Along the eastern margin, there is a broad zone of onlapping reflectors, 5-10 km in width. To the west is a zone of parallel reflectors; this is indented to the west by a prograding facies which is oriented northwest-southwest, and then a channel facies (Figure 15). The maximum thickness in the east again corresponds to the prograding facies (Figure 16). Comparison of the maximum thickness of Sequences 3-6 shows a progressive shift to the southwest which corresponds to the migration of the prograding clinoforms to the southwest.

The facies west of the prograding facies appear to be a channel with a levee complex along the western margins of the channel. The reflectors in the center and west which are part of this Sequence show remarkable continuity and parallelism for tens of kilometers with no change in their appearance.

Sequence G (Lavender)

This sequence is limited in its northward extend, with the northern limit being south of that of the Rose Sequence. Distinct facies belts, oriented northwest-southwest, are found. To the east there are onlapping reflectors, followed by parallel reflectors (Figure 17). The prograding facies are well developed; the maximum thickness again corresponds to their pattern which has shifted southwest compared to the Rose Sequence. A parallel facies occurs to the southwest (Figure 18). The unit is absent in the center and west of the large map area.

Summary of the Seismic Facies

Mapping of the seismic facies of Sequences A-G shows a progressive migration of the seismic facies across the eastern portion of the map area from north-northeast to the south-southwest. Sequences A and B are thin, and appear to be basinal with respect to the clinoform facies found in subsequent sequences. Alternatively, the pattern of progradation had not yet developed. Subsequent sequences onlap onto the eastern margin of the basin, either by parallel or shingled reflectors. A broad belt of parallel reflectors lies to the west-northwest, followed by a prograding clinoform facies, the eastern portion of which corresponds to the thickest portion of the sequence while the more southwesterly prograding facies corresponds to a thin. In sequences F and G this is apparently a channel. The latter is margined by a levee in Sequence F. Other features which suggest channels with marginal levees are found in older sequences. The width of the prograding facies reaches a width of up to 12 km and a bathymetric relief of 450 m. To the west the sequences are relatively thin and have either parallel or hummocky reflectors which are organized into broad north-south belts.

ENVIRONMENTS OF DEPOSITION

The prograding reflectors of Megaunit 2 raise the possibility of their being part of a delta or continental slope environment. Another possibility is that of a submarine fan.

There are several factors to be evaluated in determining the origin of the sequences in Megaunit 2. The first is that of external geometry. The flat reflectors to the east would represent the delta platform or continental shelf and the prograding clinoforms the respective slope environment. The upper boundary often shows toplap and the units are more wedged shaped than commonly seen in shelf or deltaic environments. The second unusual phenomenon is the channel and levee at the base of the clinoforms and the latter being the thinner part of the sequence. The third factor is the successional history of Megaunit 2; it is bracketed by units which are of known deep-water origin. It would require a very atypical uplift and then subsidence of this extensional basin to bring Megaunit 2 back into the neritic zone. The amount of vertical accumulation was not enough to do this either.

The idea of the prograding clinoforms being part of a submarine fan was another of the ideas expressed above. Submarine fans characteristically have bivariate downlap or onlap toward their edges and are supplied from one or more point sources. The asymmetry of the clinoforms in Megaunit 2 and the wedge shaped geometry work against this interpretation. Megaunit 2 is asymmetrical, broad and the progradation occurs over a broad front with no obvious single source.

The configuration of the seismic reflectors in Megaunit 2 suggests the process and direction of transport. The source of sediment was somewhere to the north or northeast. The direction of sediment transport was to the southwest. What kind of currents were responsible for this? In Figure 19 we present a diagram indicating the surface morphology during the accumulation of the Orange Sequence (E). Note the onlap to the east, the prograding surface, which is oriented north-northwest-south-southwest, the channel and the marginal levee which has the same orientation. The belt of prograding facies extends over 50 km in a northwest-southeast direction, has an east-west extent of the 12 km, and a maximum relief of 450 m. There is toplap of the upper surface. Using the shelf ridges offshore New Jersey, Phillips, et. al. 1985 suggested the origin of a sand ridge on the outer shelf was produced by currents whose stream lines crossed the feature at a transverse angle. Using this analogy, a flow field is proposed as being down the channel drawn in the diagram to suggest the flow patterns that produced the sequence (Figure 19). It should be noted that the overall flow field is parallel to the contours, not crossing them.

CONTOUR CURRENTS

Our understanding of deep-marine processes has in some respects paralleled the timing of our understanding of the lunar and planetary surfaces by manned-expeditions and remote probes. Our initial concepts focused on vertical sedimentation from suspension; thus was followed by the strong emphasis on turbidity currents and turbidites of the 1950's and 1960's. In 1966 Heezen et. al. proposed the term contour currents for deep-marine currents that flow parallel to the contours at depth. As studies of the continental rise and abyssal plain off the east coast of the United States proceeded, it became increasingly clear that contour currents had played a key role in the Tertiary in eroding the northwestern part of the slope and rise and transporting large amounts of sediment southward to form features such as the Outer Blake Ridge. The HEEBLE experiments in the continental rise off the coast of New England recorded some of the velocities associated with contour currents during underwater storms; these approached 2 km per hour.

Contour currents are a consequence of differences in either the temperature or salinity of contrasting waster masses. Judging from the distribution of contourite drifts in the North Atlantic, contour currents were important agents of transport and deposition in the late Tertiary due to the outflow of cold water from the Arctic Basin. In addition, they are found off the southwest coast of Portugal (Stow, et. al., 1986); here the Faro drift was formed by the outflow of warm saline bottom water produced by evaporation in the Mediterranean. Pickering, et. al (1989) provide a recent review of contourites and illustrate some of their reflection character as seen in airgun seismic profiles.

Macurda (1988) illustrated a line with a series of Lower Cretaceous contourite drifts in the continental rise south of New England. When mapped in three dimensions, these features are ovoid mounds. They are asymmetric in cross-section with the profile on the interpreted up-current edge being steeper with reflectors that terminate against the edge of the mound, while the reflectors below the more gently sloping surface show downlap due to progradation. The Jurassic shelf edge ran east-west; the Lower Cretaceous drifts are oriented northwest southeast with the steeper sides on the north and west. The inferred current pattern that produced these crossed the drifts transversely, flowing from west-north-west to east-south-east. Younger drifts nucleate older drifts and their leading edge is progressively displaced downcurrent from older drifts. Paleogeographically, this was the northern margin of the Tethyan Ocean and most paleographic maps suggest a west to east flow. Because of the more equitable climate of the Cretaceous, these drifts are probably a product of salinity differences due to warm saline bottom water.

ORIGIN OF MEGAUNIT TWO

Our review of the seismic stratigraphy, basin history, and prograding reflection configurations of the sequences in Megaunit 2 suggest to us that it was a product of Miocene-Pliocene contour currents which flowed from north to south direction in Porcupine Basin. The most important characteristics are the size of the prograding clinoforms in the prograding sequences, their asymmetry from northeast to southwest, with toplap to the northeast and downlap to the southwest, the progressive offset of each younger sequence to the southwest and the presence of a channel and levee complex southwest of the prograding clinoforms, establishing a current flow from northwest to southeast parallel to the contours.

What does the stratigraphy of adjacent areas suggest? The Rockall Basin which lies to the west shows a marked change in the style of sedimentation often the Lower Miocene, apparently a result of more dynamic flow of the bottom waters (M. Tate, personal communication, 1989). Kenyon (1986) reported a Late Tertiary contourite on the upper slope northwest of Scotland; he inferred a flow from southwest to northeast.

Since we have interpreted Megaunit 2 to be a product of contourite deposition this raises the larger order question as to what were the paleo-oceanographic conditions that resulted in its formation. In the northern part of Porcupine Basin there are scour features which occur at a similar stratigraphic level, suggesting strong north to south flowing currents which caused erosion at this level. We do not have any data further to the north which would allow us to examine the interval at a more regional scale. We are unaware of descriptions of similar features at the same level. Therefore, attempts to answer the larger order questions remain unresolved.

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FIGURE CAPTIONS

Figure 1. Physiographic map (54 to 2 degrees), showing the Porcupine Seabright southwest of Ireland.

Figure 2. Location of available seismic data highlighting lines 45 NS and 52 EW.

Figure 3. East-west seismic line 45.

Figure 4. North-south seismic line 52.

Figure 5. Seismic facies interpretation overlaid on the Orange Sequence (E) isochron map.

Figure 6. The Orange Sequence (E) isochron map.

Figure 7. Seismic facies interpretation overlaid on the Blue Sequence (A) isochron map.

Figure 8. The Blue Sequence (A) isochron map.

Figure 9. Seismic facies interpretation overlaid on the Green Sequence (B) isochron map.

Figure 10. The Green Sequence (B) isochron map.

Figure 11. Seismic facies interpretation overlaid on the Vermillion Sequence (C) isochron map.

Figure 12. The Vermillion Sequence (C) isochron map.

Figure 13. Seismic facies interpretation overlaid on the Light Blue Sequence (D) isochron map.

Figure 14. The Light Blue Sequence (D) isochron map.

Figure 15. Seismic facies interpretation overlaid on the Rose Sequence (F) isochron map.

Figure 16. The Rose Sequence (F) isochron map.

Figure 17. Seismic facies interpretation overlaid on the Lavender Sequence (G) isochron map.

Figure 18. The Lavender Sequence (G) isochron map.

Figure 19. Diagram indicating the surface morphology during the accumulation of the Orange Sequence. The channel is drawn to suggest the flow patterns that produced the sequence.

