SALNOR - NORTH SEA MODEL: BUILDING, DATA ACQUISITION AND INTERPRETATION

H. Roice Nelson, Jr. & other Project Contributors
Allied Geophysical Laboratory
University of Houston

PROJECT CONTRIBUTORS

Ingebret Gausland, Statoil:
- initiated the project
- released all data and results to the AGL

G. H. F. Gardner and J. A. McDonald, AGL:
- modified model design
- monitored progress

Deepak Khosla, SAL:
- coordinated and helped build the model and collect the data

Chris Wade, SAL:
- helped build the model
- helped with data collection
- documented project and drafted procedures and results

Asad Karim, SAL:
- helped build the model
- helped with data collection
- helped with drafting and clerical work

Ralph Allgood, Engineering Shop:
- machinist support

Steve Rhul, Engineering Media Center:
- photographs of model
- drafting and illustration support

David A. Fisher, SAL:
- coodinated 3D migration
- display of different data sets on the Adage

Vikram S. Sohal, IPL:
- digitization software for contour map input
- color seismic section display on ID-100

Richard W. Verm, IPL:
- program to do synthetic traces from well cores
- helped with Adage displays and color ID-100 pictures

Anjana Shah, SAL:
- digitization of horizon 3 (J-Unconformity) map
- input of depths for synthetic traces from well information

Sam Agbo:
- input of depths for synthetic traces from well information

Phillip Booth, UH Audio Visual:
- video tapes of data display and interactive interpretation

ABSTRACT

This paper describes the building, data acquisition and interpretation of a complex physical model, SALNOR. The model illustrates a "typical" complicated North Sea geological structural sequence. The model was built as a proprietary project for Statoil who then released it to the Allied Geophysical Laboratories (AGL). The model consists of seven horizons that represent the Top Paleocene, Top Cretaceous, J-Unconformity, Top Brent, Base Brent, Top Statfjord, and Base Statfjord. The model materials used were water (Tertiary), 3120 red RTV (Paleocene), 184 clear RTV (Cretaceous), 3110 white RTV (pre-J-Unconformity shales), 3120 red RTV (Brent), 3110 white RTV (pre-Brent shales), 3120 red RTV (Statfjord), and 3110 white RTV (Triassic).

The steps required to build the model are given, along with photographs of the model taken as construction progressed. The 3D data set across the model consisted of 240 traces on 240 lines. Several other data sets across this model have been collected for catalog six. In order to determine the exact relationships of all the layers, the model will be sawed into 16 square blocks. "Wells" were also cored in the center of each of these 16 blocks. An acquisition test across the reassembled blocks verified that data can be collected again without creating excessive diffraction noise.

The initial interpretation was done on paper sections. Later the raw data and 3D migrated data were evaluated using the interactive interpretation capabilities of the Adage vector refresh graphics system. The data display techniques are shown with figures and with a video presentation. An interactive interpretation is also illustrated with video tape. This model data can be used to try different interpretation procedures. The value of using a complex 3D model to teach interactive interpretation techniques is manifest in evaluating this relatively small data volume.

MODEL DESIGN AND CONSTRUCTION

In late 1981 Ingebret Gausland from Statoil requested SAL to devise a workshop on 3D interpretation methods that interpreters working in the North Sea would find applicable to their work. It was decided that the best procedure would be to build a model that represented a typical North Sea structure and geologic sequence and to base the workshop on it. From this basic concept, the SALNOR model was designed. Figure 1 is a contour map of the only horizon that was contoured, the J-Unconformity. The two layers above this were to be flat, and the layers underneath of constant thickness but dipping and parallel to each other within each fault block. Deviations from the nominal dimensions occurred during construction and introduced an added degree of realism.

Post-J-Unconformity Construction

With the basic concept defined, the map was digitized on the Tektronix 4081 and displayed in 3D on the Adage. This allowed a visualization of the best way to put the different layers together. The contour map was scaled so that 1 in. = 1000 ft. In the next step, critical contours were cut out of plywood and stacked as shown in Figure 2, so that the exposed surface represented the bottom of the Cretaceous layer above the unconformity. Figure 3 shows how the contour steps were filled in with clay to form a smoothed inverse surface. A plaster cast was made of the clay surface, and represented the top of the unconformity. Cretaceous (clear RTV) was poured on the positive plaster cast as is shown in Figure 4. The Top Cretaceous formed a flat surface after this layer had been poured.

The modeling box was not tall enough for the thick plaster base, the Cretaceous and the Paleocene (red RTV). Therefore the clear material was pulled off the plaster base and supported on 3 blocks within the 6 inch high modeling box before the red RTV was poured to create Horizon 1. At this point gravity lowered the flat surface of the Top Cretaceous between the three supports when the red material was poured on it. This became evident when the seismic data were played back from the physical model.

The Top Paleocene (Horizon 1) is fairly flat, but the isocron between the layers is not flat because of the warping of the Top Cretaceous (Horizon 2).

Pre-J-Unconformity Construction

The thick plaster mold for the J-Unconformity, shown in Figure 5, was key to building the lower layers of the model. Figure 6 illustrates how the plaster mold was shaved off with a plane to form the top of the first dipping layer, the Top Brent or Horizon 4. Note that the corner of the model at the bottom of the dip had been cut off. This corner was kept in it's origional shape in order to make sure that the spacing between the plaster mold and the clear layer was correct. To pour the white RTV in this space the model and modeling box were stood on one end. Then the plaster cast was clamped against the clear layer leaving a gap to pour into. Figure 7 shows the Horizon 4 after the pour had been completed.

Once the dip on the Top Brent was defined within each fault block, the plan was to keep all of the deeper horizons parallel so that there would be a constant thickness for each layer. To do this a set of holes was drilled into the plaster to the exact depth of the next layer. Next the plane was used to shave off the plaster to the bottom of the holes. The biggest problem with this was that the composition of the plaster was not constant. This resulted in portions shaving off faster than others. Also, the drill holes filled up with shavings, and it was hard to determine when the proper level had been reached. However, a fair approximation was made, and red material poured into the void to form the Brent Sandstone. Figure 8 illustrates the results of this pour and defines Horizon 5 (Base Brent). The red RTV is viscous and it was hard to get it to flow all the way to the end of the pinchout against the J-Unconformity. The thinnest portion of the pinchout had to be repoured for this layer.

The same procedure described above was used to modify the plaster mold for the Top Statfjord or Horizon 6. Figure 9 shows what the plaster looked like at this stage. The void between the Brent and Statfjord was filled with white RTV. The plaster was then shaved a last time to form the Base Statfjord or Horizon 7 (Figure 10). The problem that resulted from the spacing drill holes is illustrated in Figure 11. The small holes shown here did not appear until the plaster cast was pulled away from the model. Some of the silicon rubber had worked between the loose plaster grains and the plaster in the holes stuck to the model when seperated. This scraped off of the model and did not detract from the construction. It can be seen in Figure 12 that the Base Statfjord horizon is smooth, but the thickness of the sands was variable. The Basement (Horizon 8) is defined by a flat white/water interface (Figure 13).

With the faulted portion of the model completed, the last construction step was to pour the corners. Both corners were filled with 3 flat layers that were parallel to the surface. The Top Brent (Horizon 9) and Base Brent (Horizon 10) are illustrated in Figures 14 and 15 respectively. Figures 16 and 17 are a side and top view of the completed model in the modeling tank.

DATA COLLECTION AND ACUTAL MODEL MAKEUP

Seven sets of data were collected across the SALNOR model, as explained in the SAL May 1982 catalog. The common offset 3D survey with 240 traces on each of 240 lines is the basis for the examples used in this report. This is model SALNOR-7 in the catalog. The trace locations form a 100 foot scaled grid that covers the 24,000 foot square model.

When these data were analyzed, it became obvious that there were some unexpected differences from the original design. The most glaring example was the varying thickness of the Paleocene layer as described above. To measure these differences it was decided that the model would be cut into 16 blocks as shown by Figure 18. The location for 49 "wells" to further define the model are also shown on this drawing. A stylized geologic cross-section through 11 synthetic seismic traces generated from measurements of some of these wells is illustrated in Figure 19. The first few wells that were drilled had problems, in that the core disintegrated. However this was solved for most of the other wells. Figure 20 shows the location of 7 cross-sections that were made directly from the cuts across the model. These cross-sections are shown in Figures 21-23. The model does closely meet the original design.

It is interesting that good quality data can still be collected across the reassembled model, as illustrated in Figure 24 and 25. The model was cut with a band saw and up to about 1/16th of an inch of material (60 feet scaled) was removed. However, this had little effect on the data. The same holds true for the 1/4 inch wells (250 foot diameter scaled), that were drilled in the center of each block. It has been shown (Woods, 1976) that such holes have to be at least 2λ in diameter to affect reflections. In our case this dimension would need to be 0.5 inch. However, there are diffractions from the cuts that can be seen on these data.

DISPLAYING AND INTERPRETING THE 3D DATA VOLUME

This model provides a good data set for showing the problems of trying to evaluate complex geological 2D structures on the basis of a few vertical 2D sections. Of course, when there are enough vertical sections to define spatial structural changes, then there is too much paper to handle. This is where the value of interactive computer graphics becomes obvious.

Horizontal Time Slice Sections

Horizontal or time slice sections are of great benefit in reducing the data needed to evaluate the 3D data volume. Figures 26 to 32 illustrate how effective a few of these sections are in providing an overall understanding of a complex geologic structure, even when, as in these sections, each trace has been reduced to signbit data. In other words the samples are either turned on (positive polarity) or off (negative polarity). Even with this minimal display resolution, a good picture of the subsurface emerges.

This picture is further enhanced by 3D migration. The left half of each time slice has been three-dimensionally migrated and is displayed on the left of each of the raw time slices in Figures 26 to 32. Note how the contours are "focused" by 3D migration in Figures 25 and 25. This is especially evident in collapsing the diffraction "bubbles" shown in Figures 28 and 29. The top portion of the migrated time slice in Figure 30 shows a string of air bubbles that generated prominent diffraction rings on the raw data set. Figures 31 and 32 show how migration moves the horizon contours to their proper position somewhat updip of the raw data.

Mixed Horizontal and Vertical Sections

Another computer graphics display technique that helps in evaluating a data volume is to mix horizontal and vertical seismic sections (Verm and Nelson, 1982). Figure 33 illustrates this type of display at two different scales. The top picture is such that the horizontal section is properly scaled (the same as in Figure 27). However, the vertical section is so exaggerated that it does not create a readily recognizable picture. By scaling the vertical section to more closely simulate the scales of normal display, the structural relationships become more apparent. The bottom picture shows both sections scaled down in the vertical axis. This scaling also gives the horizontal section some appearance of depth, as if it were on the top side of a box. The vertical and horizontal sections look very similar when they are both displayed as signbit data.

The real value of mixing horizontal and vertical sections is shown when a sequence of one or the other is animated or moved through. Figures 34 to 40 show example frames from horizontal and vertical animation sequences. In the first sequence, vertical section 82 is displayed and horizontal sections marched through from 401 to 500 ms in 5 ms steps.

Lateral structural definition that accompanies, for example, time slice 435 ms on Figure 35 should be noted; these data have been 3D migrated. The vertical section animation is just as interesting; the dip reversal between vertical sections 80 and 75 in the center of the appropriate section on Figure 39 can be seen.

FUTURE PLANS

There are many things about this model that need further study. For example, each of the well cores that was taken has different layer thickness measurements on each side. This information provides an accurate dip of the layers, and could be used to make more accurate maps of the actual model horizons. This information needs to be integrated with the cross-section information obtained in three-dimensions. The effect of the wells and the vertical cuts needs to be studied with a better seismic source. Also, the original 3D data set needs to be closely compared to the synthetic traces that were generated from measuring the model.

There are numerous applications for this data set in terms of studying display and interactive interpretation procedures. One of the first steps will be to compare multiple bit level displays with the single bit displays shown in this paper. This type of display includes studying the effect of color. Using the SpaceGraph to display 3D data relationships is another anticipated step.

REFERENCES

Woods, J. P., 1975, A Seismic Model Using Sound Waves in Air: Geophysics, v. 40, No. 4, p. 593-607.

Verm, R. W., and Nelson, H. R., Jr., 1982, Interactively Mixing the Display of Horizontal and Vertical Seismic Sections: Sei[illegible] Acoustics Laboratory Semi-Annual Progress Review, v. 9.

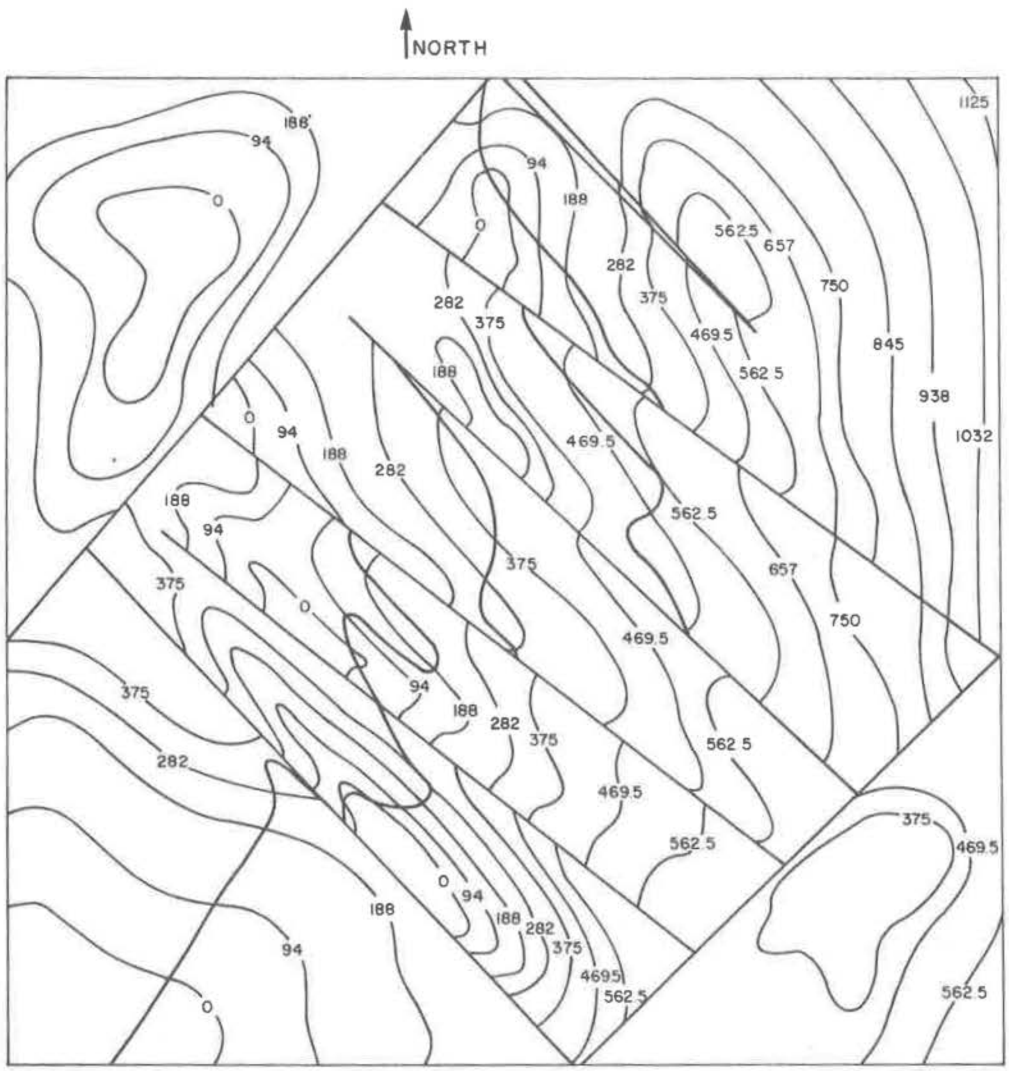

FIGURE 1. Map design for J-Unconformity (Horizon 3).

