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EXAMPLES OF DEEP-WATER-BOTTOM MULTIPLE DEREVERBERATION TECHNIQUES APPLIED TO SEISMIC-REFLECTION DATA FROM THE ATLANTIC OUTER CONTINENTAL MARGIN

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CONTENTS

LIST OF ILLUSTRATIONS

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by

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ABSTRACT

Seismic-reflection data recorded in deep water over the Atlantic Outer Continental Shelf are often dominated by multiply-reflected seismic energy. This energy reverberates between the surface of the water and the seafloor (or other strong reflectors), and makes portions of the seismic data completely useless. Several different data-processing techniques can be applied to partially suppress these multiples and enhance the interpretability of the data. These techniques include (1) the three-point operator, (2) predictive deconvolution, (3) near-trace muting, (4) spatially variant bandpass filters, (5) Nth root stack, and (6) trace distance weighting. Application of these methods to several seismic lines indicates that trace distance weighting is the most useful method studied for suppressing deep-water-bottom multiples for data from the Atlantic Outer Continental Shelf.

ACKNOWLEDGMENTS

The authors thank Robert C. Anderson, Myung W. Lee, and Robert T. Ryder, who contributed to the discussion of ideas presented in this paper.

INTRODUCTION[1]

Purpose and Scope

During the past several years, regional geological and geophysical studies have been conducted by the U.S. Geological Survey to determine the tectonic and stratigraphic framework of the Atlantic Outer Continental Shelf (AOCS). As part of this investigation, thousands of kilometers of seismic-reflection data have been acquired (fig. 1). One distinctive feature of this data is that it was recorded for over 10 seconds in water that is over 2 km deep. The energy transmitted through this deep water often reverberates between the ocean surface and the seafloor or other strong reflectors. This multiply-reflected seismic energy dominates the recorded signal and makes portions of the data completely useless.

This paper examines the results of applying several different data processing methods to this data in order to suppress deep water reverberations. These techniques are divided into two groups: (1) dereverberation filters, and (2) weighted stacks.

Because the theory of these processes is described throughout the geophysical literature, only a brief description of each method is given.

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[1]Use of brand names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

Recording and Initial Data Processing

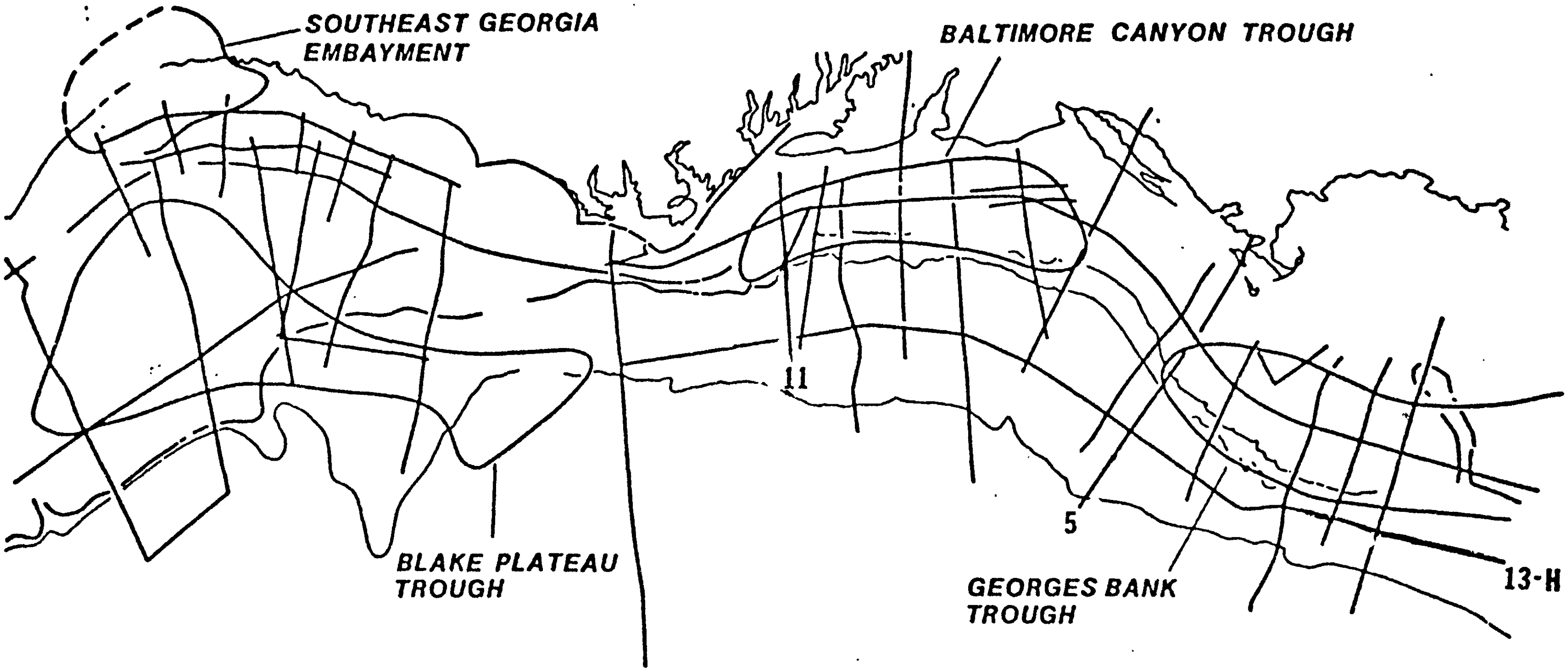
The data used in this study were collected by Digicon, using Texas Instruments DFS III recording instruments with binary-gain ranging. The energy source consisted of an air-gun array fired at 50-m intervals. The marine cable (fig. 2) consisted of twenty-four 100-m seismometer groups and twenty-four 50-m seismometer groups. The 100-m seismometer groups were nearest to the boat, with about a 350-m lead into the nearest group. Total distance between the source and farthest offset group was approximately 3,875 m. This shooting geometry resulted in a 25-m spacing between common-depth-points, with the subsurface coverage alternating between 36- and 12-fold. However, adjacent common-depth-points were combined during stacking, forming 48-fold common-depth-points at 50-m intervals. The data were initially processed using a Phoenix-I seismic-data-processing system designed by Seismograph Service Corporation using conventional analysis methods (fig. 3).

Examples of Deep-Water-Bottom Multiples

To evaluate the effectiveness of the various techniques, portions of the following seismic lines were used (fig. 1): (1) Line 11C-far; (2) Line 5; (3) Line 13H; (4) 11C-slope.

Two types of multiples can be distinguished on the single-fold (figs. 4-7) and final processed (figs. 8-11) seismic sections for these lines: (1) water bottom - water surface - water bottom (BSB), and (2) strong reflector - water surface - water bottom (RSB).

The BSB multiples (fig. 12a) consist of all ray paths that travel only between the water bottom and water surface. The second type of multiple, RSB (fig. 12b), reflects once from a strong reflector and reverberates between the water bottom and water surface.



U. S. Geological Survey Multichannel Seismic Reflection Data

ATLANTIC CONTINENTAL MARGIN

Figure 1. Location of seismic lines.

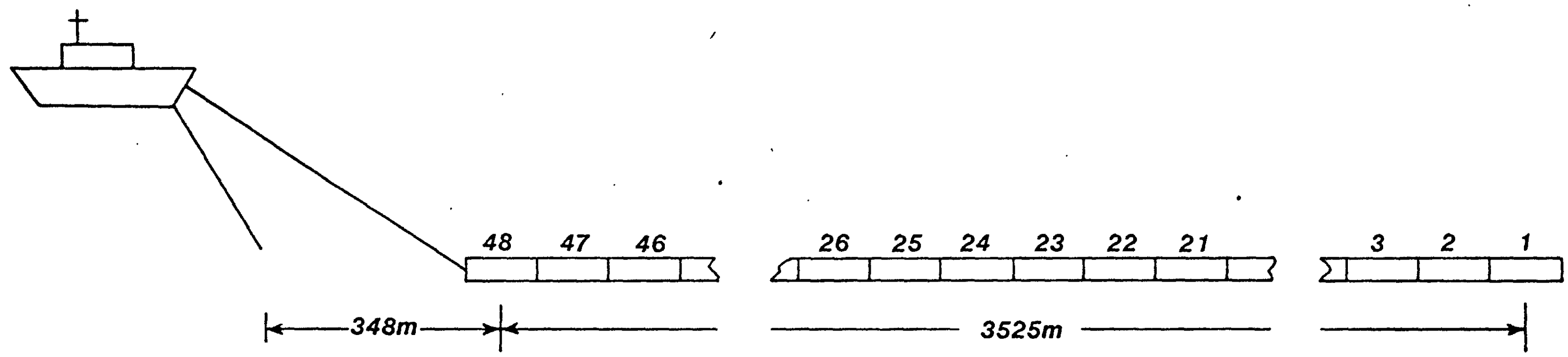


Figure 2. Recording geometry for lines 11-C and 13-H. Near trace offset for line 5 is 350m.

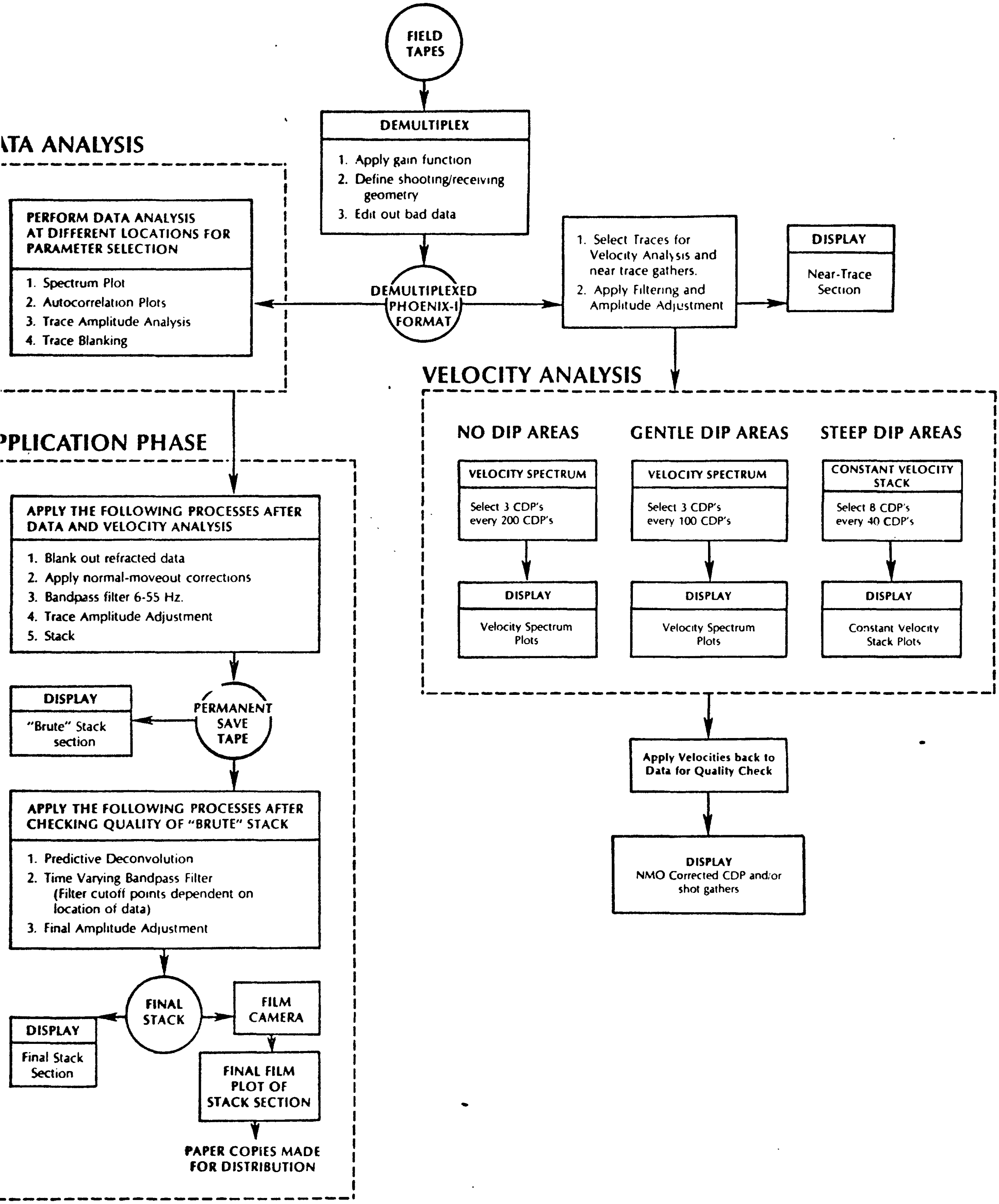


Figure 3. Basic processing sequence

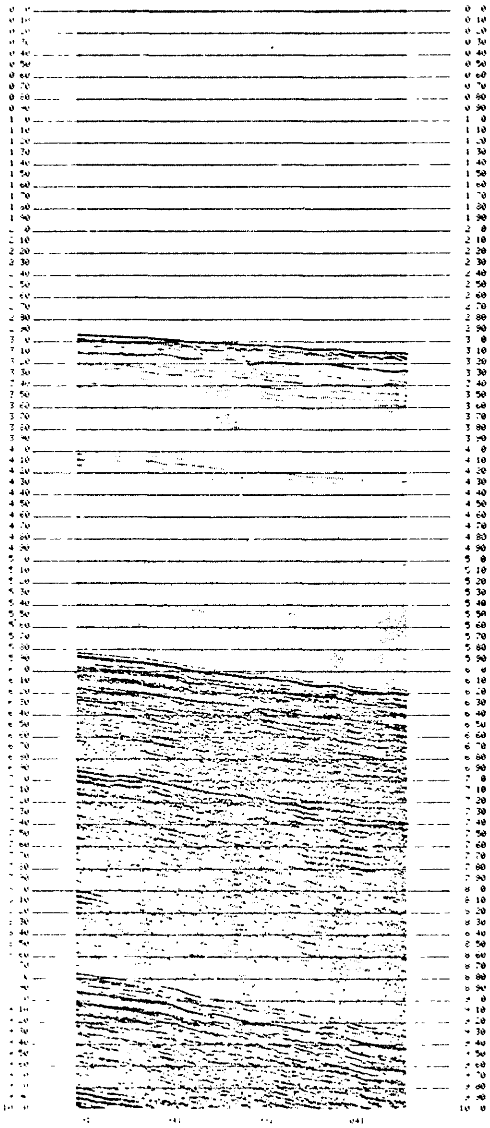


Figure 4. Near trace section for line 11-C far showing water bottom and interbed multiples