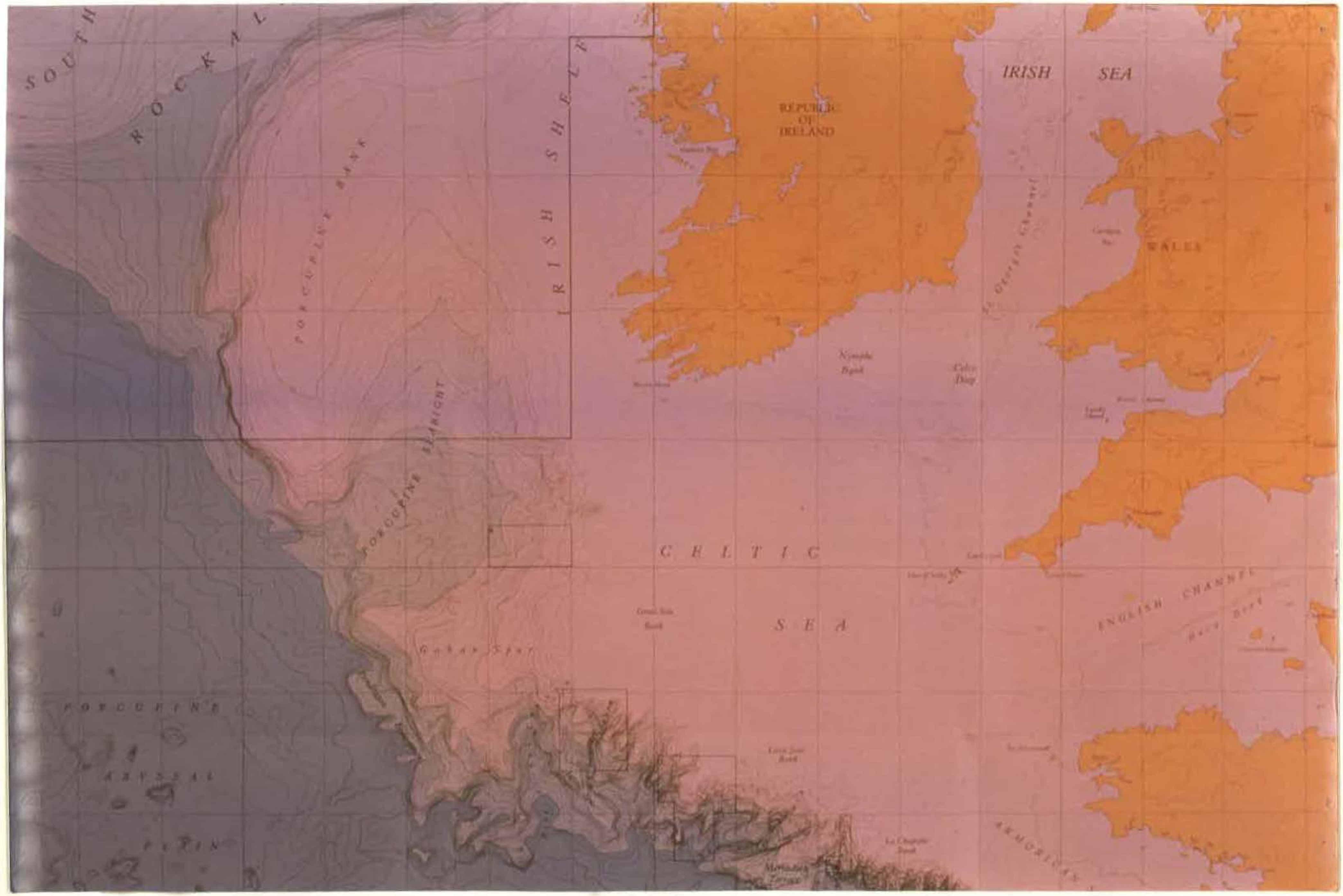

Figure 1. Physiographic map (54 to 2 degrees), showing the Porcupine Seabright southwest of Ireland showing the position of Porcupine Basin.

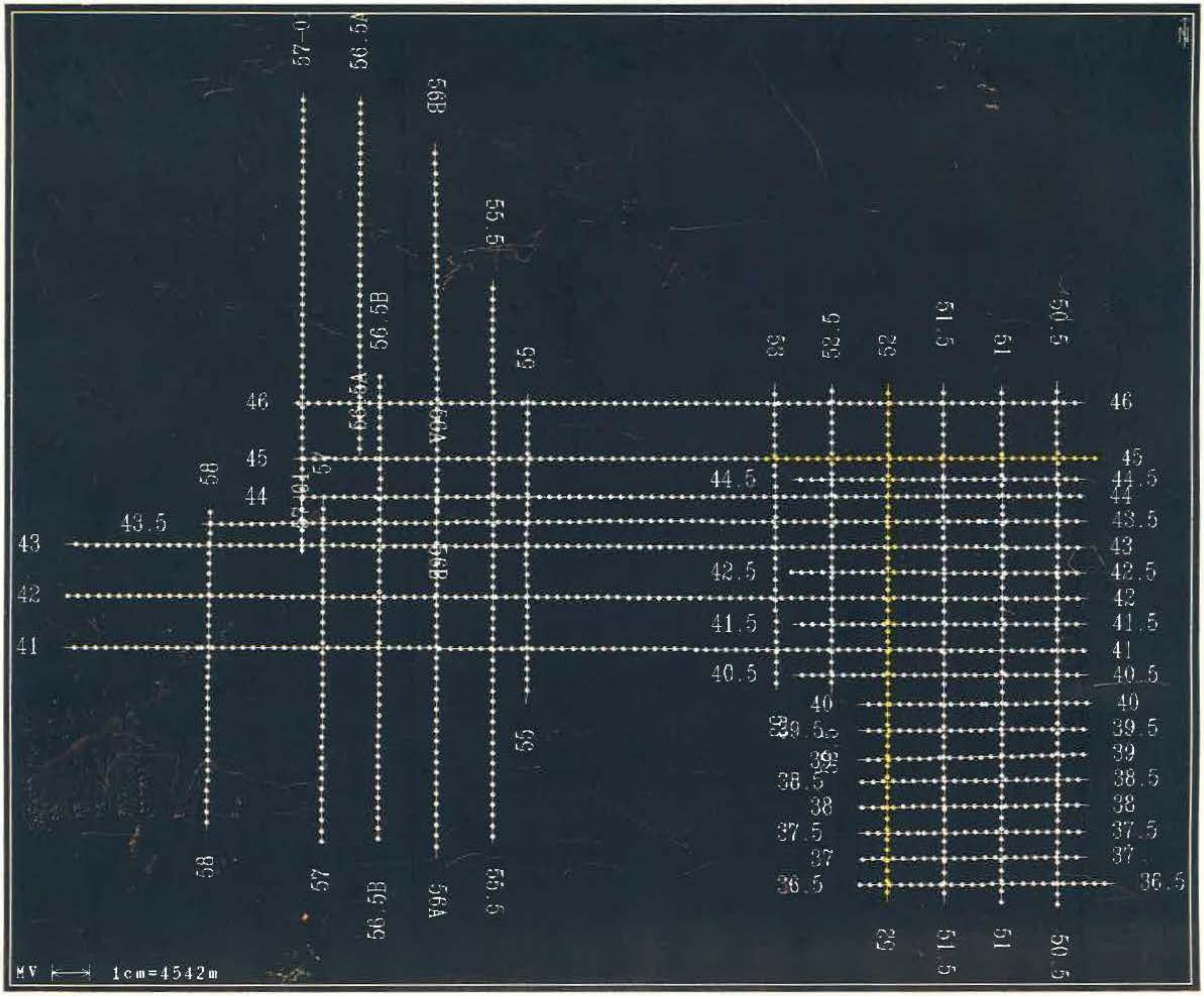

Figure 2. Location of available seismic data highlighting lines 45 north-south and 52 east-west.

Figure 3. Seismic line 45 east-west.

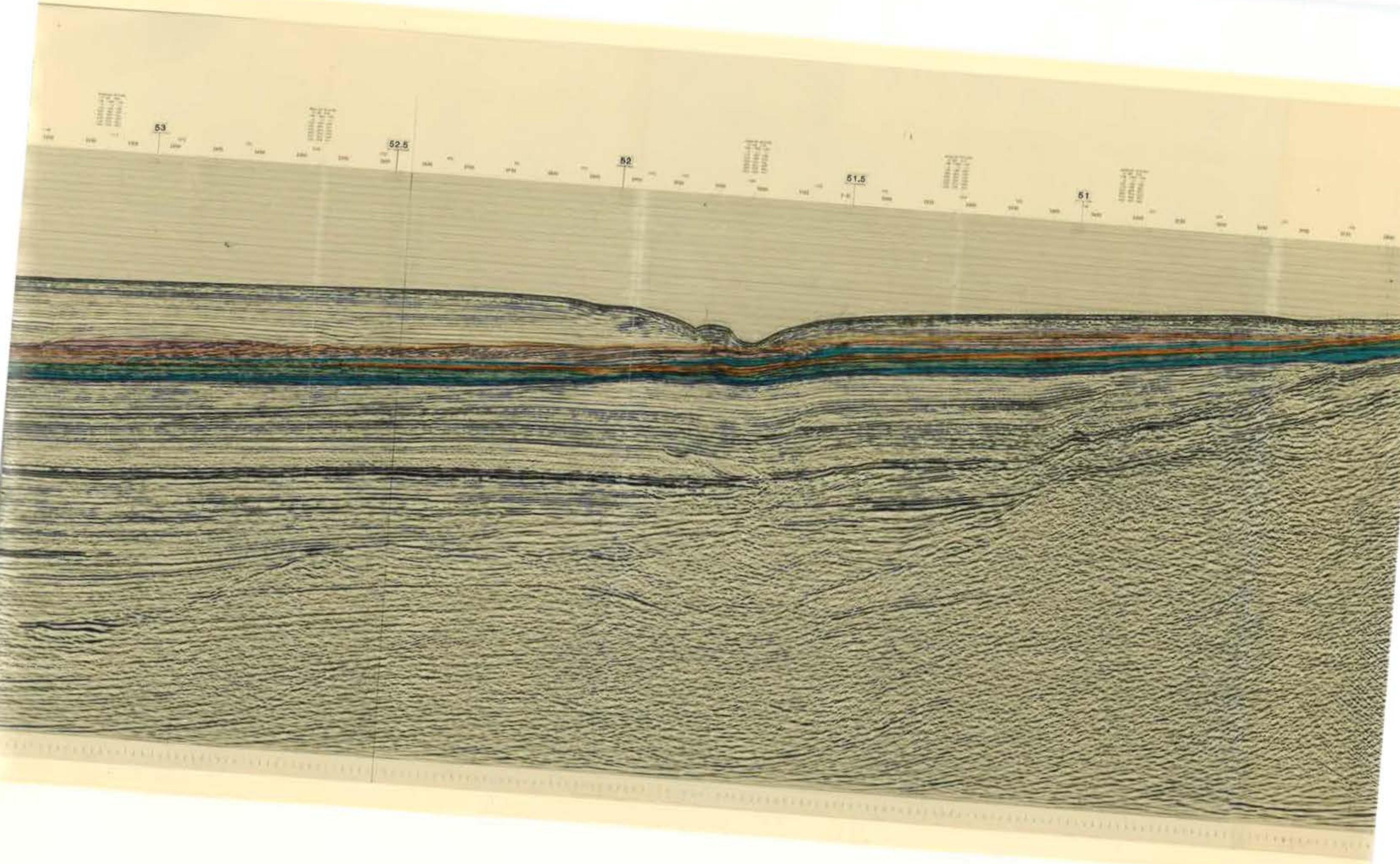

Figure 3. Seismic line 45 east-west.