FIGURE 2. Plywood mold of critical contours defining J-Unconformity (Horizon 3). This is an inverse of what the structure would look like if the Cretaceous rocks were stripped away.

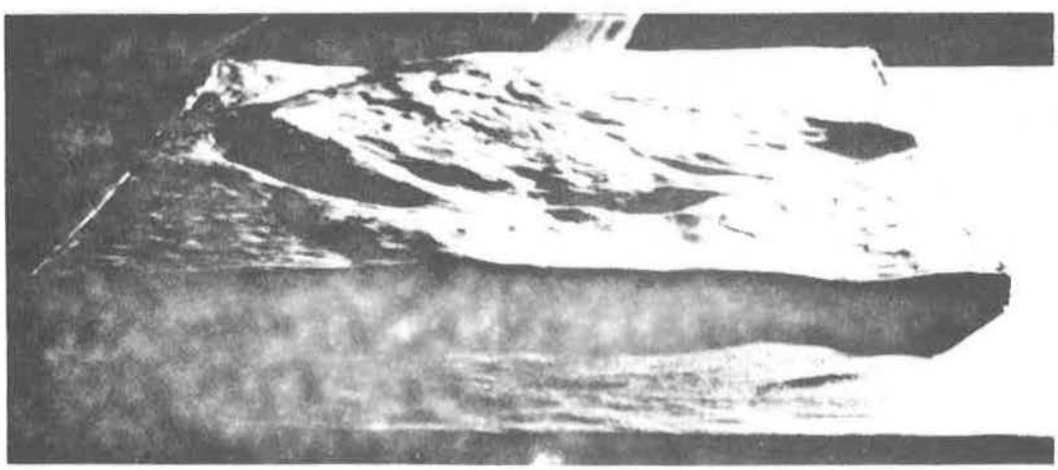

FIGURE 3. Clay mold defining J-Unconformity (Horizon 3). The clay is used to fill in the steps on the plywood contoured steps.

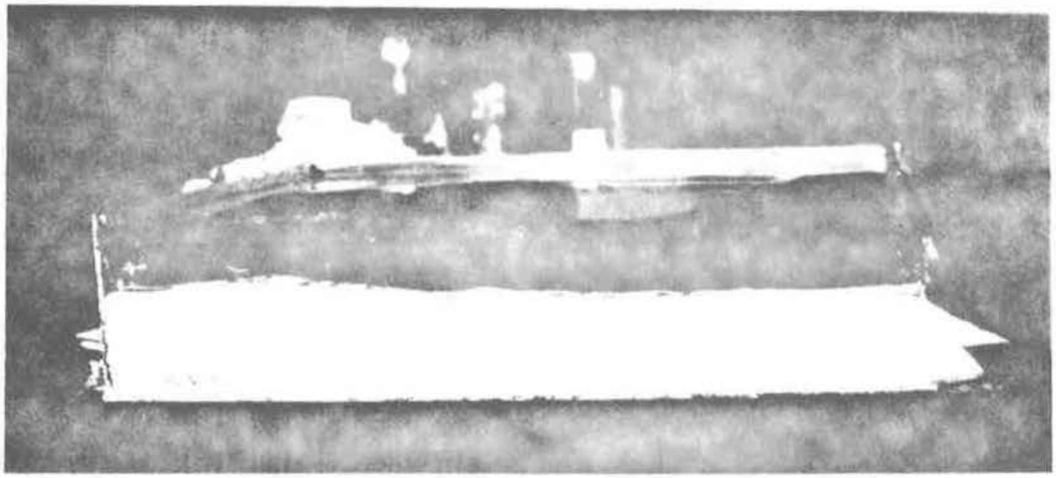

FIGURE 4. Paleocene (top 3120 RTV) and Cretaceous (Middle 184 RTV) layers sitting on plaster case of J-Unconformity. The Cretaceous was poured first (Top Cretaceous-Horizon 2) and the Paleocene poured over this layer (Top Paleocene-Horizon 1).

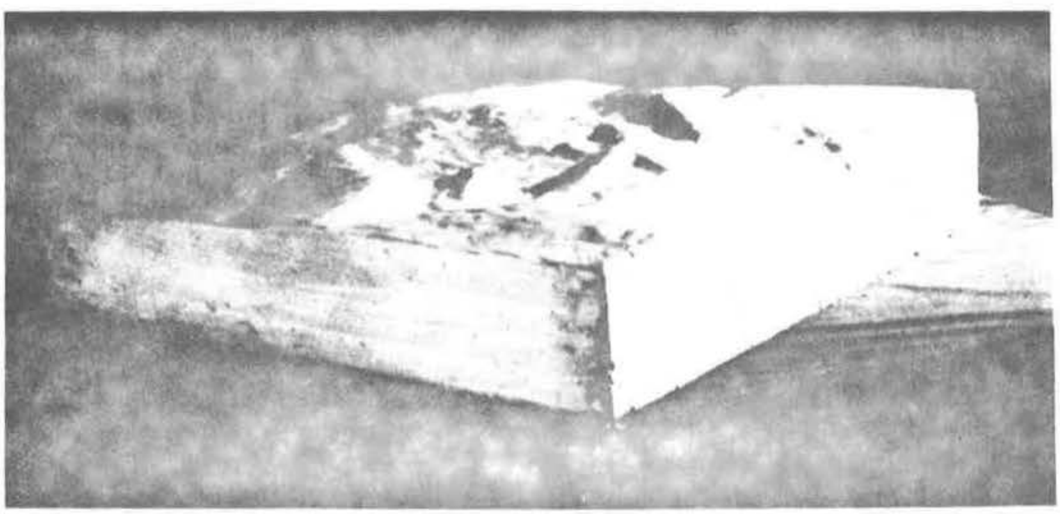

FIGURE 5. Plaster cast of J-Unconformity. (Horizon 3).

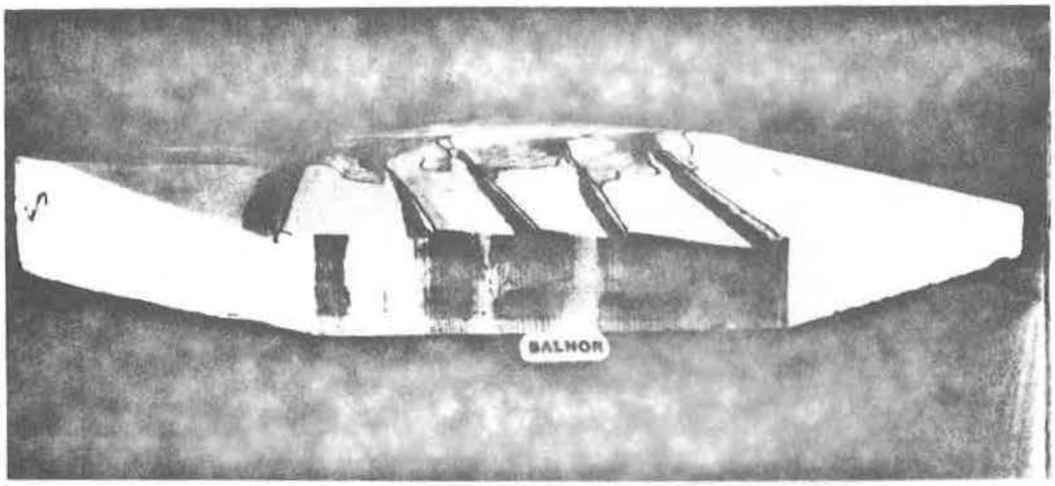

FIGURE 6. Plaster mold for Top Brent (Horizon 4). To make this the Faults were marked, and the plaster mold shown in Figure 5 was shaved off with a plane.

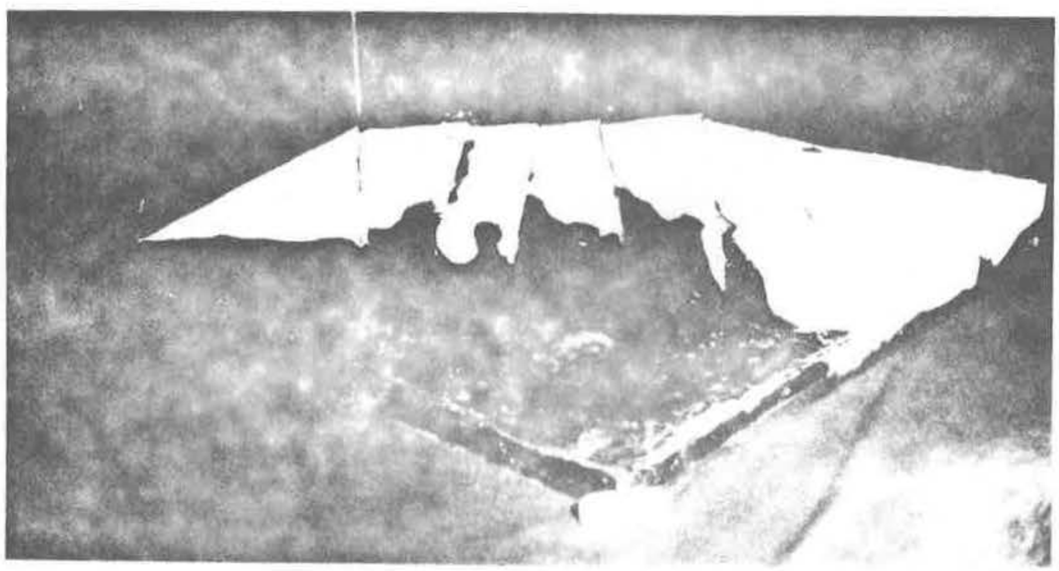

FIGURE 7. The Jurrasic layer (3110) RTV) that defines the Top Brent (Horizon 4). The model is upside down for this picture in relation to how it was placed in the tank for data collection.

FIGURE 8. The Brent Sandstone (3120 RTV) defines Horizon 5 (Base Brent). The model is upside down to show the horizon structure.

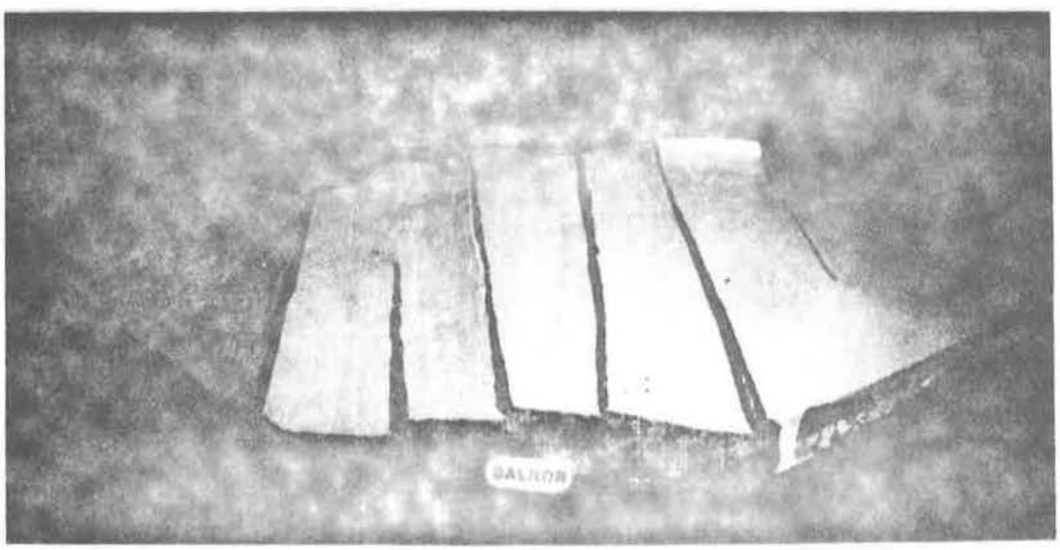

FIGURE 9. Each successive layer was made by shaving off more of the original plaster cast and pouring into the void. This is the plaster case for Horizon 6 (Top Statfjord) and was filled with 3110 RTV.

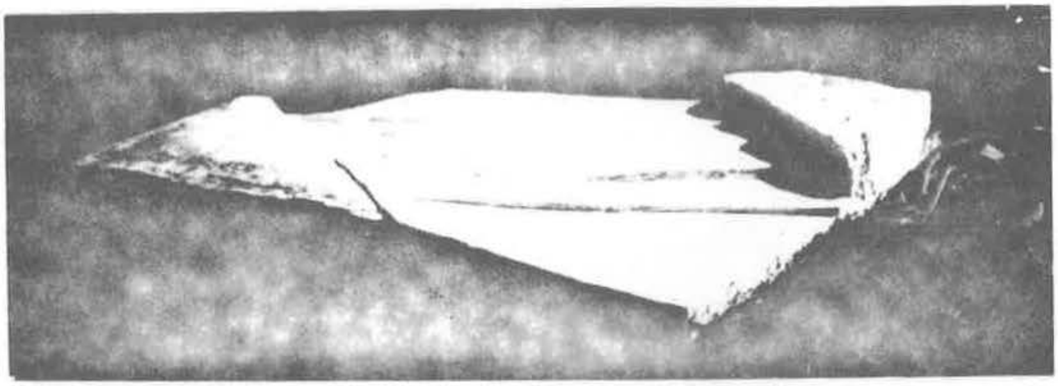

FIGURE 10. Plaster cast of Horizon 7 (Base Statfjord) which was the last shaving. Note that the two corner pieces were kept in their original shape to keep the model properly spaced from the plaster.

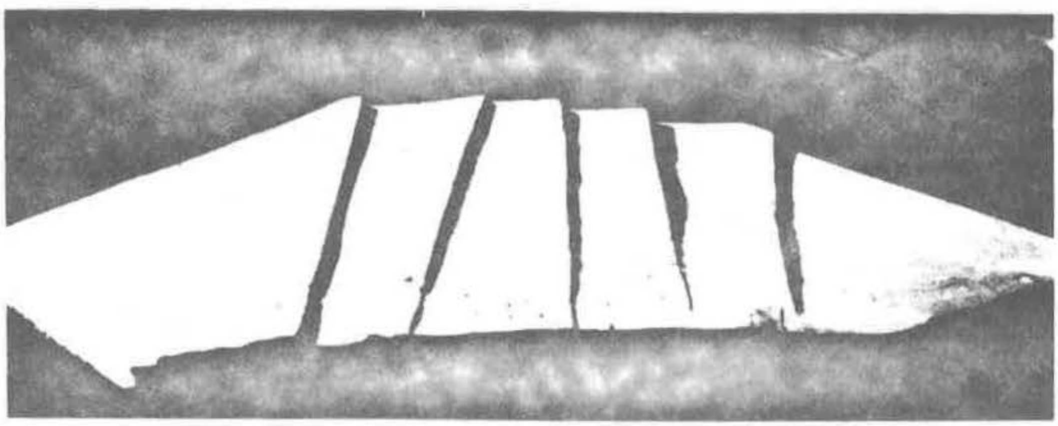

FIGURE 11. A close up on the Horizon 7 plaster cast shows small holes. These are depressions created in the plaster by the drill bit used to define how much plaster to shave off.

