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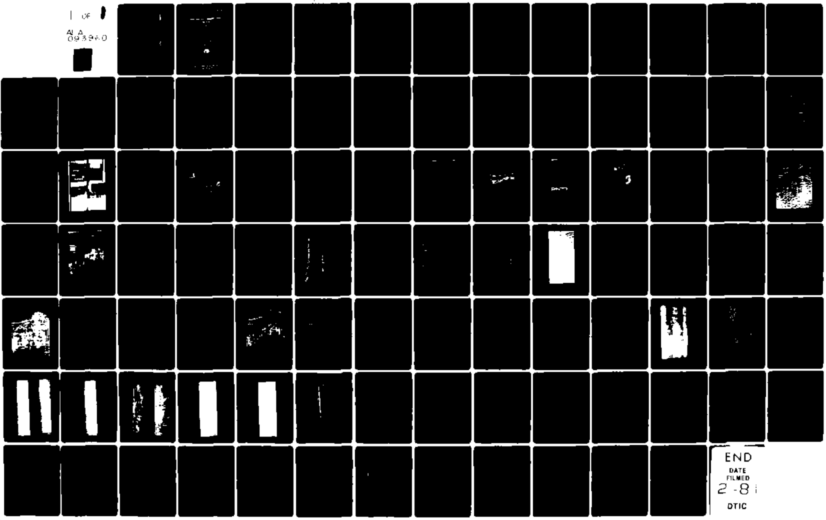

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MARINE SEISMIC DISPLAY ENHANCEMENT PROGRAM
FINAL REPORT

VOLUME I
RESULTS

MARTIN G. FAGOT

Ocean Technology Division
Naval Oceanographic Laboratory

January 1978

1976

Approved for Public Release
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NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY
NSTL Station, Mississippi 39529

FOREWORD

This report presents a summary and examples of results obtained under the Marine Seismic Data Enhancement Program. The Program concentrated on improving single channel, deep ocean, marine seismic profiling technology through the development, implementation, and evaluation of acquisition hardware/techniques, processing software, and display hardware/formats. This report is intended to demonstrate the interaction of acquisition, processing, and displaying of seismic profiling data, and to provide the geophysicist with the technology in each of these areas to enhance seismic data quality.

This report is Volume I of a three volume Final Report series on the Marine Seismic Display Enhancement Program. Volume II is a detailed description and listing of the data processing software programs. Volume III is a users handbook describing the operation of the Seismic Data Acquisition System (SDAS) and Seismic Data Display System (SDDS).

ABSTRACT

The quality of marine seismic profiling data governs the geophysicist's ability to interpret the geological character of the ocean sub-bottom structure. This report presents the results of a development program in the areas of data acquisition, processing and display to enhance single channel deep water marine seismic profiling data.

A digital data acquisition system with a multi-channel (16) analog input capability has been developed. The system has a sampling rate up to 10 kHz with 72 dB dynamic range. The digitally recorded data is compatible with either the UNIVAC 1108 or CDC 6600 computer systems.

Basic processing software has been implemented for the UNIVAC 1108 or CDC 6600 computers to enhance data quality through signal-to-noise improvement and increased resolution. The software includes time domain filtering, frequency domain filtering, Wiener filtering, spectral analysis and trace stacking. Wiggle traces can be generated through a CalComp or Zeta software routine.

A display playback system for the processed data with multi-format capability has been developed. The system generates outputs for the conventional line scan recorder, an X-Y plotter and a fiber optic recorder. Display formats include intensity modulated line scan, wiggle traces and variable area half-wave rectified wiggle traces. Playback rates up to 40 times real time acquisition are possible.

Processed and displayed field data acquired over the magnetic "J" anomaly in the Northeastern Atlantic Basin off the coast of Spain is presented. Selected sections of the field data are, also, presented in a color format. The color presentations were generated by Seiscom Delta, Inc., employing their SEIS-CHROME$^{(R)}$ technique.

Recommended field procedures for acquisition of single channel marine seismic profiling data optimized for subsequent data processing are presented.

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MARINE SEISMIC DISPLAY ENHANCEMENT PROGRAM

RESULTS

I. INTRODUCTION

The Marine Seismic Display Enhancement Program objective is to improve seismic profiling technology through the development, implementation, and evaluation of (a) acquisition hardware/techniques, (b) processing software, and (c) display hardware/formats. Figure 1 is an overview of the development program. By investigating the three prime areas involved in seismic profiling, acquisition, processing and display, an insight was gained on their interactive nature resulting in identification of the critical factors influencing each stage of seismic profiling data enhancement. The program concentrated on single channel seismic profiling but the technology developed is applicable to multichannel seismics.

A digital data recording system with a multi-channel (16) analog input capability has been developed. A flexible data sampling format and header annotation capability have been incorporated into the system. The system has a maximum 12 bit resolution capability and generates a digital tape compatible with either the Univac 1108 or CDC 6600 computer system. A description of this system's capability is presented.

Processing software has been implemented for the Univac 1108 or CDC 6600 computers to perform the following: (1) time domain filtering, (2) frequency domain filtering, (3) Wiener filtering, (4) spectral analysis, (5) vertical stacked traces, and (6) CalComp or Zeta traces. Results employing these processing routines on data acquired by the digital recording system are presented.

A display playback system for the digital processed data has also been developed. The system generates outputs for the conventional line scan recorder and also incorporates as part of the system an x-y plotter and a fiber optic recorder. Display formats include: (1) intensity modulated line scan, (2) wiggle trace, (3) variable area half-wave rectified wiggle, and (4) x-y plots. Playback rates up to 40 times real time acquisition are possible. In addition, to evaluate display techniques employing color presentations, data has been processed by Seiscom Delta, Inc. using their SEIS-CHROME(R) technique. Examples of processed data employing the playback system and the SEIS-CHROME(R) technique are presented.

A set of recommended field procedures for acquisition of single channel marine seismic profiling data that have been optimized for subsequent processing is presented in Appendix A.

The final report consists of three volumes. Volume I is a summary of the program results with examples of processed seismic profiling data. Volume II is a detailed description and listing of the processing software programs for the UNIVAC 1108 and CDC 6600 computer systems. Volume III is a user's handbook for the recording and playback systems, Seismic Data Acquisition System (SDAS) and Seismic Data Display System (SDDS).

II. SEISMIC DATA ACQUISITION SYSTEM

A seismic data acquisition system (SDAS) has been developed to digitally record seismic profiling data. The system was designed primarily to meet the requirement to digitally record single channel deep ocean seismic data for subsequent computer processing. The additional channels provide future expansion for multi-channel data acquisition.

A block diagram of the system and a listing of system specifications are presented in Figure 2. A picture of the SDAS and the seismic data display system (SDDS) is presented in Figure 3. The system (SDAS) can handle one (1) to sixteen (16) analog signal inputs with maximum single-channel sampling rate of 10 kHz at 12 bit resolution. The operator can select 6 bit resolution which increases the sampling rate to 20 kHz. The system's selectable maximum sample rates as a function of channel and bit resolution are given in Table 1. The amplification, high pass filter, and anti-aliasing filter (signal condition) hardware are external to the SDAS hardware. Commercially available units are employed.

Flexibility has been designed into the system by providing the capability to vary the data record length and delay time after shot initiation before commencing data recording. This capability eliminates the requirement to digitize the water column signal. The initiation of the recording cycle is controlled by a master clock which also triggers the sound source.

Header information is recorded for each shot. This includes day, time, sample frequency, data record length, data record delay, and 15 BCD switches for additional operator selectable annotation.

The tape transport generates a 7 channel, 556 bpi, digital compatible tape in a format to be read by either the UNIVAC 1108 or CDC 6600 computer system.

A more detailed description of the SDAS hardware is presented in Volume III.

III. PROCESSING SOFTWARE

The implemented processing software can be divided into two general categories: (1) Data enhancement software - processes seismic data by time domain filtering, frequency domain filtering, wiener filtering, spectral analysis, and vertical trace stacking routines and (2) Utility software - formats the processed data for playback through the display system. In addition to generating a display system digital tape, the processed data can be outputted for CalComp or Zeta plotting. A brief explanation of the software package is presented. Volume II contains a listing and operational procedures for the processing software.

A. DATA ENHANCEMENT SOFTWARE

General purpose programs have been implemented to enhance the quality of the seismic data. These programs will provide the geophysicist with the basic capability to (1) observe the frequency response characteristic of the sub-bottom, (2) to improve data S/N, and (3) to improve sub-bottom layer resolution. A review of the enhancement software is presented:

1. Time Domain Filter

This filter is an implementation of a routine developed by Linnette, 1961. The weights are determined for a filter which approximates the square-shaped ideal filter in the least squares sense, with correction for unity gain at zero frequency and a sine termination to reduce oscillations above cutoff. The filter response can be either (a) low-pass, (b) high-pass, or (c) bandpass.

2. Frequency Domain Filter

The input seismic data is converted to the frequency domain employing the N log N routine. The frequency domain data is then convolved with a taper function having a shape of either (a) rectangular, (b) cosine, (c) gaussian, or (d) triangular. The low and high frequency cutoff is specified for the selected taper function.

3. Vertical Stacked Traces

To improve signal-to-noise (random noise) for single channel data, a vertical stacking routine which averages consecutive records has been implemented. This routine is simply an add of N number of consecutive records and divide the total sum by N while each time adding one new record and dropping the oldest record. Care must be exercised in using this routine to assure that selecting large values of N does not degrade the data. If N is too large the results can be smearing of the display or effective spatial filtering of the data when dipping horizons exist (Levin, 1977).

4. Wiener Filter

A major area for enhancement of seismic profiling data is the use of wavelet processing. This fact has been realized for years by the oil exploration industry but only recently has extreme emphasis been placed on this technique. This has been motivated by the requirement for high resolution seismic traces which are reduced in complexity thus allowing the possibility for quantitative stratigraphic interpretation (Nath, 1977 - Wood, 1977 - Wittick, 1976).

To provide the geophysicist with the capability to explore the interpretation improvements possible with the wavelet processing technology and to help identify hardware requirements to allow acquisition of seismic data for subsequent wavelet processing, the Wiener waveshaping routine described by Robinson, 1967, was implemented.

Two configurations of this routine have been implemented. One configuration is based on card input data and possesses the flexibility to automatically optimize filter parameters and display the results in CalComp format (R. Dewan, unpublished report, 1977). The second is the operational configuration which processes directly the SDAS data tape based on fixed filter parameters. As a subroutine of this operational configuration, the desired wave shape with zero phase response for a cosine or gaussian bandpassed spike is generated. This zero phase bandpass spike is also outputted in card format for use in optimizing Wiener filter parameters.

5. Spectral Analysis

To provide the capability to determine the frequency content of seismic data either for the total record or a shorter time interval, an N log N (and the inverse) routine is provided. The output is in CalComp format with the frequency domain and the time domain displayed. A unique feature of this routine is that the frequency content of the seismic record as a function of penetration depth can be displayed. This provides the interpreter with the capability to examine the frequency content of seismic reflection off specific interfaces. This spectral routine is also used to examine the source signature frequency content.

B. UTILITY SOFTWARE

This software generates an output display data tape containing a maximum of 1977 processed data samples per record. A record is defined as a digitized shot-return sequence. The software performs one of the following options:

1. Selects 1977 consecutive data samples within the shot-return sequence if there are more than 1977 data samples per input record. The location of the selected data samples is operator controlled.

2. If there are more than 1977 data samples per input record an interpolative process (Davis, 1970) resamples the input data producing a new sample set containing only 1977 points. This will allow displaying the total input record but has the effect of low-pass filtering the data.

3. If there are less than 1977 data samples per input record, an output record equaling input data samples is generated.

IV. SEISMIC DATA DISPLAY SYSTEM

Generally the seismic data interpretation analysis performed by the geophysicist within the Navy R&D community has been based on seismic records produced on line scan recorders. These recorders display each record (shot-return sequence) as a single trace with the intensity (darkness) proportional to the amplitude of the reflected energy. A series of traces are displayed parallel to each other with the reflecting interfaces correlating trace-to-trace. This display technique provides a time representation of interface location (vertical and horizontal) and to a limited extent the amplitude of the reflecting energy (23 db dynamic range typical for line scan recorder paper). For most reconnaissance type surveys this has proven adequate. In addition, the need exists to display more information than available through the line scan recorder for examining in detail the bottom interaction effects of propagating acoustic energy. For instance, knowledge of the shape of the propagating wavelet and how it changes with penetration depth is desired. The capability to display wiggle trace information is required.

Hardware has been developed to allow playing back processed digital data not only in the line scan format but also in a wiggle trace format. In addition, to evaluate the state-of-the-art in seismic color presentation technology employed by the oil exploration industry, five hours (at a 10 sec. shot repetition rate) of deep ocean single channel seismic data has been processed by Seiscom Delta, Inc.

A. DISPLAY HARDWARE

A Seismic Data Display System (SDDS) was developed to provide a playback capability for computer processed data. Figure 3 is a picture of the system and Figure 4 is a block diagram and a listing of system specifications.

The system will accept either a UNIVAC 1108 or CDC 6600 generated digital data. The tape format is given in Volume III. There are a maximum of 1977 data points per record which can be displayed at a sweep rate of 0.25 sec. to 10.0 sec. The faster rate is used with a fiber optic recorder.

The amplitude resolution is fixed at 6 bits which provides 36 db dynamic range. The dynamic range was limited to 6 bits for compatability with the fiber optic recorder paper. As noted earlier the paper used with line scan recorders has a 23 db dynamic range.

A controller initiates the recorder sweep. All recorders are run asynchronous and in addition the line scan recorder can also be operated synchronous. The only requirement for synchronous operation is that the sweep frequency of the line scan recorder be locked to the SDDS master oscillator. The present configuration uses a Raytheon Co. Model 196C Universal Graphic Recorder for generating line scan records.

Incorporated into the system is an X-Y recorder, HP Model 7045 A. This allows displaying a short section (limited by paper size) of seismic data in a wiggle trace format.

Also incorporated into the system is a Honeywell Model 1856A fiber optic recorder with a trace width of 12.7 cm (sweep distance). Sweep rates up to 0.25 sec for the total 1977 data points are possible. Fast recorder sweep rates combined with external sweep delay initiation results in expanding a section of the seismic data. The prime utility of the recorder is its capability to display data in the following formats: (a) intensity modulate line scan, (b) a wiggle trace, and (c) a half-wave rectified filled wiggle. The fiber optic system requires a high degree of operator familiarization due to the interaction of the factors (sweep speed, signal amplitude, processing heat) controlling presentation quality.

B. COLOR ENHANCEMENT

There has been much discussion on the seismic data enhancement capability provided by the use of color displays. This technique for seismic data is being primarily developed and applied by the oil exploration industry (Balch, 1971; Sheriff, 1976). To provide a comparison between the color display technique and the more conventional displays discussed earlier, a section of single channel, broad frequency (10-170Hz), normal incidence seismic data has been processed by Seiscom Delta, Inc. employing their SEIS-CHROME$^{(R)}$ technique.

The SEIS-CHROME$^{(R)}$ displays color-encodes the following seismic measurement parameters:

(a) Reflection Strength - Depicts relative reflection strength in steps of color gradations. The reflection amplitude is measured completely independent of phase.

(b) Phase - Displays each oscillation of the seismic trace into discrete color bands and is insensitive to amplitude effects.

(c) Instantaneous Frequency - This display is a representation of the frequency content on a sample-by-sample basis. Computed from the time derivative of instantaneous phase.

(d) Average Frequency - This display weighs instantaneous frequency according to reflection strength.

(e) Apparent Polarity - This displays events according to the polarity of the strongest part of the reflection envelope with density related to strength.

V. RESULTS

This section will present a discussion and examples of the results that have been obtained through the acquisition, processing and display of seismic data. Emphasis is placed on the capability afforded the geophysicist by the techniques presented for future data acquisition and processing.

A. SEISMIC DATA ACQUISITION

The SDAS hardware was employed during a geophysical operation to investigate the magentic "J" anomaly in the Northeastern Atlantic Basin off the coast of Spain. A total of 80 hours of digital data, at a 10 second shot repetition rate, was recorded with post processing concentrating on two lines of 3 hours and 2 hours in duration. Figure 5 presents the location of these survey lines. Data recorded for line 2 is near the Glomar Challenger drill site number 136 (34° 10.13'N; 16° 18.19'W), Hayes (1972).

Line 1 was shot with a multi-gun sound source consisting of four Bolt air guns with volumes of 2622 cm^3 (160 in^3), 1311 cm^3 (80 in^3), 656 cm^3 (40 in^3), and 328 cm^3 (20 in^3). Line 2 was shot with a single 2622 cm^3 (160 in^3) Bolt air gun. The hydrophone array consisted of 100 hydrophones with paralleled outputs equally spaced over a 46 meter active aperture.

The data was recorded at sampling rate of 1 msec with the anti-alias filter cut-off set to 250 Hz at a 96dB/octave slope.

Source signatures for the air gun array were recorded at different source depths with the ship on station. Amplitude spectra for 6.1 m (20 ft.), 9.1 m (30 ft.), and 12.2 m (40 ft.) were computed and the results are presented in Figures 6, 7 and 8, for the respective depths. These figures reveal the source array was not tuned. (Note positive pressure on the time domain data is down.) There is a large amplitude bubble pulse and evidence that one of the smaller guns was firing prior to the remaining guns, two conditions that result from a poorly tuned array. Present techniques employ near field phones at each gun to monitor exact firing time and also provide the capability to advance or retard individual gun firing to maintain simultaneous firing of all guns (Lauhoff, 1977). This type of instrumentation was not available for the field operation. Without the proper tuning of an array and the capability to maintain the array in tune, the use of a single gun whose operation and acoustic characteristics are more predictable is a better choice. See the recommended procedure for real time source signature acquisition presented in Appendix A. Source signatures for the single 2622 cm^3 (160 in^3) air gun were not measured.

In addition to acquiring data with SDAS, real time line scan records were obtained employing a TELEDYNE Hydrophone Amplifier System Model 24220 acquisition system. The data was acquired simultaneously on a line scan recorder running at 10 second sweep rate (shot repetition rate) and a slave recorder running at a 4 second sweep rate. The records obtained at the 10 second and 4 second sweep rates are present for line 1 in Figures 9 and 10, respectively, and for line 2 in Figures 11 and 12, respectively. The system filter parameters for line 1 were 20 Hz to 98 Hz for the first 1/3 of the record and 16 Hz to 205 Hz for the remainder of the record. For line 2 they were 31 Hz to 160 Hz for the total record. Generally for the total operating period the seas were high (sea state 3 to 4). The resulting high noise level is more readily evident for line 1 than line 2. These records were adjusted in the field for optimum presentation and without a recording capability would represent the final data presentation. These records provide a basis to judge the data after processing.