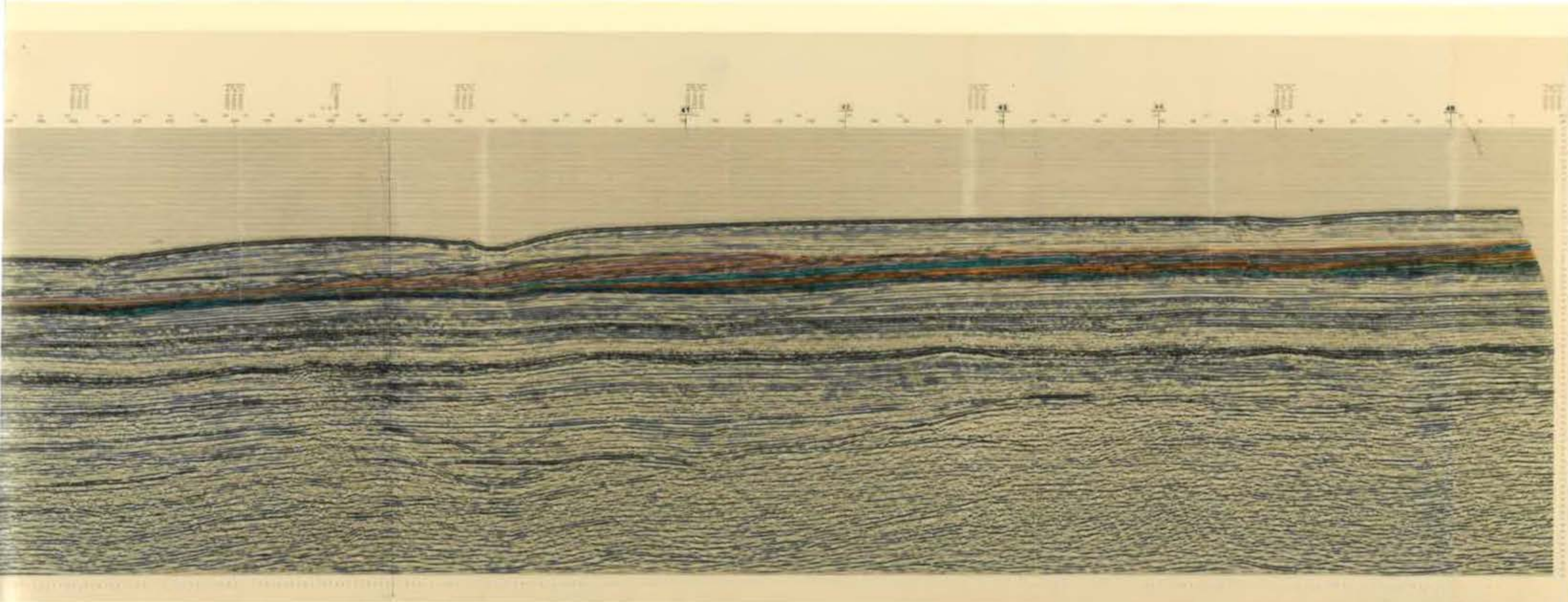

Figure 4. Seismic line 52 east-west.

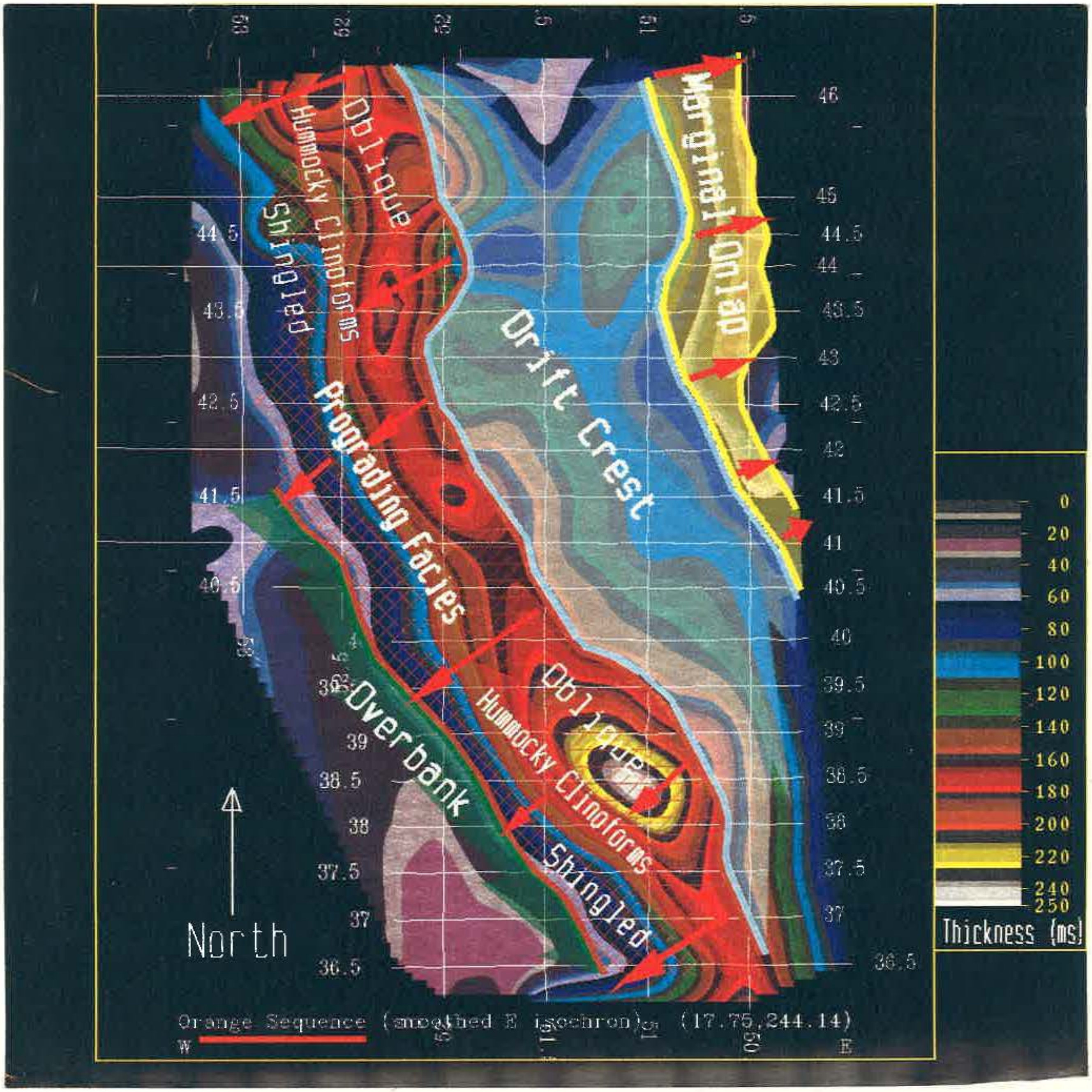

Figure 5. Seismic facies interpretation overlaid on the Orange Sequence (E) isochron map.

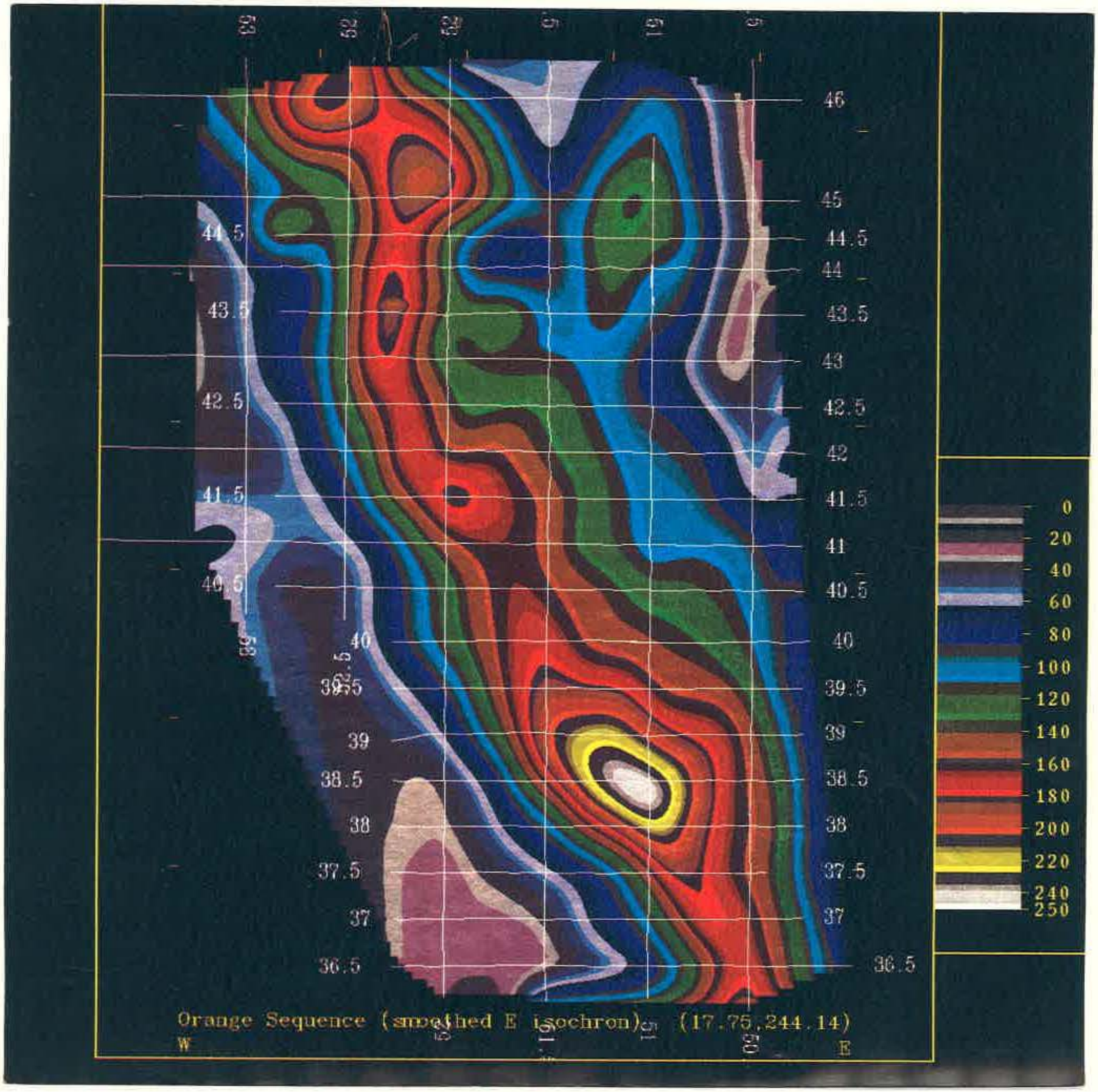

Figure 6. The Orange Sequence (E) isochron map.