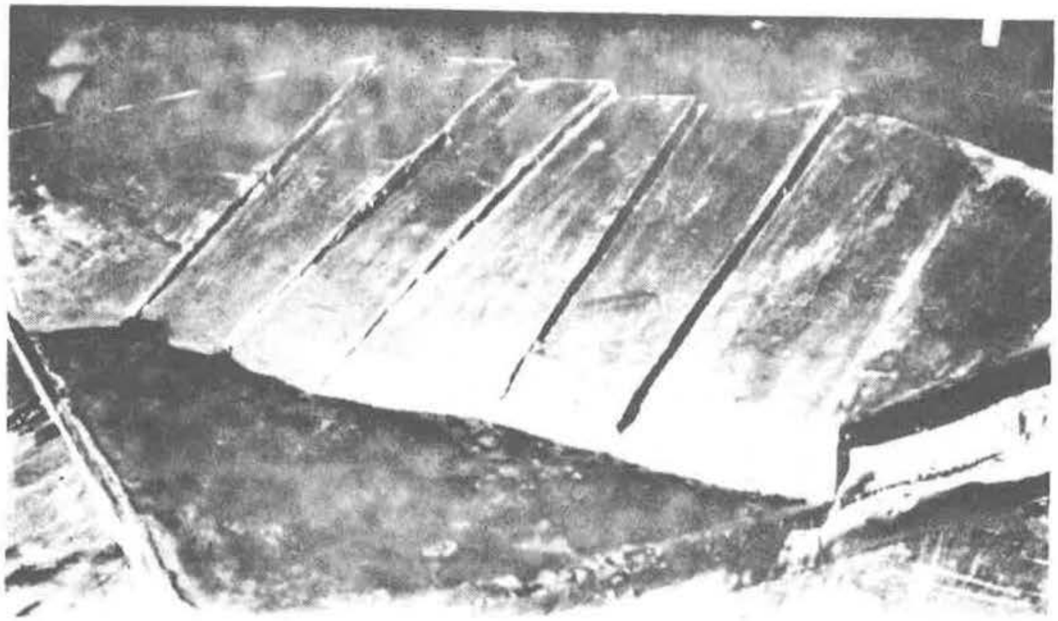

FIGURE 12. The Statfjord Sand (3120 RTV) was the last shaped layer. The Base Statfjord is Horizon 7.

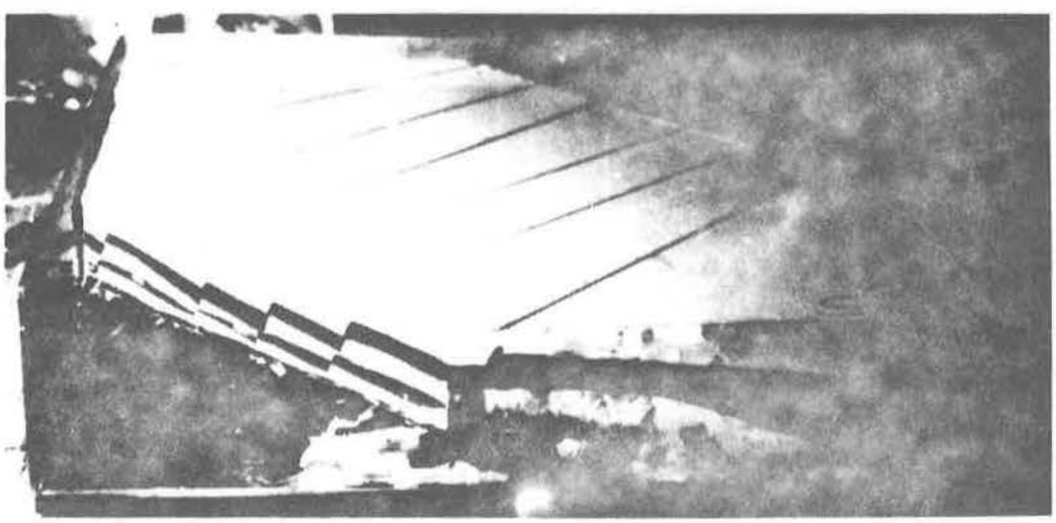

FIGURE 13. The Triassic (3110 RTV) continues to a flat basement (Horizon 8).

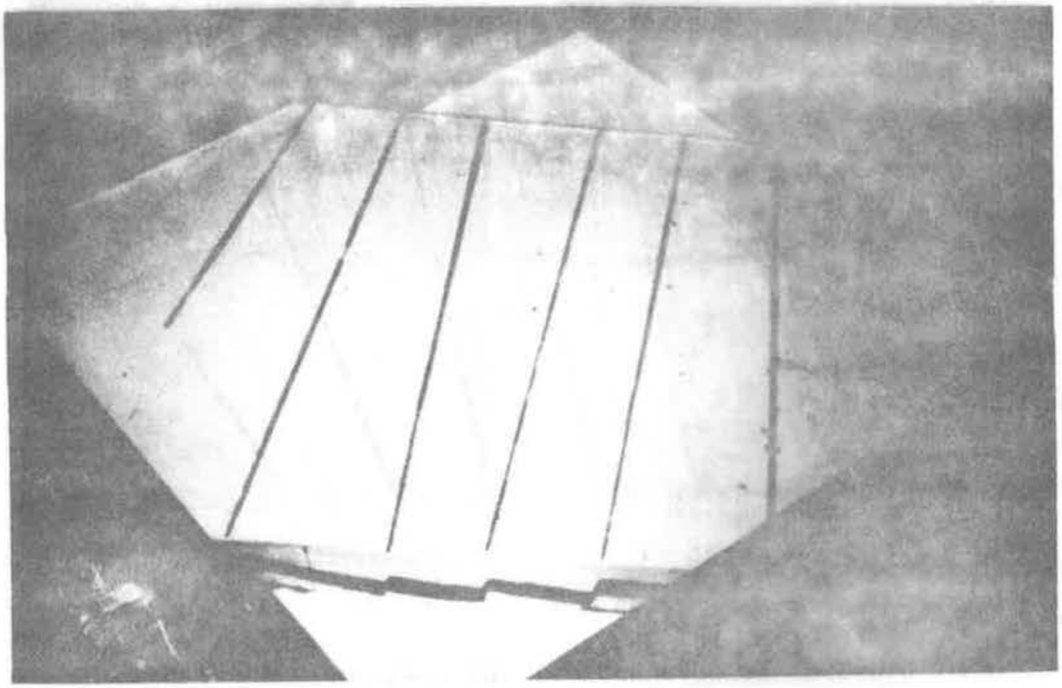

FIGURE 14. Horizon 9 (Top Brent) is the base of a flat layer (3110 RTV) in the two corners. The faulted area was defined as being moved between these flat layers by strike slip faults.

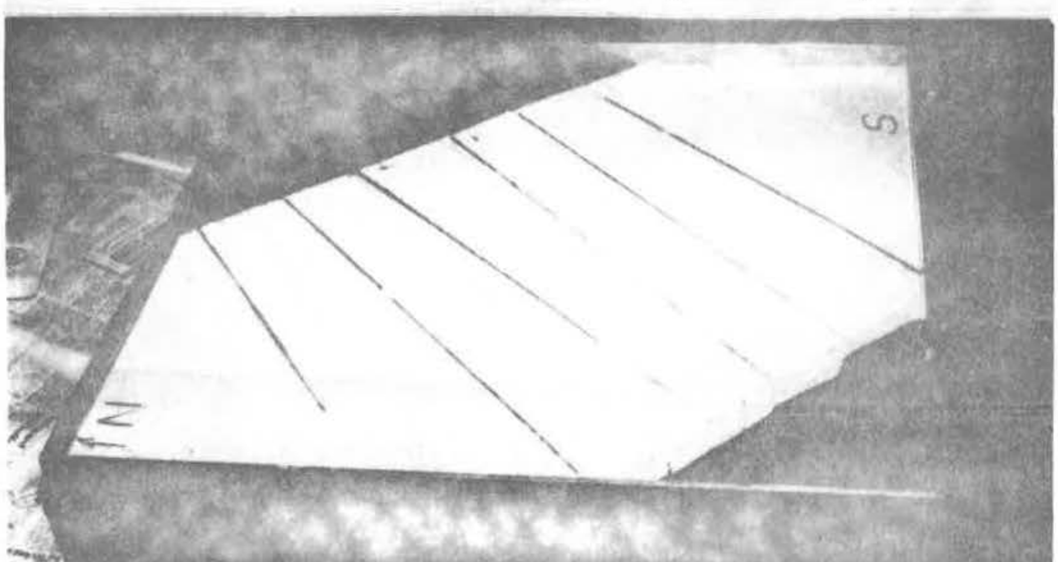

FIGURE 15. Horizon 10 (Base Brent) is the base of a second flat layer (3120). The Triassic (3110 RTV) goes to the flat basement (Horizon 8).

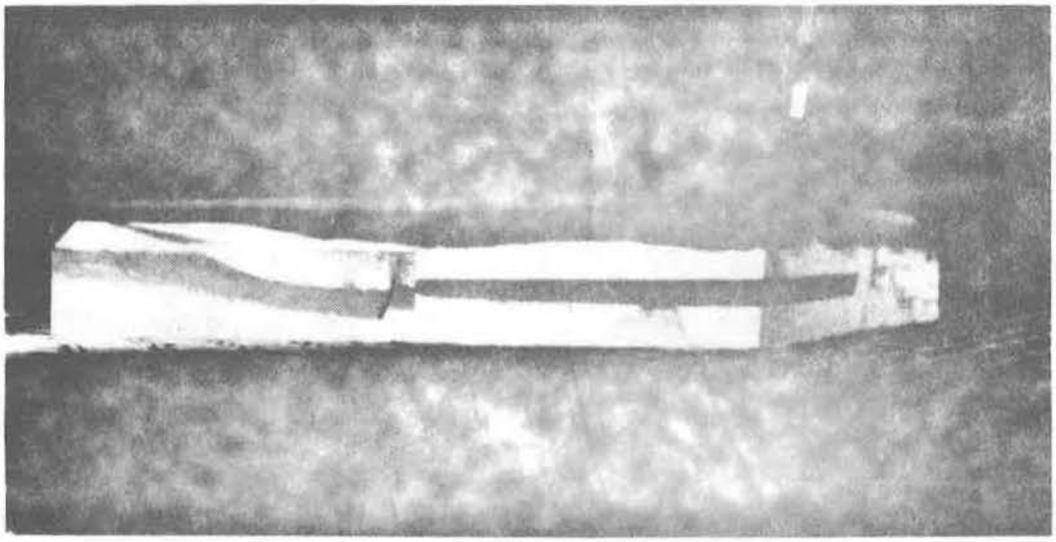

FIGURE 16. The North Sea Model, SALNOR, as seen through the tank window when on the platform for data collection.

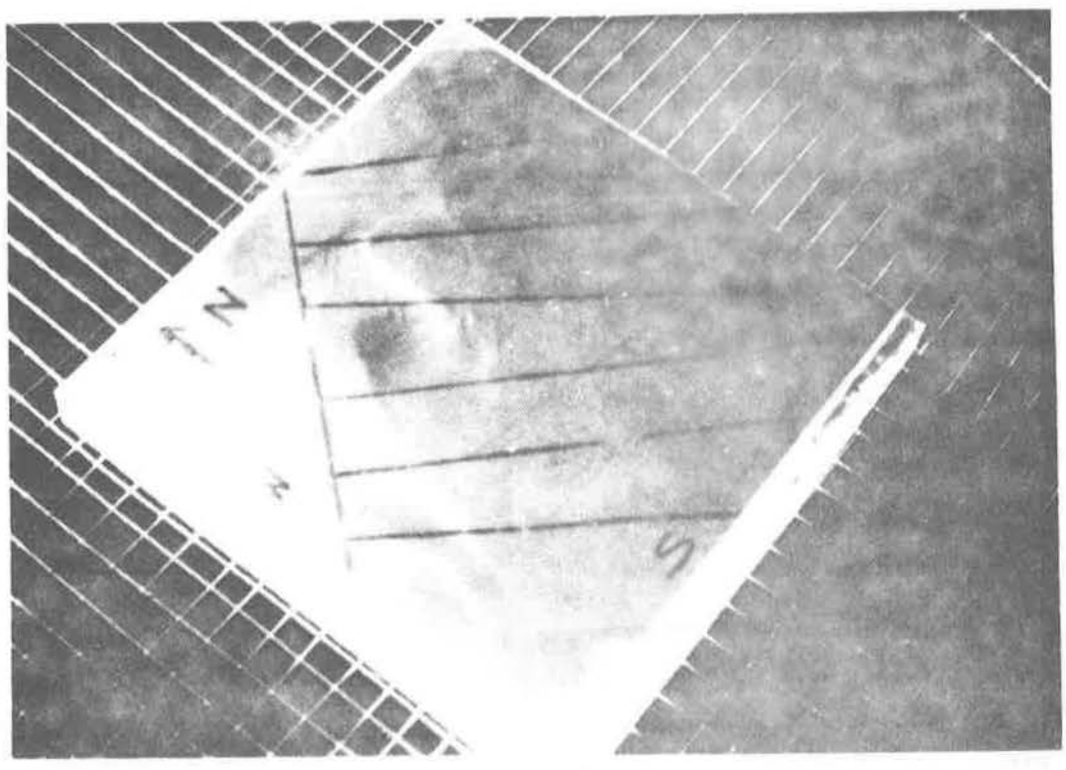

FIGURE 17. Top view of SALNOR in the modeling tank.