B. FILTERING

The digitally recorded field data was filtered using the processing software previously discussed and employing SDDS for data playback and display. The examples presented are typical of the filtering capability provided the interpreter and demonstrate the utility of the software.

The frequency spectrum/time domain plot for a single unfiltered file for line 1 is presented in Figure 13. The excessive low frequency noise level would seriously degrade data interpretation if filtering was not used. This high level was typical for the total field operation period and is the result of the high sea states encountered. The frequency spectrum/time domain plot after frequency domain filtering over a bandwidth of 10 Hz to 170 Hz with a cosine shaded response for the same file is presented in Figure 14 and the corresponding filtered line scan record for the total line 1 data is presented in Figure 15. Line scan record displays employing the same frequency domain filter but for bandwidth of 35 Hz to 70 Hz and 125 Hz to 250 Hz is presented in Figures 16 and 17, respectively. The dark streaks at the top of Figure 17 are a result of a minor SDDS malfunction that only exists during this playback condition.

Figure 18 presents a frequency spectrum/time domain plot for single file from line 1 that has been frequency domain filtered over the 10 Hz to 170 Hz band but with gaussian shading. The gaussian shading provides less ringing than cosine shading but does not provide as sharp a frequency cut-off. The impulse response for the 10 Hz to 170 Hz frequency domain filter with cosine and gaussian shading is presented in Figures 19 and 20, respectively. The time shift of the pulse for the time domain data presentation is done for presentation purposes only. The frequency domain filter is a zero phase response filter and thereby does not introduce time shifts into the filtered data.

Figure 21 presents the frequency spectrum/time domain plot for a single file from line 1 employing the time domain filter with a 21 Hz to 250 Hz bandwidth. In addition this figure also represents the presentation format when performing a spectral analysis for selected depth intervals. In this case four intervals of 210 msec. each are shown. Figure 22 is the inpulse response for the time domain filter and Figure 23 is the line scan record for line 1 using the time domain filter.

Line 2 data was filtered with the frequency domain filter parameters employed for line 1 (bandpass 10 Hz to 170 Hz: Shading-cosine: Inpulse response Fig. 19). A frequency spectrum/time domain plot for a single file from line 2 is shown in Figure 24 and the line scan record for the total line 2 data is presented in Figure 25.

Examples of frequency filtering, time domain filtering, and spectral analysis have been presented to show the capability provided by the software. Although the filtering routines are not unique in themselves, the software configuration to readily utilize these routines for processing seismic data acquired by SDAS and displaying the data in a format to improve interpretation does provide a unique capability.

C. VERTICAL STACKED TRACES

To improve S/N for non-coherent noise a vertical stacking routine has been implemented. This routine simply adds a fixed number of traces and then divides by this number producing a single stacked trace. For each iteration through the process the oldest trace is deleted and a new trace is added. Figure 26 is a wiggle trace output for a 16 trace average performed on data from line 1.

D. WAVELET PROCESSING

Data from line 1 has been processed employing the Wiener waveshaping routine described by Robinson, 1967. The results of this processing have provided insight into techniques, hardware and software, to improve the capability to perform wavelet processing.

The key factor to optimum use of this processing technique is a well defined source wavelet (Watters, 1977, Shugart, 1977). Acquisition of the source wavelet has been obtained by past investigators through (a) far field hydrophone measurement (on station/ underway), (b) detecting the reflection off a high salinity layer within the water column, (c) near field hydrophone measurements, or (d) detecting a strong reflection off a sub-bottom interface. It was found that the on station far field source signatures recorded for the airgun array (Fig. 6, Fig. 7, and Fig. 8) did not adequately describe the source signature characteristics while operating in an underway (survey) configuration. The prime complication was the variability of tow depth resulting in fluctuation of bubble period. Instrumentation (depth transducer) was not available to permit mathematical correction for this variability. A high salinity test area or instrumentation for constant near field source monitoring were also not available.

The technique employed for the data to be presented was to extract the source signature from the reflection off the ocean-sediment interface. The prime problem encountered with this technique was determining the bubble pulse component of the source signature, due to high noise levels and the presence of a strong second reflector located, in time, between initial ocean-sediment interface reflection and its corresponding bubble pulse. This type of problem is a prime reason the ocean-sediment interface reflection technique should be avoided in the future. This approach could provide good results if there was a strong single isolated reflector in a low noise environment. The recommended future approach is using a near-field hydrophone, constantly monitoring the source signature and then correcting for the source and streamer ghost during processing. The field procedure for this approach is presented in Appendix A.

The initial attempt at Wiener filtering employed the following data parameters with the corresponding frequency spectrum/time domain plots in the figures as noted: (1) The source wavelet (input data) is a 30 record average from the ocean-sedimate interface. The source wavelet was hand picked by manually eliminating all returns from other reflecting interfaces. Each record was frequency domain filtered with cosine shading over a bandwidth of 10 Hz to 170 Hz (Figure 27). (2) The desired wavelet is a bandpassed (10 Hz to 170 Hz) zero phase, gaussian shaded spike (Figure 20). Throughout the Wiener filter effort a zero phase desired wavelet was employed to optimize resolution. The uniqueness of the zero phase wavelet to optimize resolution as compared to minimum or mixed phase has been previously established by other investigators (Berkhout, 1974 - Schoenberger, 1974 - Shugart, 1976).

The Wiener filter parameters, input data (source signature), desired output, filter weights, and actual output, generated from the Wiener parameter optimization routine are displayed in Figure 28. The RMS error between the desired and actual out is 7% for this case. The actual output trace shows sidelobes only 18 db below the desired spike. It is felt these resulted from a large processing bandwidth. Wiener filtered wiggle traces for the first 20 records of the line 1 data are presented in Figure 29 and a line scan record for the total area 1 Wiener filtered data is presented in Figure 30. The high side-lobe level is evident in this last figure when these results are compared to the before processing results presented in Figure 15. It is also felt the variability of the source from shot-to-shot also contributed to poor Wiener filter performance. Compensation for this variability was attempted through averaging 30 records to obtain an average source signature (basic wavelet), but this did not appear to help. The averaging did assist detection of the first return by improving S/N by about 15 db.

Wiener filtering was also performed with a reduced bandwidth of 20 Hz to 120 Hz. The field data for line 1 was frequency domain filtered with gaussian shading over this bandwidth. The desired wavelet was a bandpassed (20 Hz to 120 Hz) gaussian shaded (zero phase) spike. The frequency spectrum/time domain plot for the desired wavelet is presented in Figure 31. The source wavelet was picked from a single record for the ocean-sediment interface return. Figure 32 contains the plotted Wiener filter parameters for the record on which the filter parameters were designed. Observing the before and after Wiener filter presented in this figure does show some resolution improvement and reduced sidelobes. A twenty record wiggle trace for these filter conditions is presented in Figure 33 and a line scan record for the total line 1 Wiener filtered data is presented in Figure 34. Note that the best record enhancement resulted on the trace (see Figure 33) for which the Wiener filter parameters were designed. This emphasizes the problem that is encountered when there is variability in the source signature from shot-to-shot. For optimum data enhancement through wavelet processing the field system configuration (streamer depth, source depth, source parameters, and signal conditioning) must remain constant or the changes noted so processing correction can be made. This assumes that some technique is employed to record the source signature.

In summary, through implementation of the Wiener filter routines critical factor effecting wavelet processing have been identified. The prime factor influencing performance is adequate knowledge of the propagating source wavelet. This emphasizes the requirement for proper field instrumentation and the maintenance of constant system parameters. In addition, processing routines are now available in a format compatible with exisiting hardware (SDAS) that provide the geophysicist with the capability to explore the interpretation potential of wavelet processing.

E. DISPLAY FORMATS

A series of display formats available as a result of this project have already been presented. In addition the display system (SDDS) has the ability to present data in either wiggle trace or filled wiggle format. Examples of these output formats will be presented.

Figures 35 and 36 are wiggle traces generated by the X-Y recorder for line 1 and line 2, respectively. As a comparison, CalComp outputs for line 1 and line 2 but not identical files are presented in Figures 37 and 38. The X-Y recorder output provides a quick look capability to examine selected records for wave shape detail.

A wiggle trace format output generated by the fiber optic recorder for line 1 data is presented in Figure 39. This recorder also provides the capability to expand selected portions of the traces for more detailed examination. Figure 40 is an expanded trace for line 1 records containing the ocean-sediment interface return.

The fiber optic recorder is also capable of generating an intensity modulated line scan record. It was found that the recorder amplitude adjustments for the required playback condition (speed) to display line 1 and line 2 were critical and the true presentation potential of the recorder to playback data in this format was not achieved. Figure 41 is an example of line 1 data played back in the intensity modulated format.

An interface between the SDDS and the fiber optic recorder is required to generate a half-wave filled wiggle trace. The initial effort on the design of this interface resulted in an output with a high amount of trace blooming (base line of dark intensity) which degraded the presentation. An experimental bread board of a more optimum design was completed but the final circuit configuration has not been fabricated. The results of the type presentation produced by a bread board of this new design are presented in Figure 42. This data is not from the survey area preciously presented. In addition it is recommended that the capability be provided to generate a wiggle trace with either the positive or negative envelope filled (variable area). This type of trace is similar to those employed by the oil exploration industry.

Data is acquired by SDAS with a 72 db dynamic range, but all SDDS formats contain 36 db dynamic range. The reduced dynamic range for the SDDS format, as noted earlier, was for compatability with the fiber optic recorder paper (3M brand type 7770 Dry-Silver Paper) when generating intensity modulated traces. Due to the desire for greater resolution when generating wiggle traces (X-Y or fiber optic recorder), an increase of SDDS dynamic range is recommended.

In summary, the capability has been provided the geophysicist to display data in a variety of formats, thus allowing for more detailed analysis of the ocean sub-bottom acoustic and geologic character.

F. COLOR ENHANCEMENT

Seismic data for line 1 and line 2 was color processed by Seiscom Delta, Inc., employing their SEIS-CHROME$^{(R)}$ technique. Prior to color processing, the data had been frequency domain filtered with cosine shading over a bandwidth of 10 Hz to 170 Hz. Conventionally displayed seismic records employing the same filter parameters were presented in Figures 15 and 25 for lines 1 and 2, respectively and provide a comparison for the color records to be presented. The color records are also for 1 second two-way travel time.

A discussion will be presented on the basic characteristics of the color encoded parameters (Sheriff, 1976) with examples for line 1 and 2. The data acquisition hardware and configuration influences the geophysicist's basic ability to properly interpret color displays. A review of some technical factors in this area to be considered by the interpreter will also be presented.

1. General

According to Sheriff, 1976, a seismic wave can be thought of as a signal with real and imaginary parts. The real part of the seismic trace g(t) can be expressed by $g(t) = R(t) \cos \theta(t)$ where R(t) can be considered the envelope of the seismic trace and $\theta(t)$ is the instantaneous phase. By employing Hilbert Transform techniques the imaginary part (quadrature trace), h(t), can be generated. The quadrature trace can be expressed by $h(t) = R(t) \sin \theta(t)$. These two parts, g(t) and h(t), of the seismic wave are the basic components used to generate the color encoded parameters for the SEIS-CHROME$^{(R)}$ displays.

2. Reflection Strength

The equation for g(t) can be solved for the quantity R(t) giving $R(t) = [g(t)^2 + h(t)^2]^{1/2}$. The quantity R(t) is the reflection strength at any instance of time (t). The reflection strength, R(t), is not merely the amplitude of the largest peak or trough of the real part of the seismic trace, but is equal to the square root of the total energy of the seismic wave at any instant of time.

The color-encoding of reflection strength for each event within a given section (line) is normalized for the strongest reflection strength on that line. This reflection strength is assigned a magenta color and all weaker reflections are assigned a different color in fixed dB steps.

If clipping or saturation of the seismic signal occurs during data acquisition, the presentation of reflection strength would not be a true representation of the reflective character of the sub-bottom structure. Since reflection strength levels are influenced by the phase of the recorded signal, linear phase in the data acquisition and recording hardware must be maintained. The dynamic range of the acquisition must be sufficient to cover the color-encoded display range.

Figure 43 is a relative reflection strength presentation for line 1 with 20 different colors spanning a 40 dB range. Figure 46 is a similar presentation but for line 2 with the 20 different colors spanning a 20 dB range. It should be noted that the strongest reflection strength is not from the ocean sediment interface but from the sub-bottom structure.

3. Instantaneous Frequency and Weighted Average Frequency

Solving g(t) and h(t) for $\theta(t)$ results in the quantity $\theta(t) = \tan^{-1} [h(t)/g(t)]$. The time deviate of $\theta(t)$ is termed Instantaneous Frequency, which is a point value for frequency rather than an average over some interval as is done, for example, with the Fourier-Transform method.

The value of instantaneous frequency is weighted according to reflection strength resulting in the display termed Weighted Average Frequency. This display tends to smooth the frequency presentation as compared to the instantaneous frequency display.

The frequency displayed seismic records are highly dependent on the field acquisition hardware and the subsequent data processing. Knowledge of the frequency content of the propagating sound source energy and the effect of the hydrophone array tow depth on altering the received energy spectrum is necessary for comprehensive interpretation.

Peaks in the source spectrum can be evident in the color encode frequency display. Appendix A discusses characteristics of the air gun sound source which control the frequency content of the propagating energy and presents techniques for measuring source spectra. The hydrophone array and sea surface act as a tuned circuit with the peak response controlled by hydrophone array tow depth. For example, constructive interference occurs at a frequency f = c/4d where c = sound speed and d = tow depth.

The frequency response of the data acquisition amplifiers, filters and recording system must be considered. The data acquisition hardware should be optimized to minimize frequency distortions.

Data processing which can affect the frequency characteristics of the seismic data must be known by the interpreter. For example, the response of the digital filtering needs to be known.

Figure 44 presents an instantaneous frequency display for the line 1 seismic data. Although the exact sound source spectrum for this data is not known, the general characteristics of the spectrum are typical of those presented in Figures 6, 7 and 8. The impulse response for the frequency domain filter used on this data is presented in Figure 19. Figure 44 shows an excessive low frequency noise. There is, also, significant reflected energy around 140 Hz. The source spectra, Figures 6, 7 and 8, do not show significant energy levels at this frequency. Does this high level result from the geological character of the sub-bottom structure or a peak in the received spectrum resulting from constructive interference at 140 Hz due to the tow depth of the hydrophone array? Solving the equation d = c/4f for f = 140 Hz results in a tow depth of 2.7 m. The hydrophone array was not instrumented for depth, but discussions with field personnel indicate this depth was possible. This deficiency emphasizes the difficulty the interpreter can encounter without proper instrumentation. The reason for the dominant 140 Hz energy has not been determined.

Figure 47 and 48 present a weighted average frequency and an instantaneous frequency display, respectively, for the line 2 seismic data. Interpretation of this data is difficult since source signatures are not available. Computations of the general characteristics of the source spectra based on knowledge of the type and size of the sound source would aid in the analysis of these records.

4. Phase

The quantity $\Theta(t)$ is the color-encoded parameter used in this display, every peak, every rough, every zero-crossing and every phase angles in between have each been assigned a unique color. The plus 180° and the minus 180° phase angles are assigned the same color. This type display emphasizes the continuity of events and is helpful in picking seismic boundaries. Figures 45 and 49 present phase displays for the line 1 and line 2 seismic data, respectively.

5. Apparent Polarity

The sign of the seismic trace is determined when the reflection strength has its maximum value. The plus (+) polarity is assigned a pink color and the negative (-) polarity is assigned a blue color. The intensity of these colors are varied according to the magnitude of the reflection strength maximum.

Figure 50 presents a polarity display for the line 2 seismic data.

VI. RECOMMENDATIONS

The development program to enhance seismic profiling data through the implementation of acquisition, processing and display hardware/techniques has identified areas to improve seismic data quality. As a result recommendations are presented which identify general areas for improvement and more specific areas are identified to improve the seismic data acquisition (SDAS) and seismic data display (SDDS) systems.

A. ACQUISITION

1. Maintaining constant system acquisition configuration and instrumenting those parameters which are variable is critical for good data quality. Fundamental in this area is the tow depth of the source and hydrophone array. These two components act as tuned circuits and when varied alter the frequency spectrum of the propagated and received energy. The hydrophone array must be instrumented with a depth sensor. This is a standard instrument which can be interfaced to existing hydrophone arrays.

The depth of the sound source can be obtained through an indirect technique of monitoring a unique characteristic of the source signature that is a function of source depth. This technique for the air gun source consists of monitoring the bubble pulse period with a near field hydrophone provided the source pressure is maintained nearly constant. In addition, the near field hydrophone provides a method of recording the source signature for each shot thus providing information required in performing wavelet processing.

Appendix A presents a discussion of air gun characteristics on controlling source frequency spectrum and also recommends an instrumentation approach for the near field hydrophone measurement.

2. It is recommended that a set of standard field data acquisition procedures be adopted which are optimized for subsequent data processing. This includes such areas as: (a) establishing high pass cutoff frequency, (b) technique for recording noise records, (c) establish standard recorder channel designations, and (d) establishing a standard log sheet. A recommended field data acquisition procedure including the above noted areas is presented in Appendix A.

3. Air gun arrays are used primarily to provide higher resolution and more readily interpretable data through bubble pulse reduction and to provide deeper penetration by increasing source energy. The tuning and maintaining a tuned array requires instrumentation which constantly monitors each gun and maintains constant firing synchronization. It is recommended that air gun arrays not be employed unless adequate instrumentation is provided to maintain proper tuning.

4. If it is determined through more detailed analysis of data acquired with SDAS that the fixed gain with 72 dB dynamic range is not adequate, it is recommended a gain ranging (TVG, AGC, binary) signal amplifier system be employed. The gain value can be recorded on a second SDAS channel. Care must be exercised in selecting the amplifiers to minimize phase and frequency distortion.

5. It is recommended that the SDAS be modified to increase the tape bit packing density to 800 BPI. This is a minor hardware change that will result in a 30 percent reduction in field tape usage.

B. PROCESSING

1. Implement a software routine to correct the near field source signature for surface source and hydrophone array ghost. This will provide a basic source wavelet that is required in performing wavelet processing.