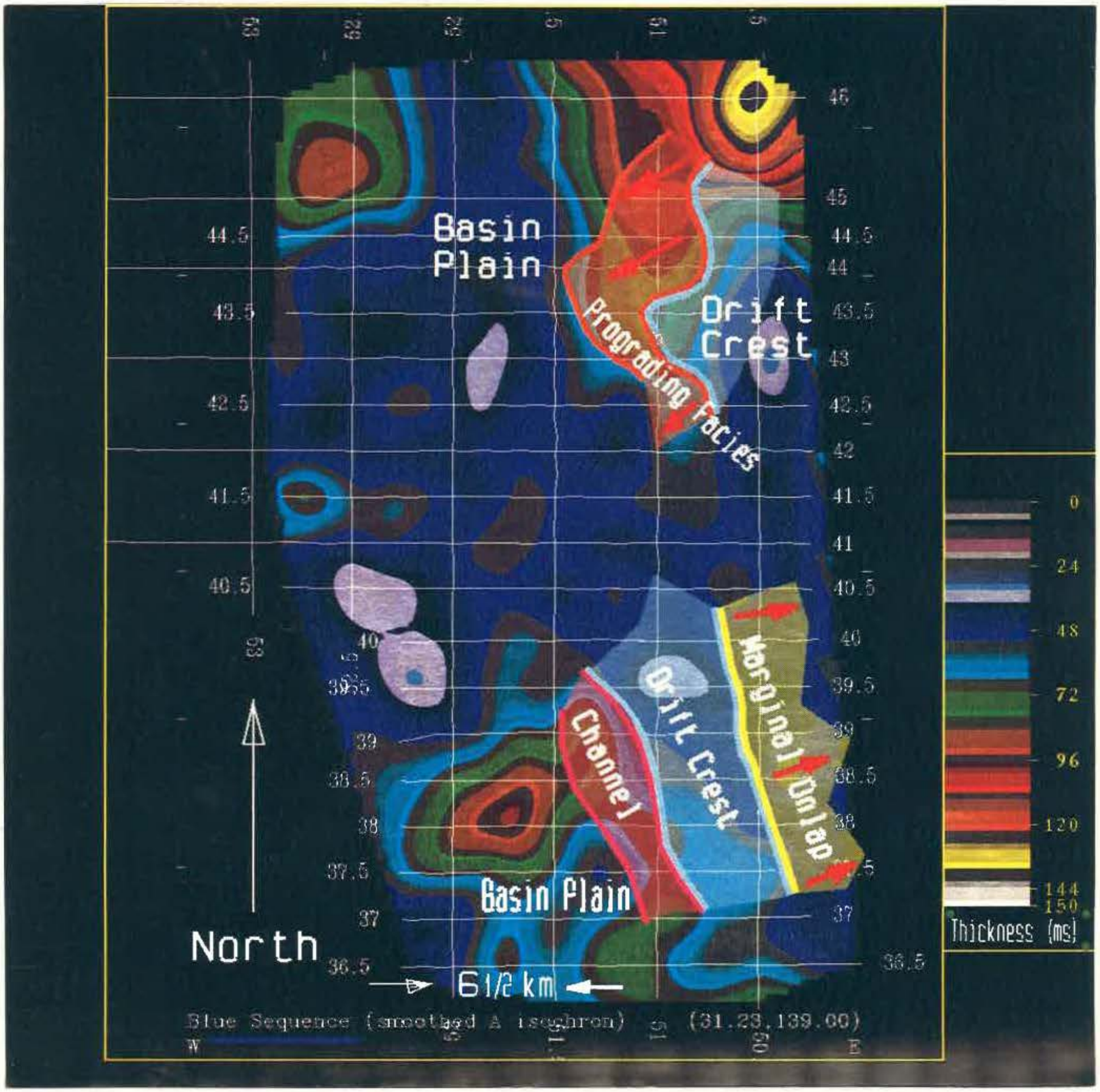

Figure 7. Seismic facies interpretation overlaid on the Blue Sequence (A) isochron map.

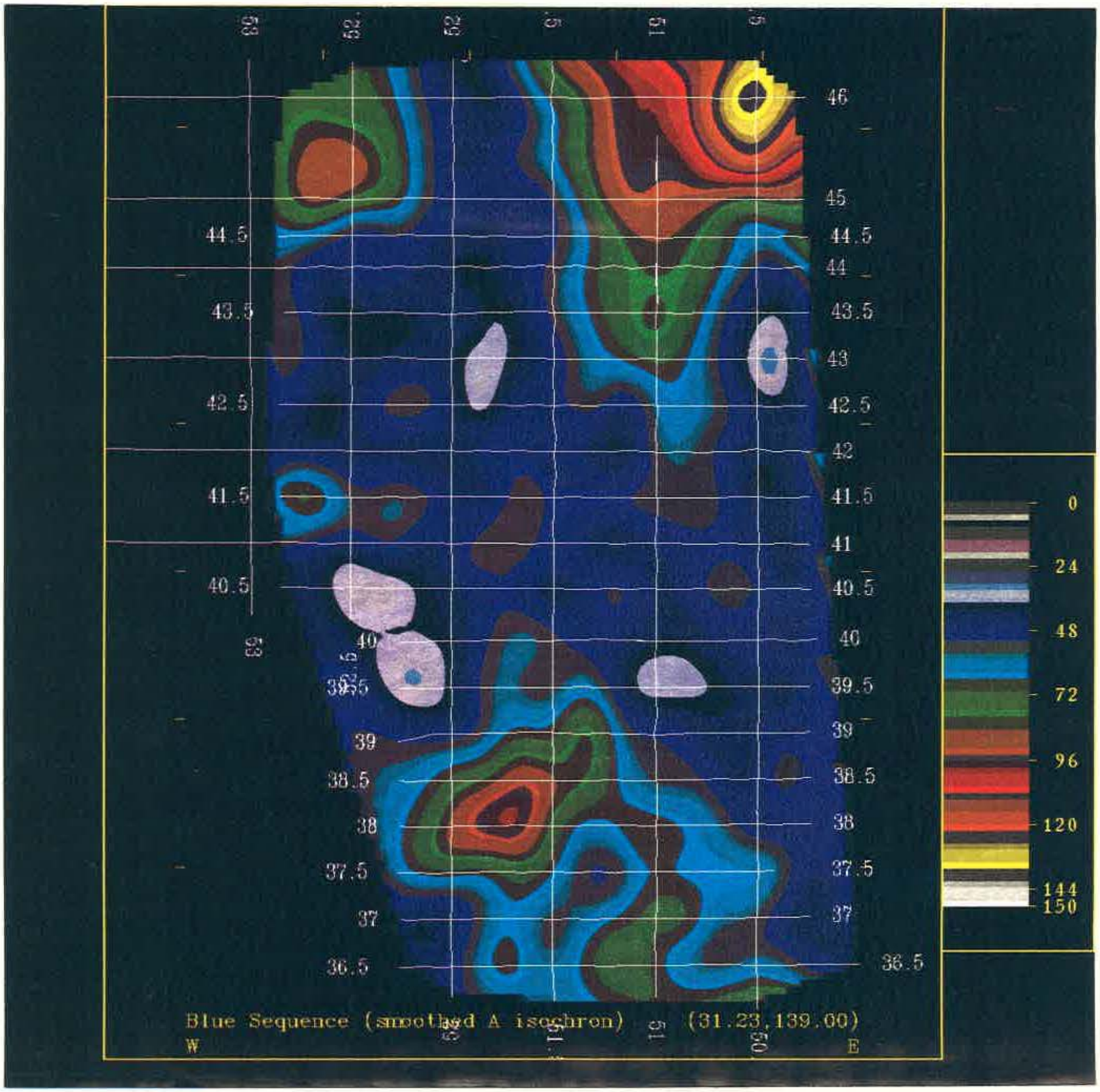

Figure 8. The Blue Sequence (A) isochron map.