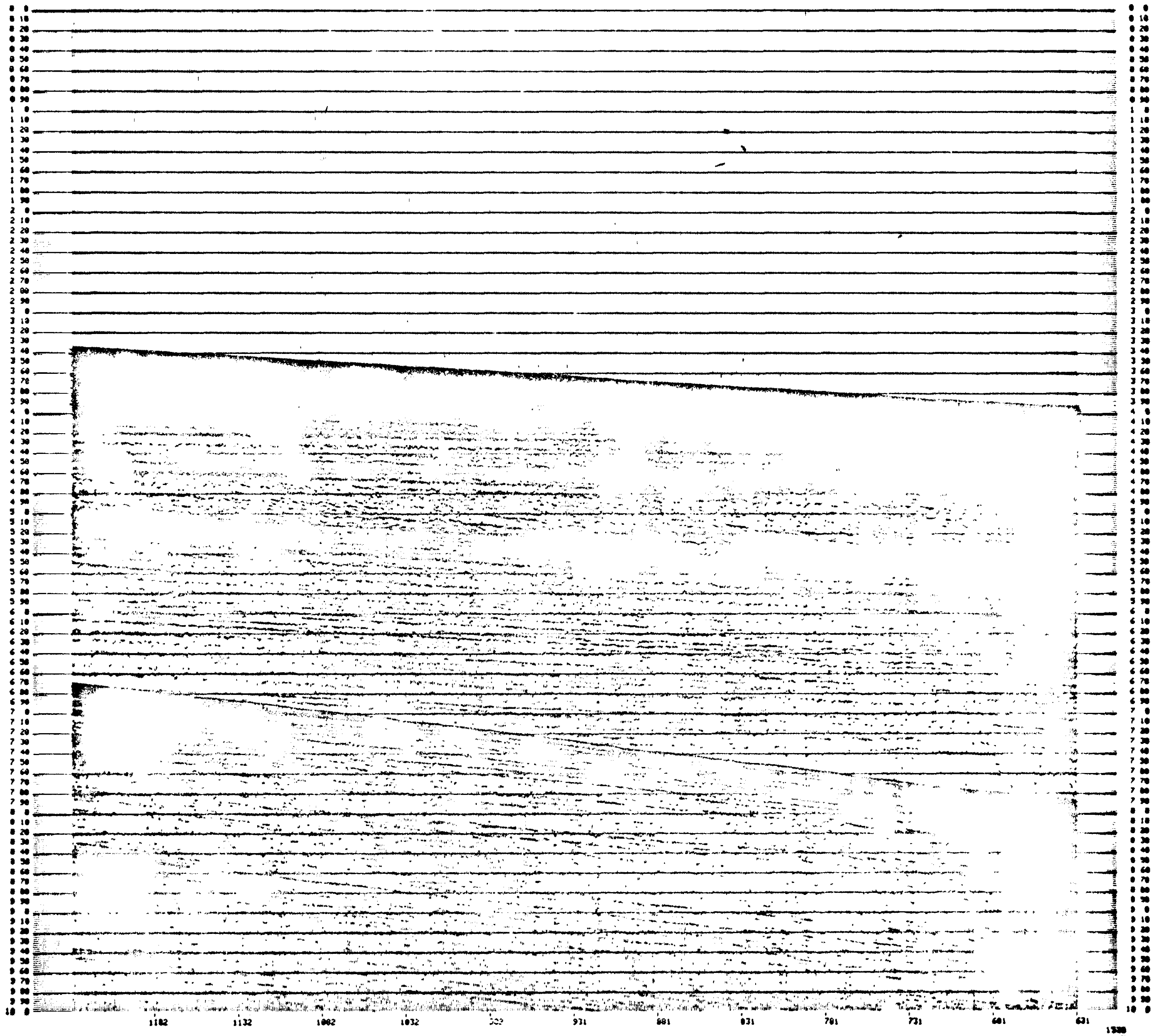


Figure 5. Near trace section for line 5 showing water bottom and interbed multiples.

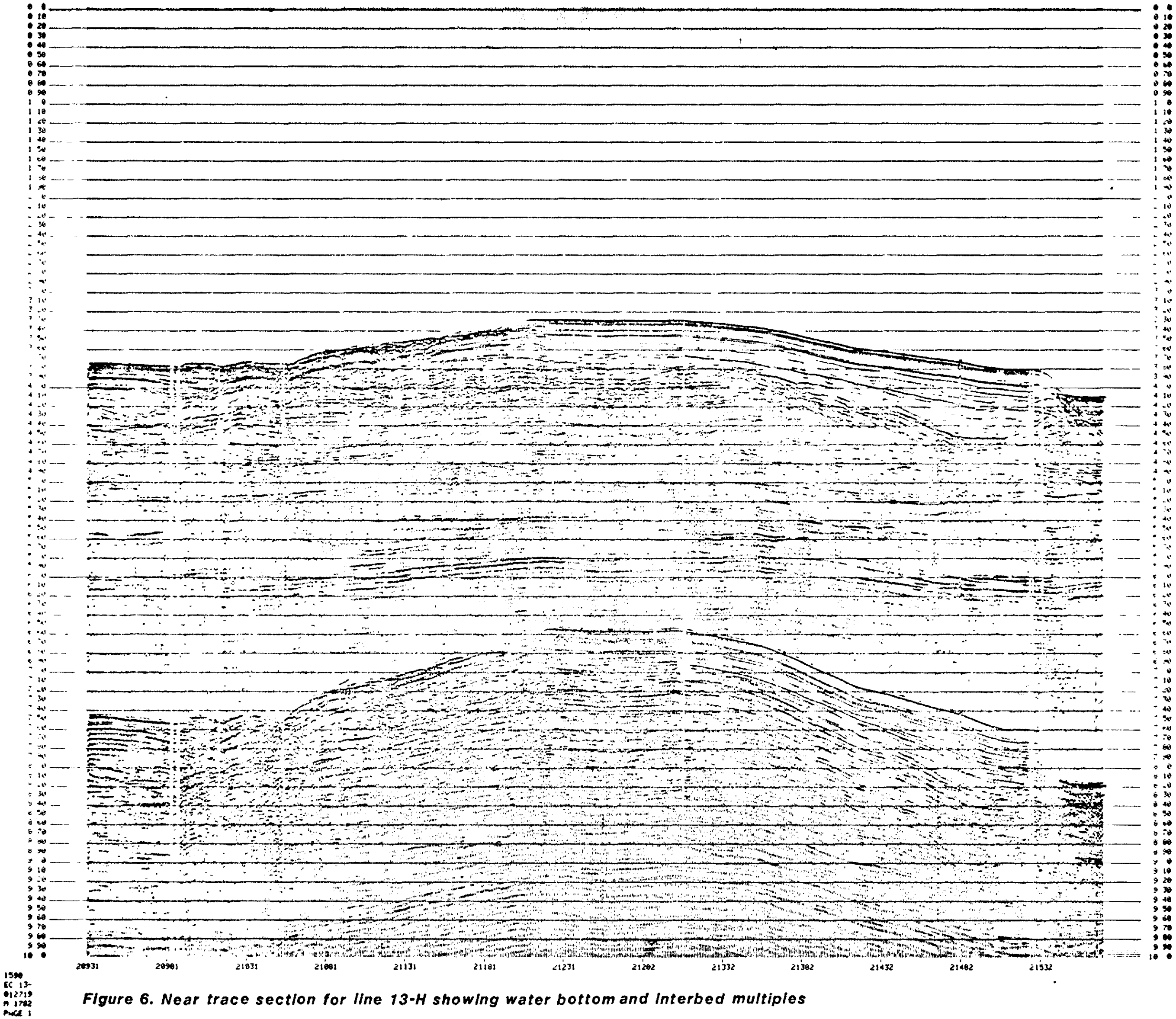


Figure 6. Near trace section for line 13-H showing water bottom and interbed multiples

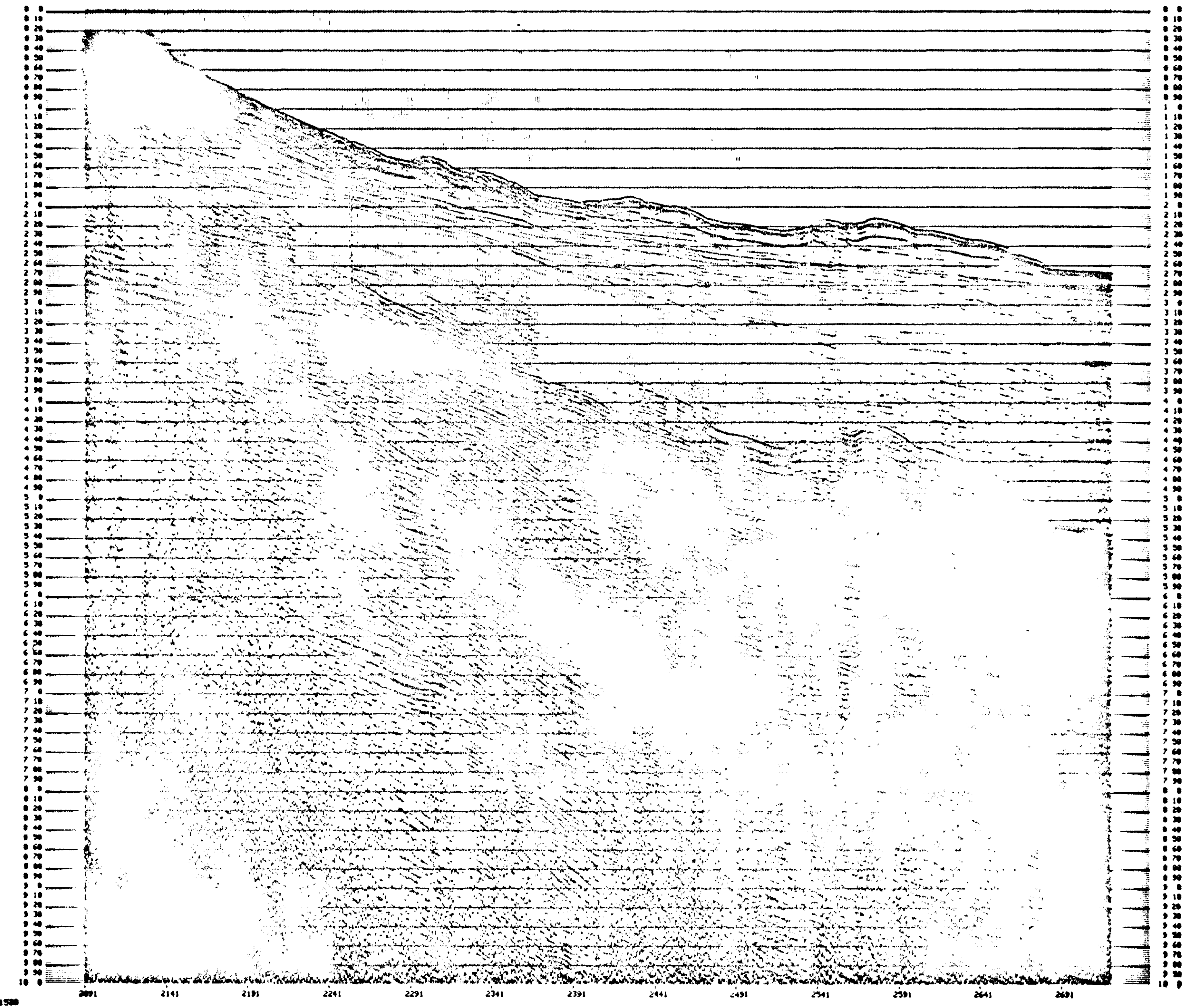


Figure 7. Near trace section for line 11-C slope showing water bottom and interbed multiples