2. The interpreter should utilize the routines that have been implemented to provide a more detailed operational evaluation. These routines provide a basic processing capability and through their use the requirement will be identified for more sophisti-

cated and detailed software to meet the specific needs of the seismic data interpreter.

C. DISPLAY

1. Incorporate into the playback system (SDDS) an interface for the fiber optic recorder to display data in a filled wiggle format (variable area).

2. Modify the playback system (SDDS) to increase display dynamic range to 12 bits.

3. Utilize color displays only on selected areas as identified from the more conventional display techniques. Use wavelet processed data for color enhanced displays due to its less complex trace and higher resolution.

4. It is recommended to provide increased display capability the seismic data also be outputed through a high speed electrostatic plotter. This would provide high data playback rates for large volumes of data with a variety of display formats (wiggle trace, variable area, and variable area superimposed on wiggle trace). This is a capability that should be provided at the computer facility.

VII. SUMMARY

Through the development and evaluation of acquisition, processing, and display hardware and techniques, improvements in seismic profiling technology have resulted. Hardware for acquisition and playback of seismic profiling data has been developed and tested.

Critical data acquisition parameters have been identified and recommended field procedures generated. Processing software compatible with the hardware to perform basic data enhancement has also been implemented. A series of recommendations to improve the future acquisition, processing, and display of seismic profiling data have been identified.

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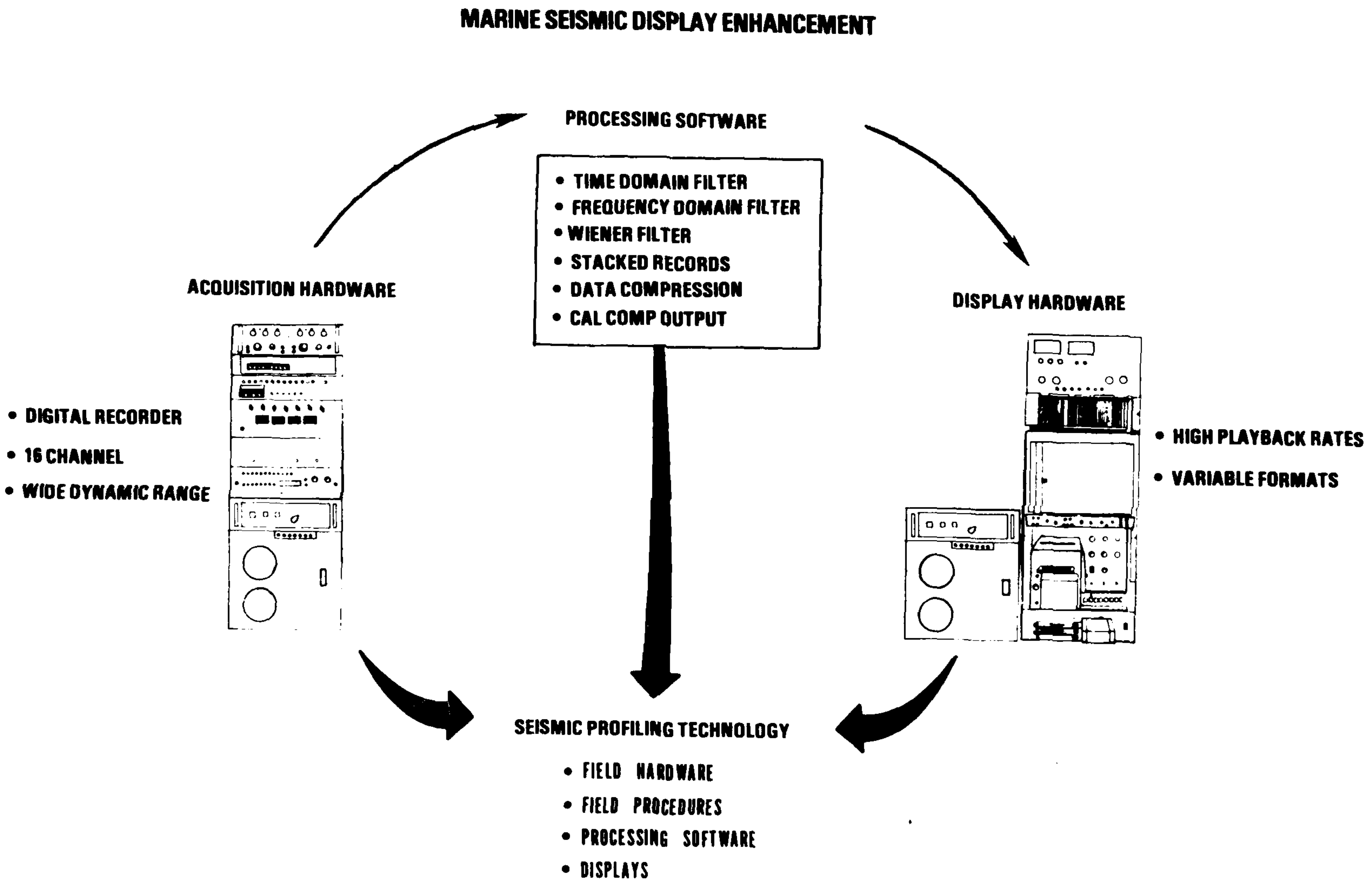
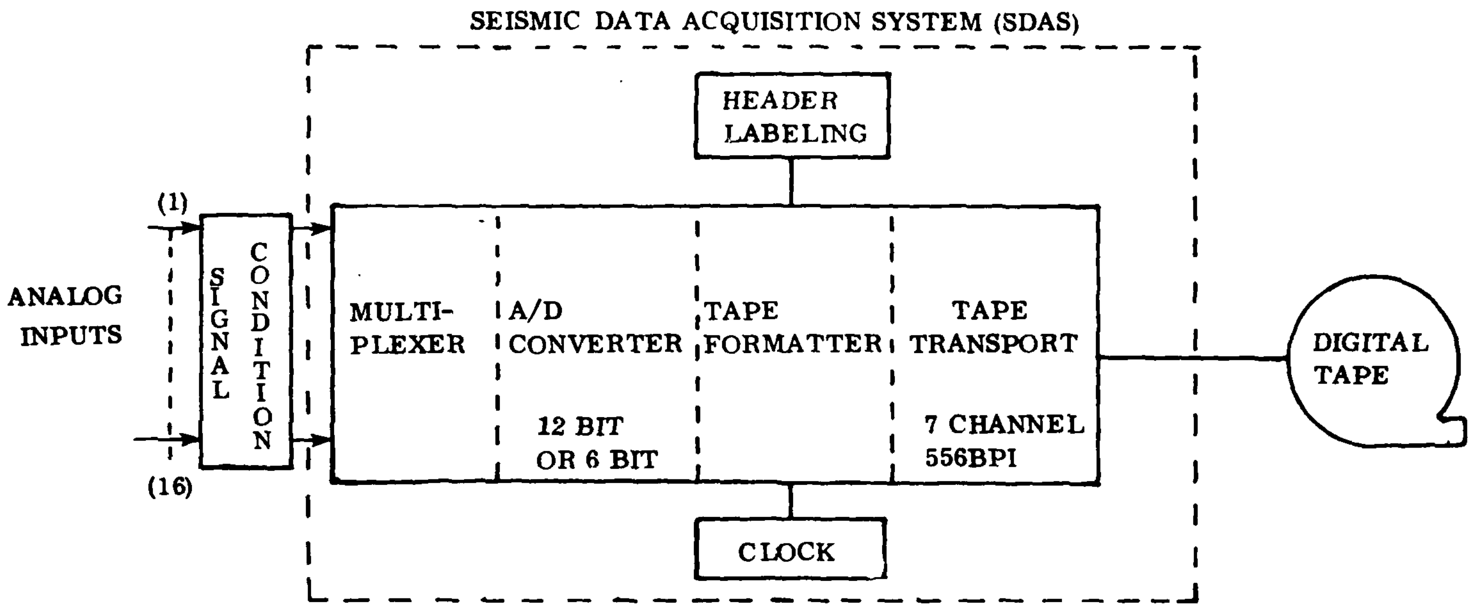


Figure 1. Marine Seismic Display Enhancement Program overview



SPECIFICATIONS:

ANALOG INPUT:	1 TO 16 CHANNELS
MAX INPUT:	± 10 VOLTS PEAK
RESOLUTION:	11 BIT + SIGN OR 5 BIT + SIGN
DYNAMIC RANGE:	72 DB OR 36 DB
NOISE LEVEL:	6 MV, RMS

SAMPLE FREQUENCY:	200HZ TO 10 KHZ (12 BIT) 200HZ TO 20 KHZ (6 BIT)
DATA RECORD LENGTH:	0.5 SEC. TO 15 SEC.
DATA RECORD DELAY:	0.4 mSEC. TO 15 SEC.
TAPE FORMAT:	UNIVAC OR CDC COMPATIBLE 7 CHANNEL, 556 BPI
HEADER INFORMATION:	DAY, TIME, SAMPLE FREQUENCY, DATA RECORD LENGTH, AND DATA RECORD DELAY, PLUS 15 BCD SWITCHES FOR ADDITIONAL ANNOTATION

Figure 2. Seismic Data Acquisition System (SDAS) description

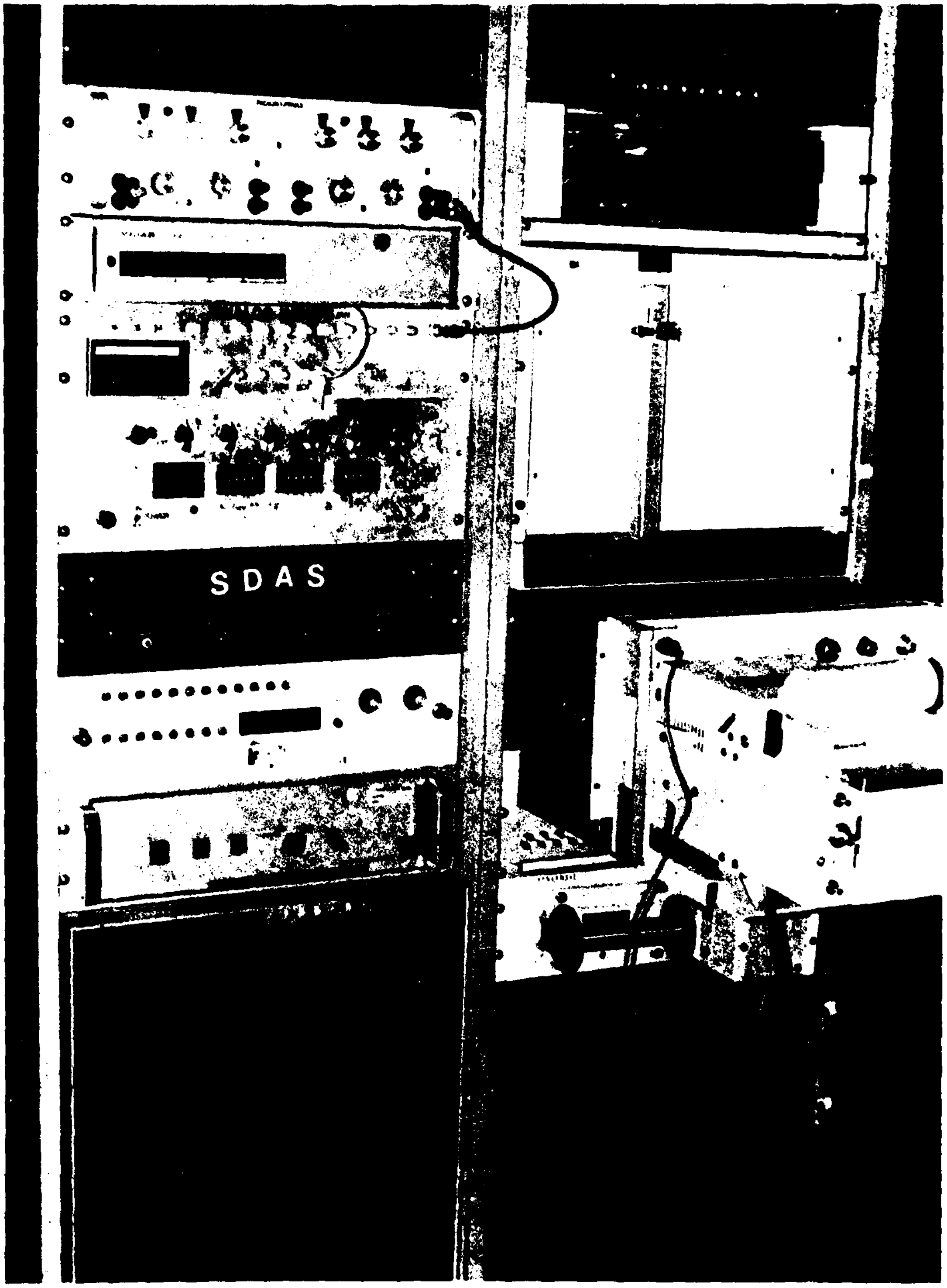
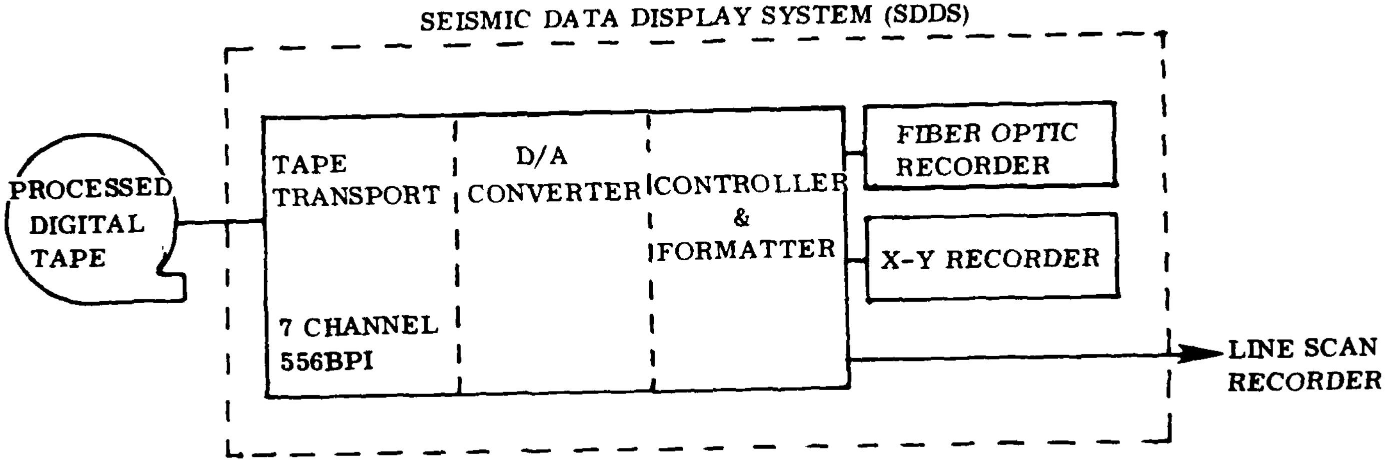


Figure 3. Seismic Data Acquisition System and Seismic Data Display System



SPECIFICATIONS:

DATA POINTS: 2000/SWEEP

SWEEP RATES: 0.25, 0.5, 1.0, 2.0, 5.0, 10.0 SECONDS

DYNAMIC RANGE: 36 DB

AMPLITUDE RESOLUTION: 5 BITS + SIGN

DISPLAY DEVICES: TRACE WIDTH

FIBER OPTIC RECORDER: 12.7 CM

X-Y RECORDER: 25.4 CM

LINE SCAN RECORDER: (EXT.) 48.3 CM

OUTPUT FORMATS:

INTENSITY MODULATED LINE SCAN

WIGGLE TRACE

HALF-WAVE FILLED WIGGLE

INTENSITY MODULATED WIGGLE

Figure 4. Seismic Data Display System (SDDS) description

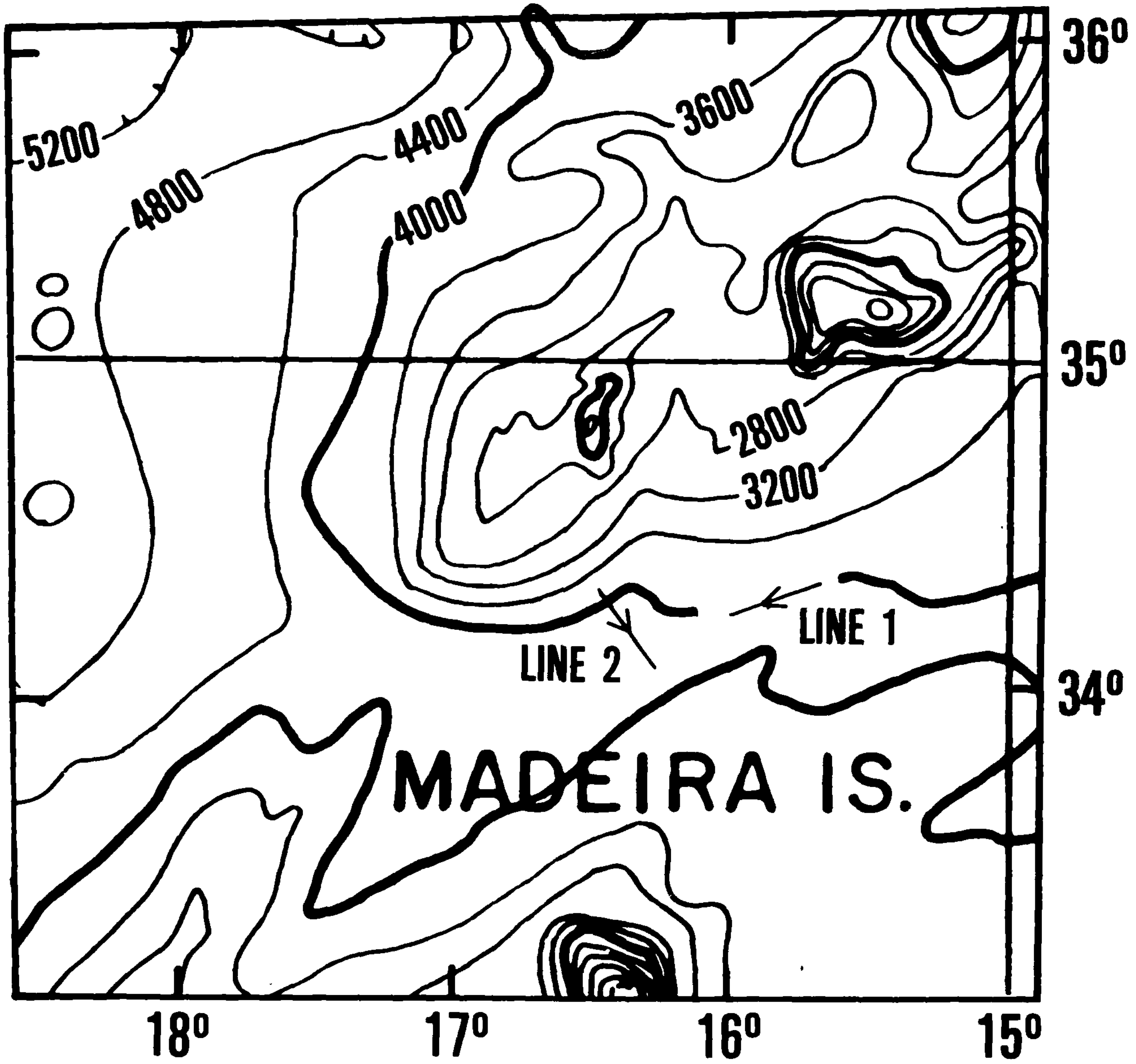


Figure 5. Location of survey lines for digital data processing

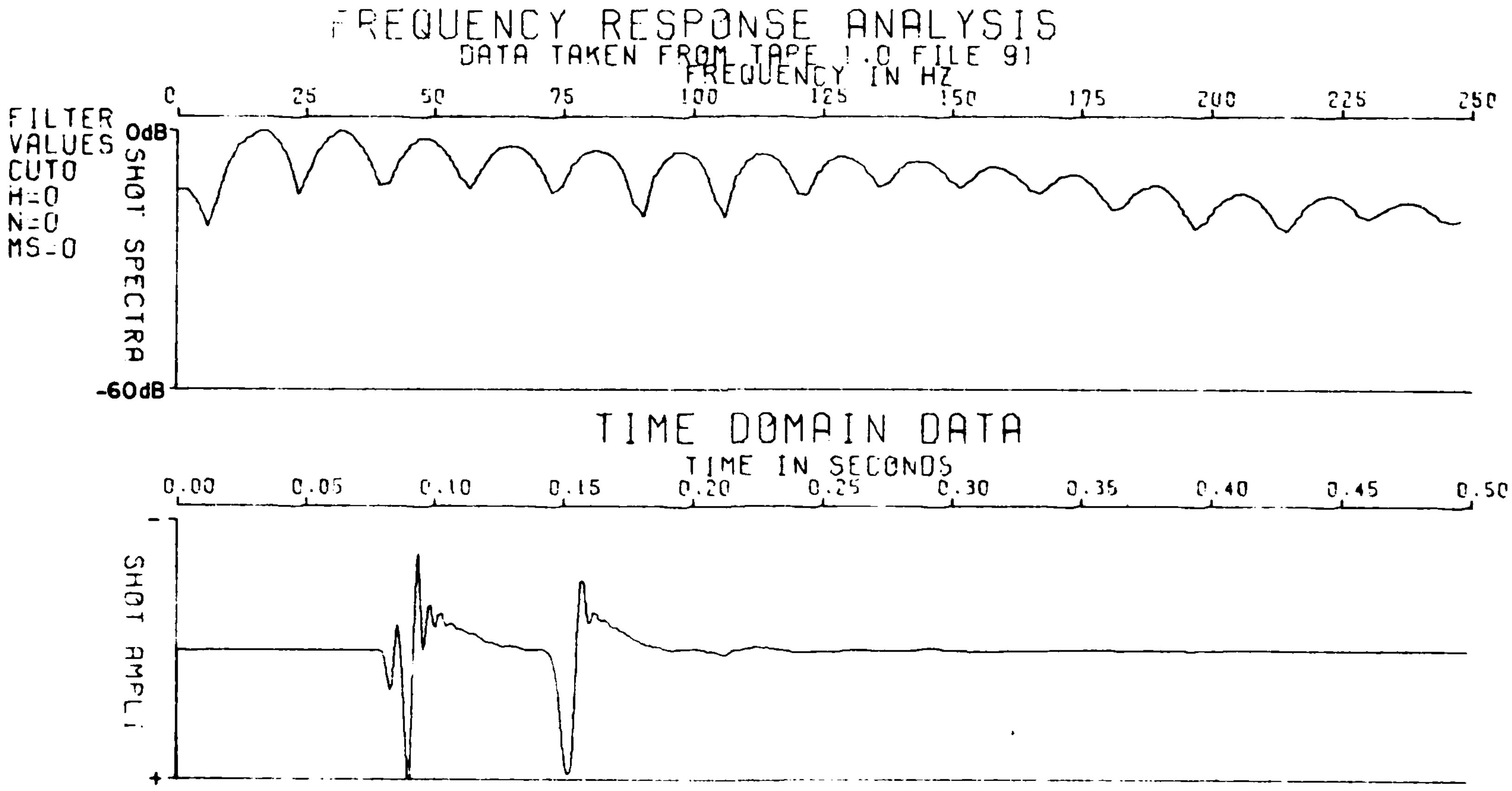


Figure 6. Airgun array source signature and spectrum (6.1m depth)

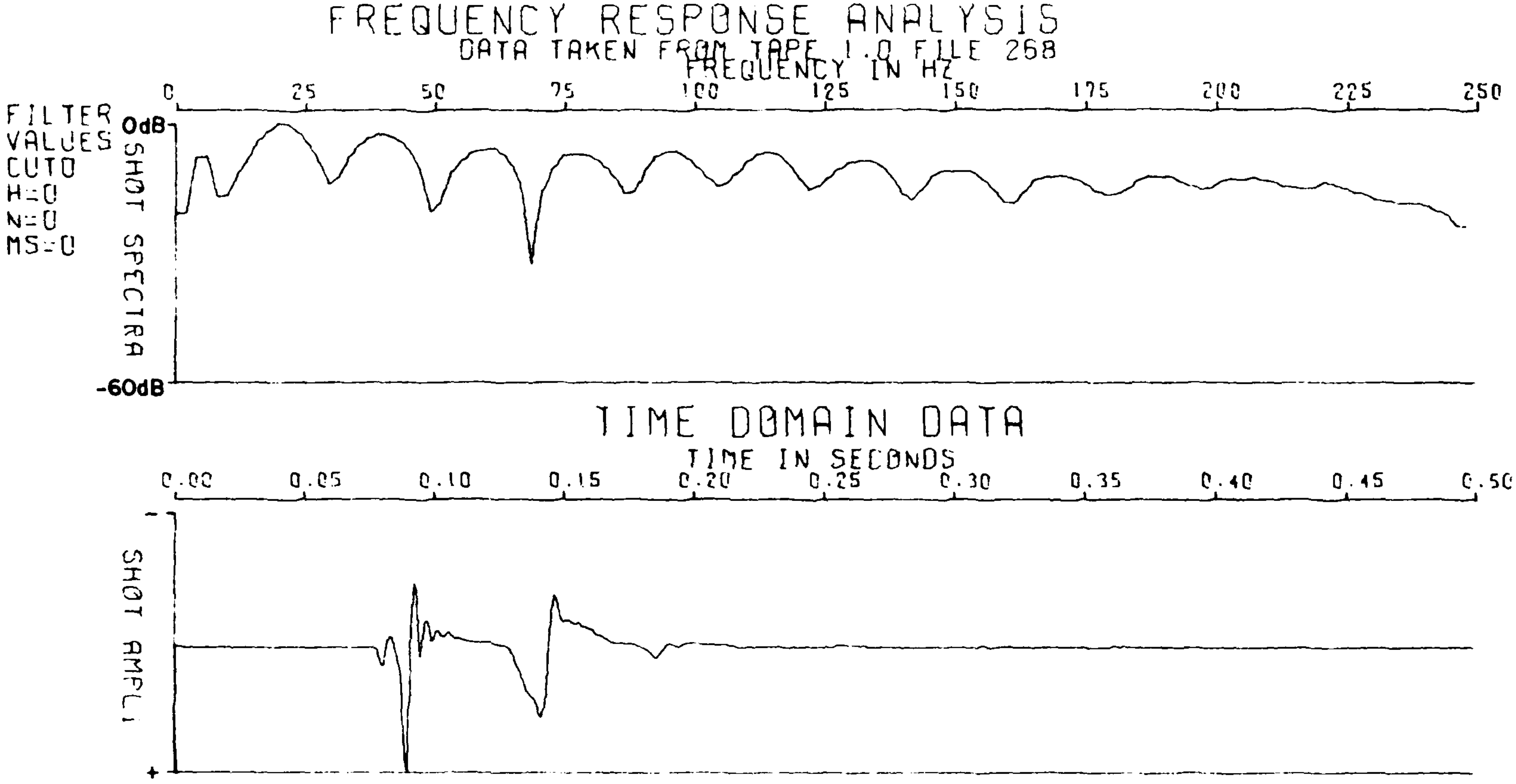


Figure 7. Airgun array source signature and spectrum (9.1m depth)

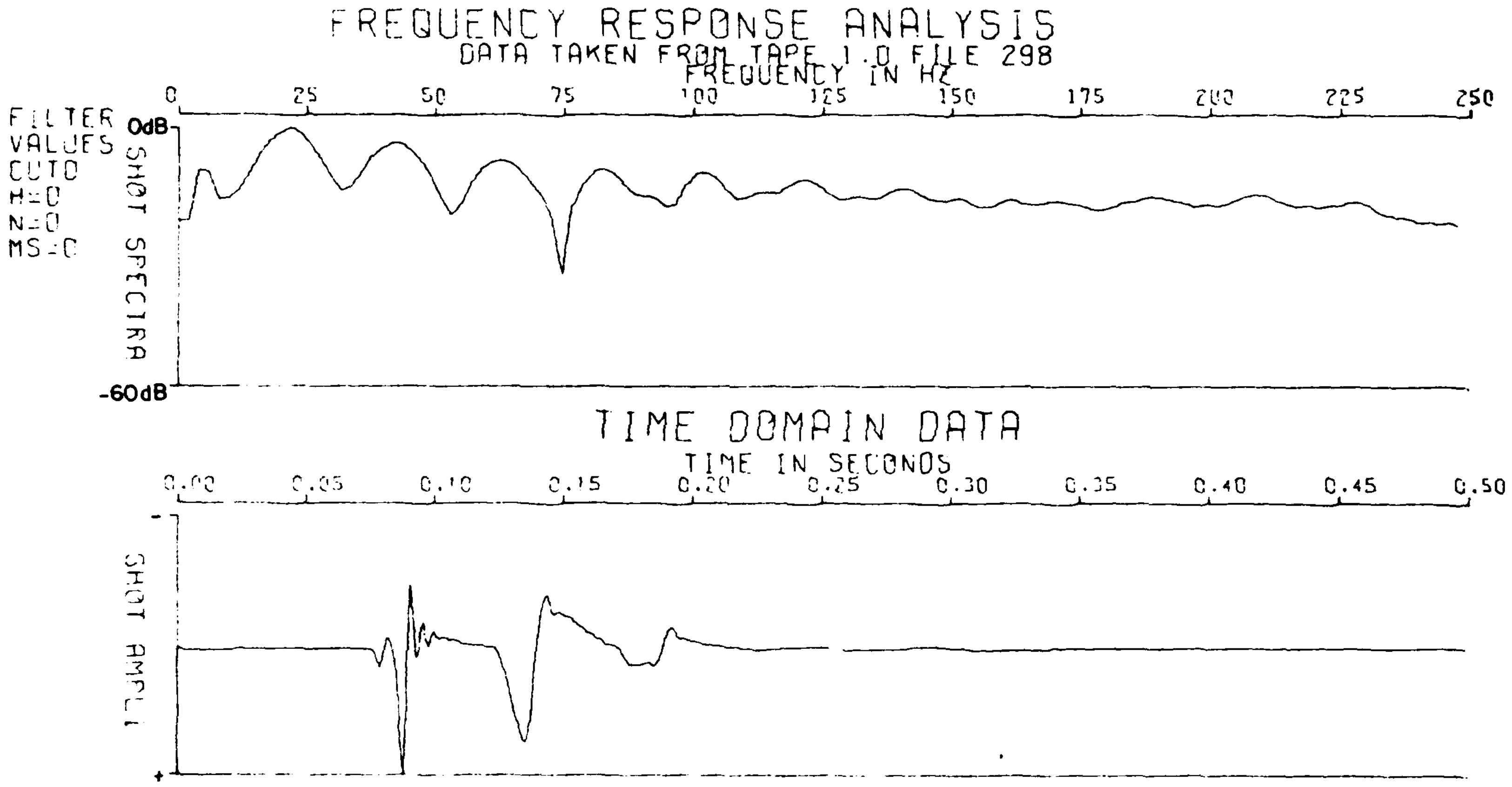


Figure 8. Airgun array source signature and spectrum (12.2m depth)

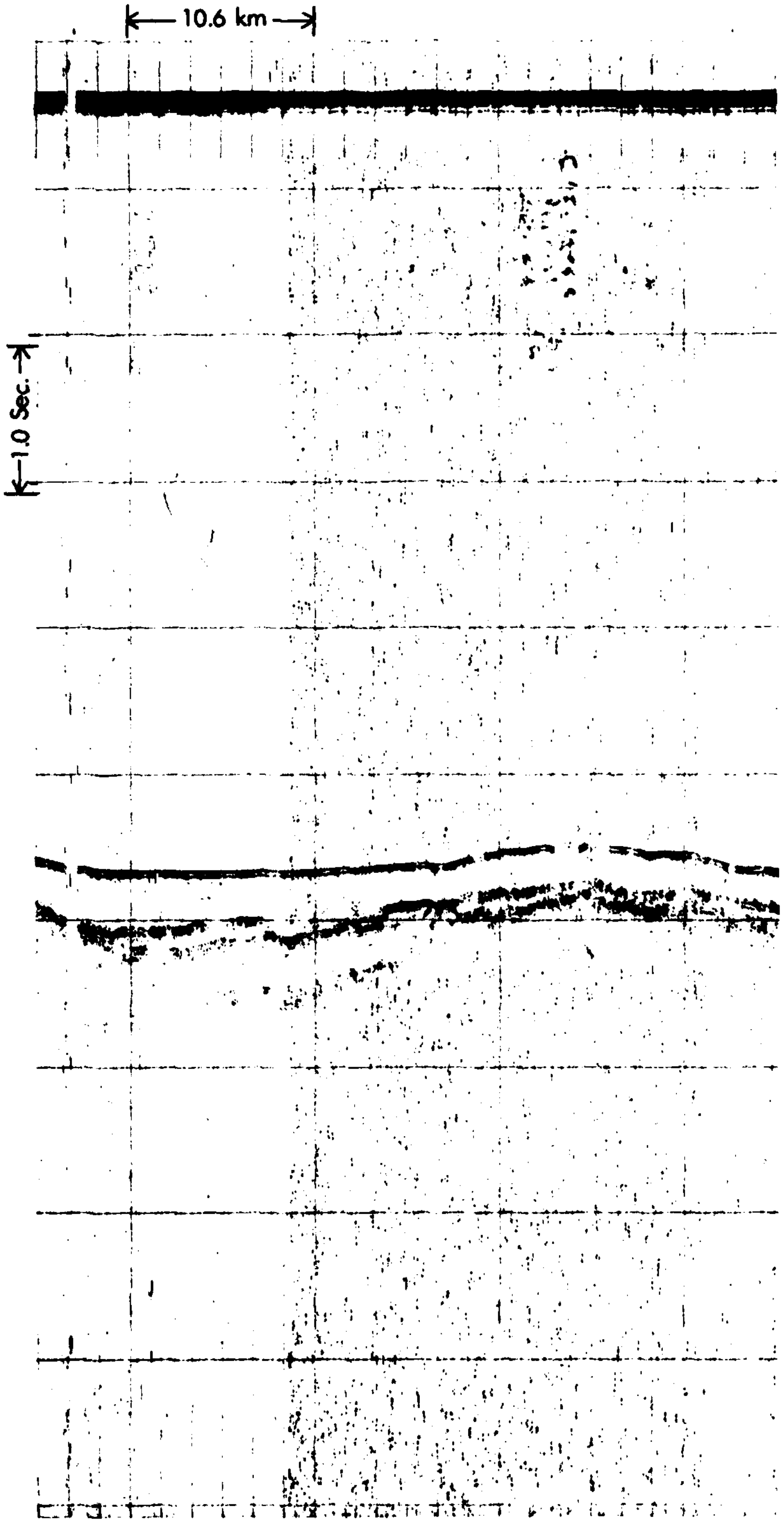


Figure 9. Line 1 field seismic record. (10 second recorder sweep rate)

Figure 10. Line 1 field seismic record. (4 second recorder sweep data)