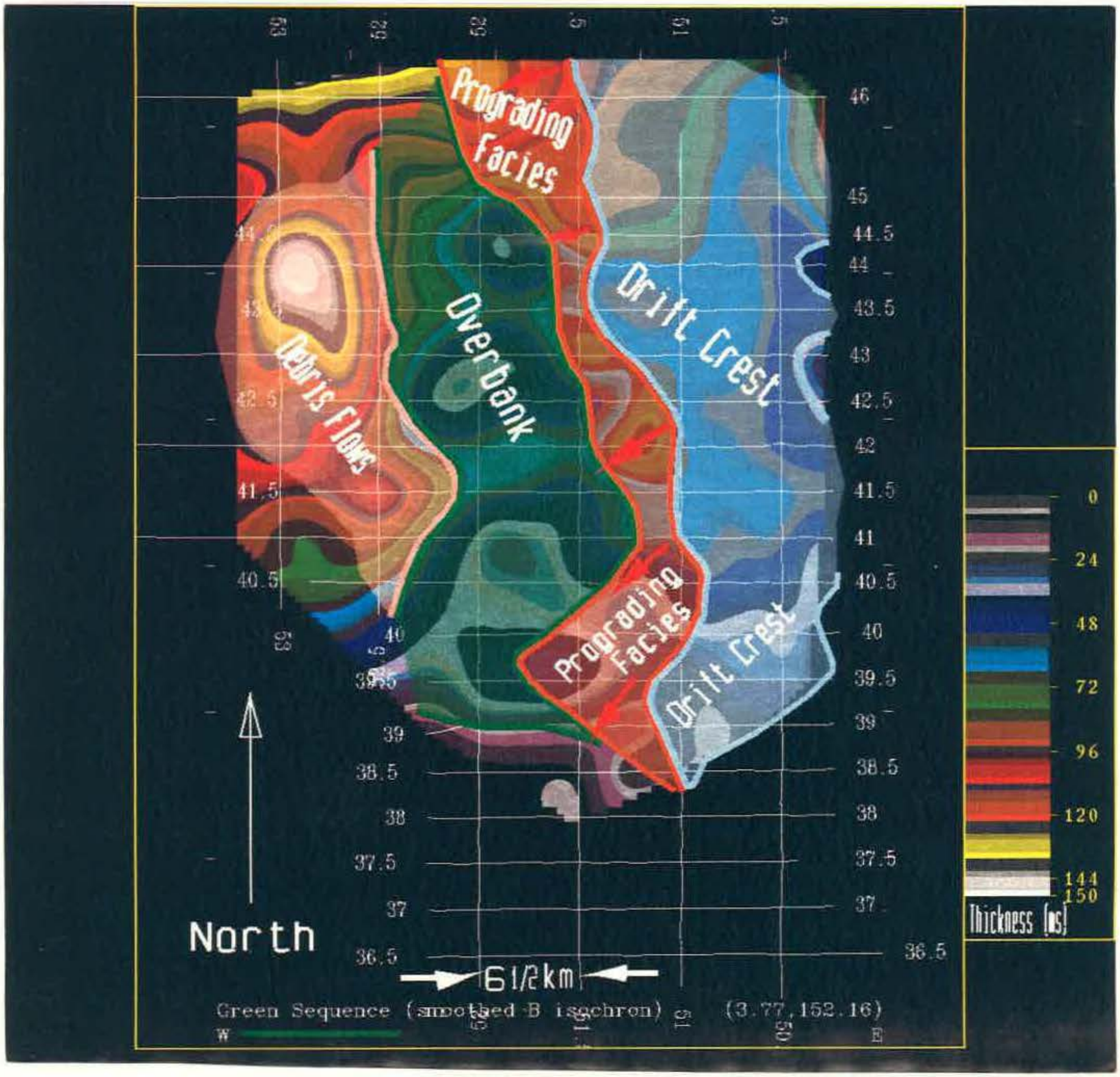

Figure 9. Seismic facies interpretation overlaid on the Green Sequence (B) isochron map.

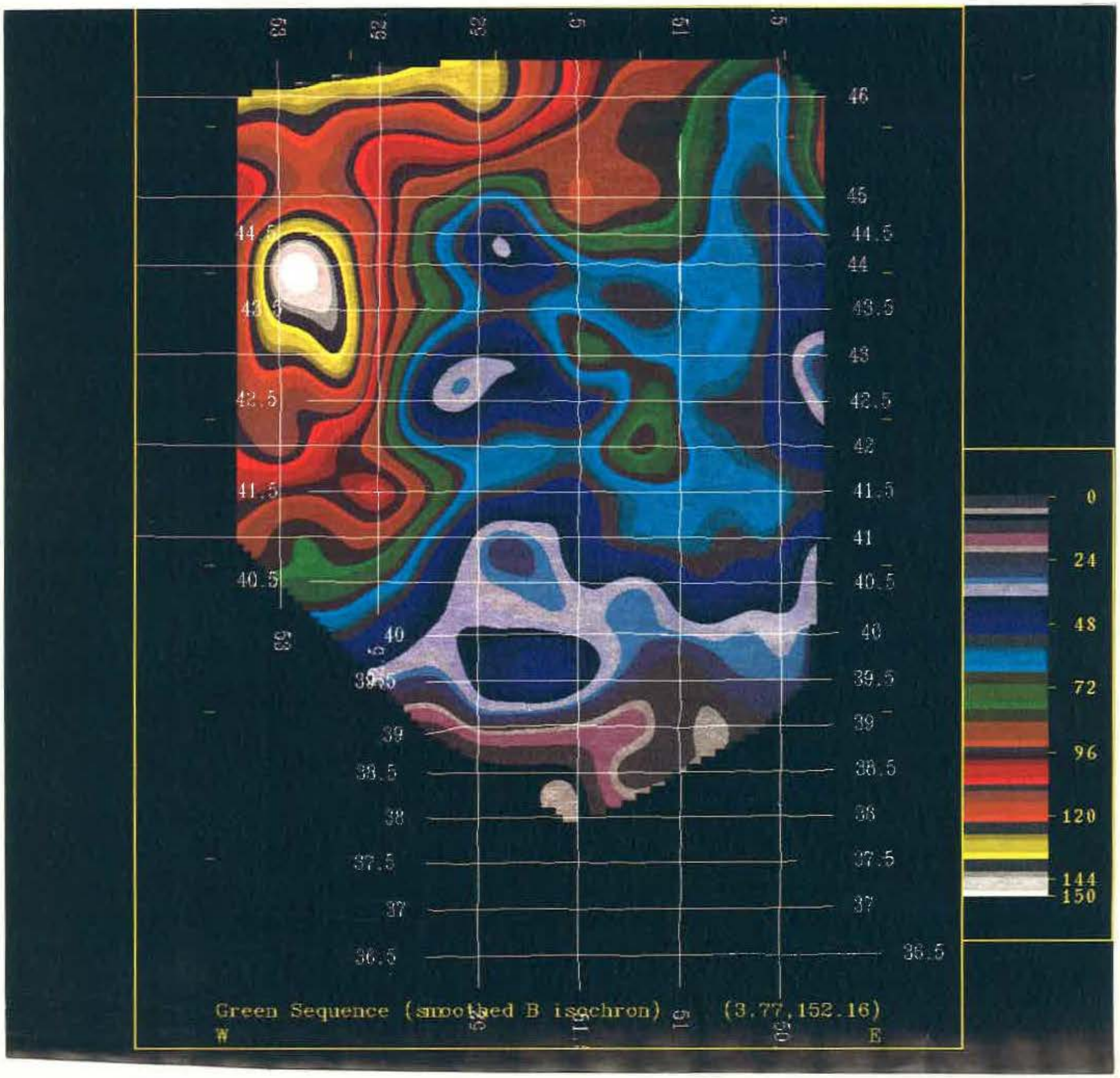

Figure 10. The Green Sequence (B) isochron map.

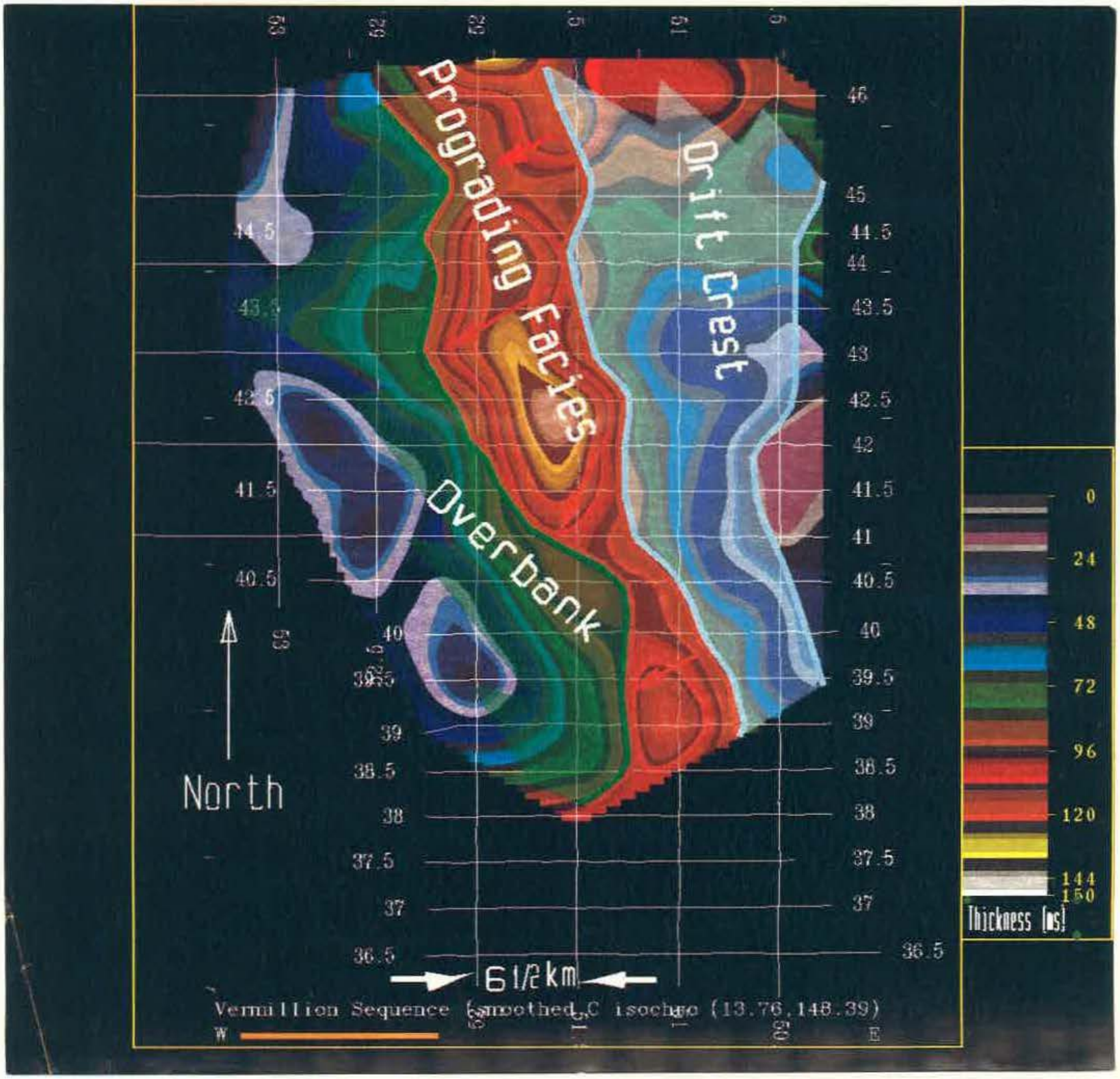

Figure 11. Seismic facies interpretation overlaid on the Vermillion Sequence (C) isochron map.