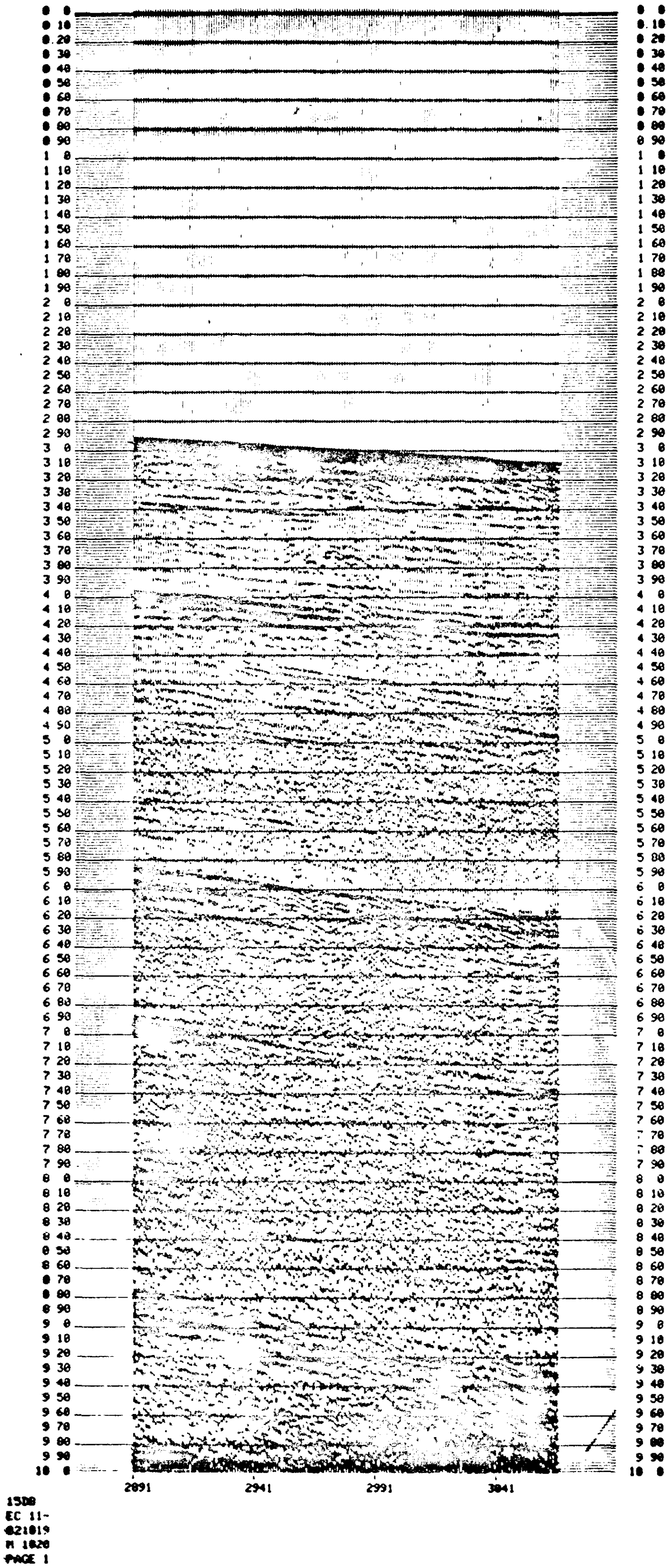


Figure 8. Final section for line 11-C far with basic processing only

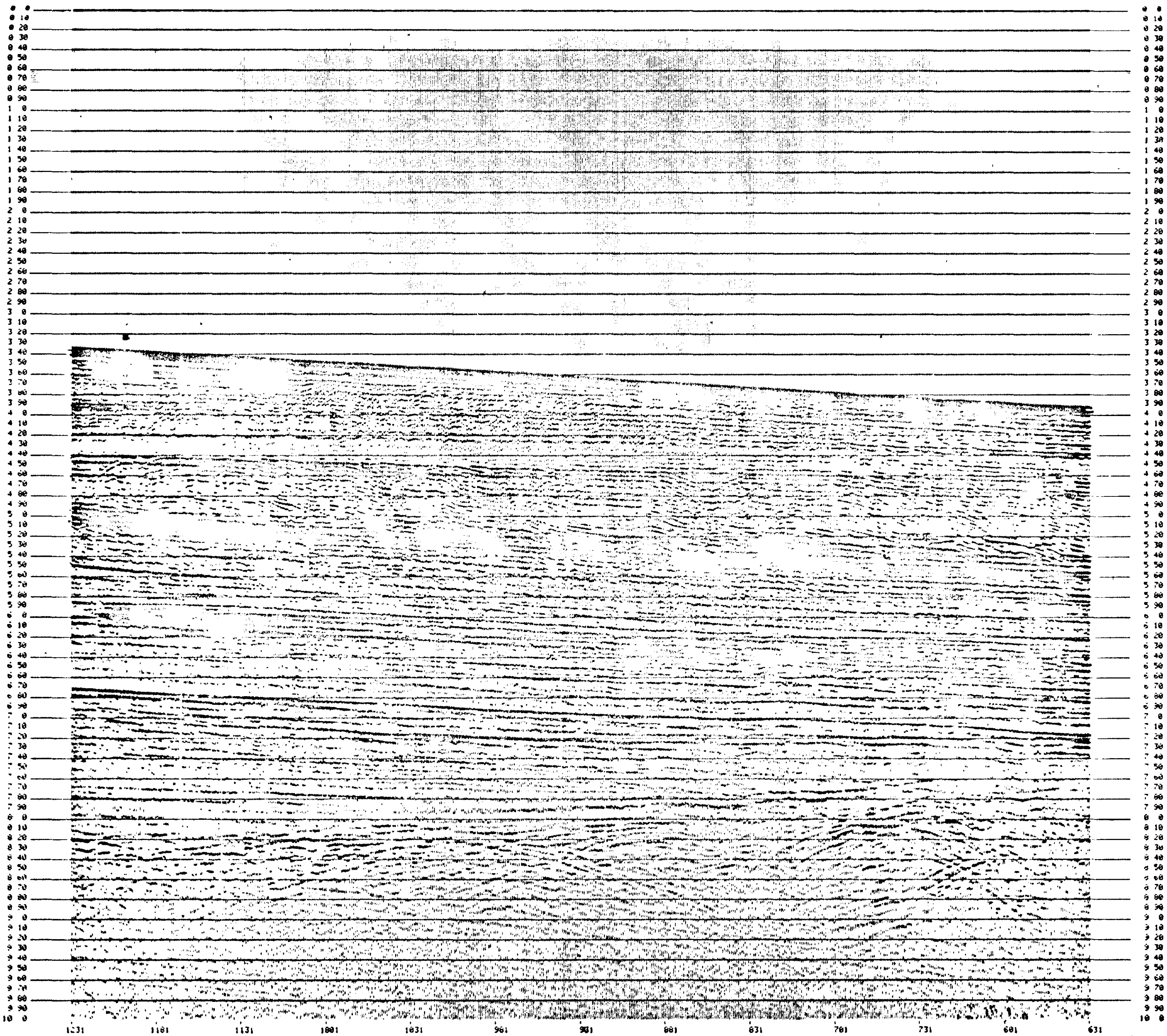


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Figure 9. Final section for line 5 with basic processing only