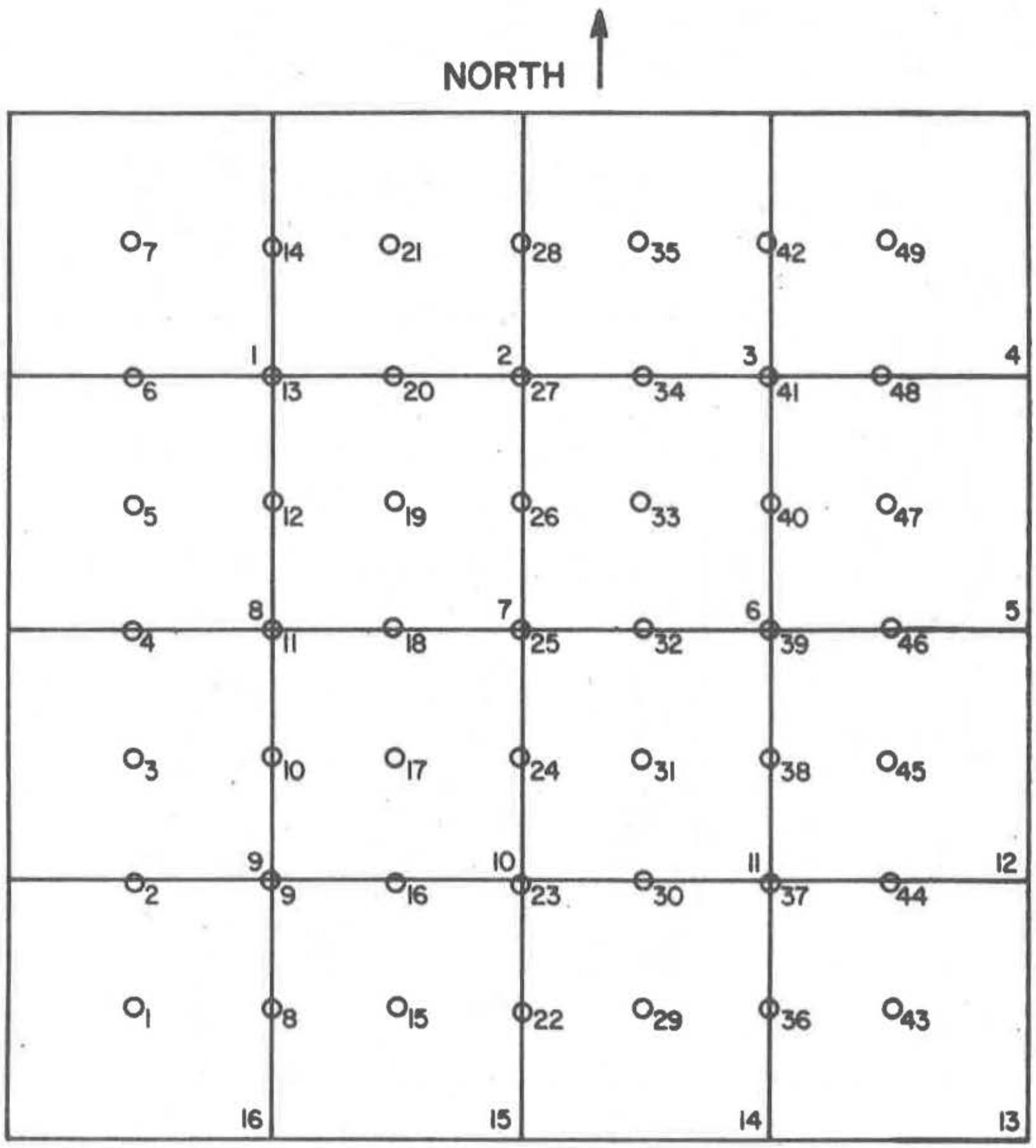

FIGURE 18. Location map of the North Sea model showing the 16 blocks it was divided into, and 49 locations where thickness measurements were made.

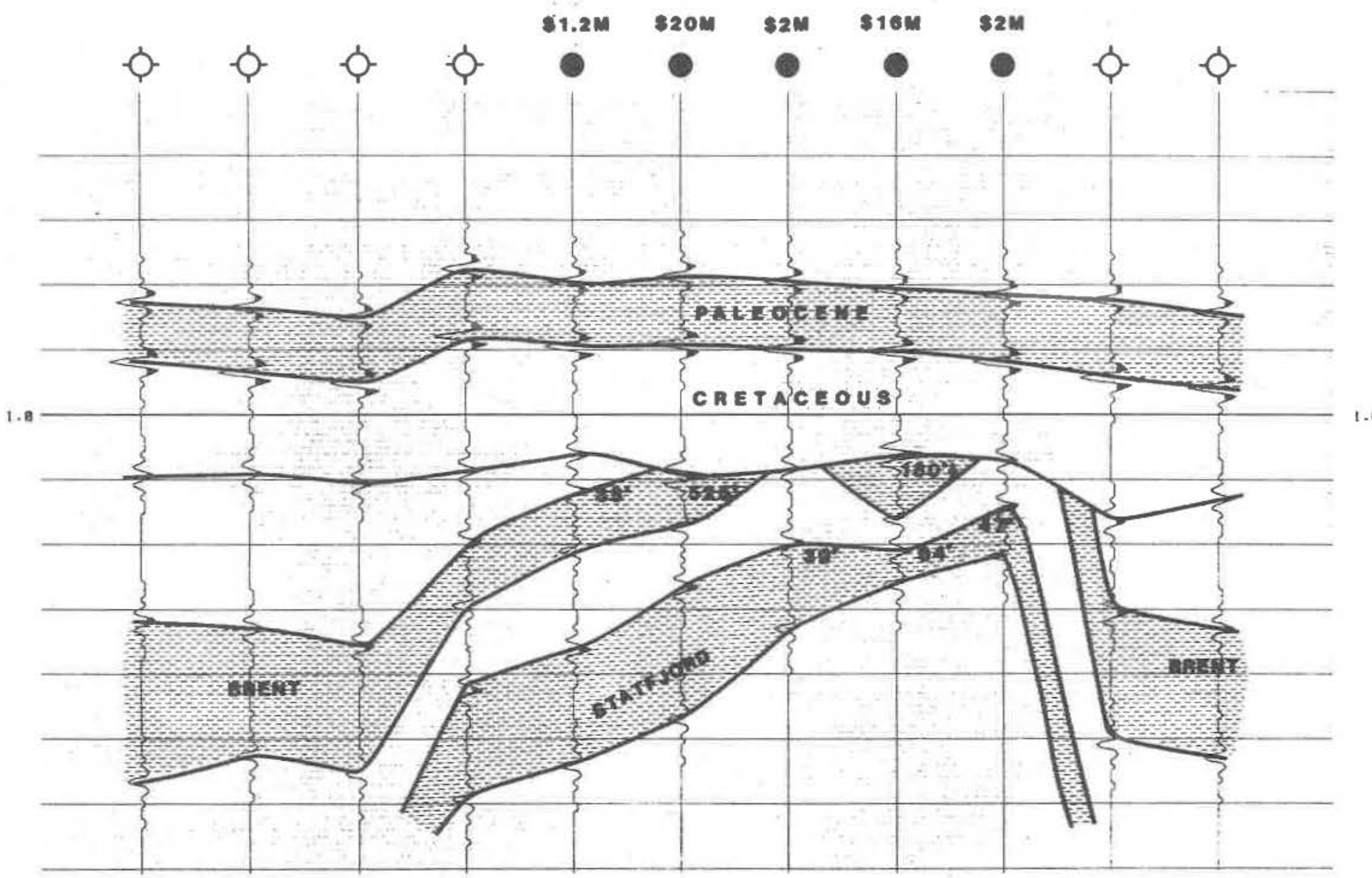

FIGURE 19. Sample Synthetic Seismic traces from measurements of North Sea model thicknesses.

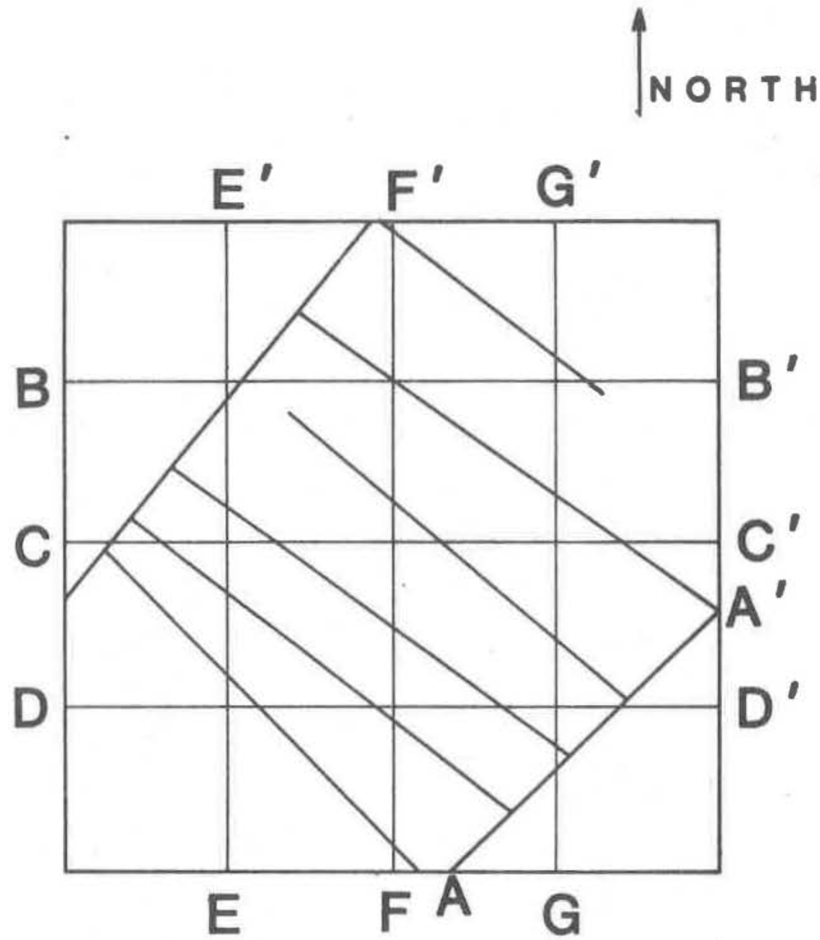

FIGURE 20. North Sea model cross section location map.

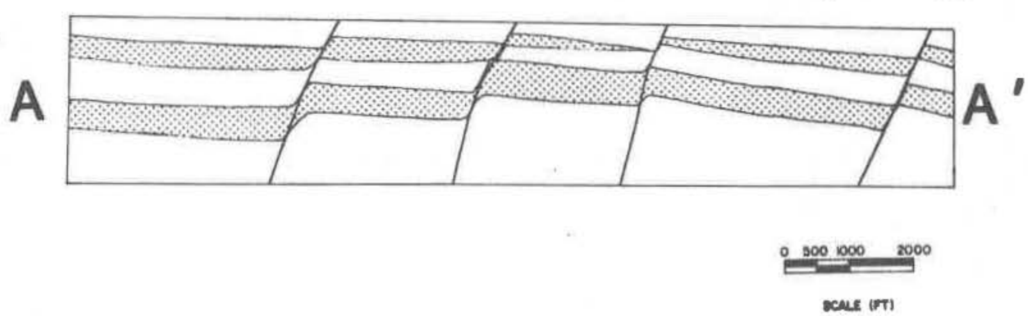

FIGURE 21. North Sea model cross section A-A'

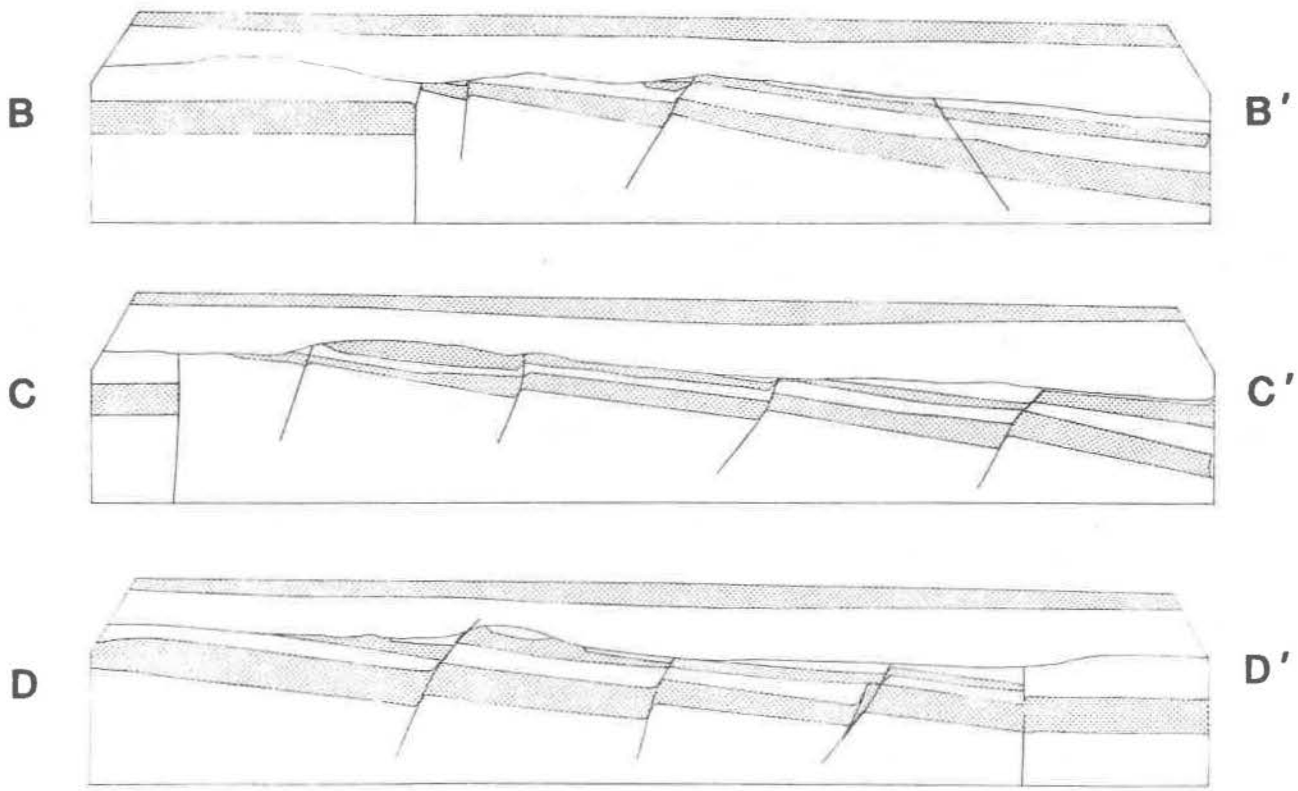

Figure 22. North Sea Model Cross-sections B-B', C-C', D-D'.

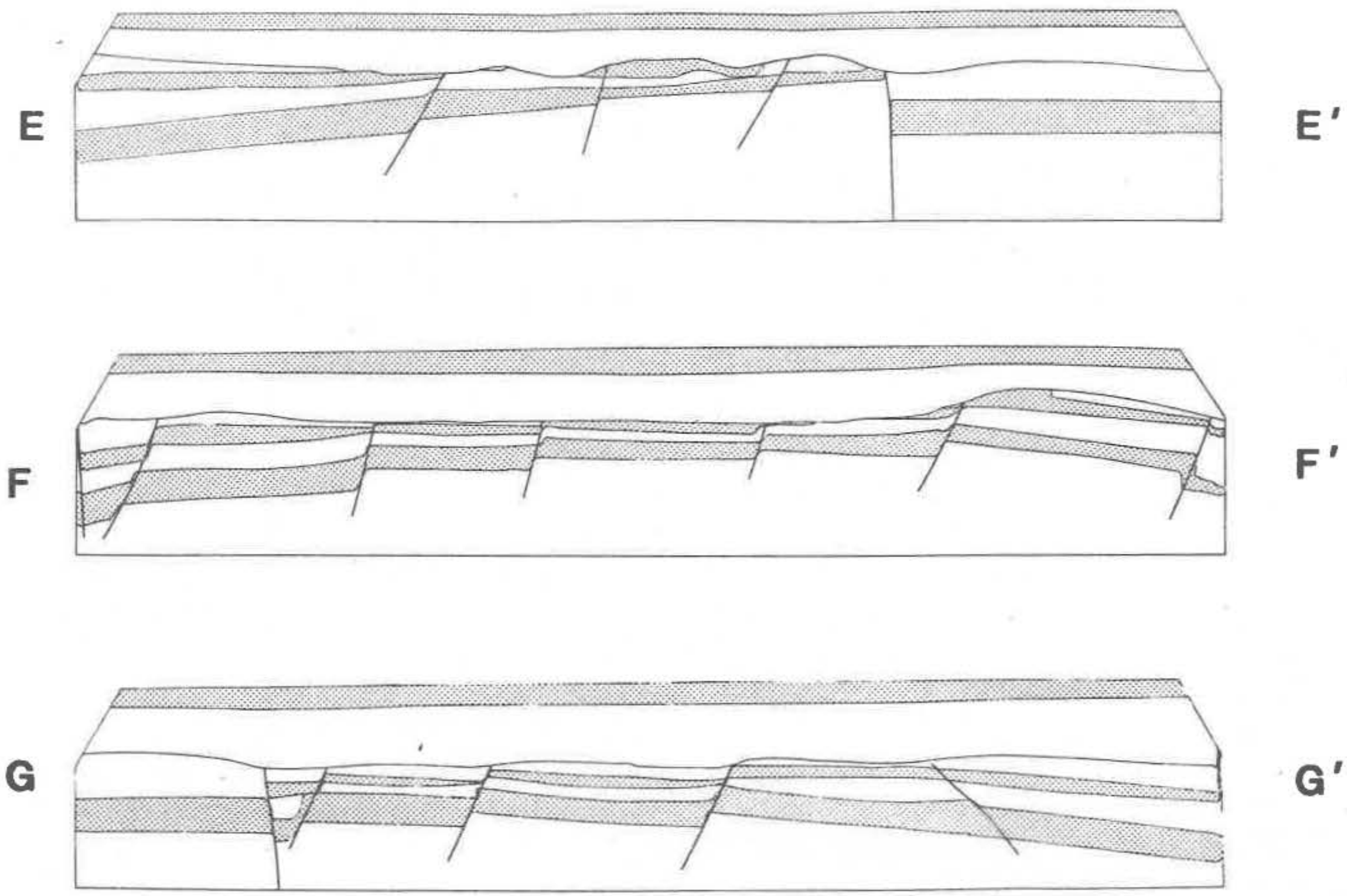

Figure 23. North Sea Model Cross-sections E-E', F-F', G-G'.