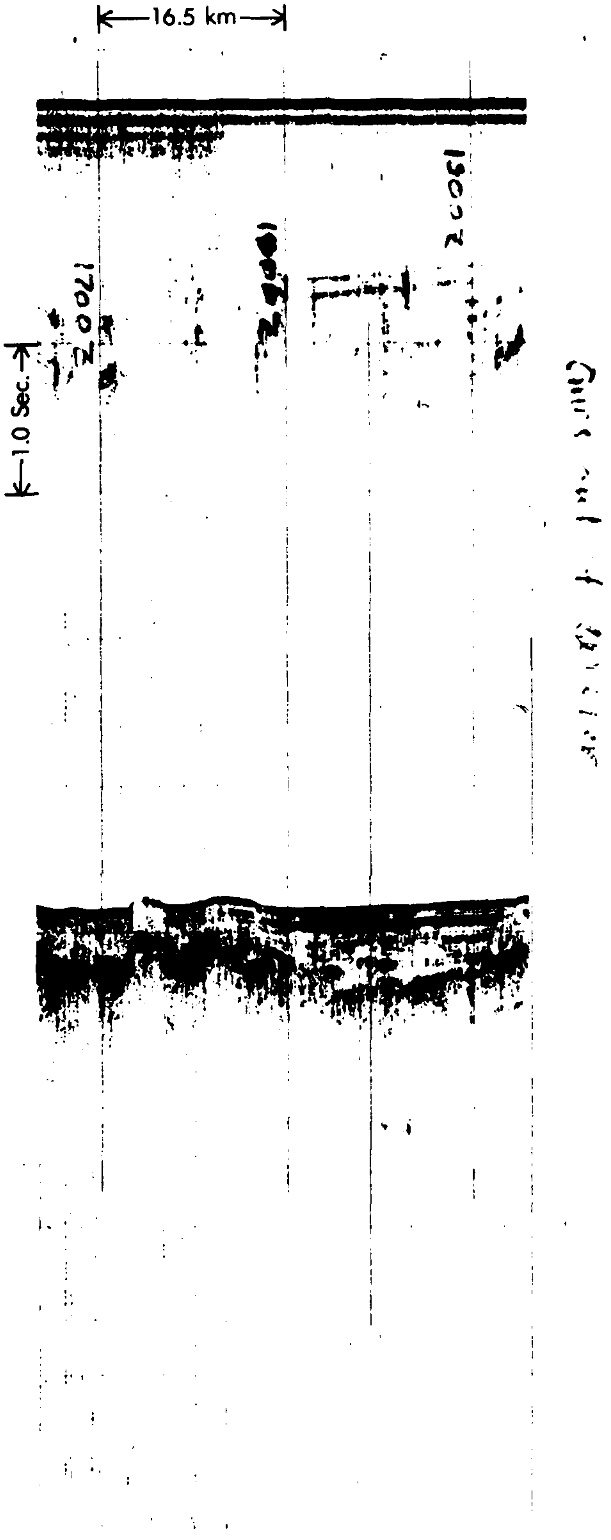


Figure 11. Line 2 field seismic record. (10 second recorder sweep rate)

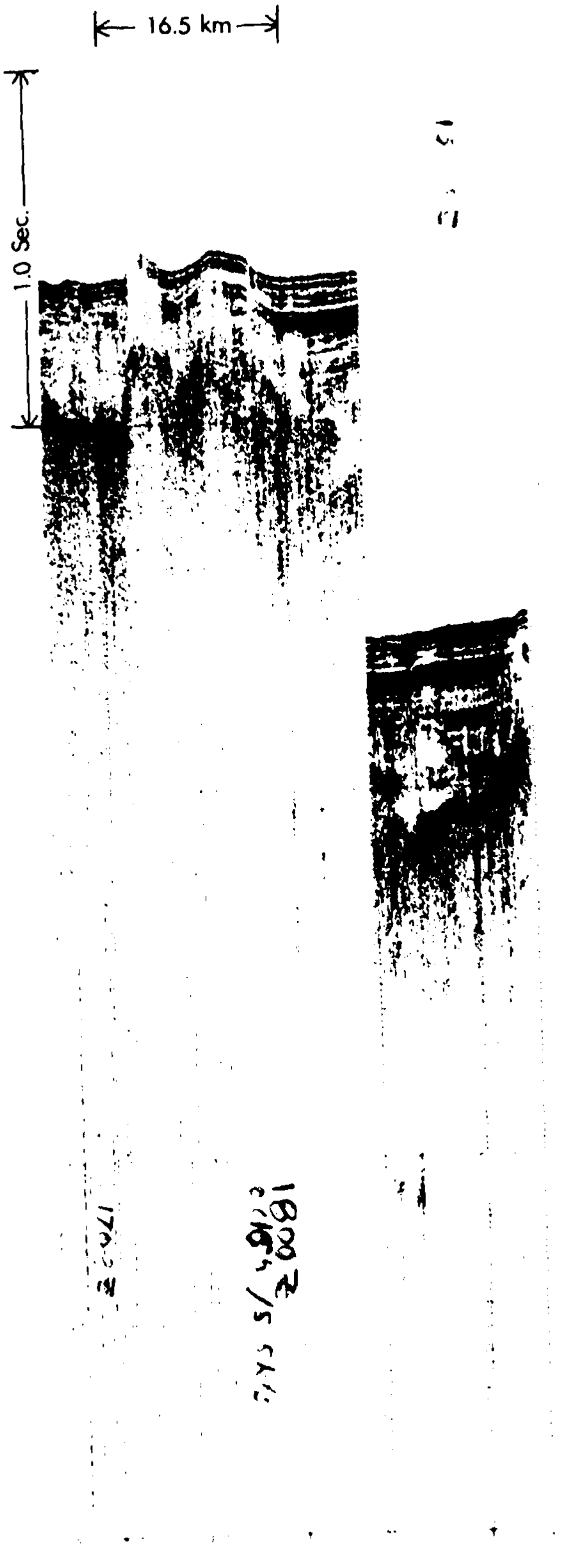


Figure 12. Line 2 field seismic record. (4 second recorder sweep rate)

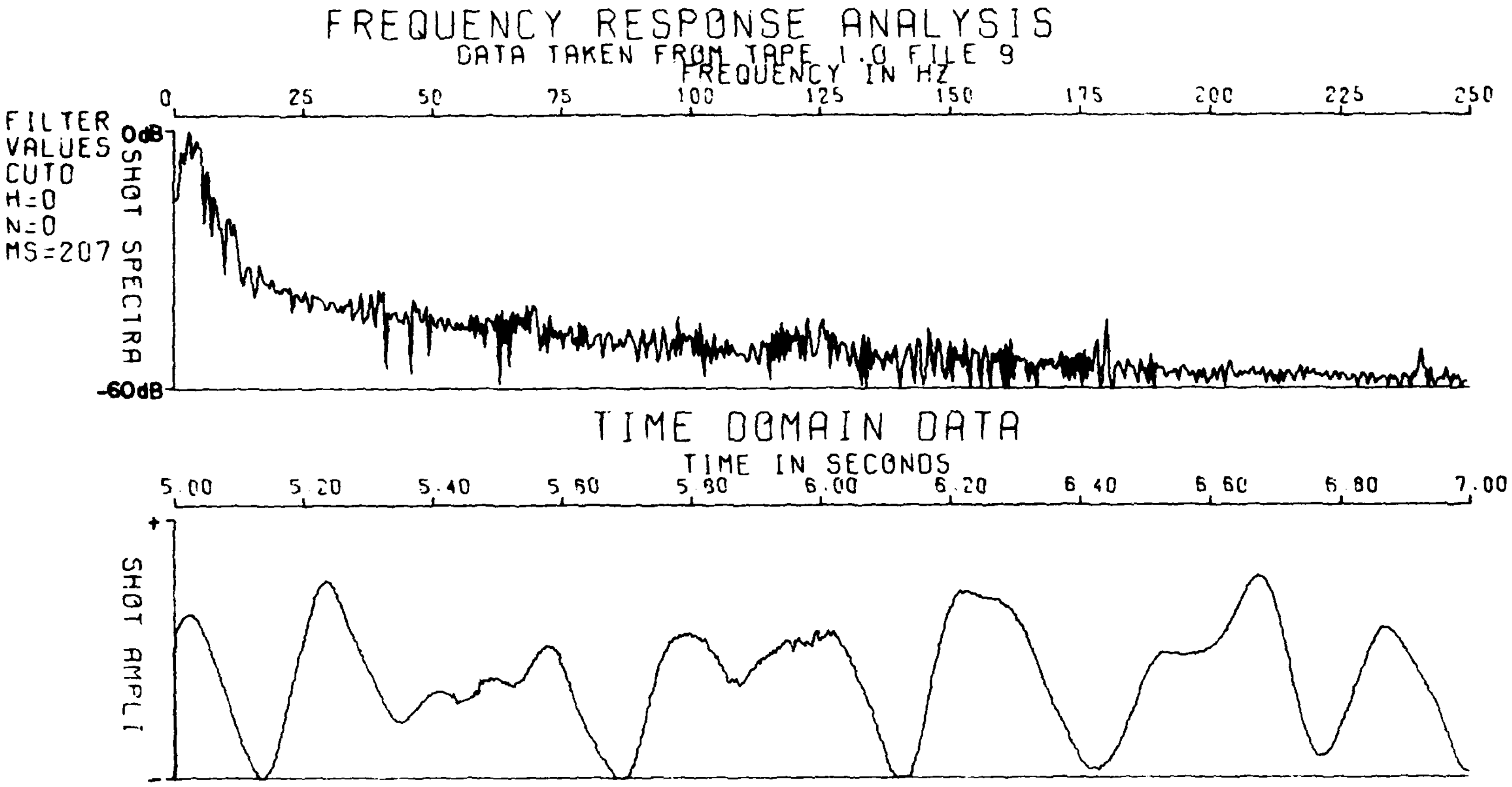


Figure 13. Line 1 file. Frequency/time plot. Unfiltered

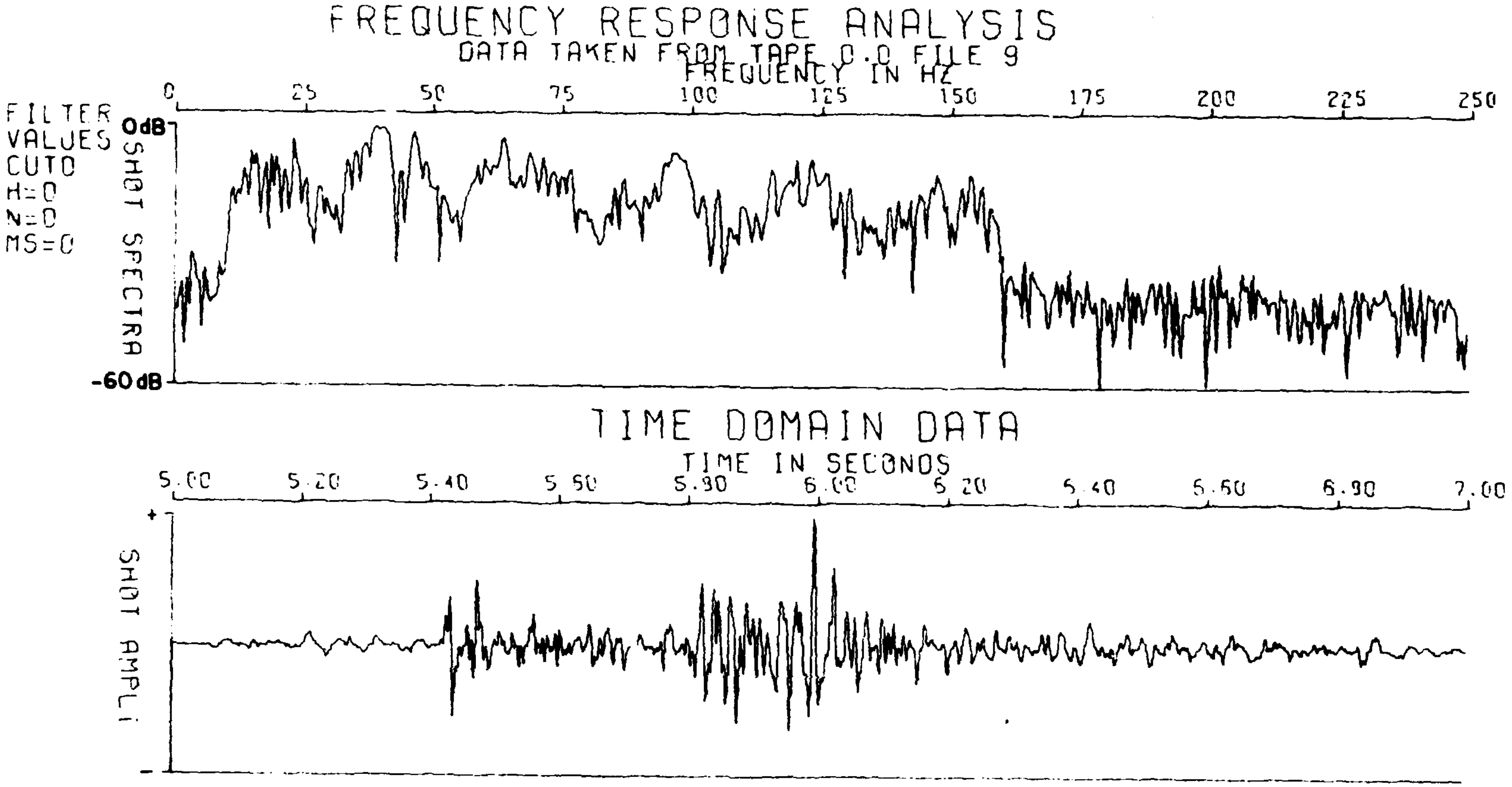


Figure 14. Line 1 file. Frequency/time plot. Frequency domain filter (10 Hz to 170 Hz: cosine shaded)

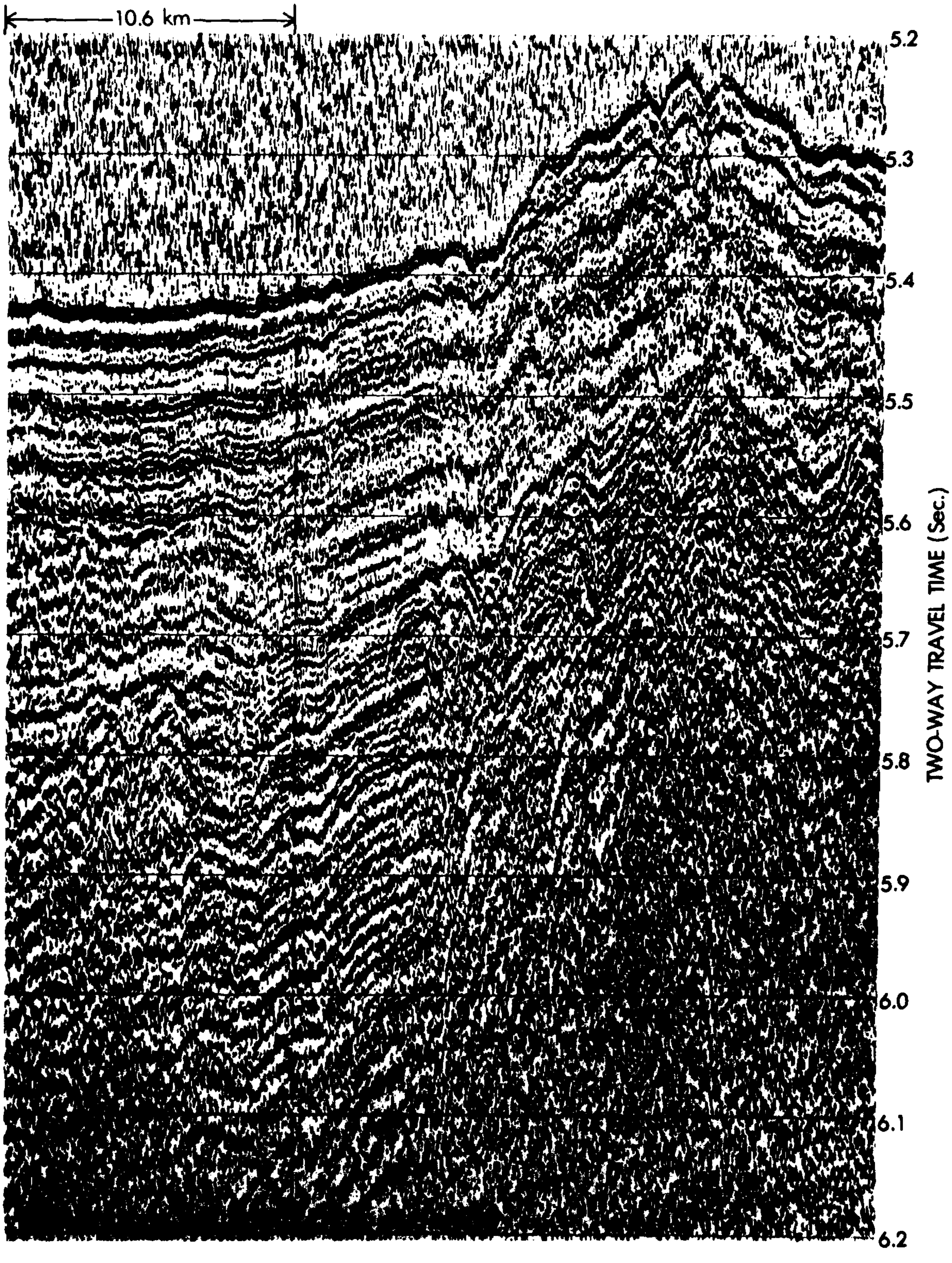


Figure 15. Line 1 seismic record. Frequency domain filter (10 Hz to 170 Hz: cosine shaded)

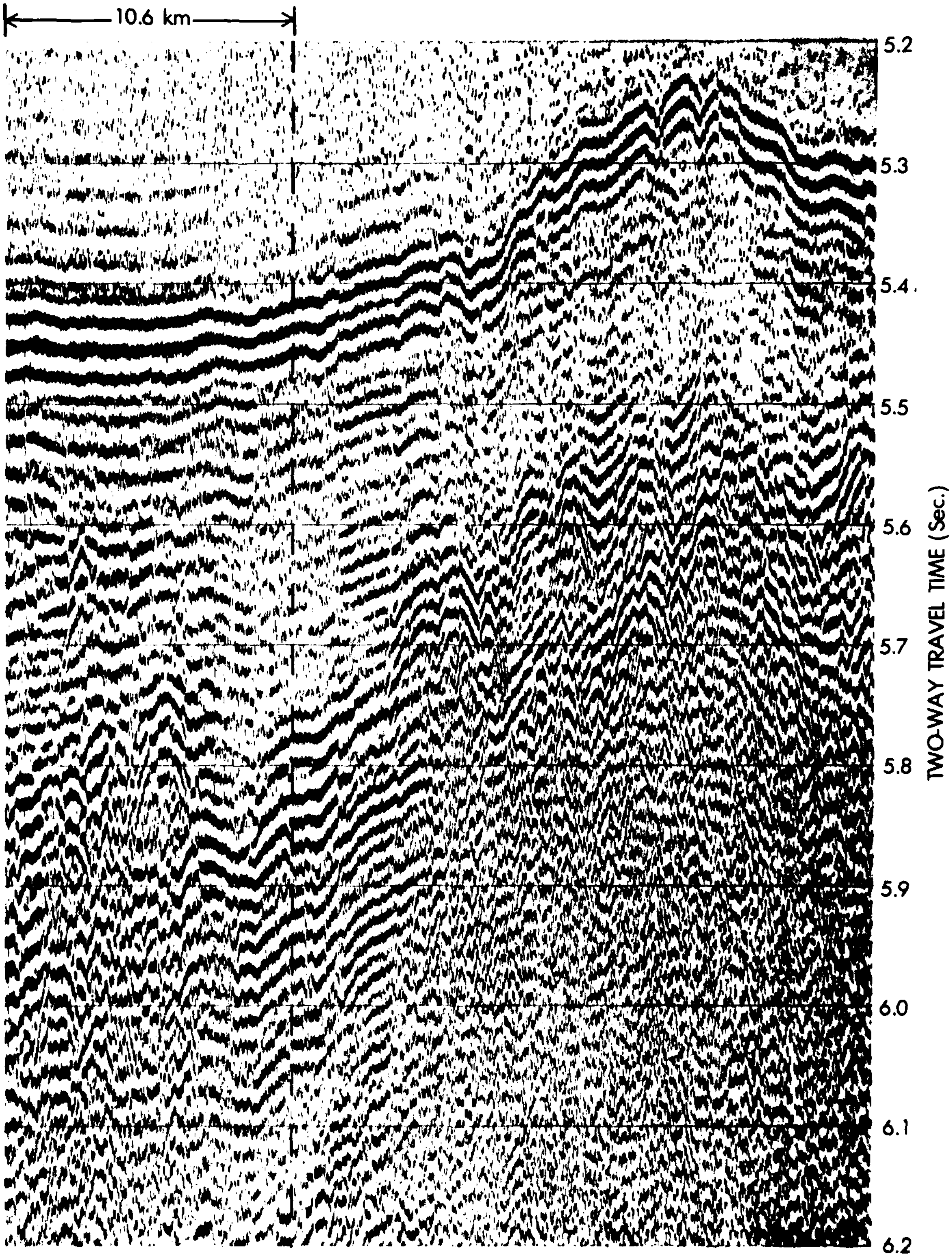


Figure 16. Line 1 Seismic Record. Frequency Domain Filter (35 Hz to 70 Hz: cosine shaded)