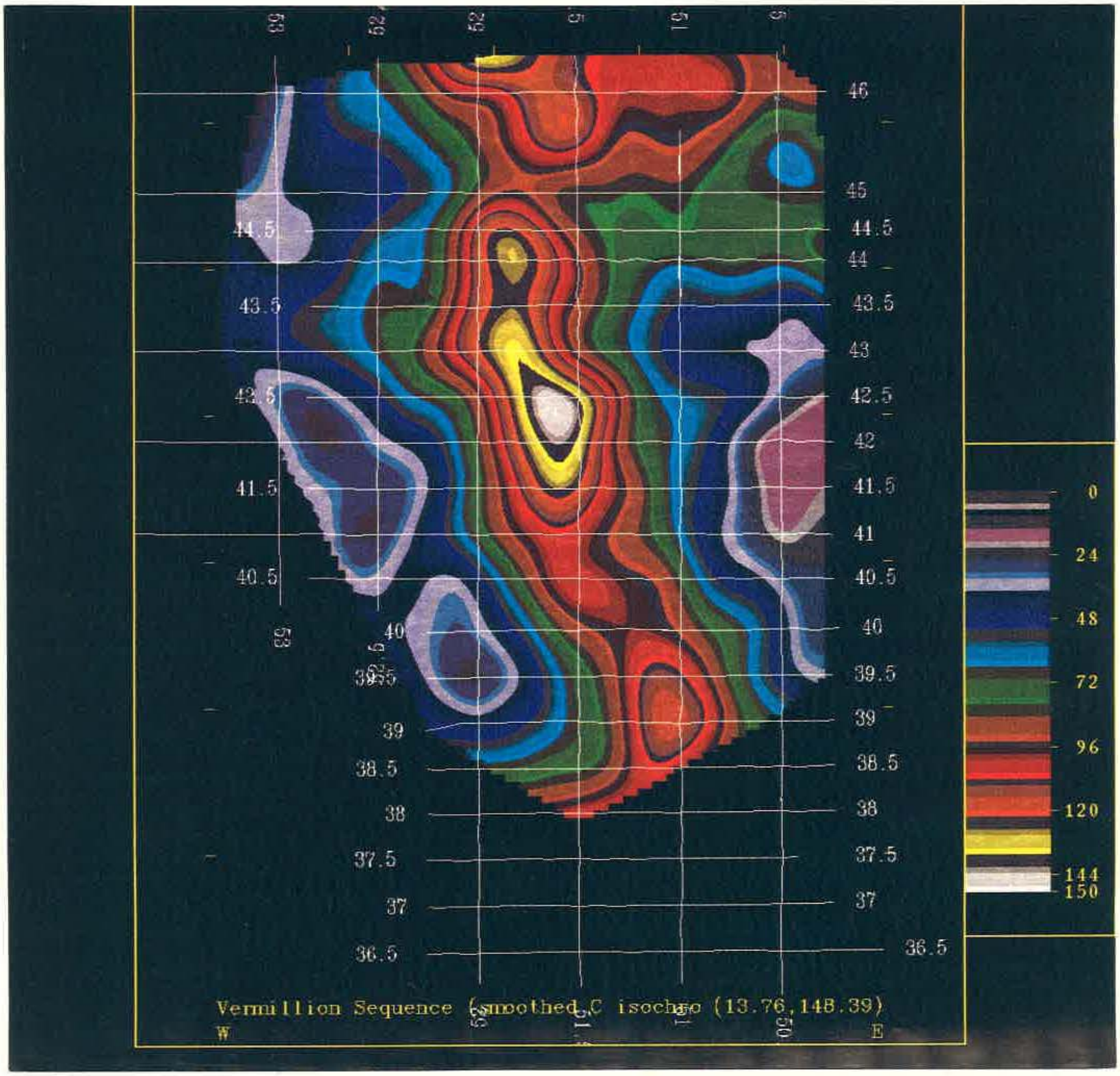

Figure 12. The Vermillion Sequence (C) isochron map.

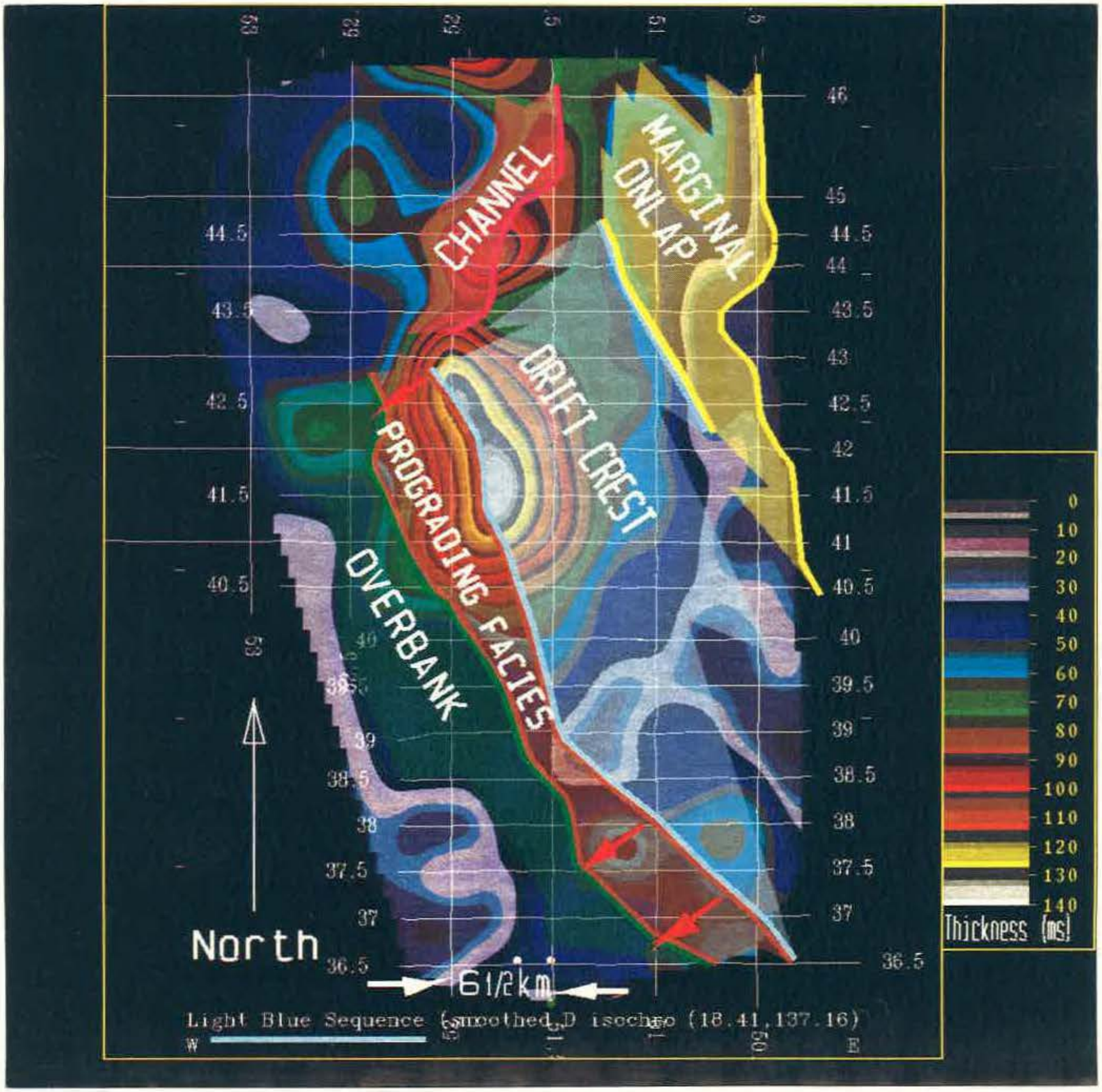

Figure 13. Seismic facies interpretation overlaid on the Light Blue Sequence (D) isochron map.

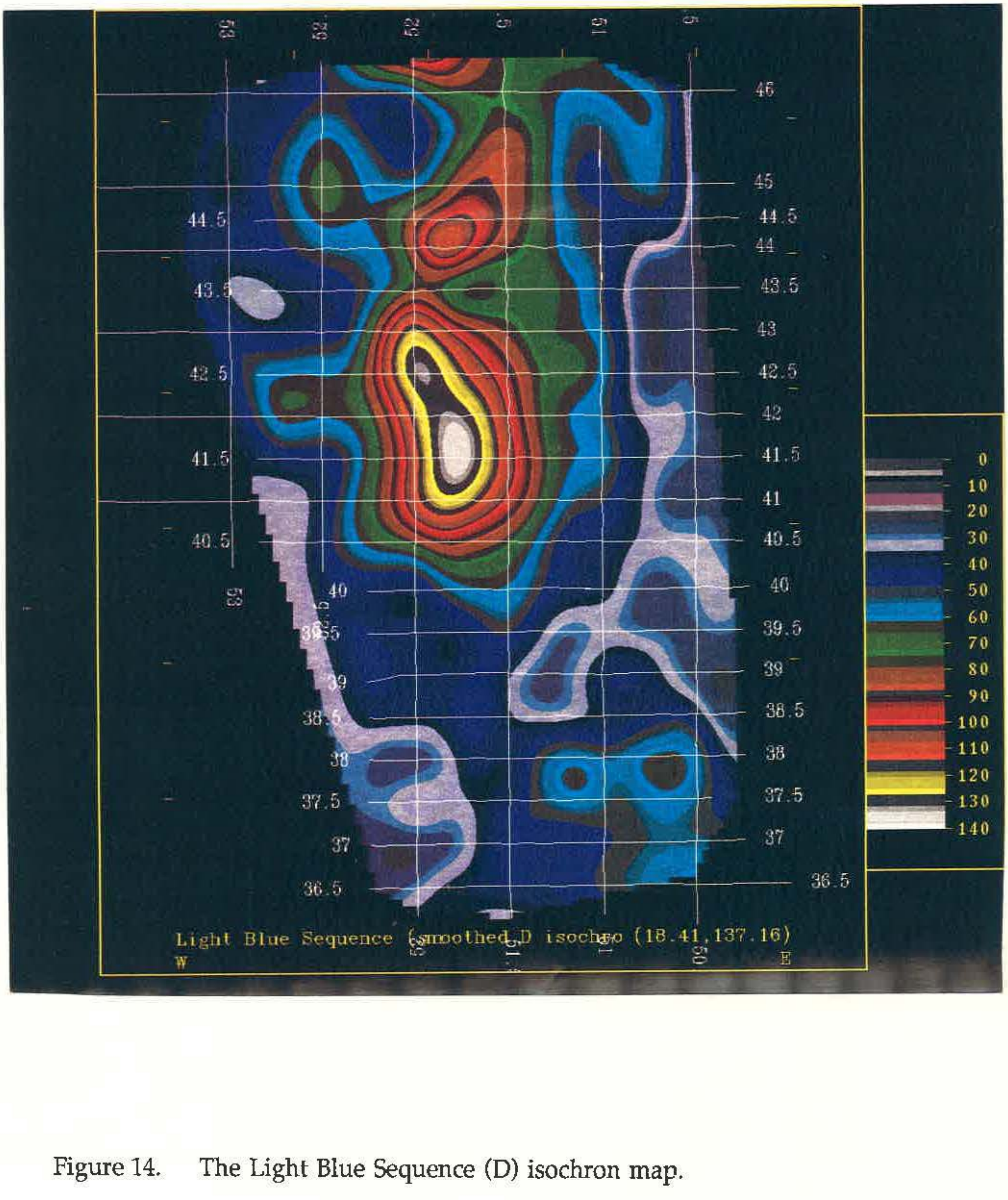

Figure 14. The Light Blue Sequence (D) isochron map.