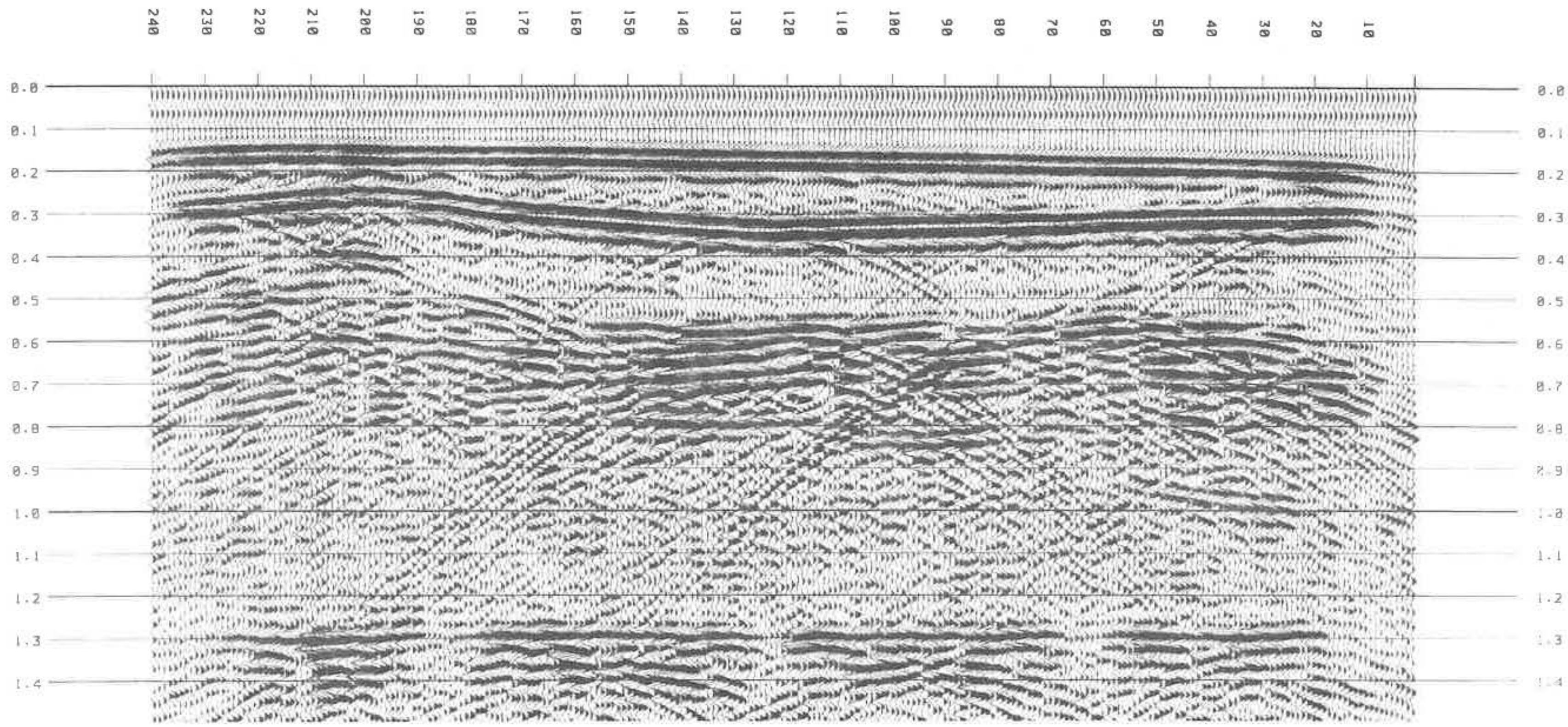

Figure 24. Line 228 collected across the reassembled North Sea Model. Note the apparent breaks in data coverage on the basement horizon.

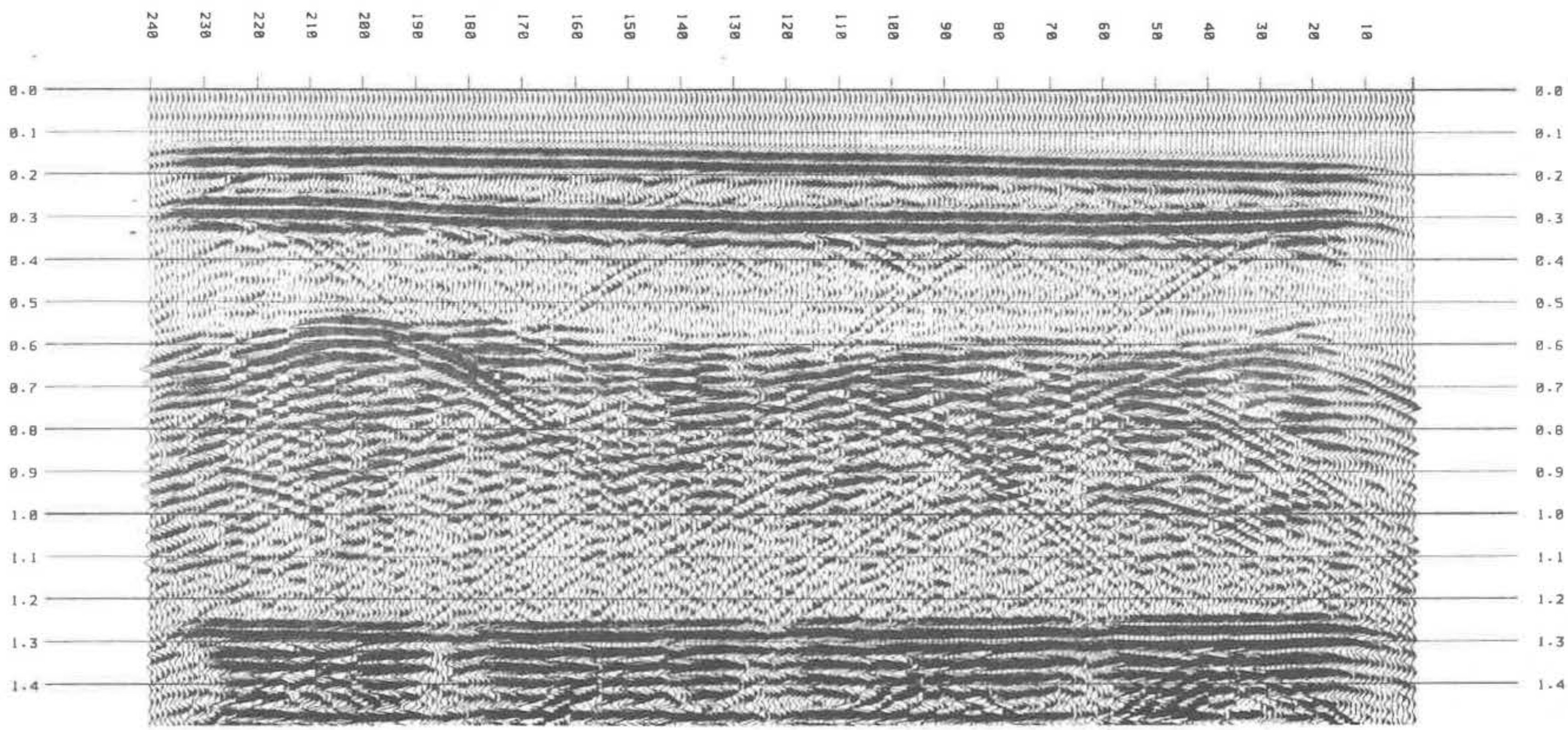

Figure 25. Line 232 collected across the reassembled North Sea Model. Note the diffractions from the cuts below Horizon 2.

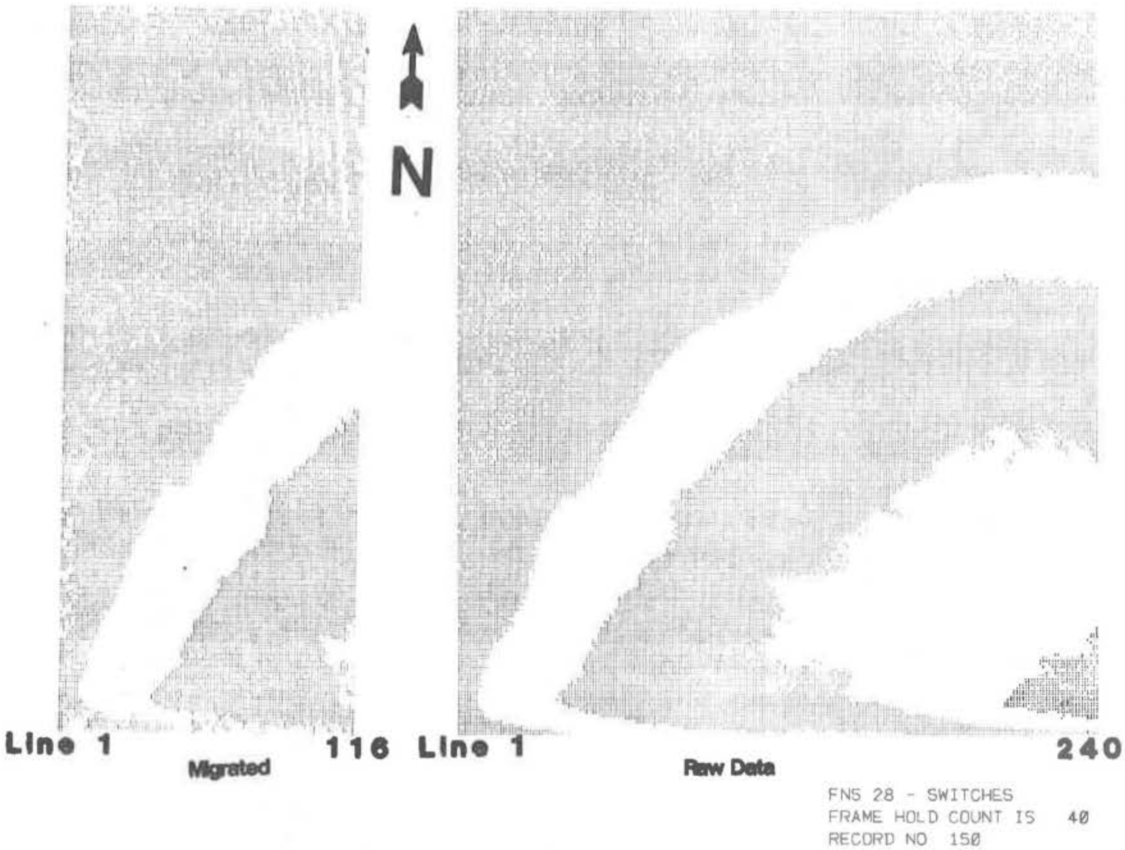

FIGURE 26. Time slice through North Sea model at the top Paleocene layer (Horizon 1).

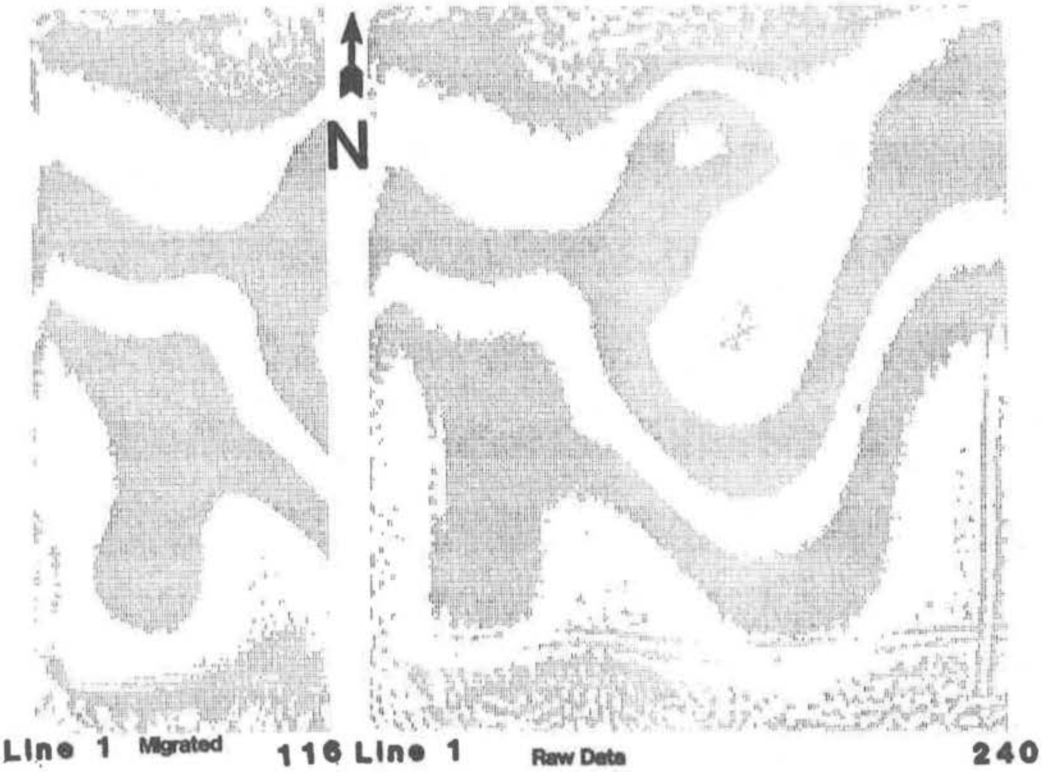

FIGURE 27. Time slice through North Sea model at the top Cretaceons layer (Horizon 2).