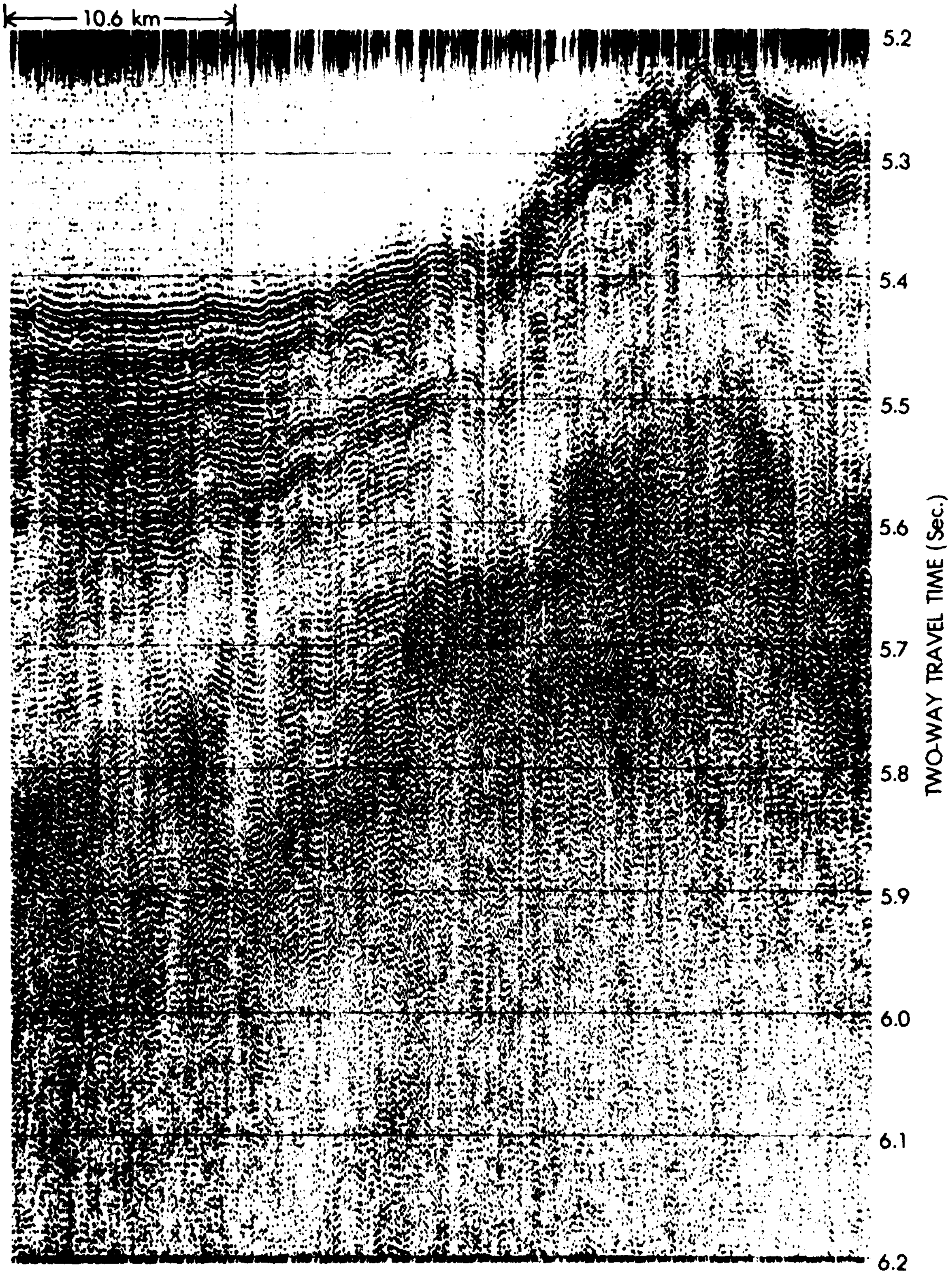


Figure 17. Line 1 Seismic Record. Frequency Domain Filter (125 Hz to 250 Hz: cosine shaded)

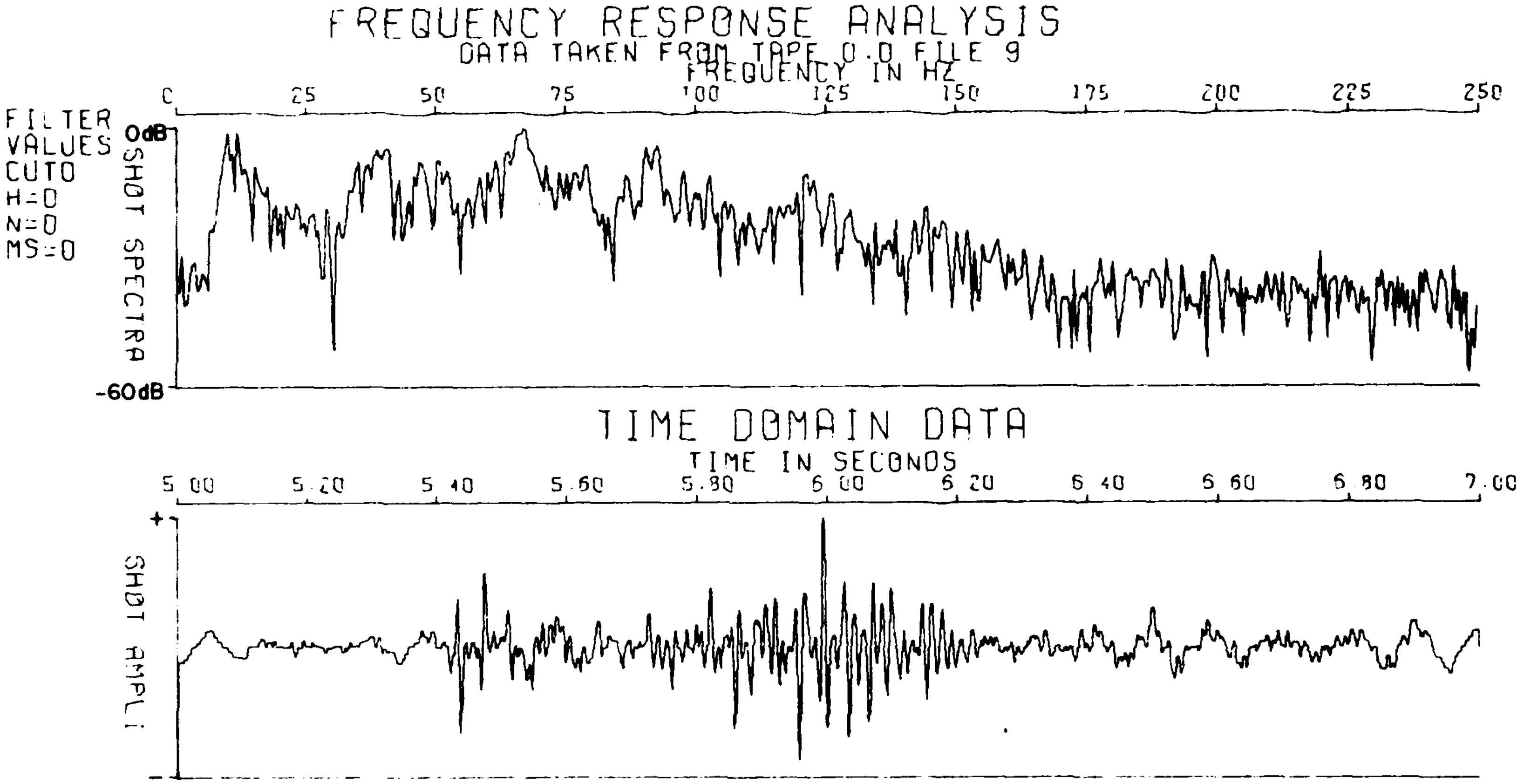


Figure 18. Line 1 file frequency/time plot. Frequency domain filter (10 Hz to 170 Hz: Gaussian shaded)

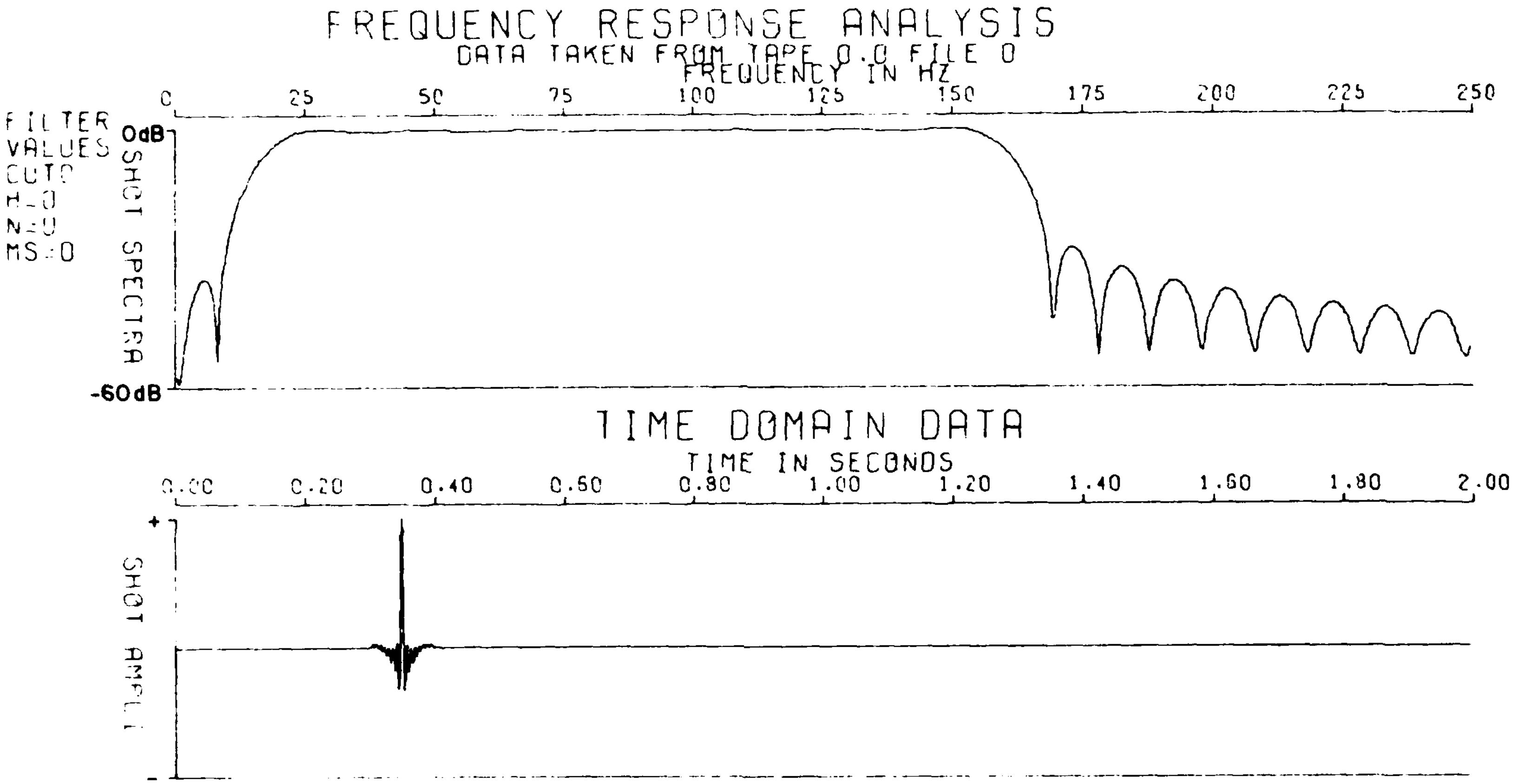


Figure 19. Impulse response. Frequency/time plot. Frequency domain filter (10 Hz to 170 Hz: cosine shaded)

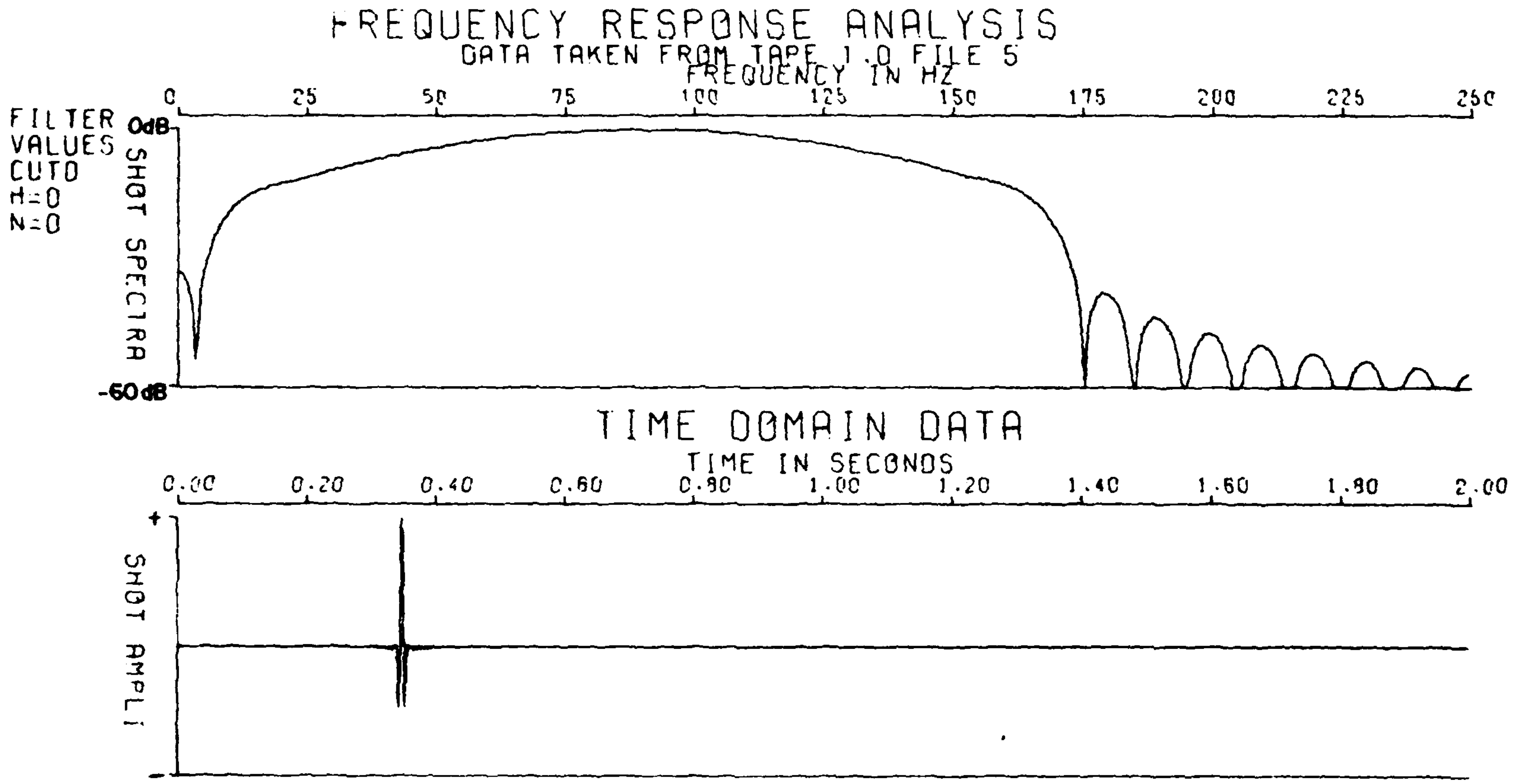


Figure 20. Impulse response. Frequency/time plot. Frequency domain filter (10 Hz to 170 Hz: Gaussian shaded)