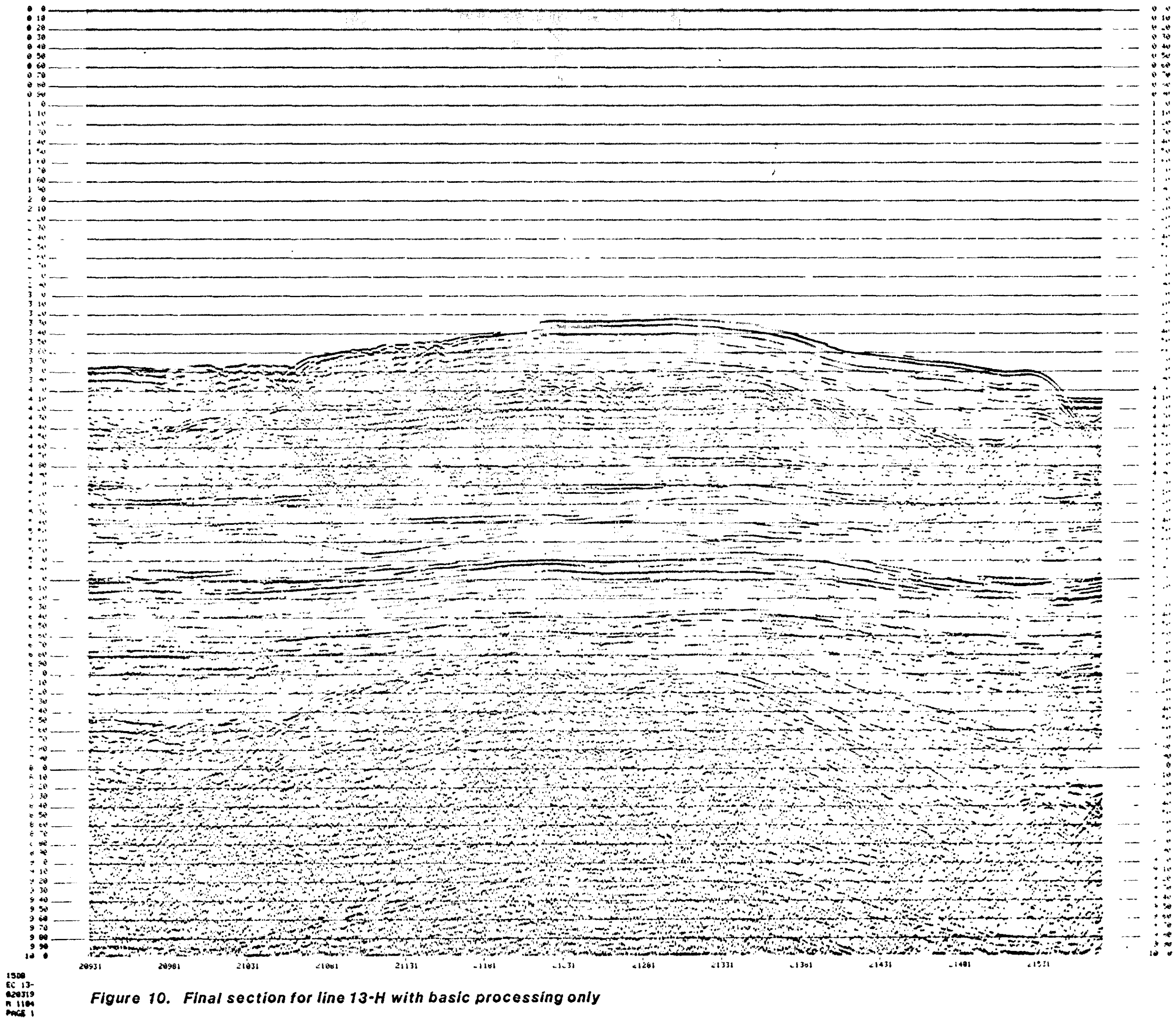


Figure 10. Final section for line 13-H with basic processing only

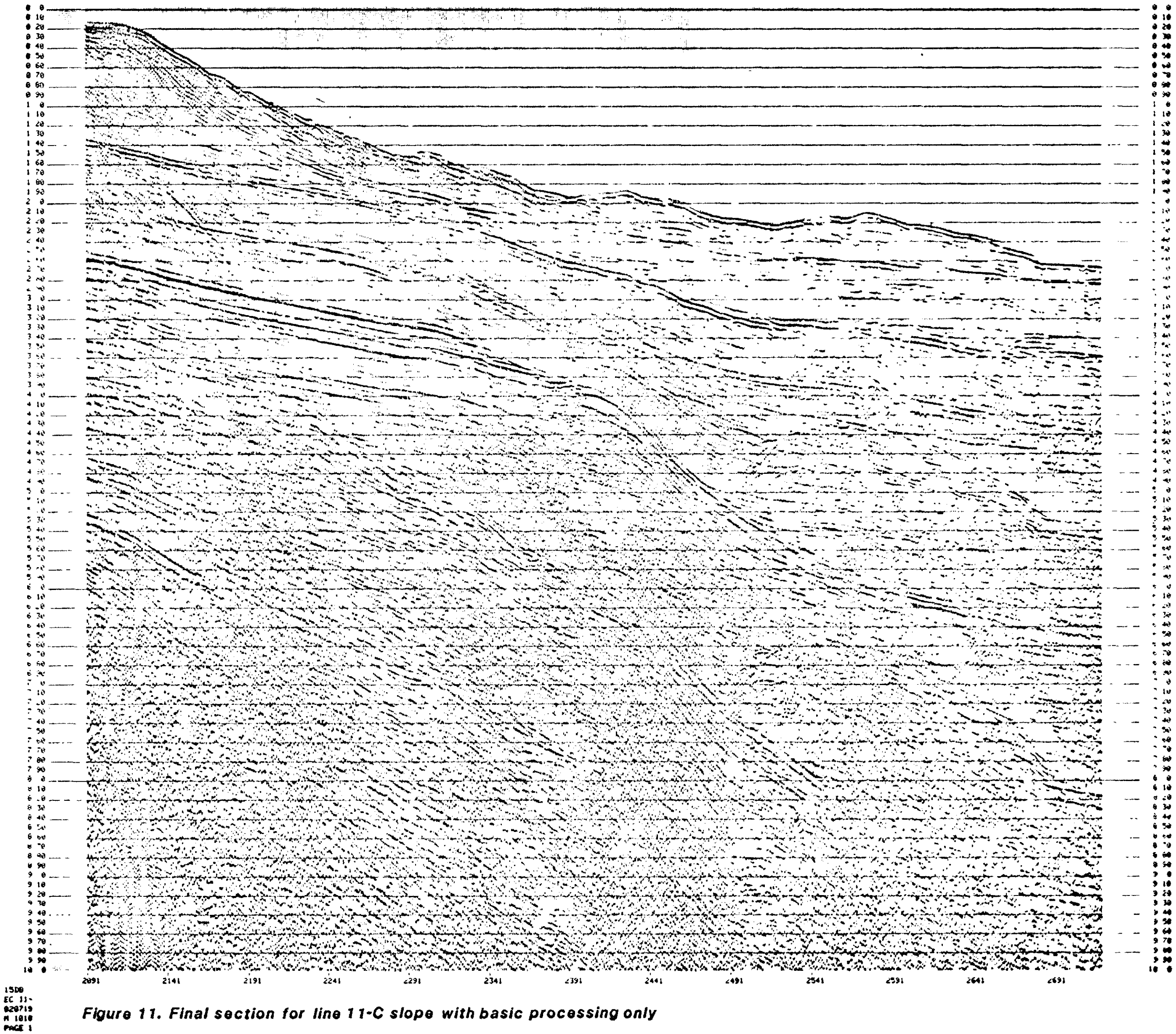


Figure 11. Final section for line 11-C slope with basic processing only

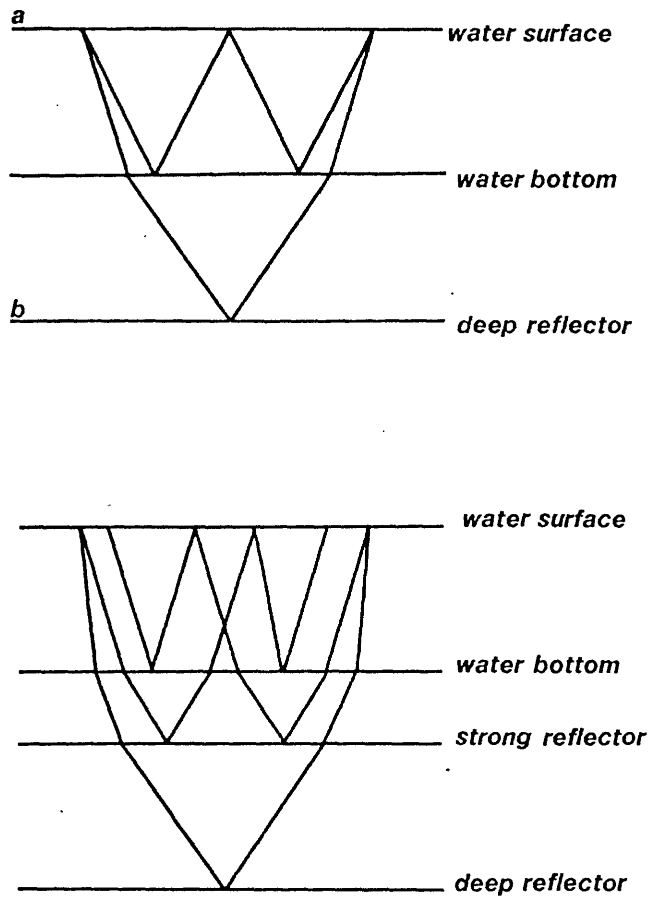


Figure 12. Simple reverberation model shows two types of multiples:

a. water bottom-water surface-water bottom (BSB)
b. strong reflector-water surface-water bottom (RSB)

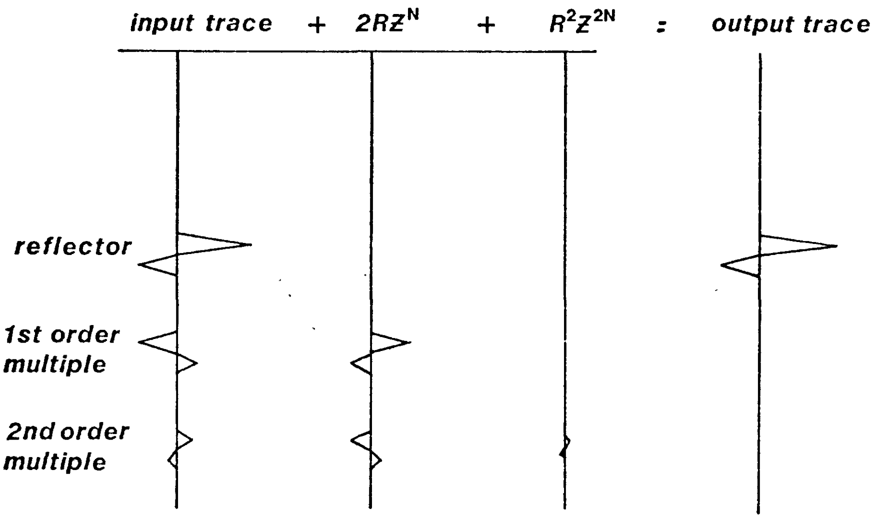


Figure 13. Application of three point operator to a single synthetic trace.

Although the seismic model depicted in figure 12 is simple, it helps define the two types of multiples, provides insight into the design of the operators, and indicates the applicability of each method.

DEREVERBERATION FILTERS

General Remarks

Dereverberation filters predict the reverberated signal and then subtract it from the total recorded trace. The estimate of the reverberation is based on a model that involves major assumptions about the trace. The two types of dereverberation filters applied were a three-point operator and a predictive deconvolution filter with long prediction distance.

Three-Point Operator

The reverberation system of figure 12b can be regarded as a filter (Peacock and Treitel, 1969, p. 166). As the returning signal comes to the surface, the z-transform of the output signal is

$$1-2Rz^{N} + 3R^{2}z^{2N} - 4R^{3}z^{3N} + \quad ,$$

where N = two-way travel time through the water, and

R = reflection coefficient of the water bottom.

The inverse of this reverberation system, which is the digital filter that collapses the reverberating waveform to a spike, is

$$1 + 2Rz^{N} + R^{2}z^{2N}.$$

Application of this filter to synthetic data (figs. 13, 14) indicates that the filter works well when the reflection coefficient and two-way travel time are accurately known and when the seismic pulse is a spike.

This filter was applied to the near-trace section of lines 11C-far (fig. 4) using R = 0.5 (fig. 15) and R = 0.99 (fig. 16). There is a slight reduction in the amplitudes of the multiple energy that arrives below six seconds.

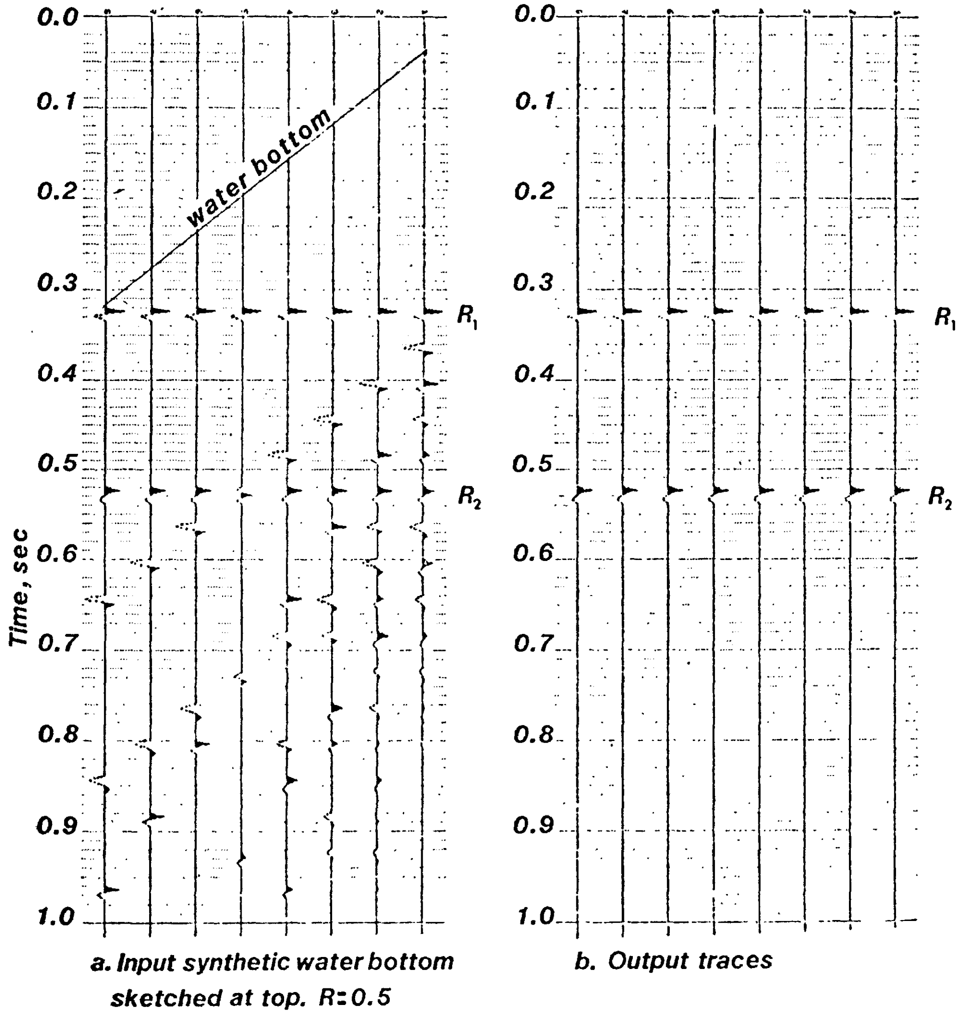


Figure 14. Application of three point operator to synthetic traces with dipping water bottom and two flat reflectors.

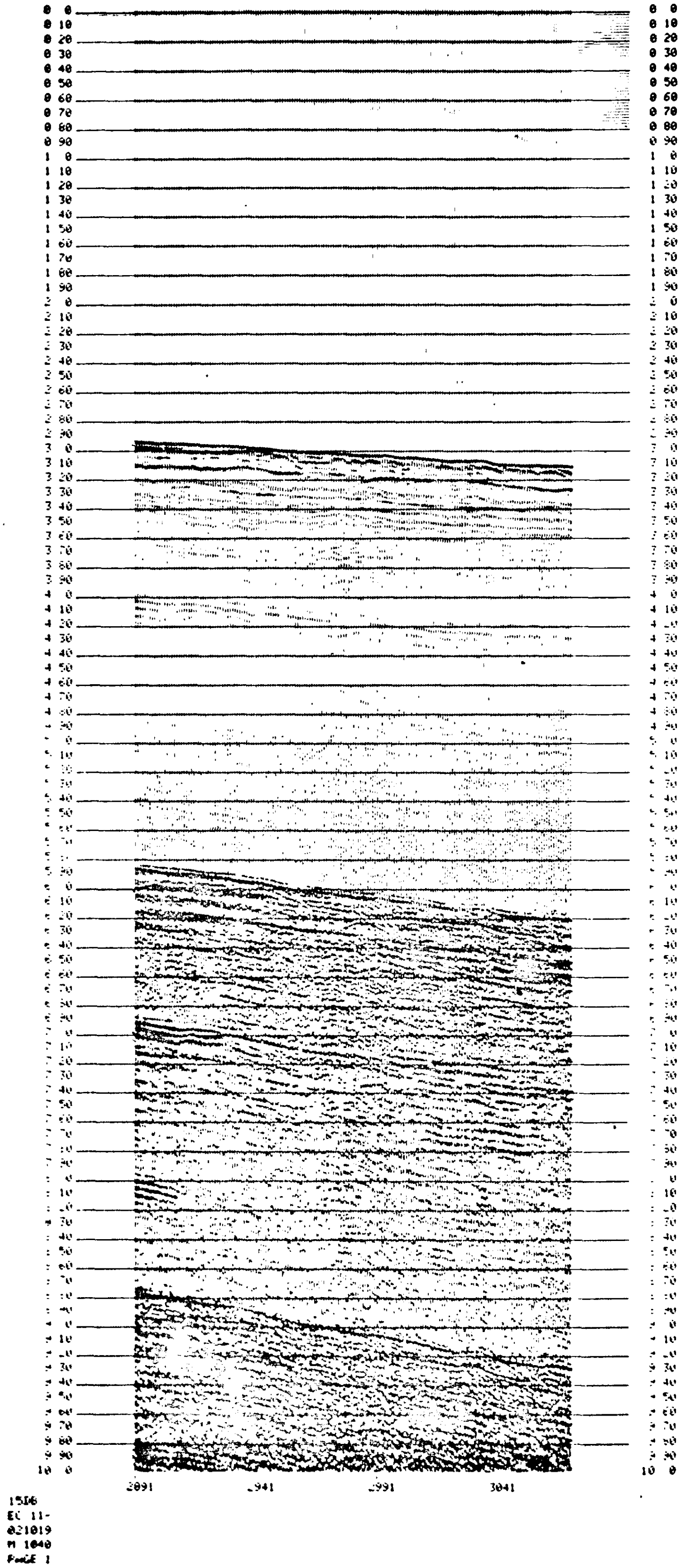


Figure 15. Near trace section for the line 11-C far using three-point deverberation filter R = 0.5