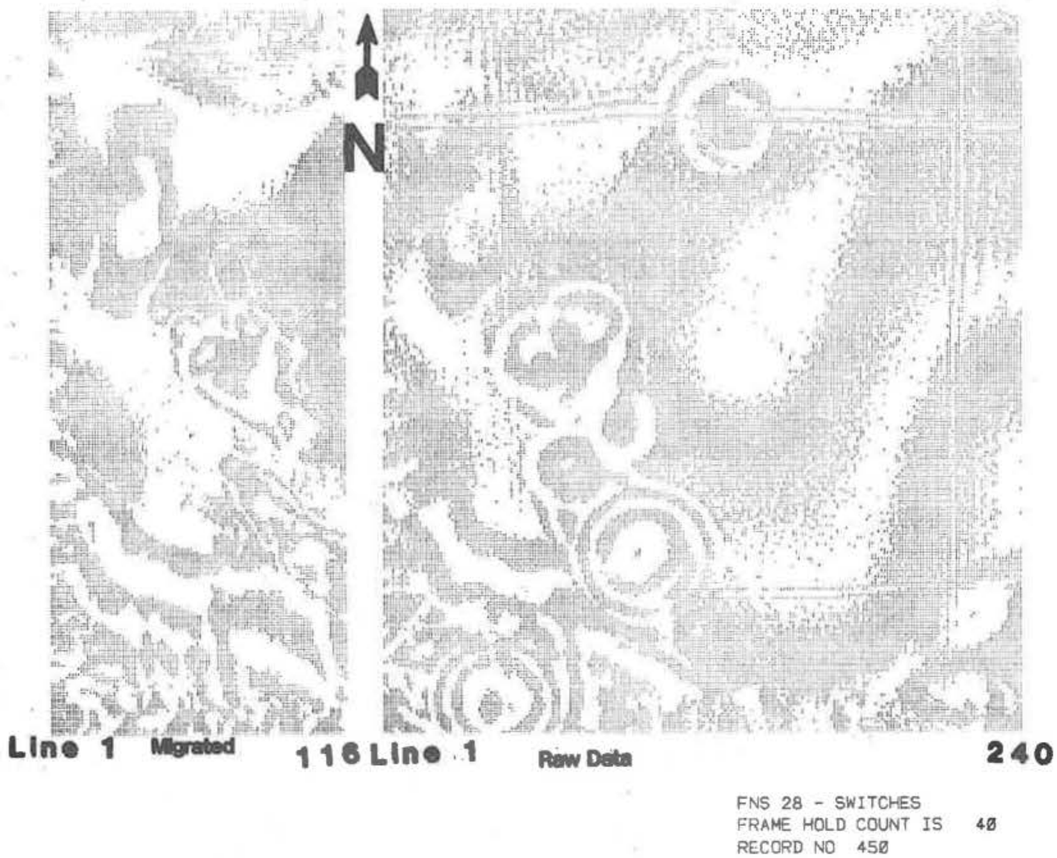

FIGURE 28. Time slice through North Sea model at the J - Unconformity (Horizon 3).

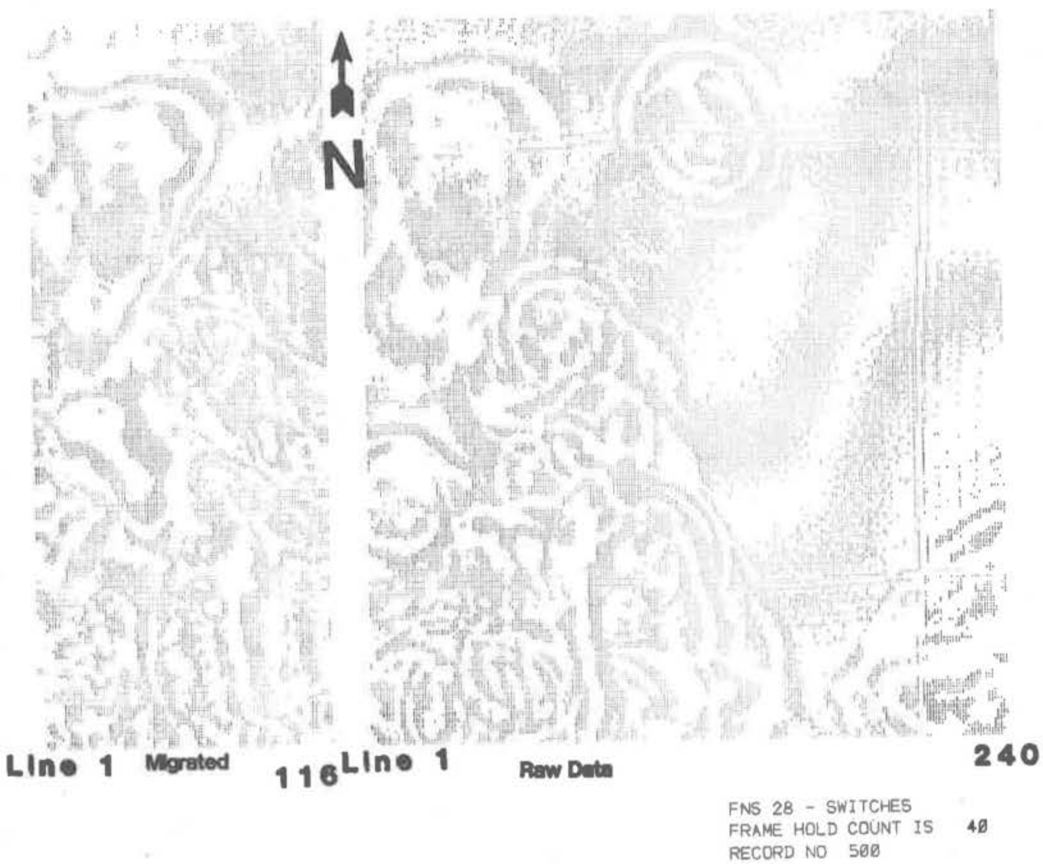

FIGURE 29. Time slice through North Sea model at the J - Unconformity (Horizon 3).

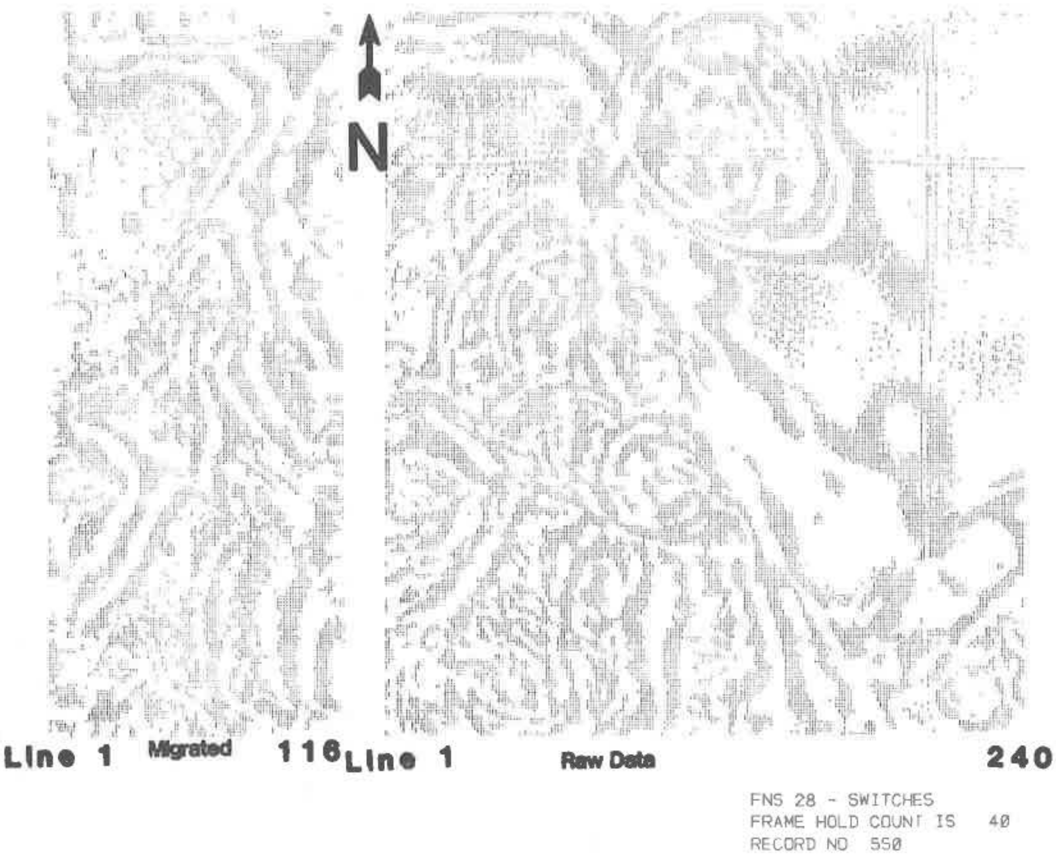

FIGURE 30. Time slice through North Sea model showing the Brent dipping horizons (Horizons 4 and 5). Note the air bubbles at the top, on the 3D migrated display.

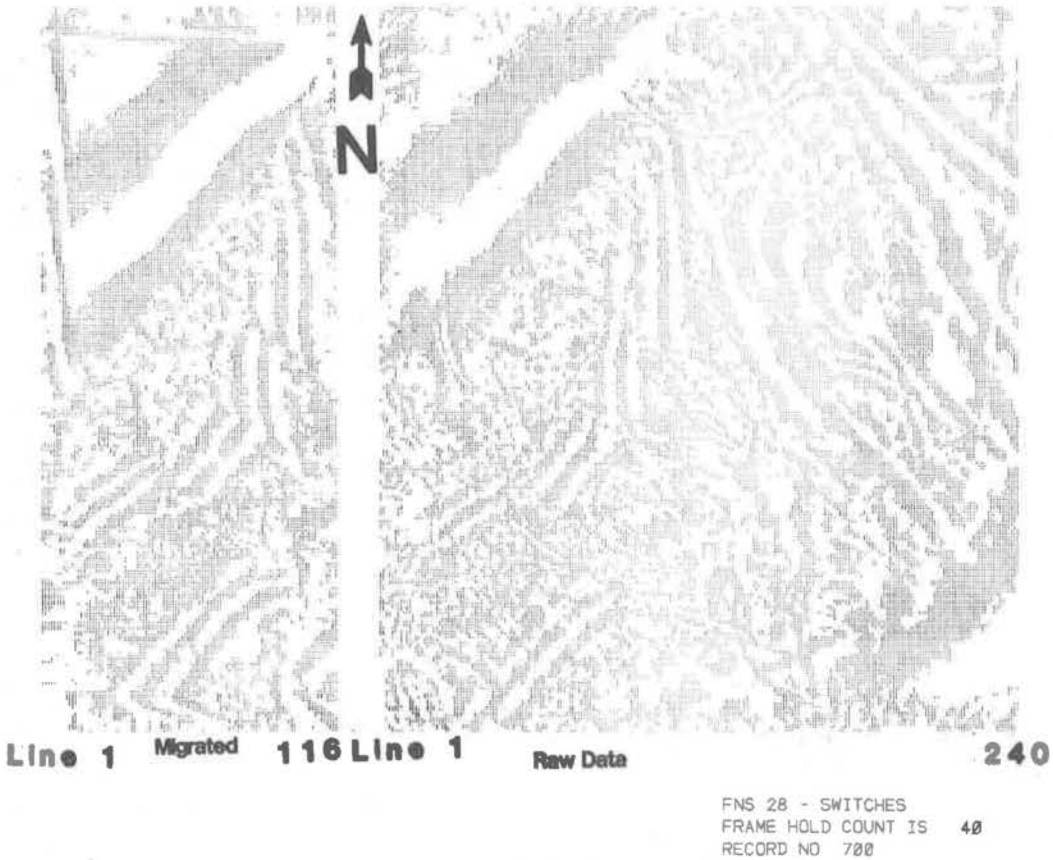

FIGURE 31. Time slice through North Sea model at the NW corner Top Brent flat layer (Horizon 9).

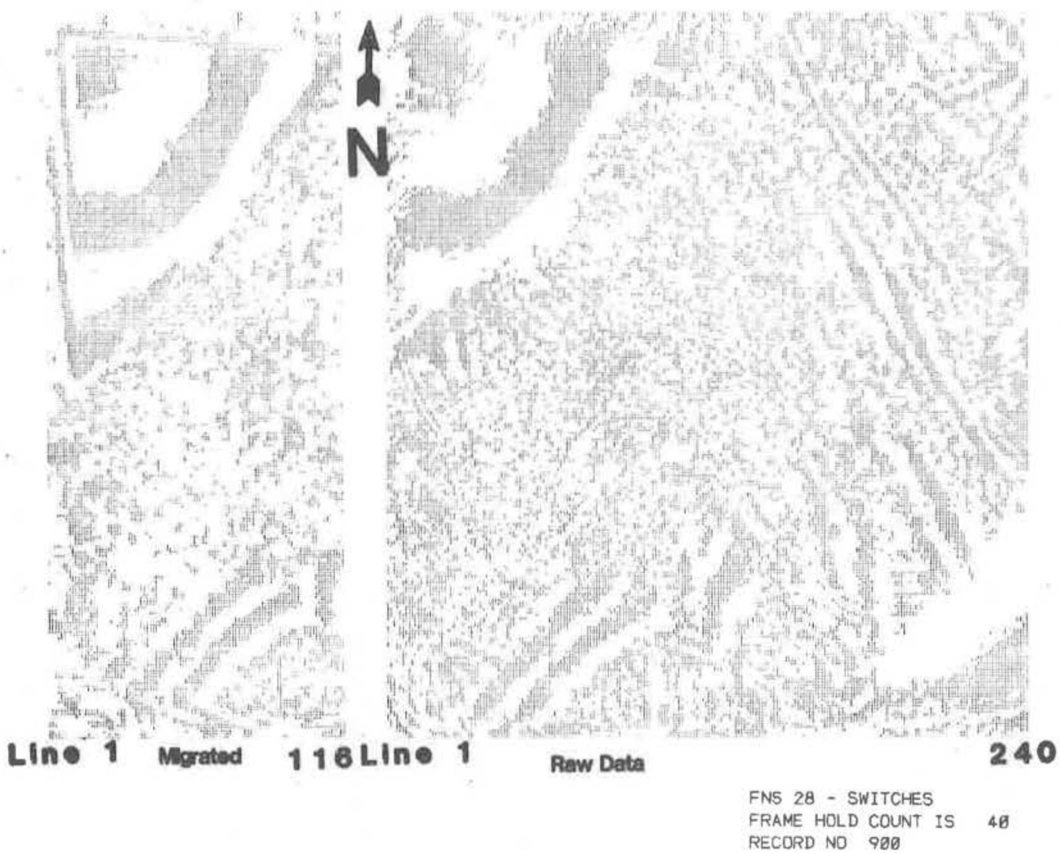

FIGURE 32. Time slice through North Sea model at the NW corner Base Brent flat layer (Horizon 10).