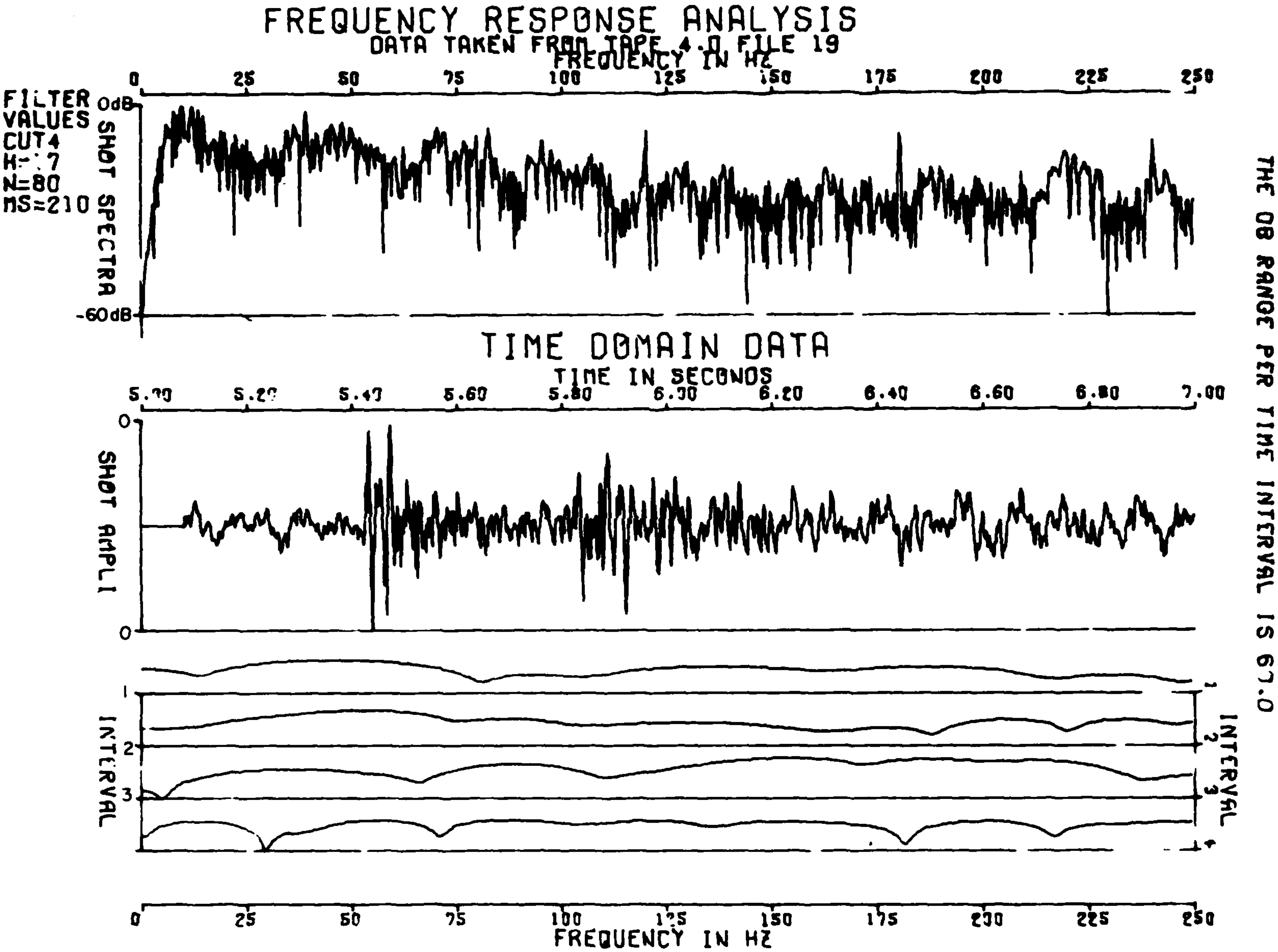


Figure 21. Line 1 file. Frequency/time/interval plot. Time domain filter (21 Hz to 250 Hz)

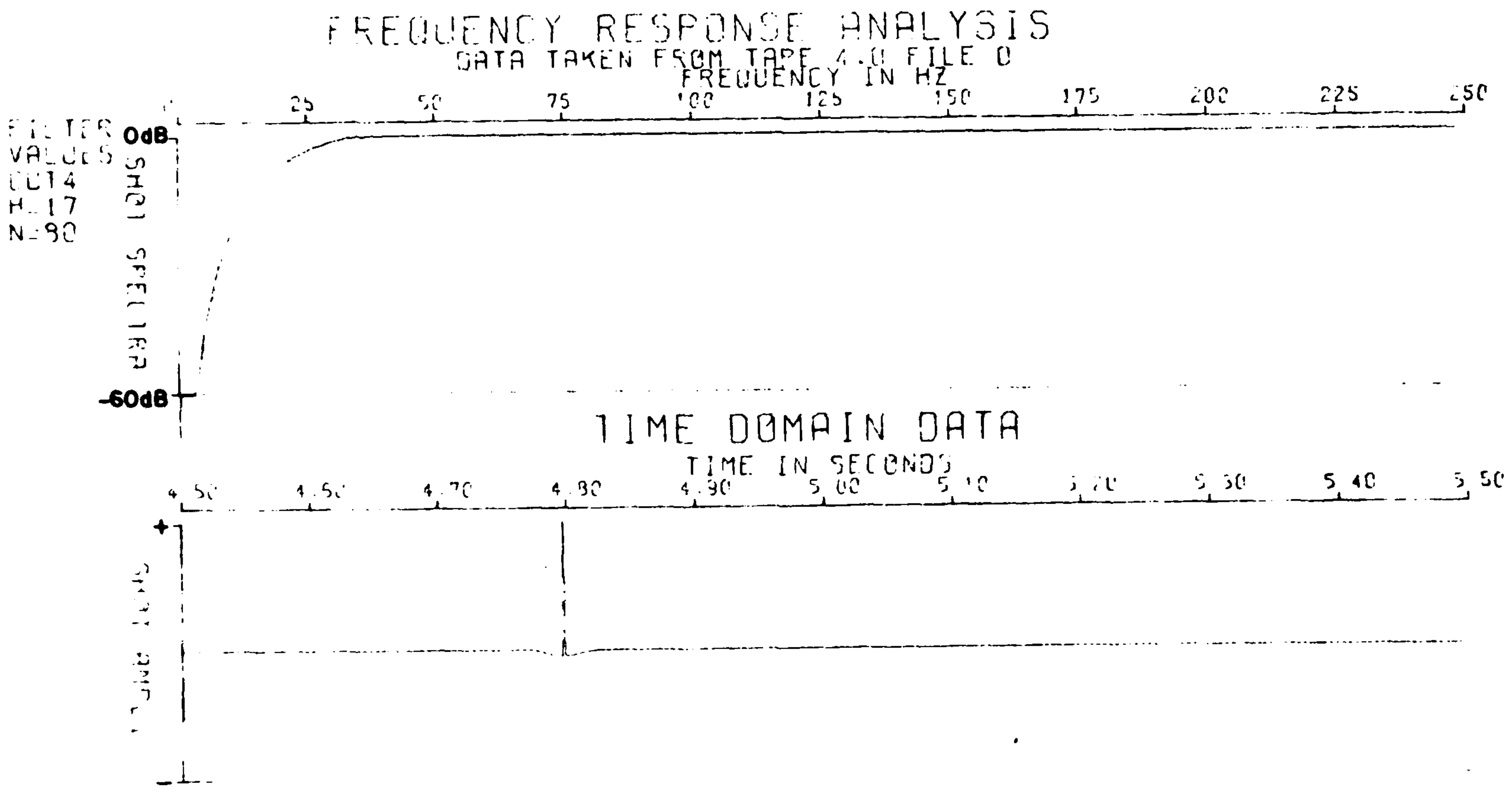


Figure 22. Impulse response. Frequency/time plot. Time domain filter (21 Hz to 250 Hz)

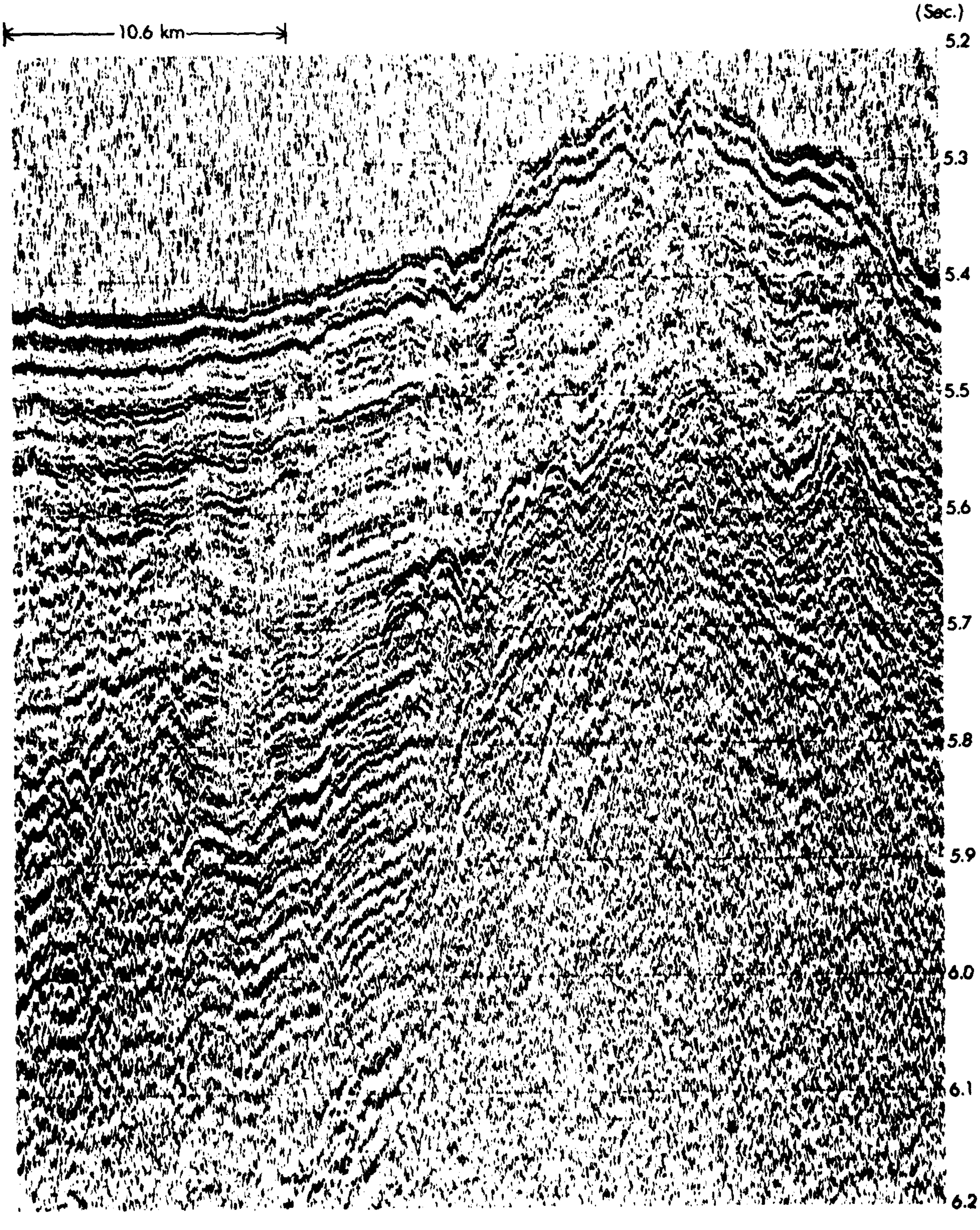


Figure 23. Line 1 seismic record. Time domain filter (21 Hz to 250 Hz)

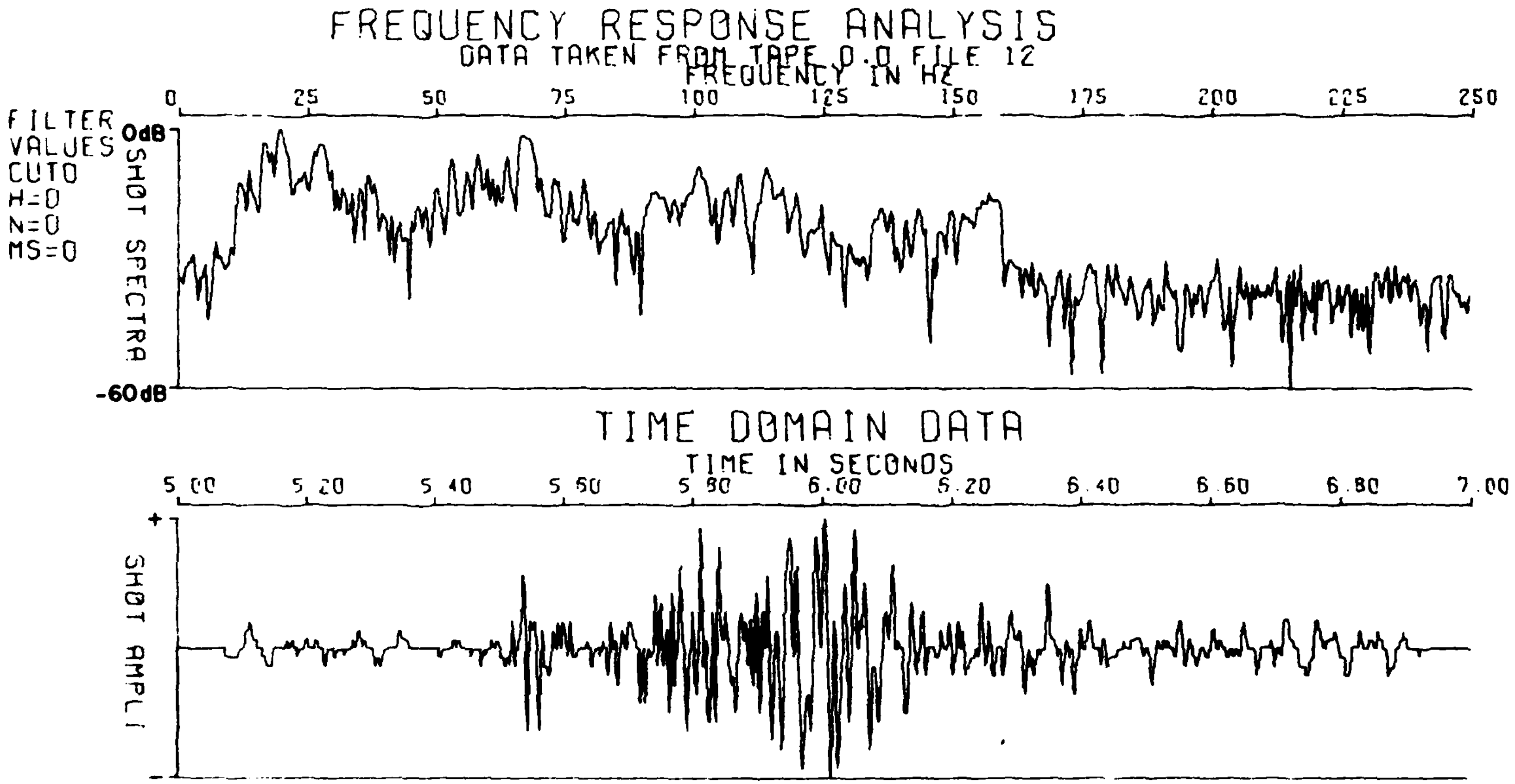


Figure 24. Line 2 file. Frequency/time plot. Frequency domain filter (10 Hz to 170 Hz: cosine shaded)

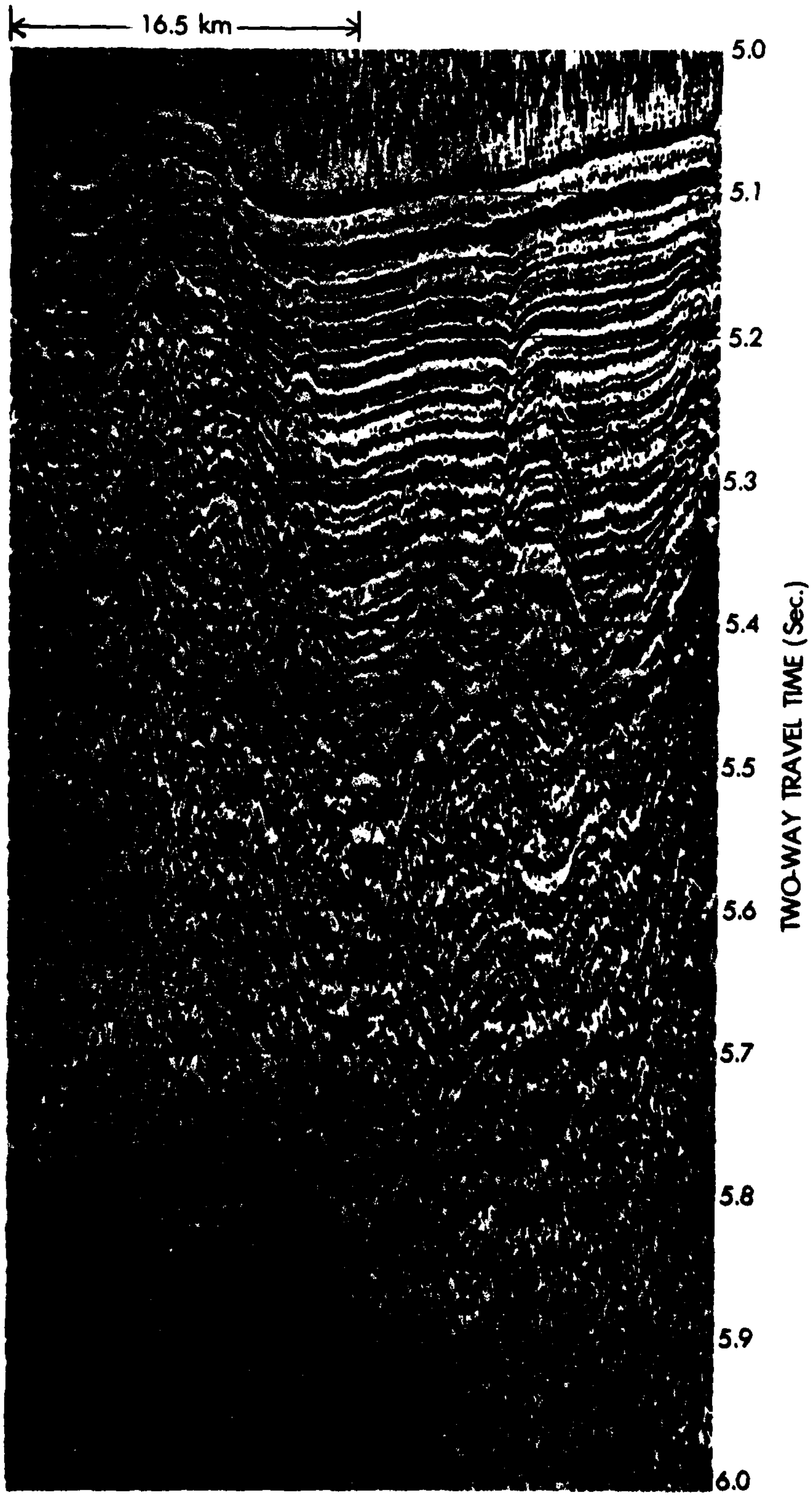


Figure 25. Line 2 seismic record. Frequency domain filter (10 Hz to 170 Hz: cosine shaded)