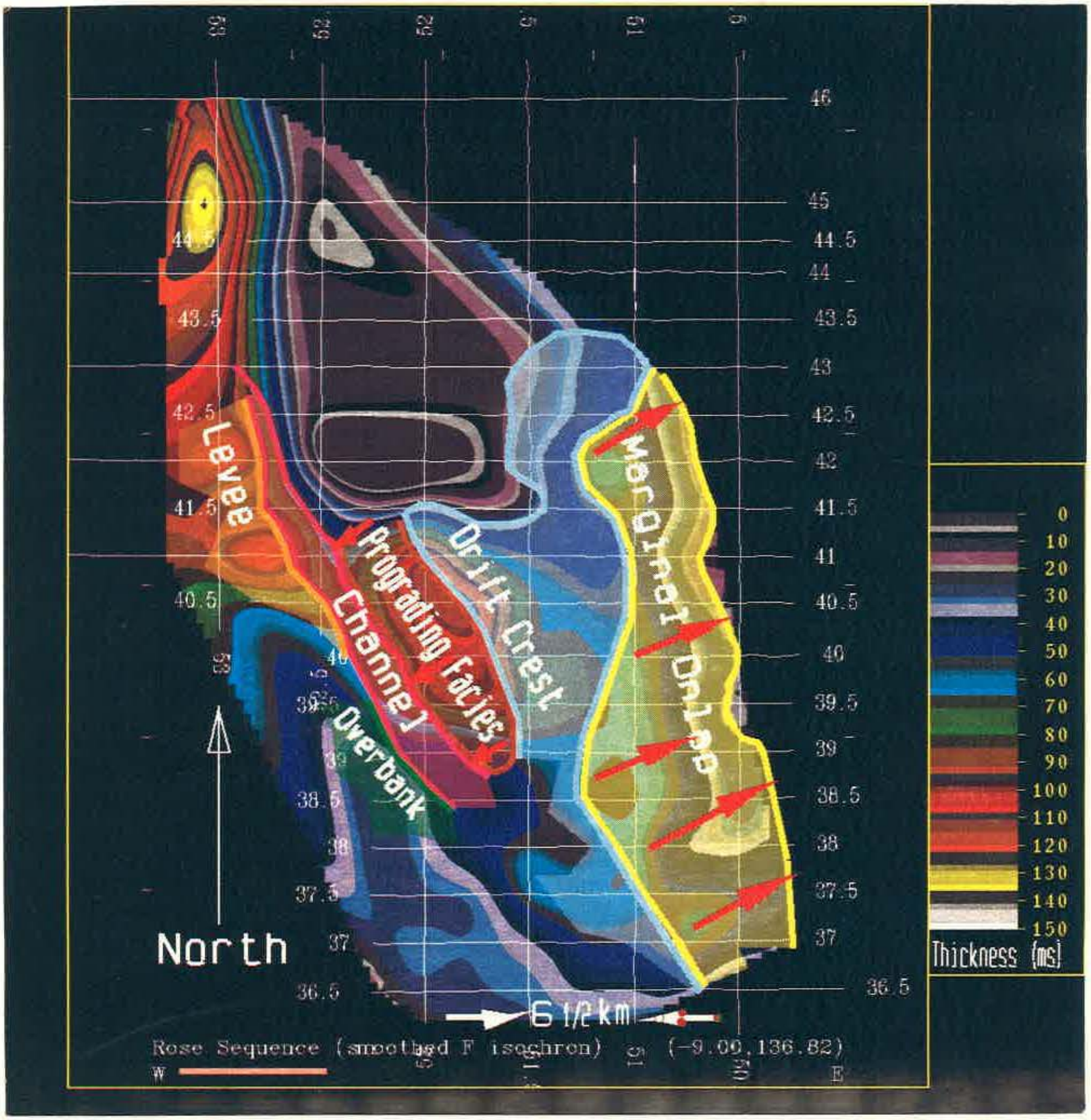

Figure 15. Seismic facies interpretation overlaid on the Rose Sequence (F) isochron map.

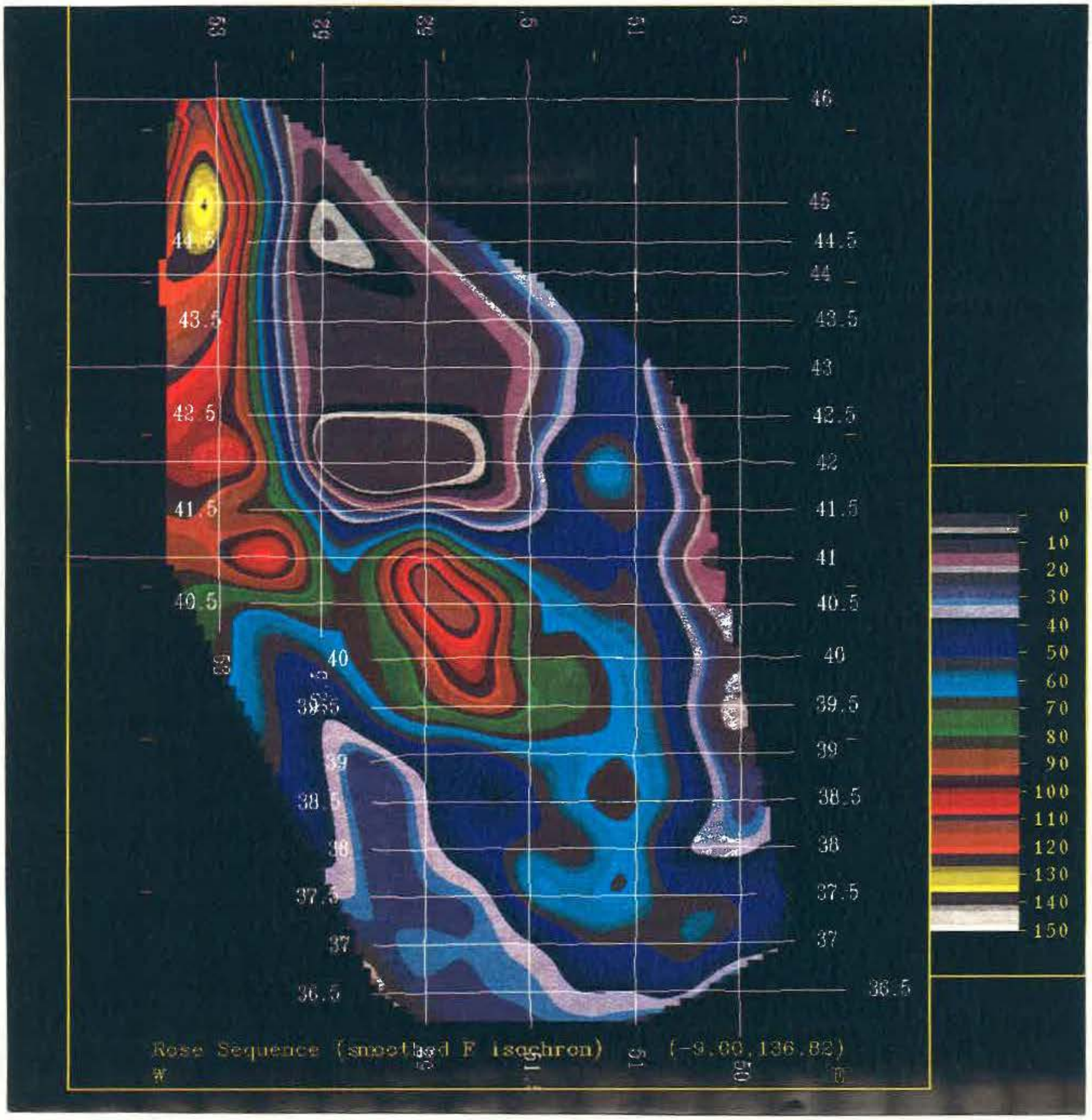

Figure 16. The Rose Sequence (F) isochron map.