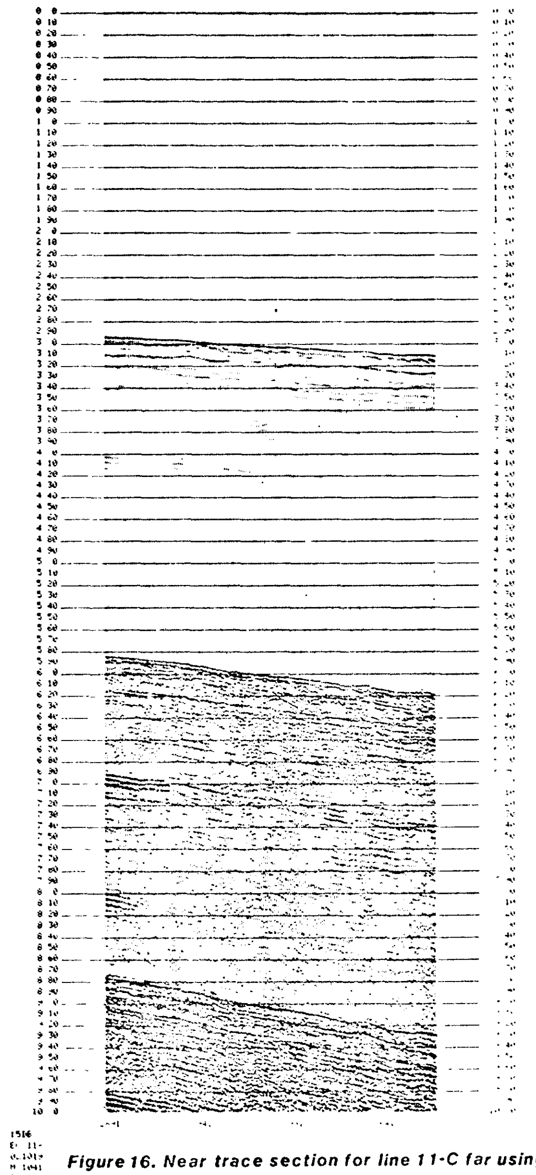


Figure 16. Near trace section for line 11-C far using three-point dereverberation filter, R = 0.99

One reason can be suggested for the shortcomings of this operator; during the reformatting of the data, a gain function was applied that did not correctly preserve the amplitudes of the multiples relative to the primaries. This is the reason why large values of R were used. Care must be taken so that the data is restored to amplitudes that approximate vertically traveling plane waves.

Second, for this case it may not be adequate to assume that the seismic pulse is a spike. Finally, the operator under consideration is mainly designed to suppress a RSB type of multiple. The multiple in Line 11C-far is a BSB multiple. Although this operator failed for these initial cases, further study should be undertaken to try and solve these problems.

Predictive Deconvolution With Prediction Distance Equal to Two-Way Travel Time of the Water Bottom

The predictive-deconvolution filter is a well-known technique used to eliminate multiple energy. Much literature has been published on deconvolution. A brief description of this method follows.

For reverberating records, the trace is composed of overlapping waveforms (fig. 17). In predictive deconvolution a least-squares filter is designed whose desired output is the reverberation wave train (fig. 18) from the trace. By delaying this output by the water-bottom time and subtracting it, the primary is left. The algorithm for this method is based on the Weiner-Hopf equation (Peacock and Treitel, 1969, p. 165) in which the predicting filter is a function of the autocorrelation and cross-correlation of reverberation train (fig. 19) with the trace.

Predictive deconvolution was applied to line 13H (fig. 20) with moderate success.

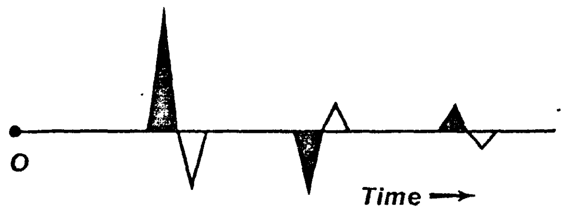


Figure 17. Reverberating trace composed of overlapping waveforms

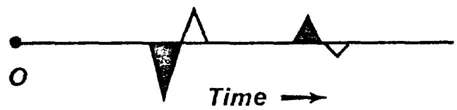


Figure 18. Desired output for predictive deconvolution

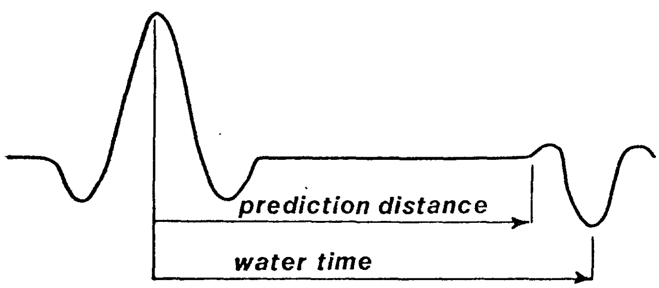


Figure 19. Autocorrelation for trace with deep water bottom multiple

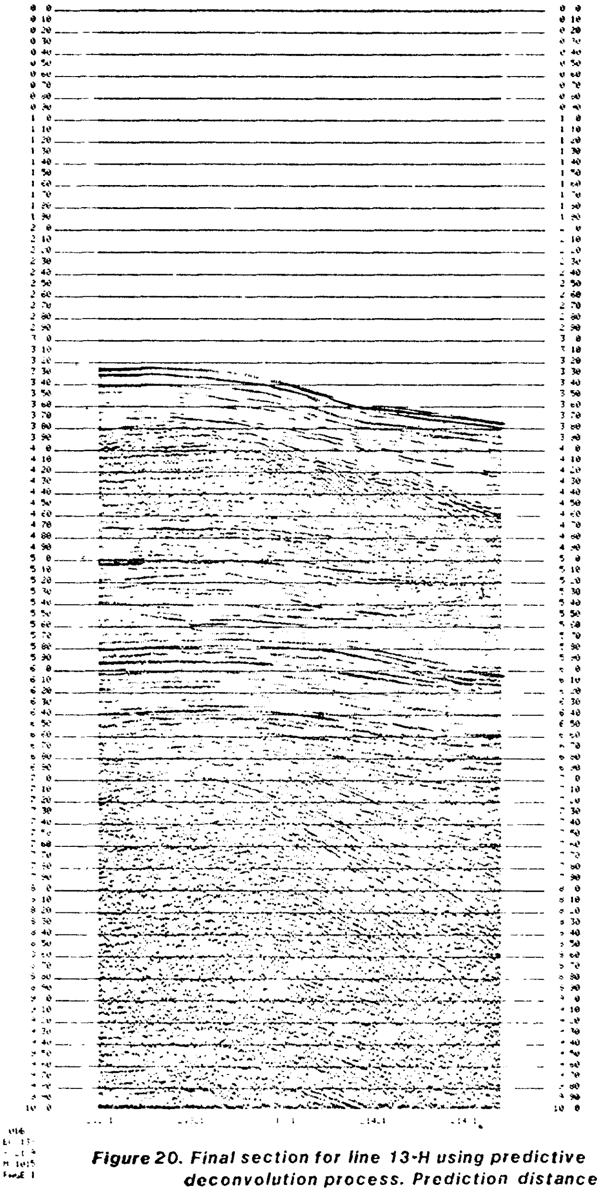


Figure 20. *Final section for line 13-H using predictive deconvolution process. Prediction distance equal to time to water bottom*

WEIGHTED STACKS

General Remarks

A comparison of the near-trace sections (figs. 4-7) and the final stacks (figs. 8-11) demonstrates that a large amount of suppression of the multiple occurs during stacking. This suppression of the multiple is explained as follows: After the data have been corrected for normal-moveout (NMO), primary reflections should be aligned at constant times (fig. 21). The multiples, which have traveled at a slower velocity, still have a large amount of residual normal-moveout (RNMO), so when the seismic section is stacked, the reflector is enhanced and the multiple is suppressed since it is not aligned. This suppression of the multiple during stack suggests that perhaps the stacking process may be improved. The following weighting methods were applied to selected portions of AOCS seismic data: (1) Near-trace surgical muting, (2) spatially variant bandpass filtering, (3) Nth-root stacking, and (4) trace distance weighting.

Near-Trace Surgical Muting

The traces of figure 21 show that the smallest change in moveout for the traces occurs at the shortest distance from the receiver. This suggests that the best cancellation of the water bottom occurs for the far traces, and the multiples contained in the near traces should be zeroed or "surgically muted." The stacking process then averages only a portion of the data, which contains multiples with the largest amounts of RNMO.

Surgical mutes were applied to lines 13H (fig. 22) and 5 (fig. 23). The results were encouraging since some suppression of the multiple occurs. However, the multiple is still apparent but at a slightly lower time. The reason for this is unknown at the present time and research is continuing.

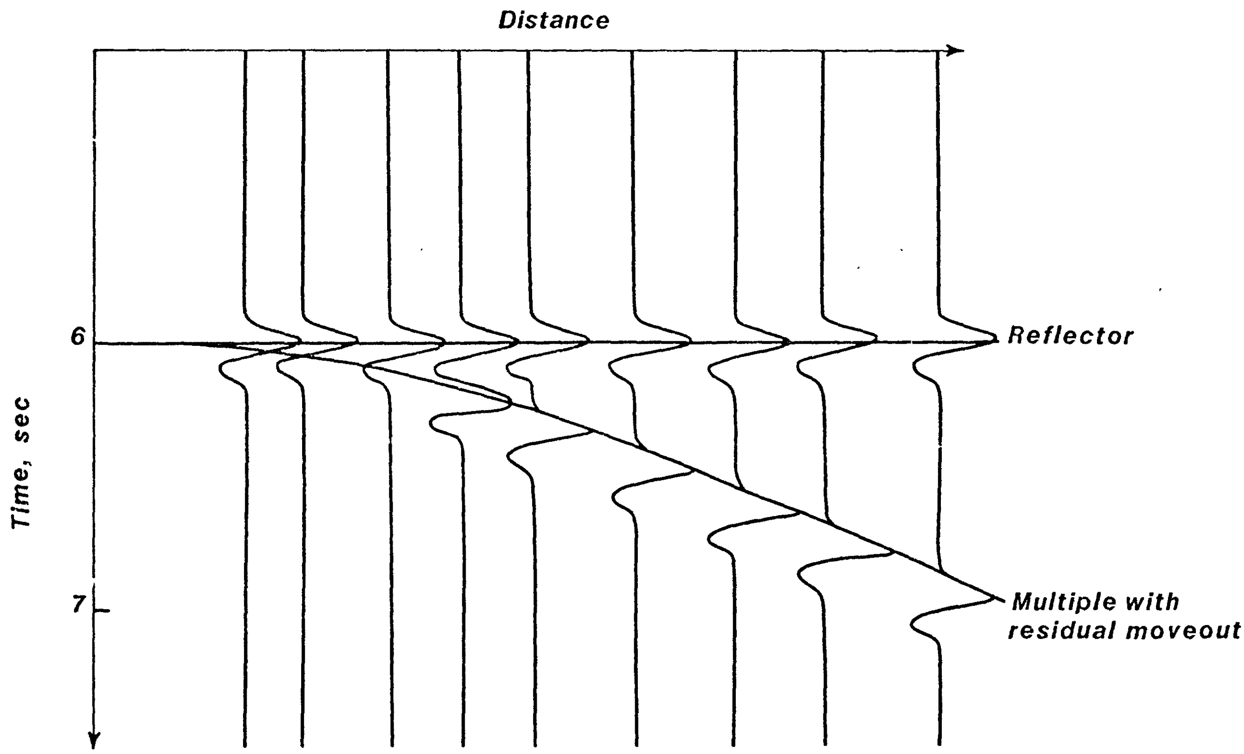


Figure 21. A sketch of suppression of multiple during stack caused by residual normal moveout