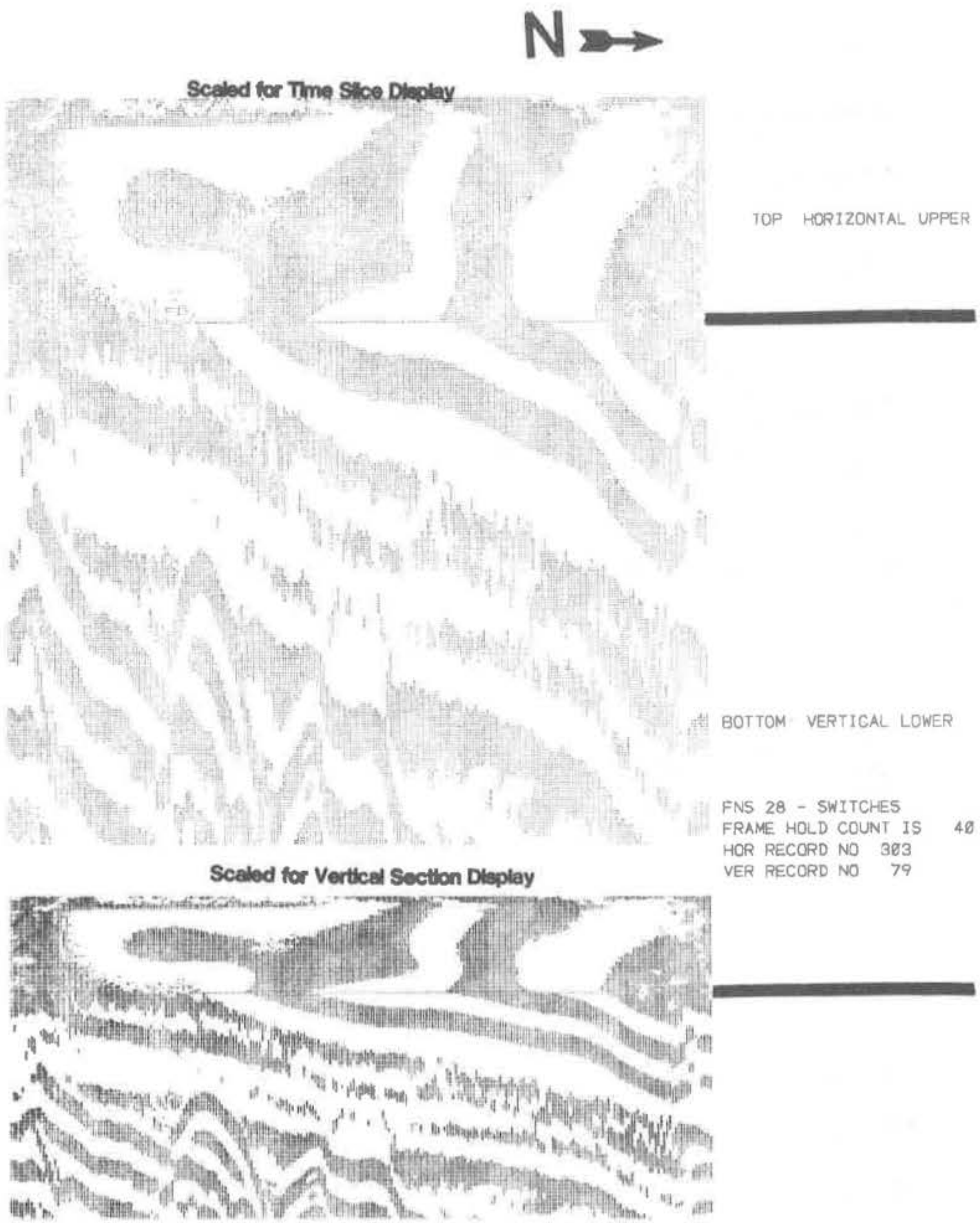

FIGURE 33. Mixed horizontal and vertical sections from the North Sea model. Both sections are at 1 bit resolution. The horizontal section is on top and is at the Top Cretaceons level (Horizon 2).

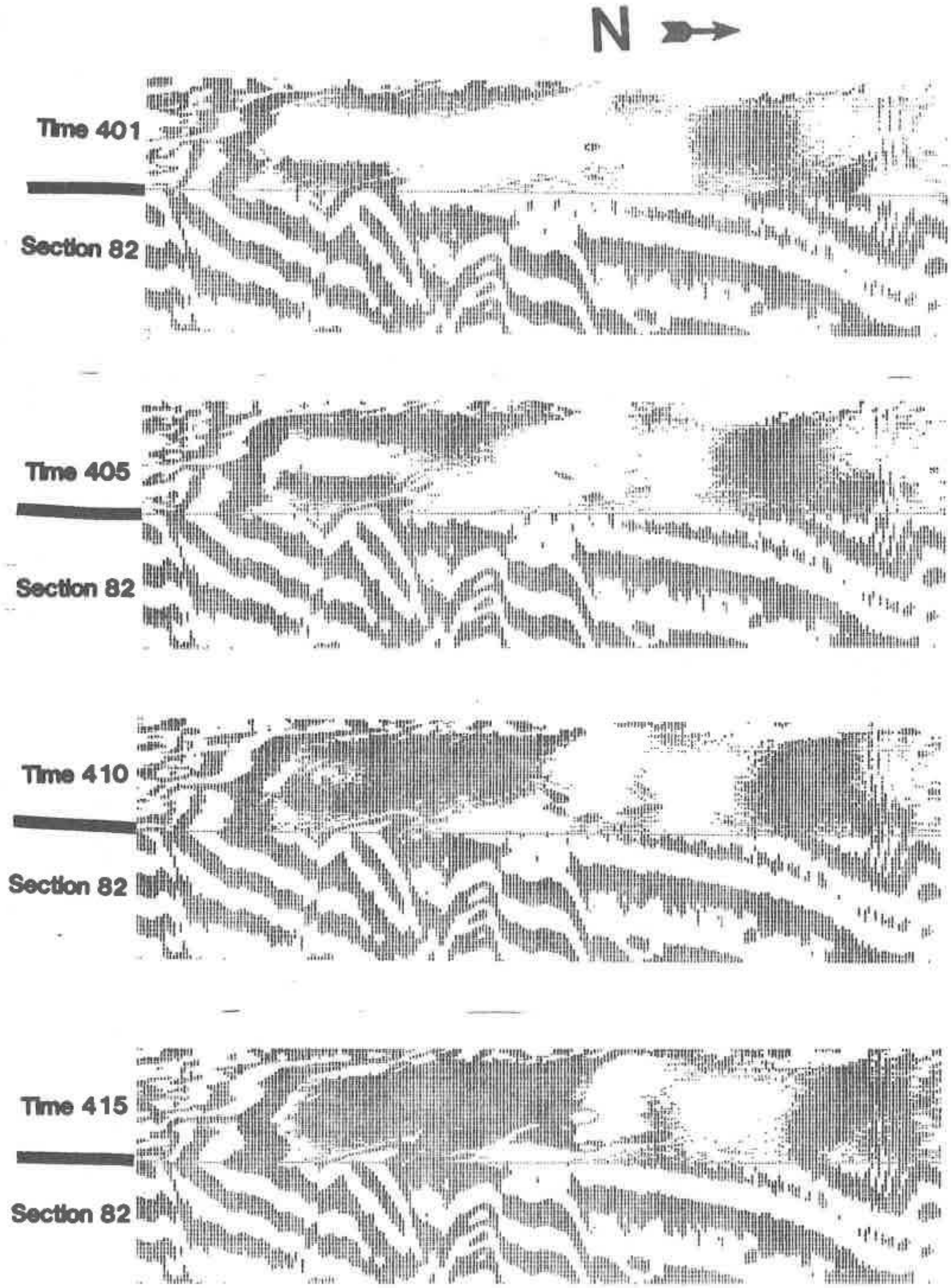

FIGURE 34. Animation sequence through the North Sea model data volume. Horizontal sections are moved down from time 401 ms to 415 ms.

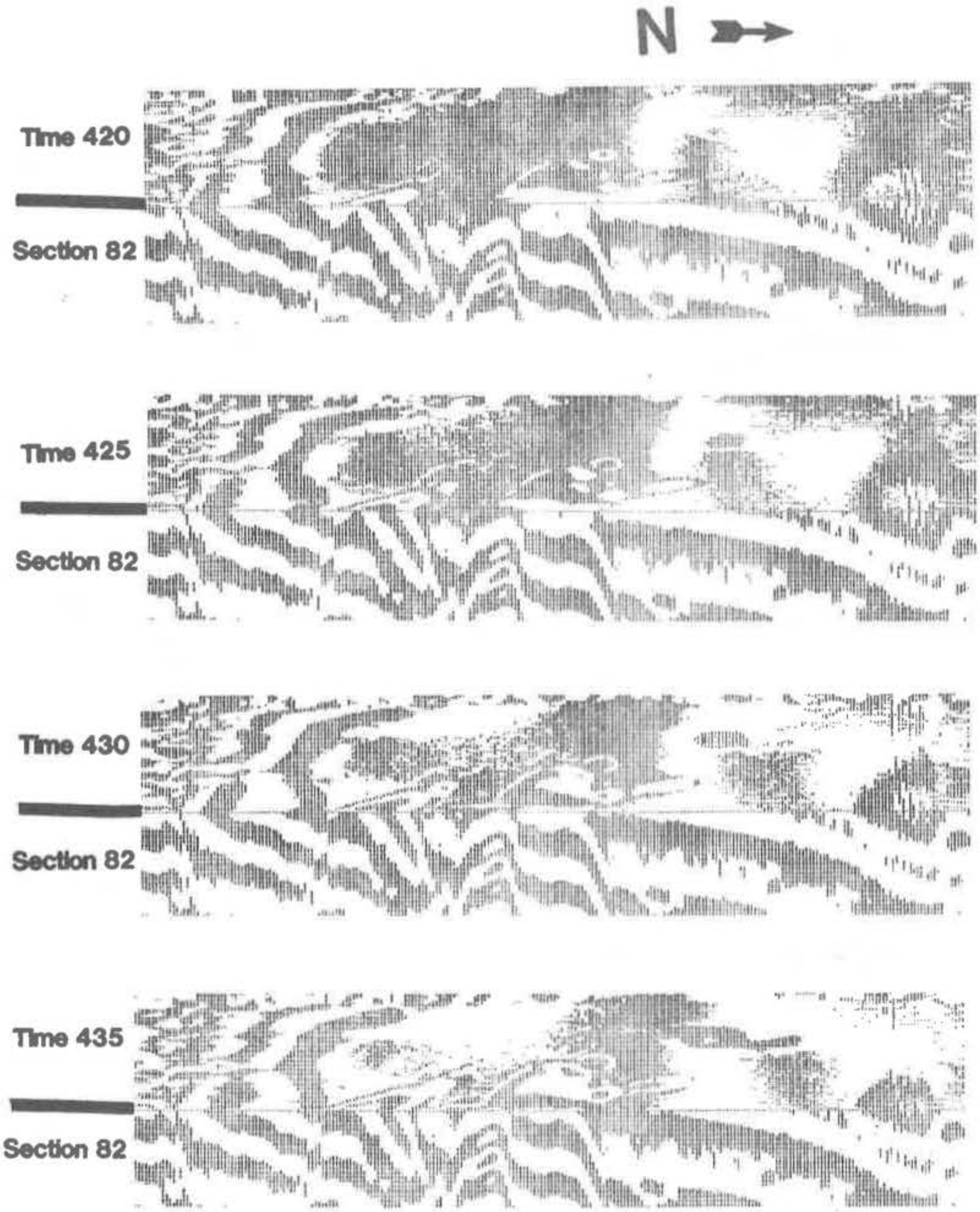

FIGURE 35. Animation sequence through the North Sea model data volume continued. Horizontal Sections are moved down time 420 ms to 435 ms.

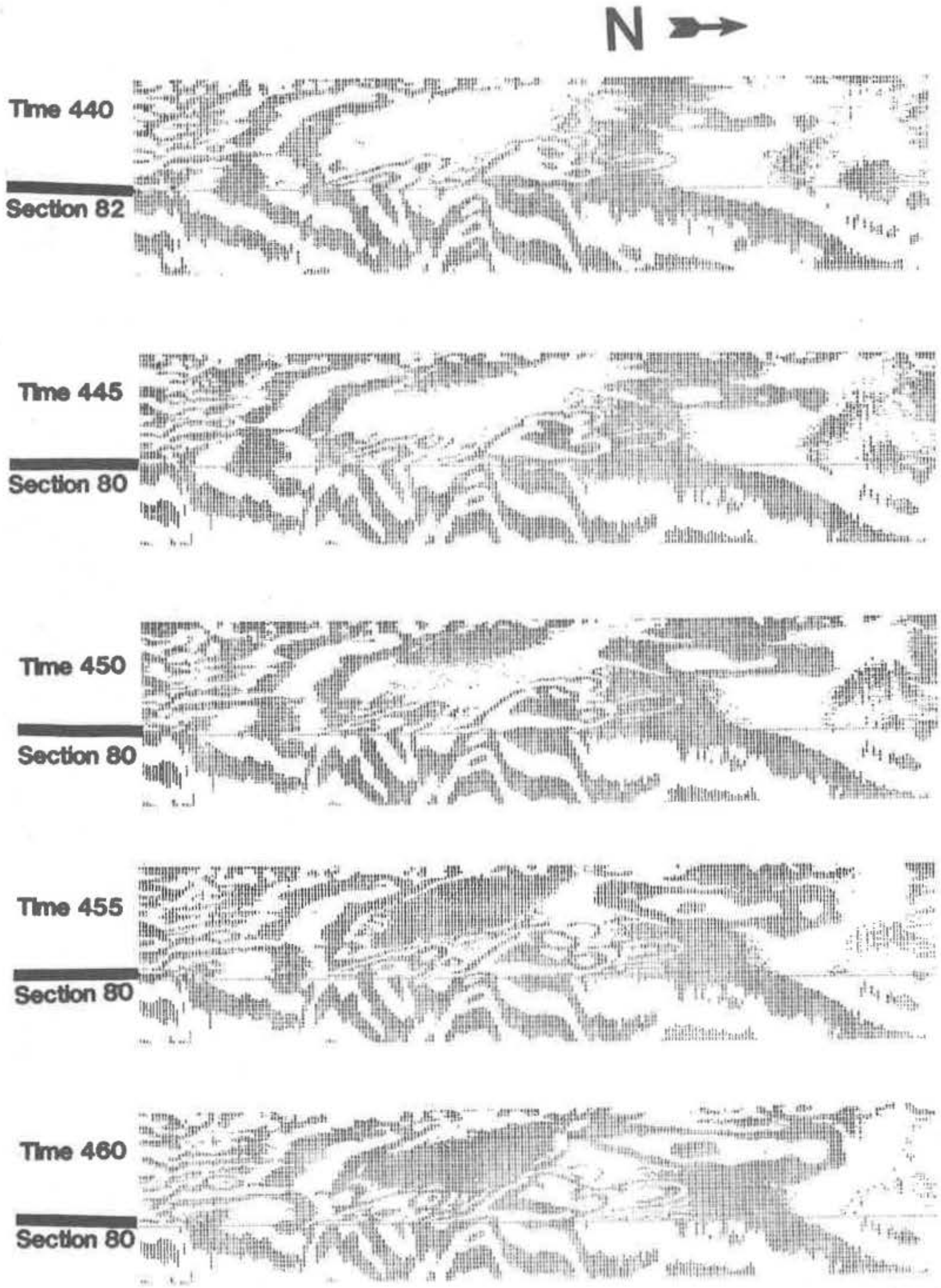

FIGURE 36. Animation sequence through the North Sea model data volume continued. Horizontal sections are moved down from time 440 ms. to 460 ms.