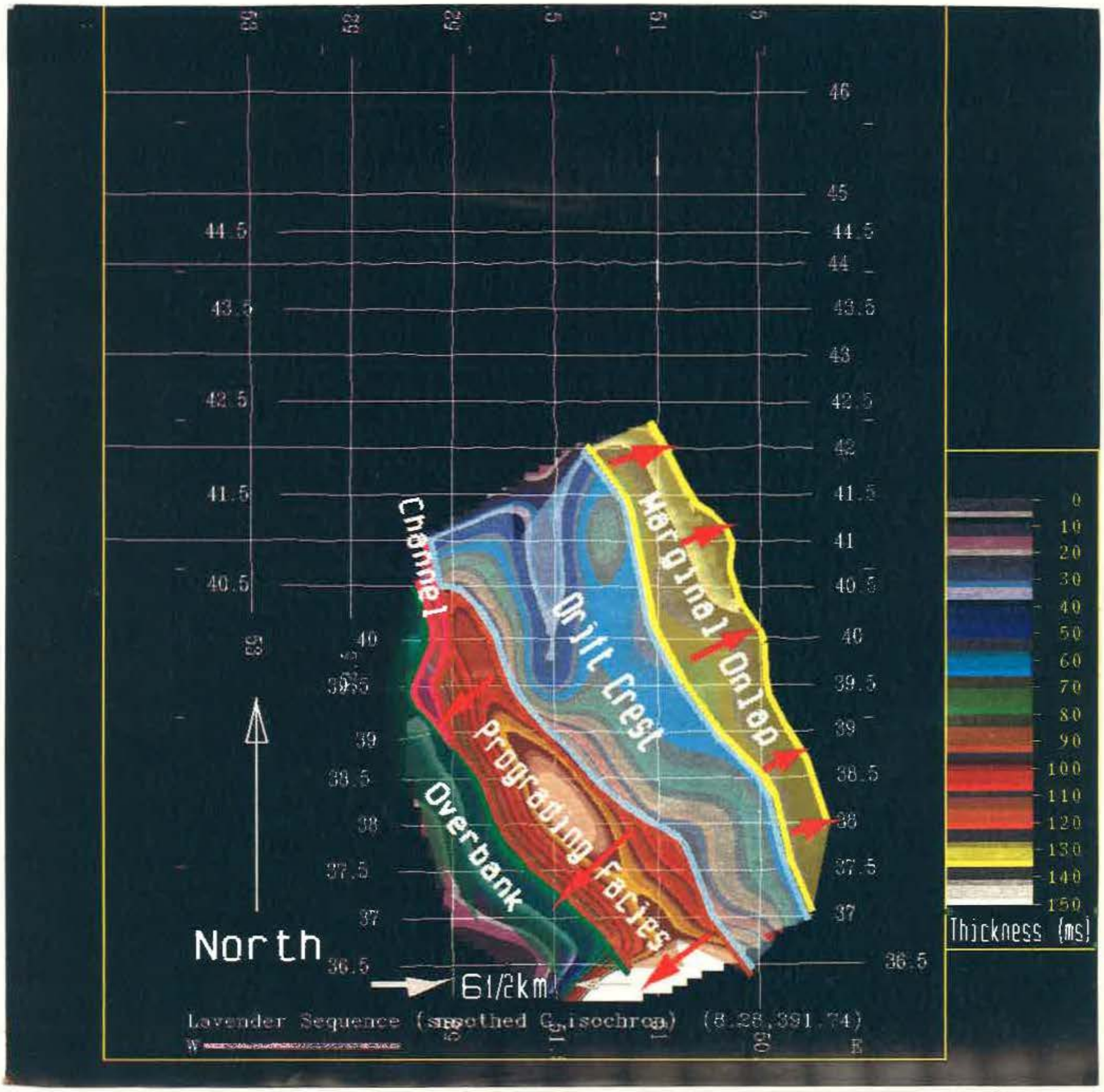

Figure 17. Seismic facies interpretation overlaid on the Lavender Sequence (G) isochron map.

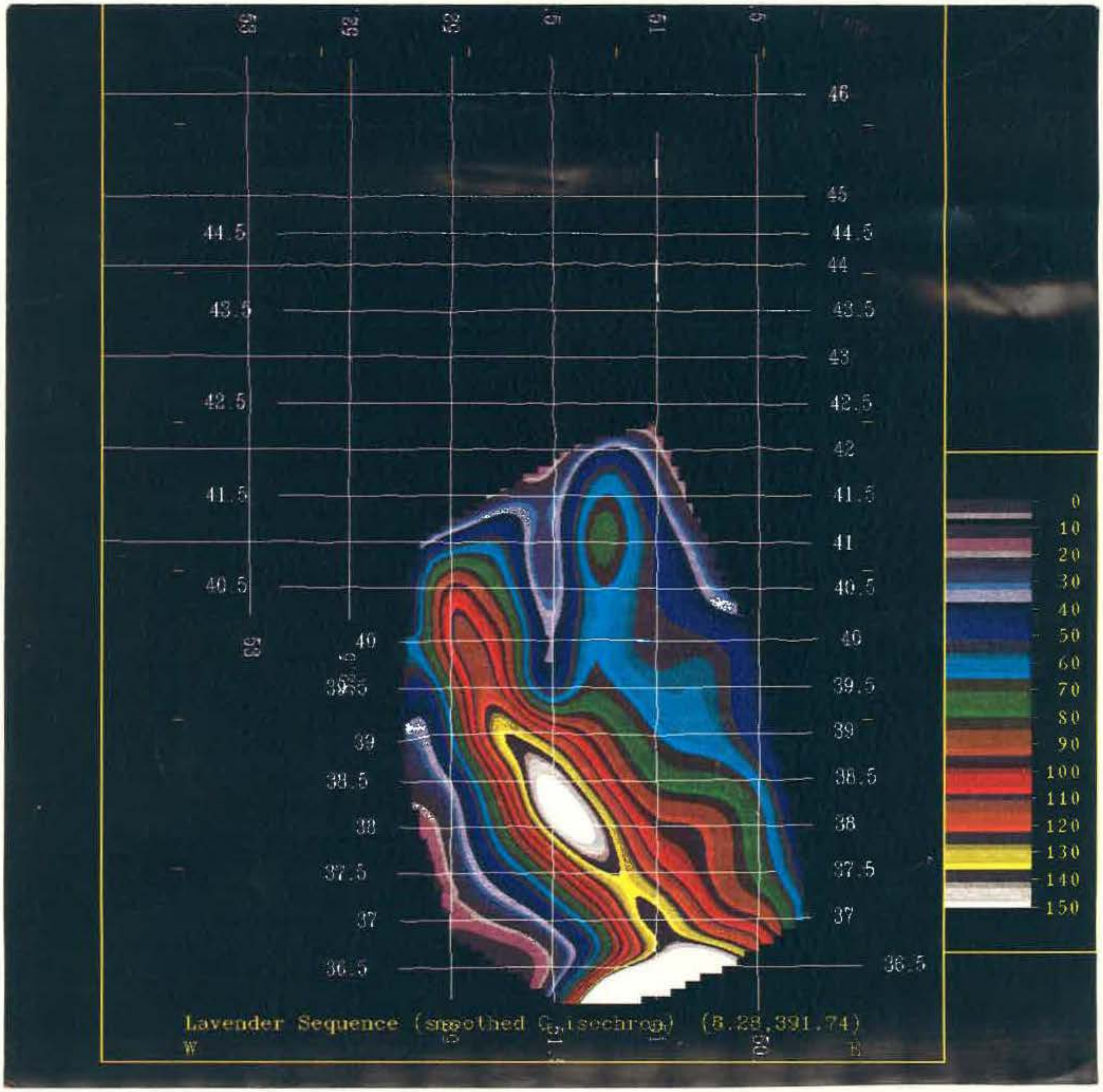

Figure 18. The Lavender Sequence (G) isochron map.

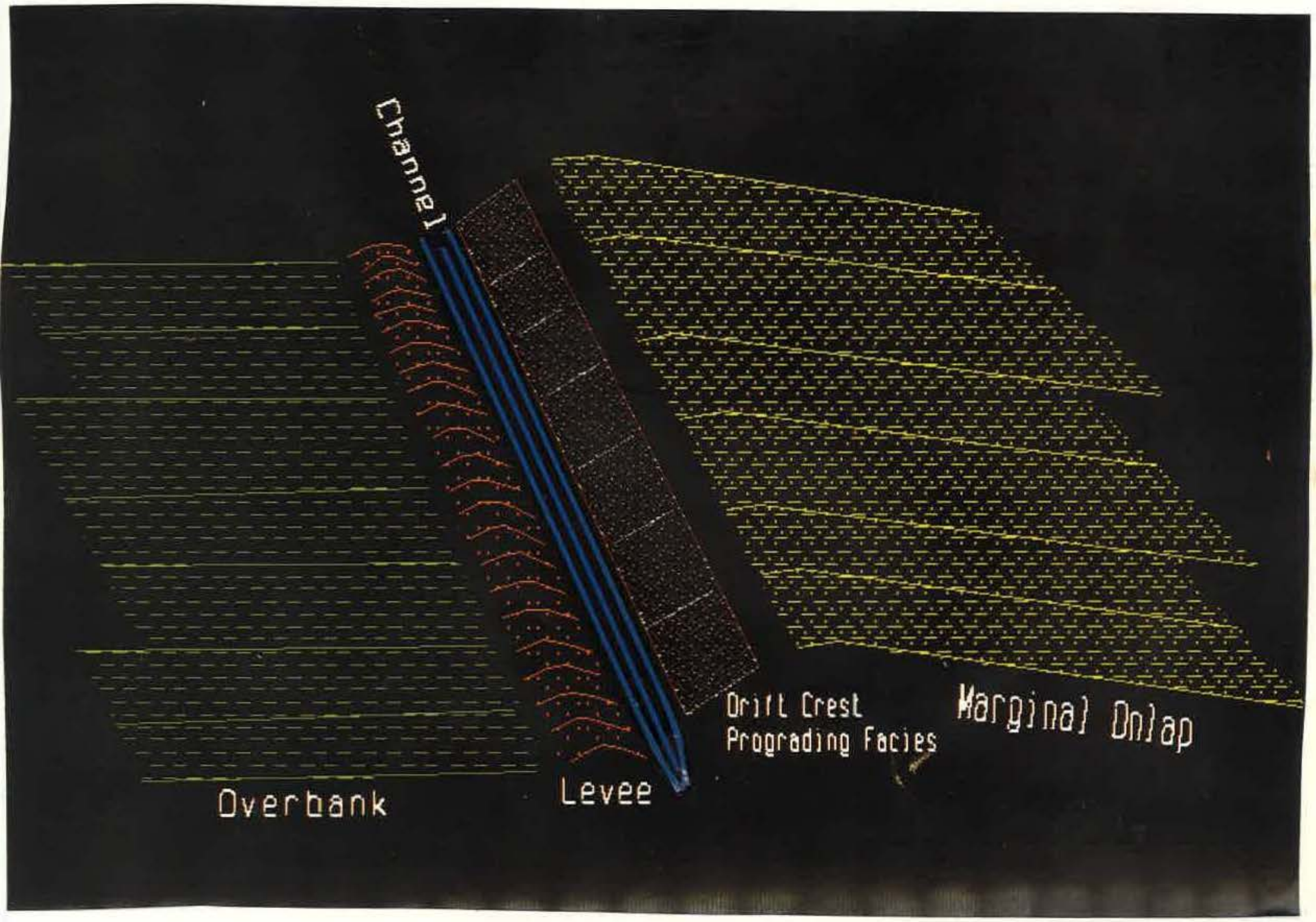

Figure 19. Diagram indicating the surface morphology during the accumulation of the Orange Sequence. The channel is drawn to suggest the flow patterns that produced the sequence.