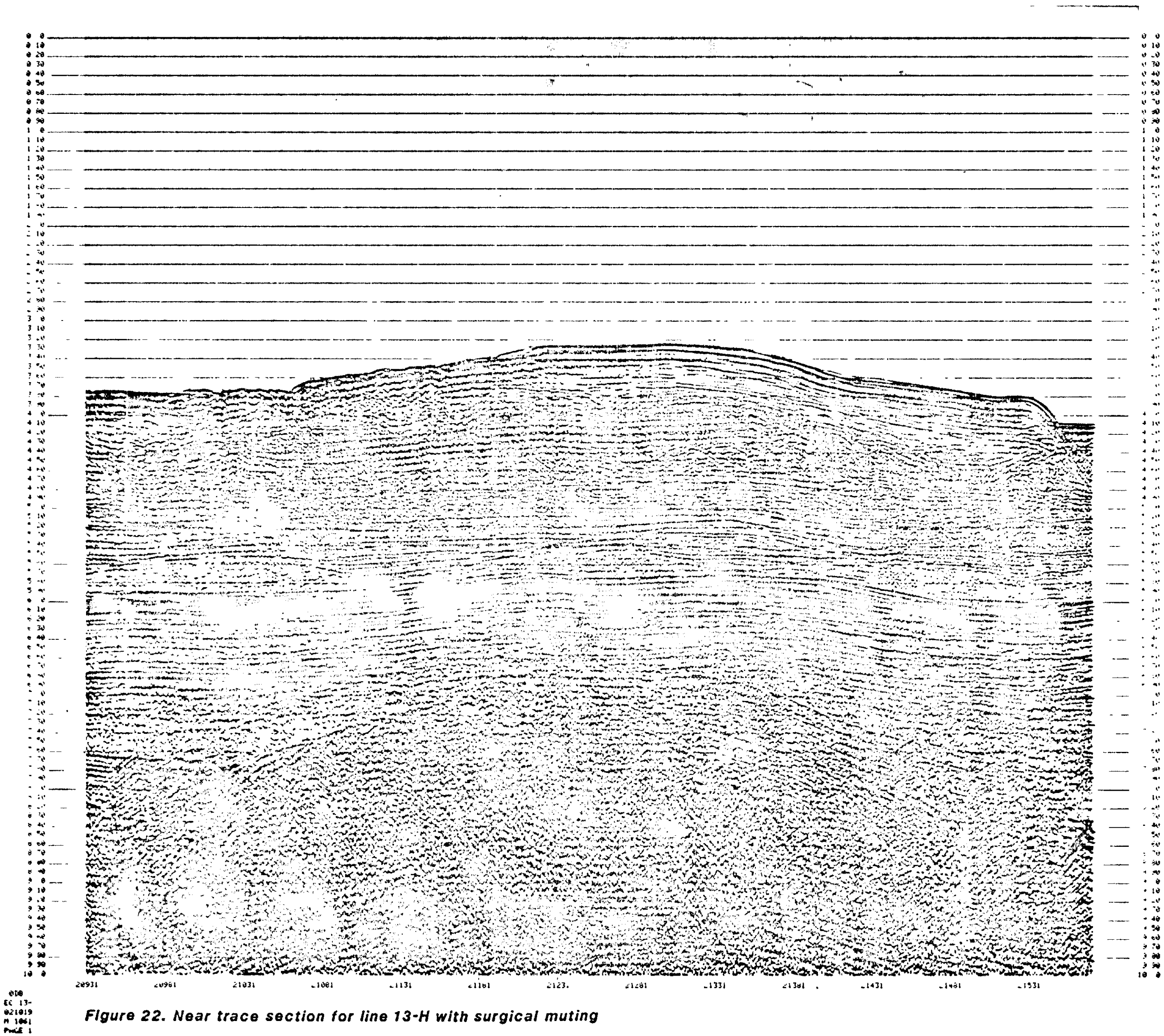


Figure 22. Near trace section for line 13-H with surgical muting

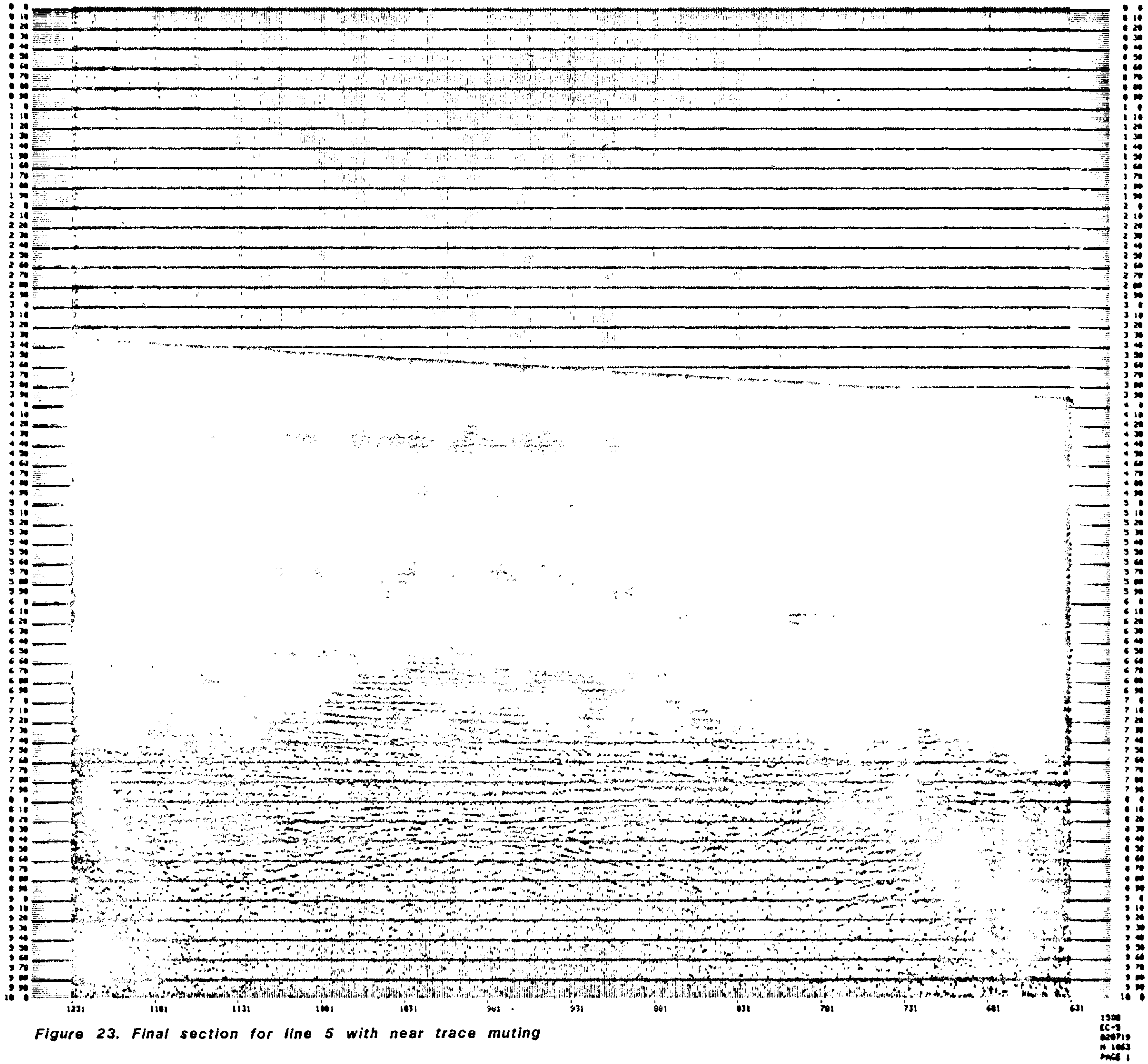


Figure 23. Final section for line 5 with near trace muting

Spatially Variant Bandpass Filters

The success of the near-trace surgical mutes leads one to try other forms of weighting. In figure 24, the high frequencies cancel better on the near traces, and the low frequencies cancel better on the far traces. Perfect cancellation occurs when the RNMO between adjacent traces equals one-half the period of the multiple. A bandwidth of acceptable frequencies with periods equal to one-fourth to three-fourths the RNMO describes a set of bandpass filters which vary with trace offset (fig. 25). These spatially variant filters were applied to data of line 13H with only marginal success (fig. 26). Model studies may suggest the reasons for the failure of this method.

Nth-Root Stack

The Nth-root stack (Kanasewich and others, 1973, p. 327) attempts to enhance coherent data through a nonlinear operator. The basic process (fig. 27) involves evaluating the Nth root of the data values, averaging (or stacking) these numbers, and then calculating the Nth power of the numbers. Care is taken to retain the sign of the data values. (A conventional stack can be considered to be a "1st-root" stack.)

A comparison of an 8th-root stack with a conventional stack demonstrates the effectiveness of the Nth-root stack if the noise consists of sharp random pulses (fig. 28). However, the results of applying a 4th-root stack to line 13H (fig. 29) are very unpleasant since the data (along with the multiple) were destroyed.

Trace Distance Weighting

Pulju and others (1974, p. 810) recommended that a scaling function increasing with trace offset should be applied to suppress multiples. Several scaling functions can be suggested. A scaling factor equal to the trace