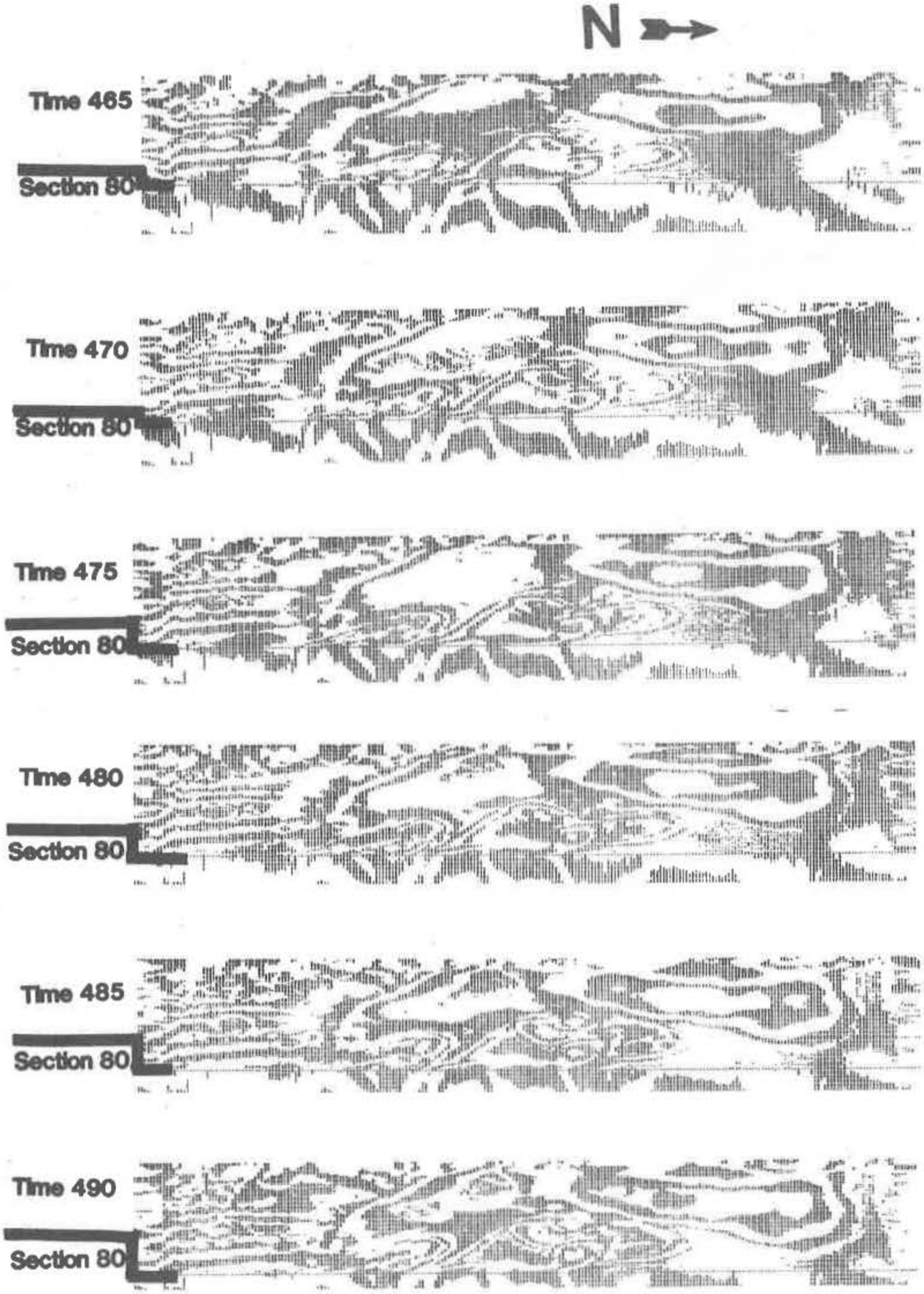

FIGURE 37. Animation sequence through the North Sea model data continued. Horizontal sections are moved down from 465 ms. to 490 ms.

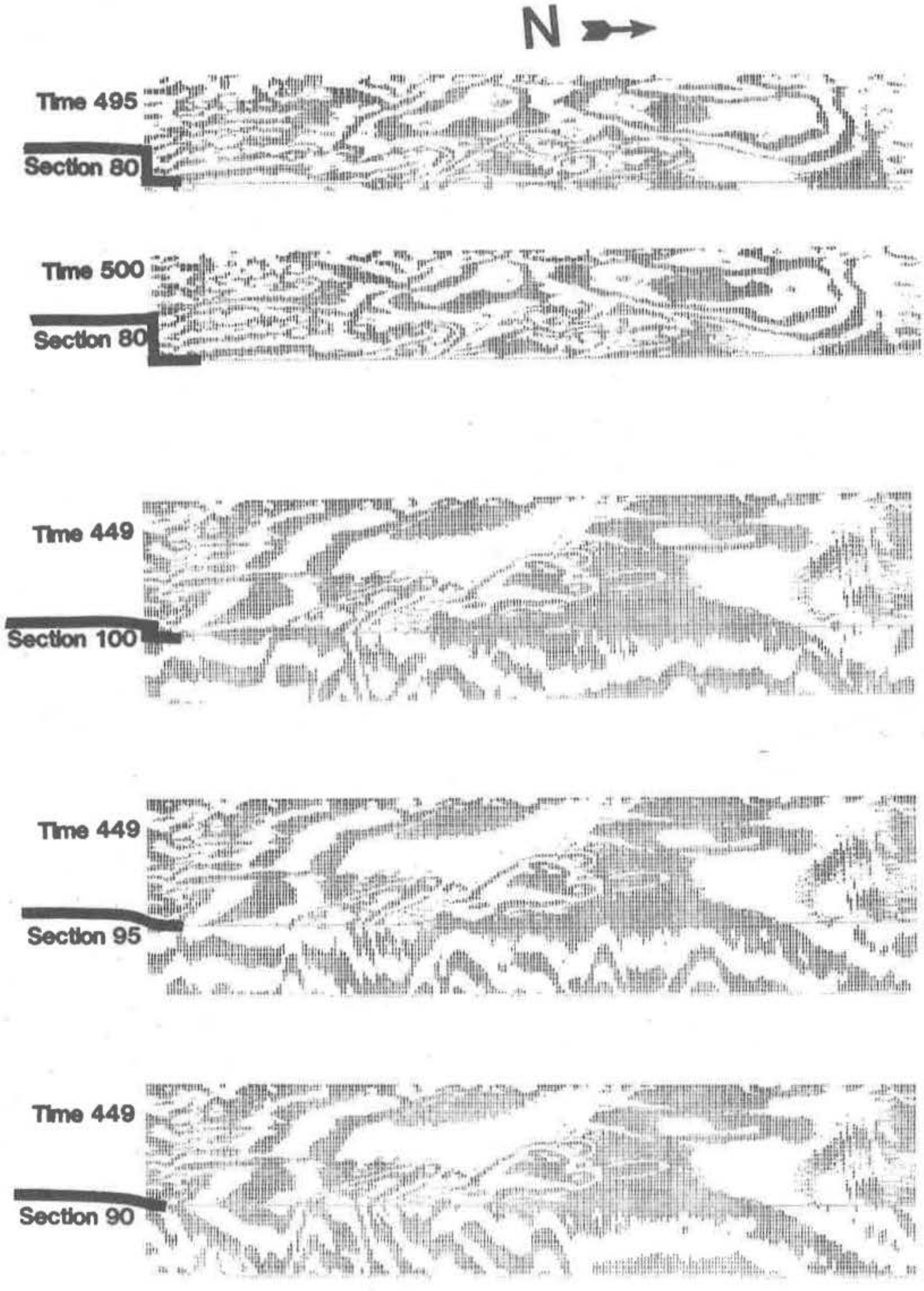

FIGURE 38. Animation sequence through the North Sea model data volume continued. Horizontal sections at times 495 ms. and 500 ms. are on top. Then the time slice section is fixed at 449 ms. and the vertical sections 100 to 90 moved through.

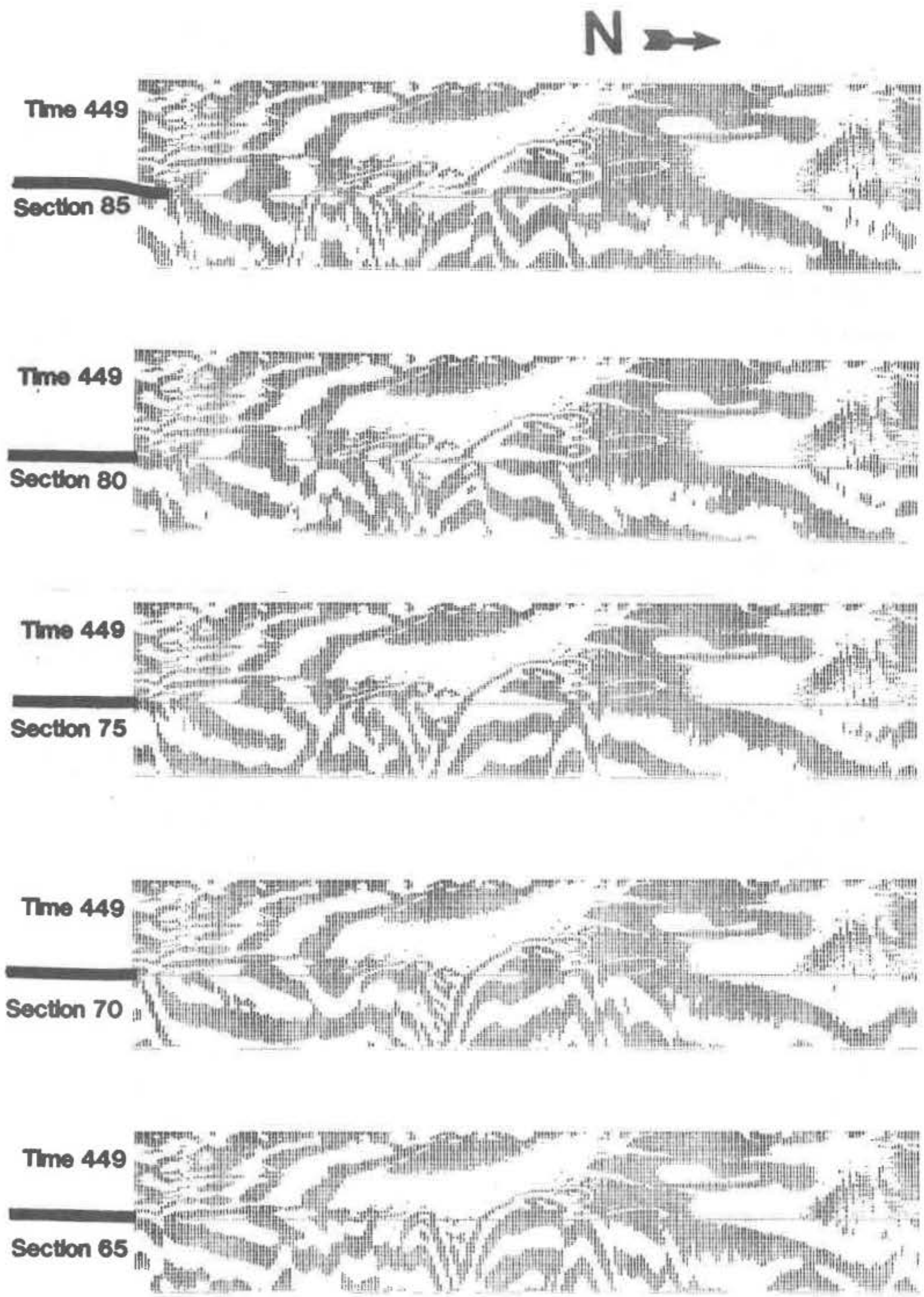

FIGURE 39. Animation sequence through the North Sea model data volume continued. Vertical sections 85 to 65 are moved through here.

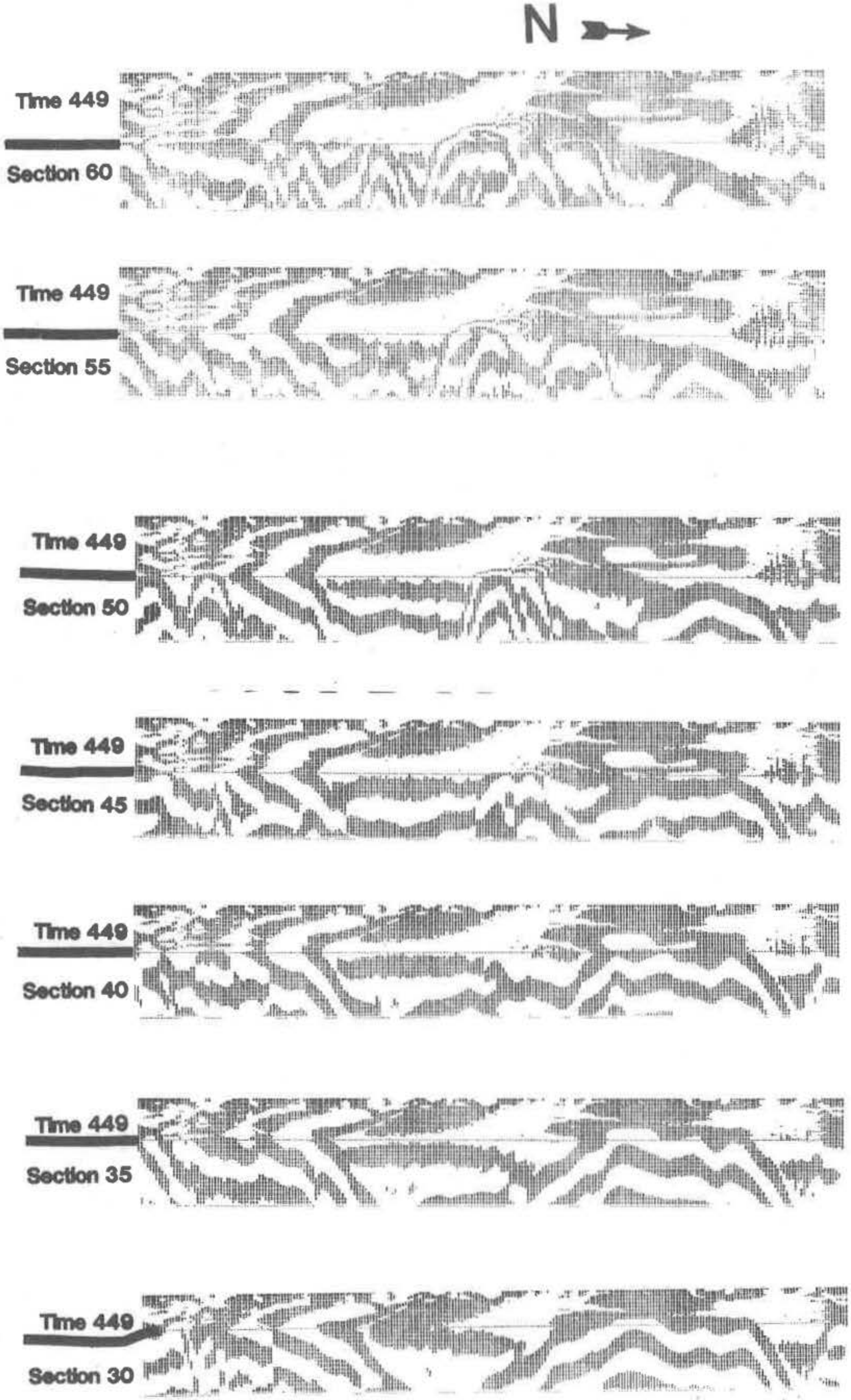

FIGURE 40. Animation sequence through the North Sea model data volume continued. Vertical sections 60 to 30 are moved through here.