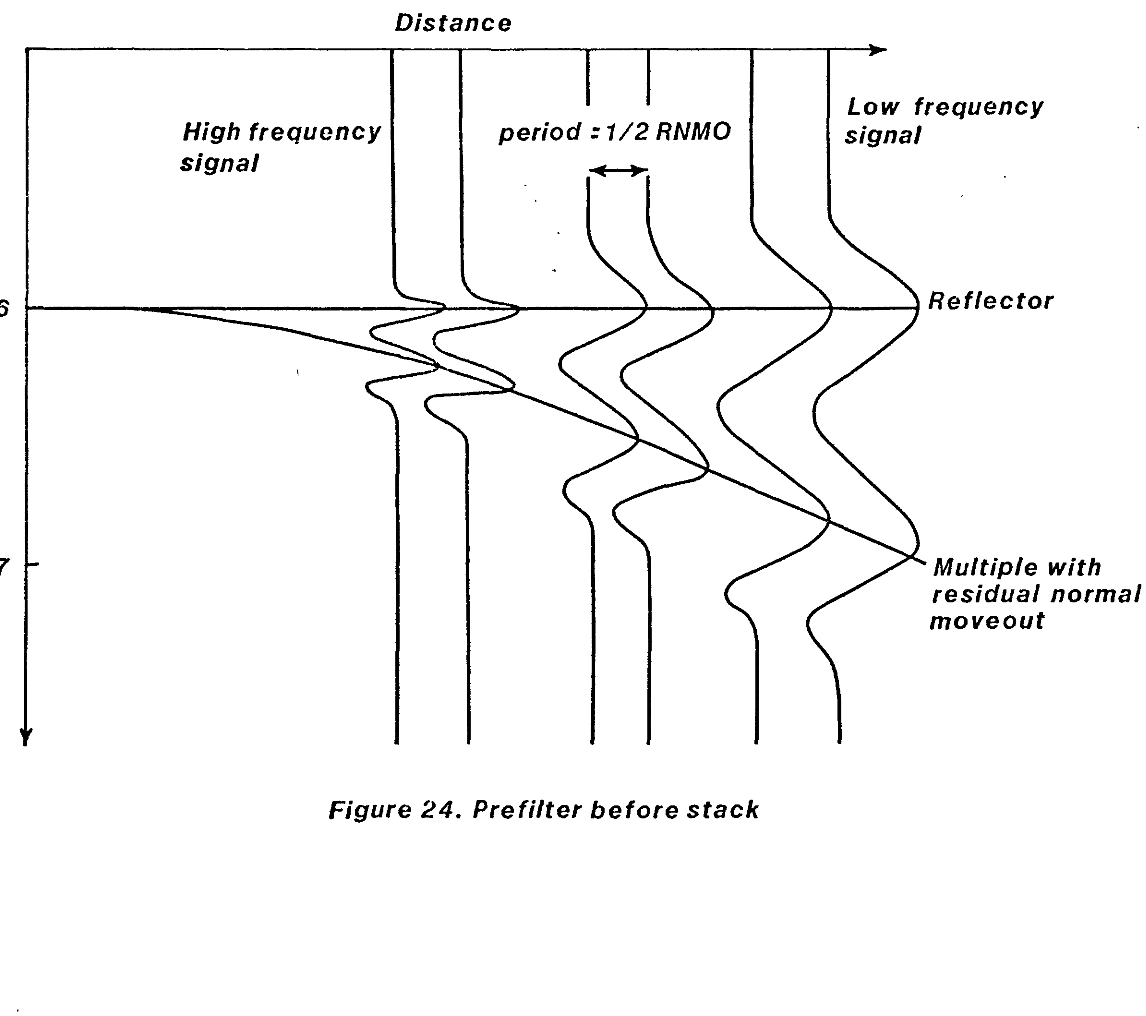


Figure 24. Prefilter before stack

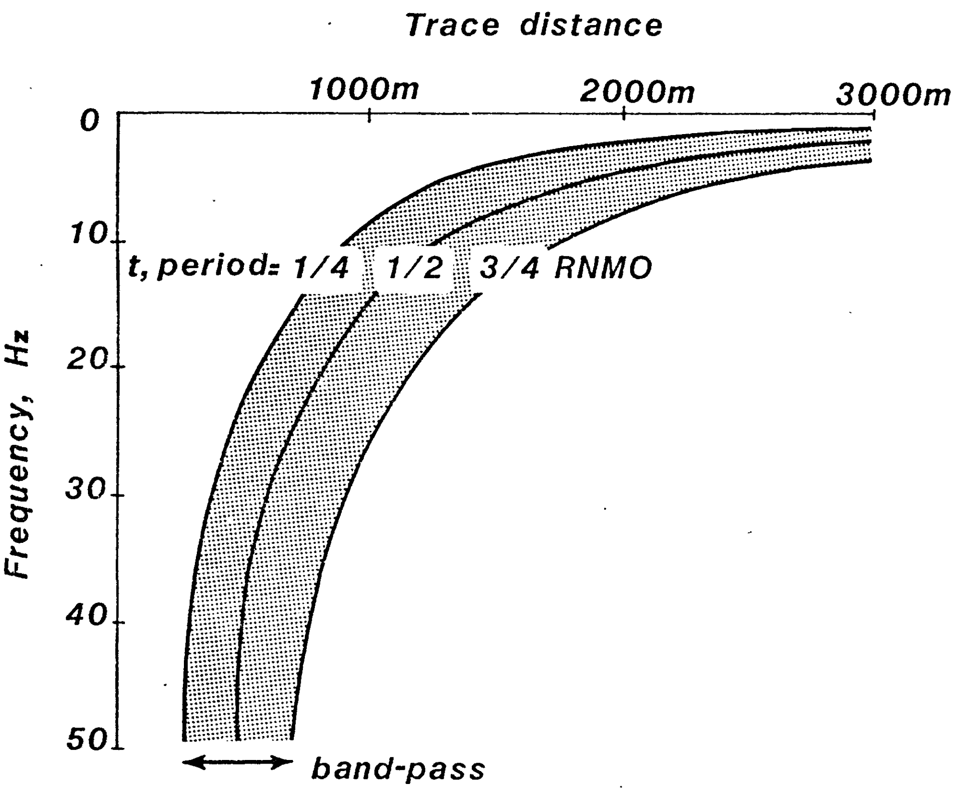


Figure 25. Space variant band-pass.

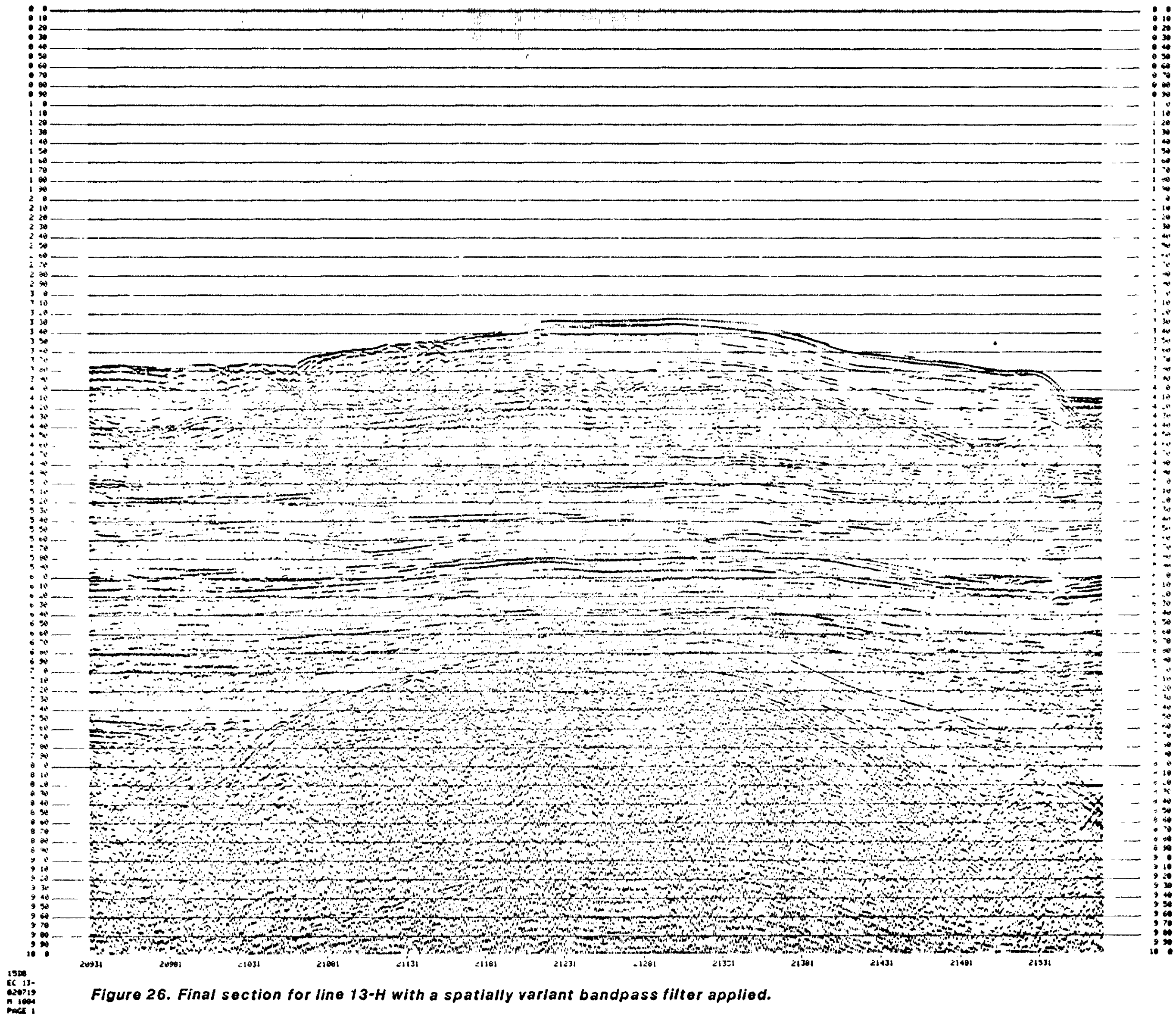


Figure 26. Final section for line 13-H with a spatially variant bandpass filter applied.

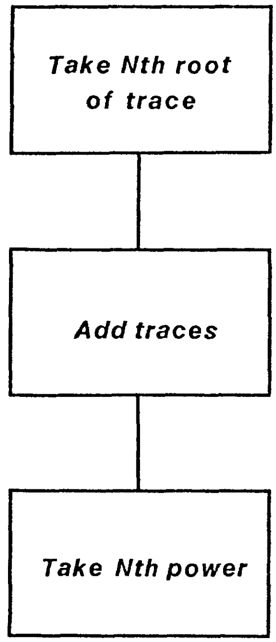
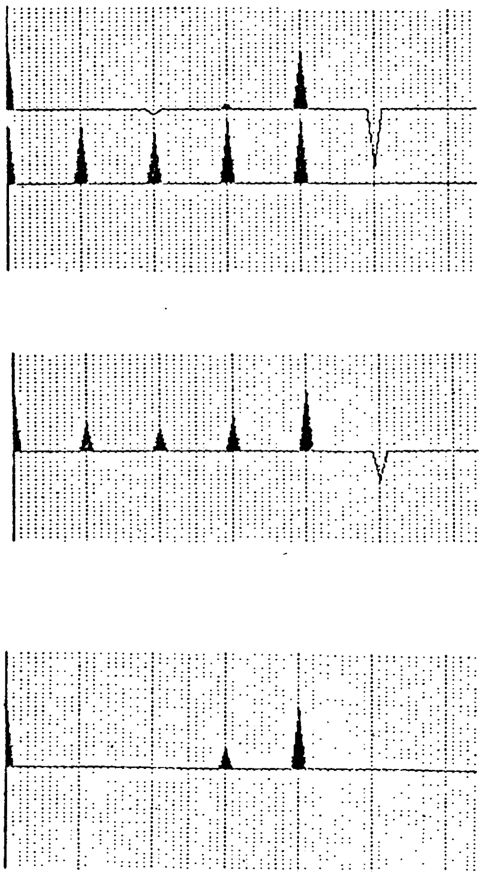


Figure 27. Process sequence for Nth root stack



Input traces

N=1
Conventional
stack

N= 8

Figure 28. Application of 8th root stack to spikes

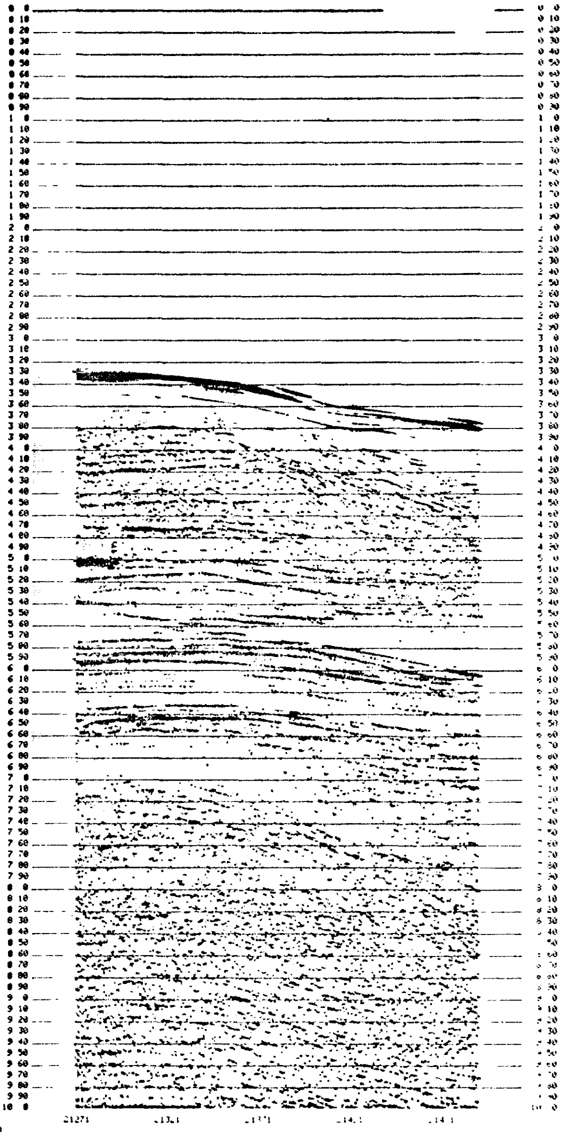


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Figure 29. Final section for line 13-H using the fourth-root stack process

distance is proposed. For the data used in this study, the far scale factor (3875) is about 11 times greater than the near-trace scale factor (350). This scaling routine was applied to lines 13H, 5, and 11C. For lines 13H and 5 the multiple (BSB) is almost completely suppressed. However, for line 11C (fig. 32), the trace distance weighting is not as successful and does not appear to work for the multiple off the interface (RSB).

In general, the application of trace distance weighting depends on the time to the water bottom, amount of dip, and type of multiple considered. The trace distance weighting works better for (BSB) multiples than for (RSB) multiples. The success of this method is data dependent. For the data in this study, trace distance weighting was the most successful method applied.

CONCLUSIONS

Seismic-reflection data recorded on the Atlantic Outer Continental Shelf are often dominated by multiply-reflected seismic energy that reverberates between the surface of the water and the water bottom or other strong reflecting horizons. These deep-water-bottom multiples often cause portions of the data to be completely useless. Several data- processing techniques can be applied to attempt to suppress these multiples. These include:

1. Three-point dereverberation operator.
2. Predictive deconvolution with a long prediction distance.
3. Near-trace surgical mutes.
4. Spatially variant bandpass filters.
5. Nth-root stack.
6. Trace distance weighting.

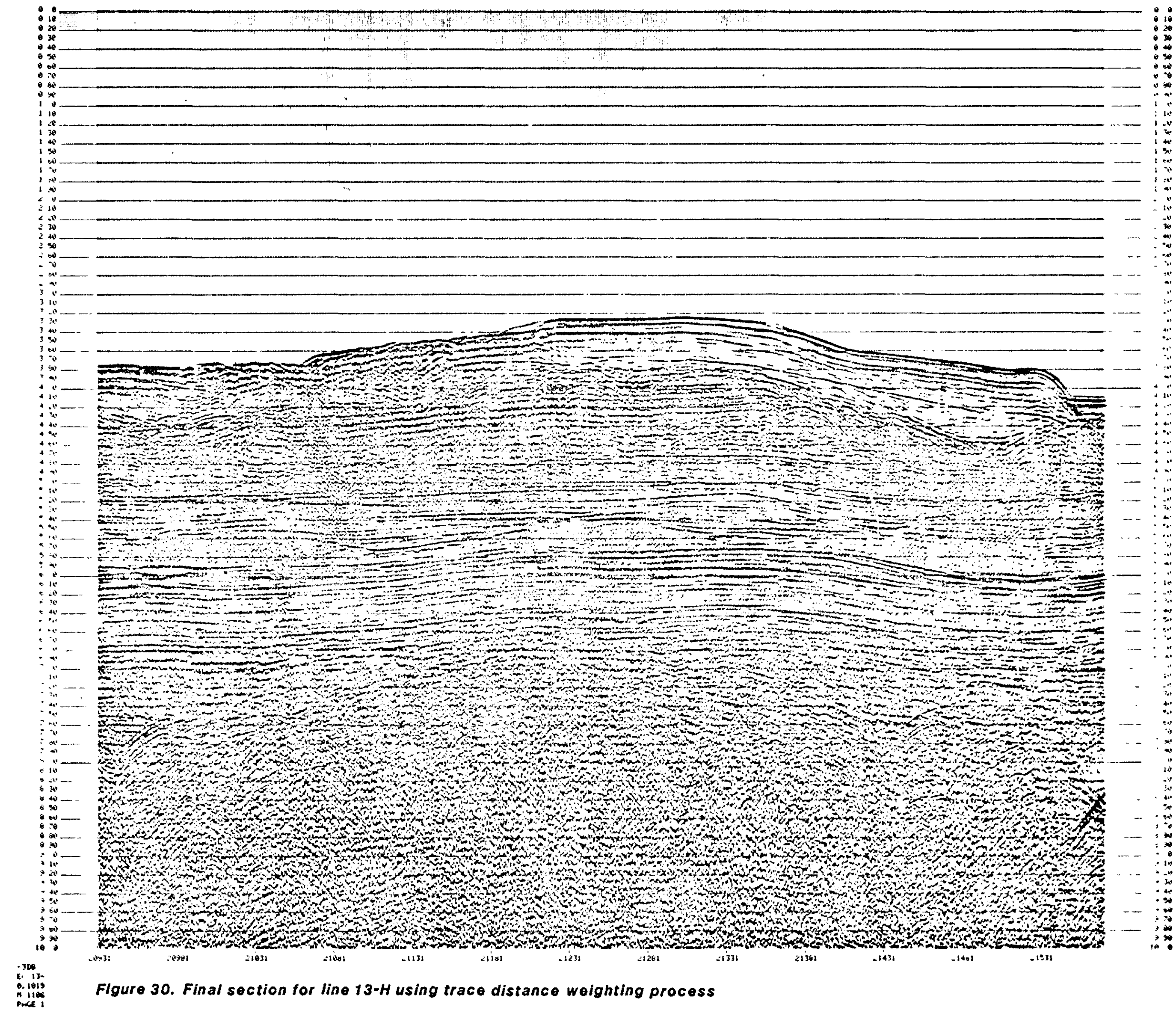

Figure 30. Final section for line 13-H using trace distance weighting process

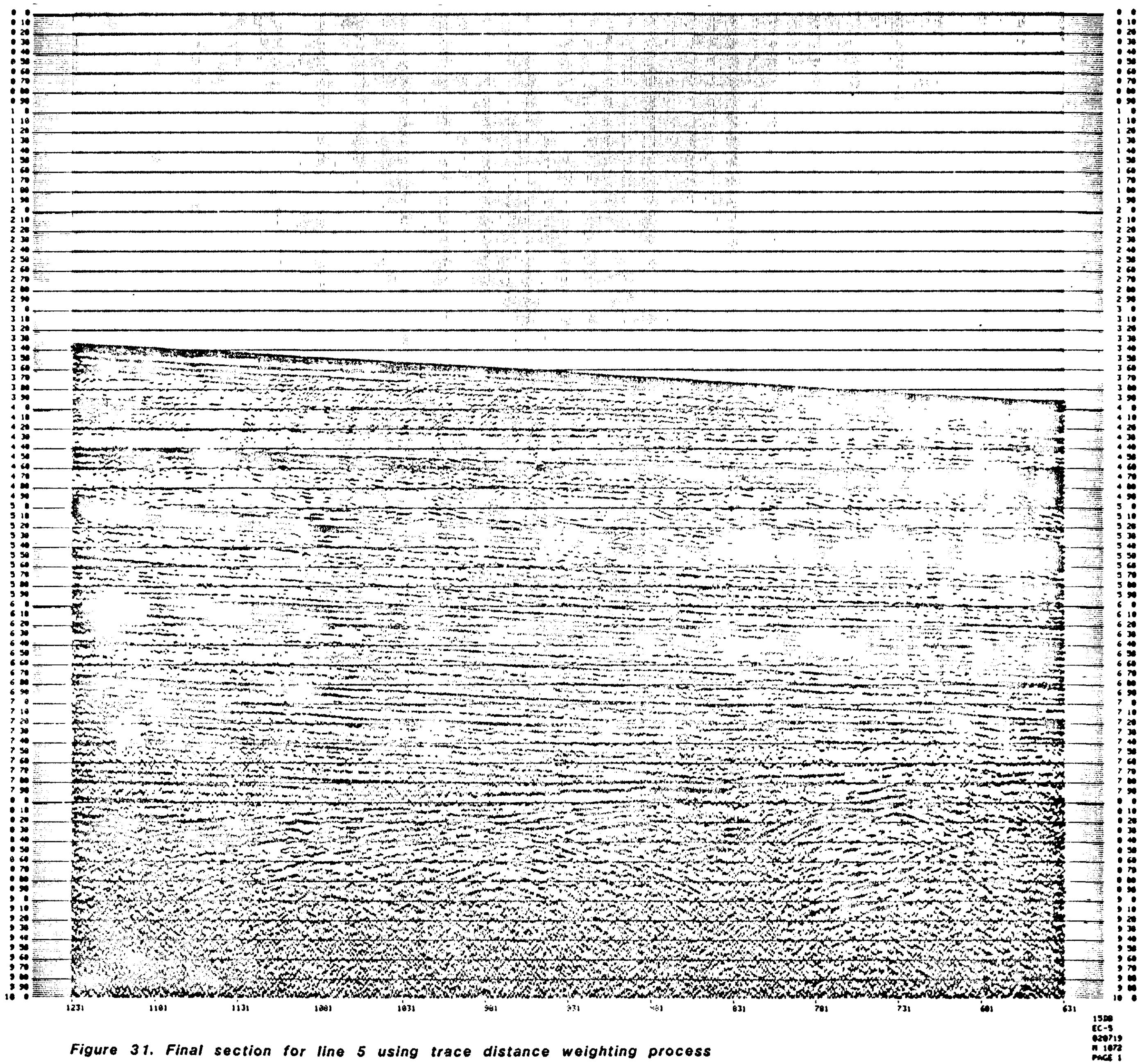

Figure 31. Final section for line 5 using trace distance weighting process

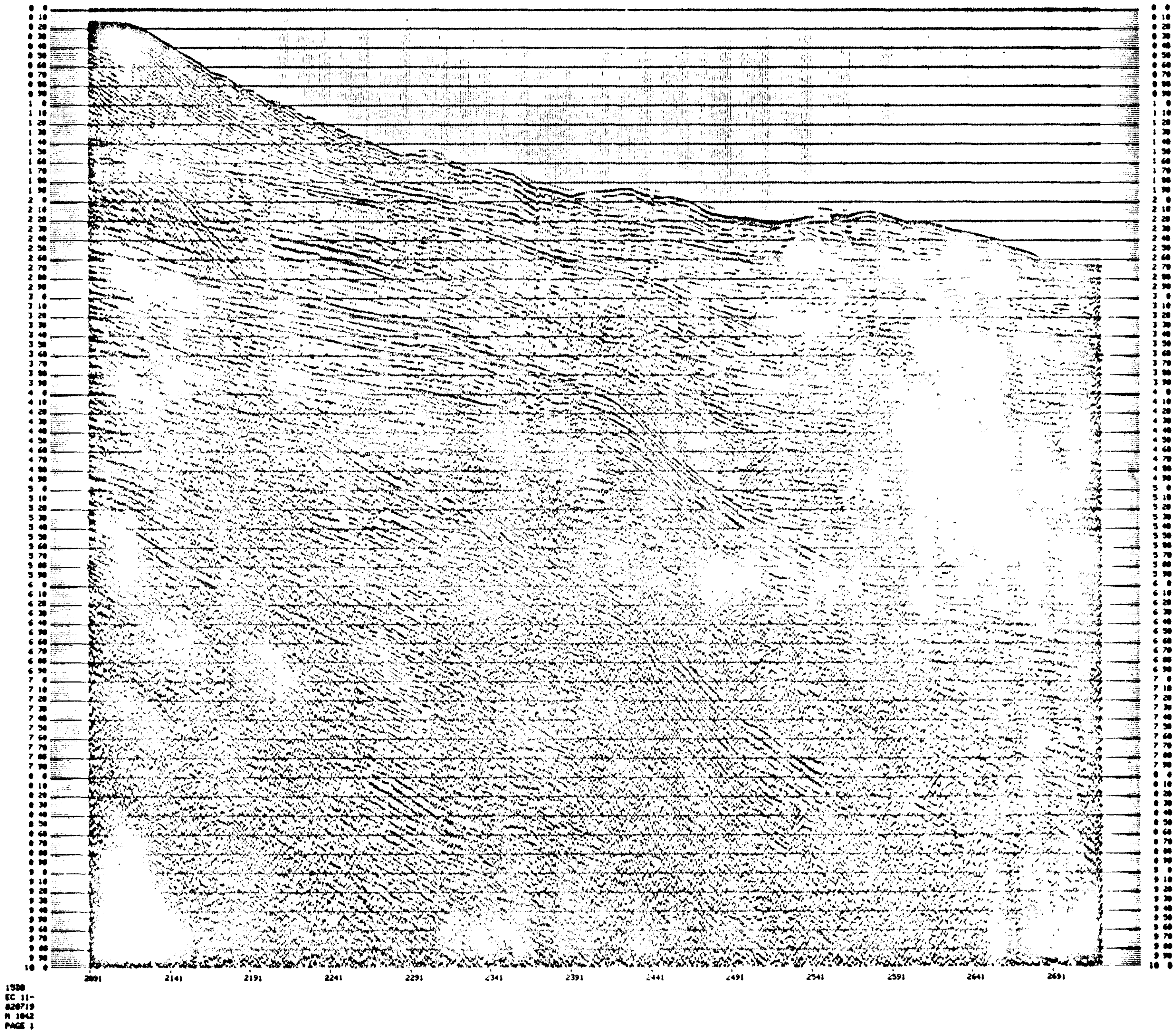

Figure 32. Final section for Line 11-C slope using trace distance weighing process.

Application of these techniques to several seismic lines indicates that:

1. All methods are data dependent.

2. The greatest amount of deep-water-bottom multiple suppression is achieved during a conventional stack.

3. Trace distance weighting was the most successful method studied. This process suppresses the simple water-bottom multiple (BSB) better than the multiple from a strong reflector (RSB).

RECOMMENDATIONS FOR FUTURE INQUIRIES

Multiples in seismic signals will continue to annoy geologists for years. The success or failure of any specific processing method depends on both the characteristics of the seismic data and the characteristics of the dereverberation process. Both of these aspects should be considered. Specific projects should (1) examine the differences in the data of lines 13H and 5; (2) compare the filter characteristics of the linear weighting function to both the spatially varying bandpass filters and the near-trace mutes; (3) apply the three-point dereverberation operator to the pegleg (RSB) multiple in line 11C-slope; and (4) develop another operator that is based on a simple water-bottom model.

The amount of multiple suppression that occurs during a conventional stack can vary. For example, in line 13H (fig. 10) the multiple is easily recognized, while in line 5 (fig. 9) a great deal of suppression of the multiple has occurred. The differences between these lines should be examined.

A weighted stack with a linear function of trace distance was the most successful method that has been applied to the data. Although several additional weighting functions can be suggested, including hyberbolic and trigonometric functions of distance, a more fruitful investigation should first consider the reasons for the success of the linear function of distance as compared to the near-trace mutes or spatially variant bandpass filters. Models may suggest why the linear weighting function failed to suppress portions of the multiple for line 11C-slope (fig. 32).

One of the reasons that the three-point operator failed was that the multiple to which this operator was applied was not a pegleg multiple (RSB) but a simple water-bottom reverberation (BSB). Therefore, the three-point operator should be applied to the pegleg multiple in line 11C-slope, while another simple operator should be designed and applied to line 11C-far. This simple operator would be based on a simple water-bottom model.

More than one type of multiple may be present in the seismic section (figs. 7 and 11). Since some of the operators were more effective in suppressing a specific type of multiple, perhaps multi-purpose filters should be designed which combine several operators.

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