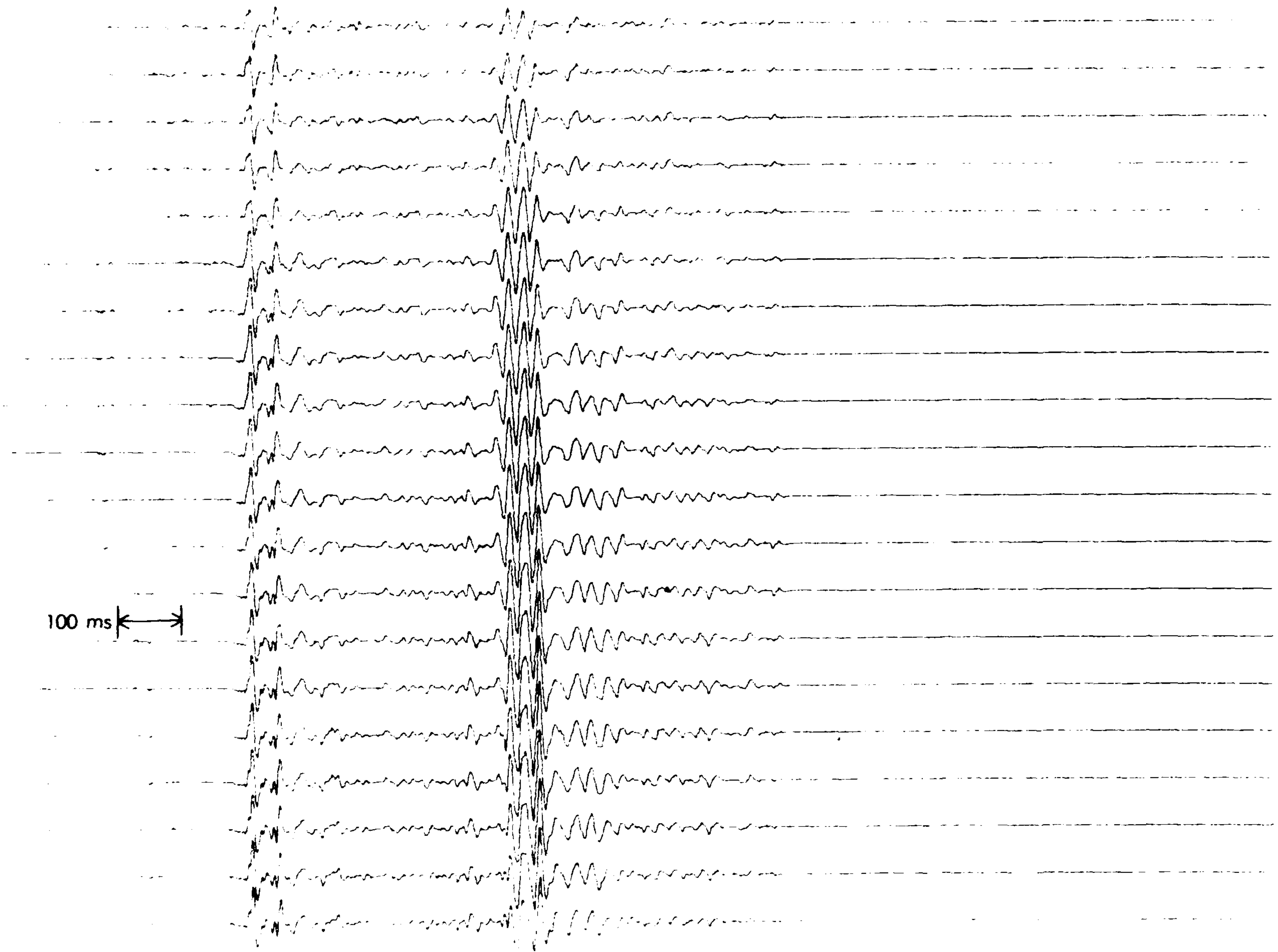


Figure 26. Line 1 vertically stacked 16 file wiggle traces

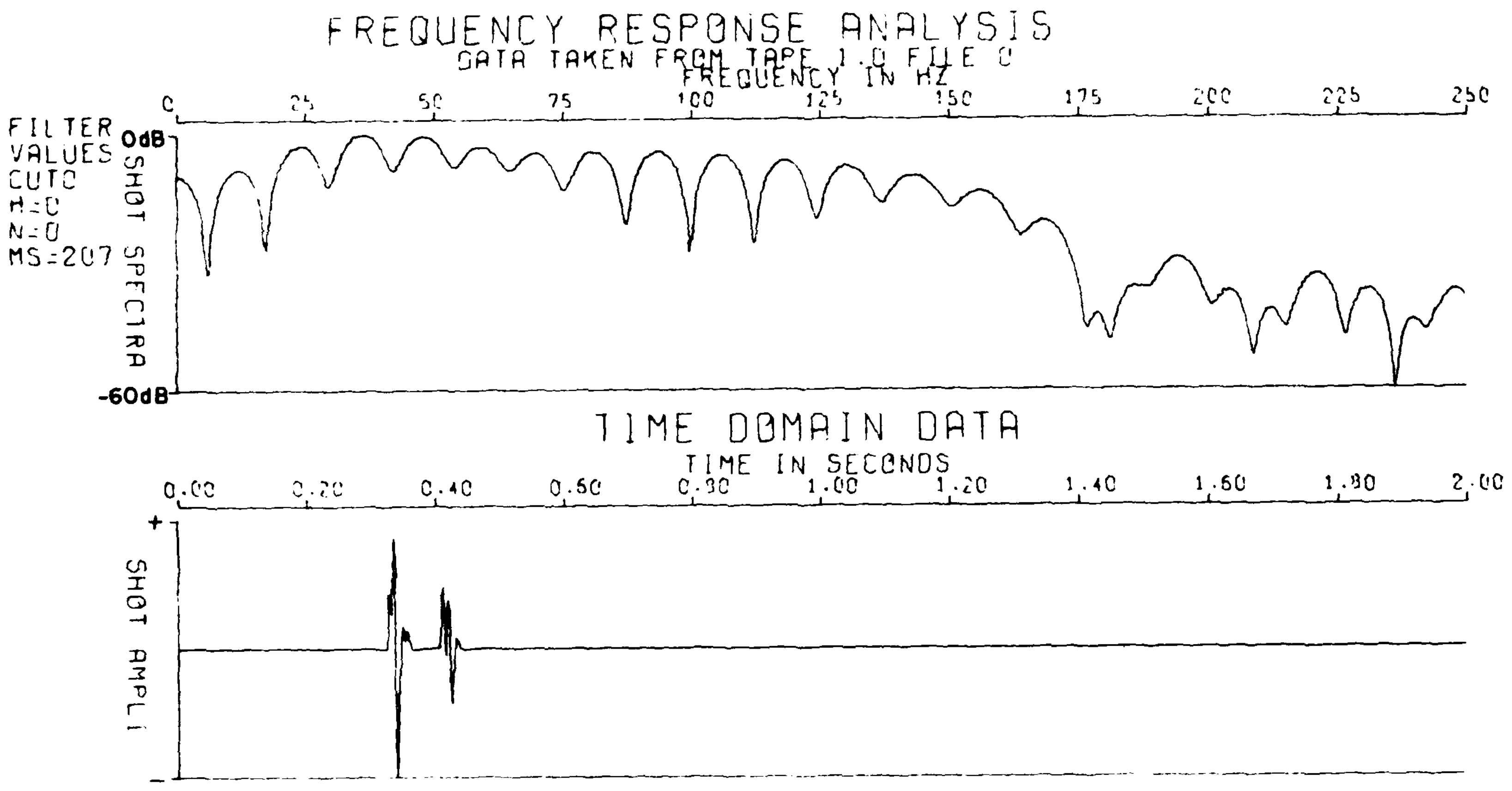


Figure 27. Line 1 30 record average frequency/time plot. Frequency domain filter (10 Hz to 170 Hz: cosine shaded)

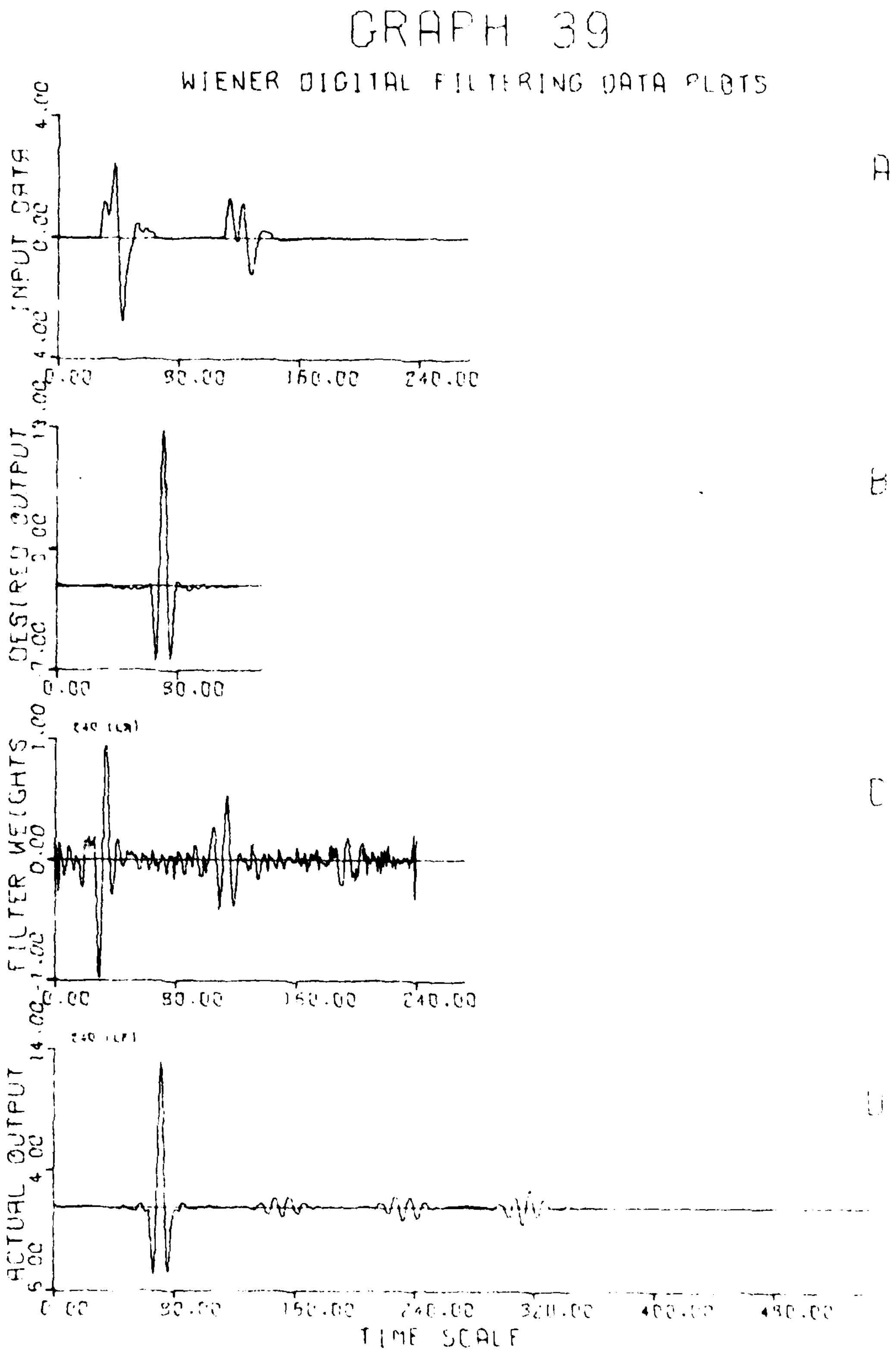


Figure 28. Line 1 Wiener filter parameters. Input data - ocean sediment return (Figure 27). Desired output - zero phase bandpassed spike (Figure 20 response: 10 Hz to 170 Hz: cosine shaded)

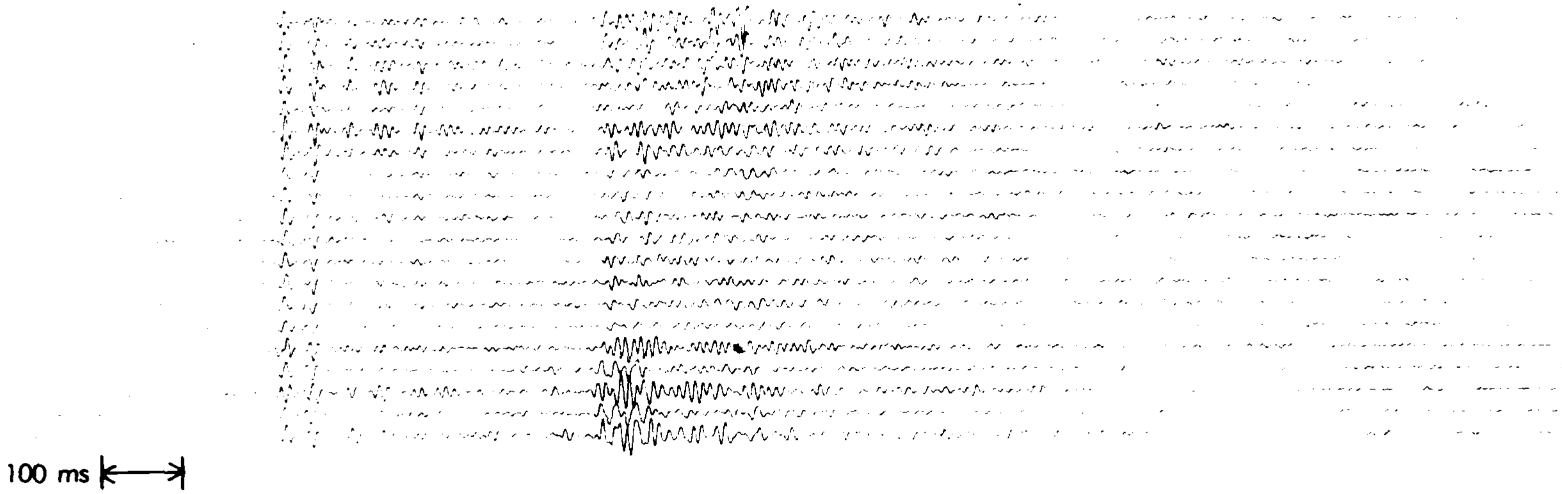


Figure 29. Line 1 Wiener filtered wiggle traces. (Figure 28 parameters)

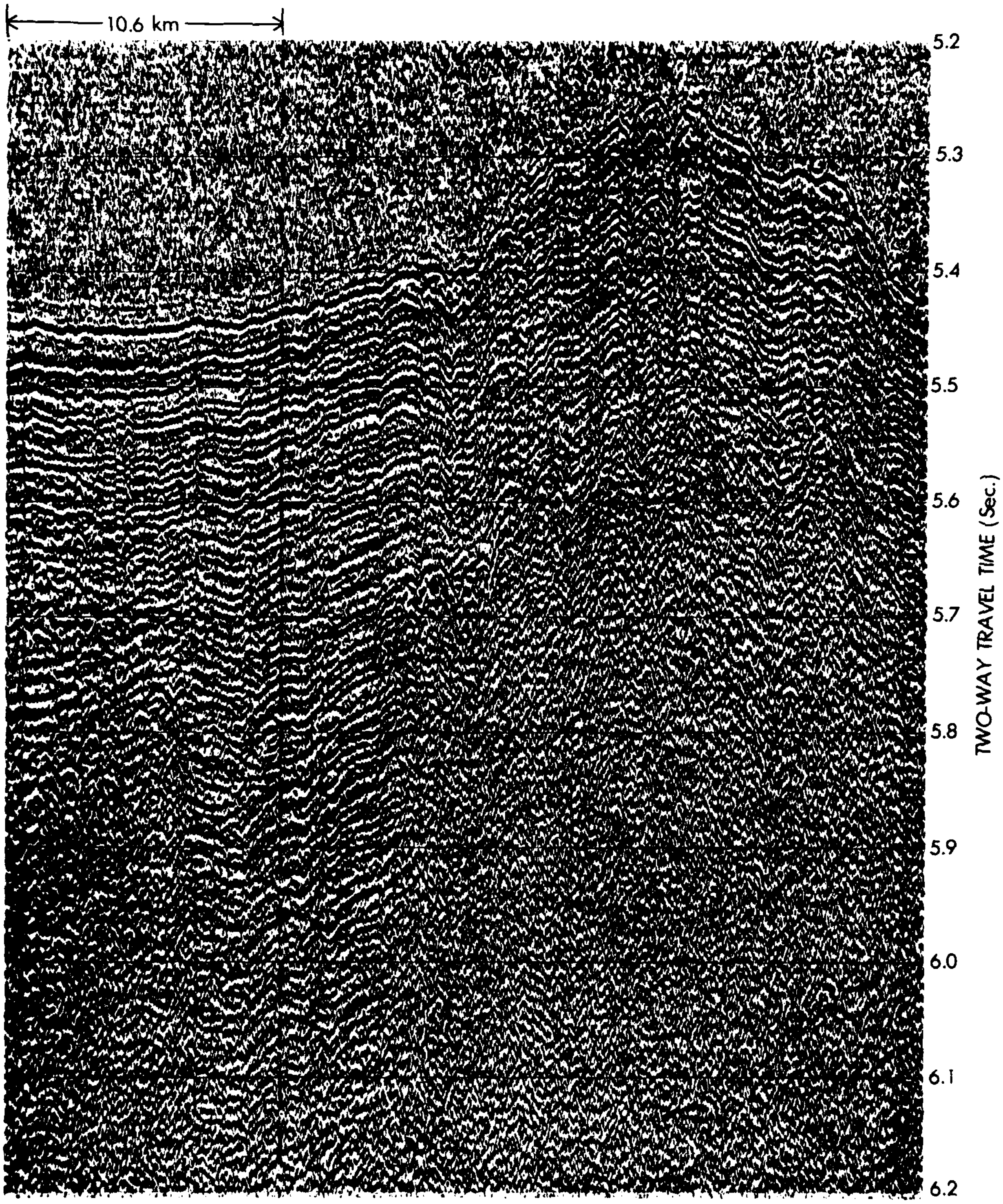


Figure 30. Line 1 Wiener filtered seismic record. (Figure 28 parameters)

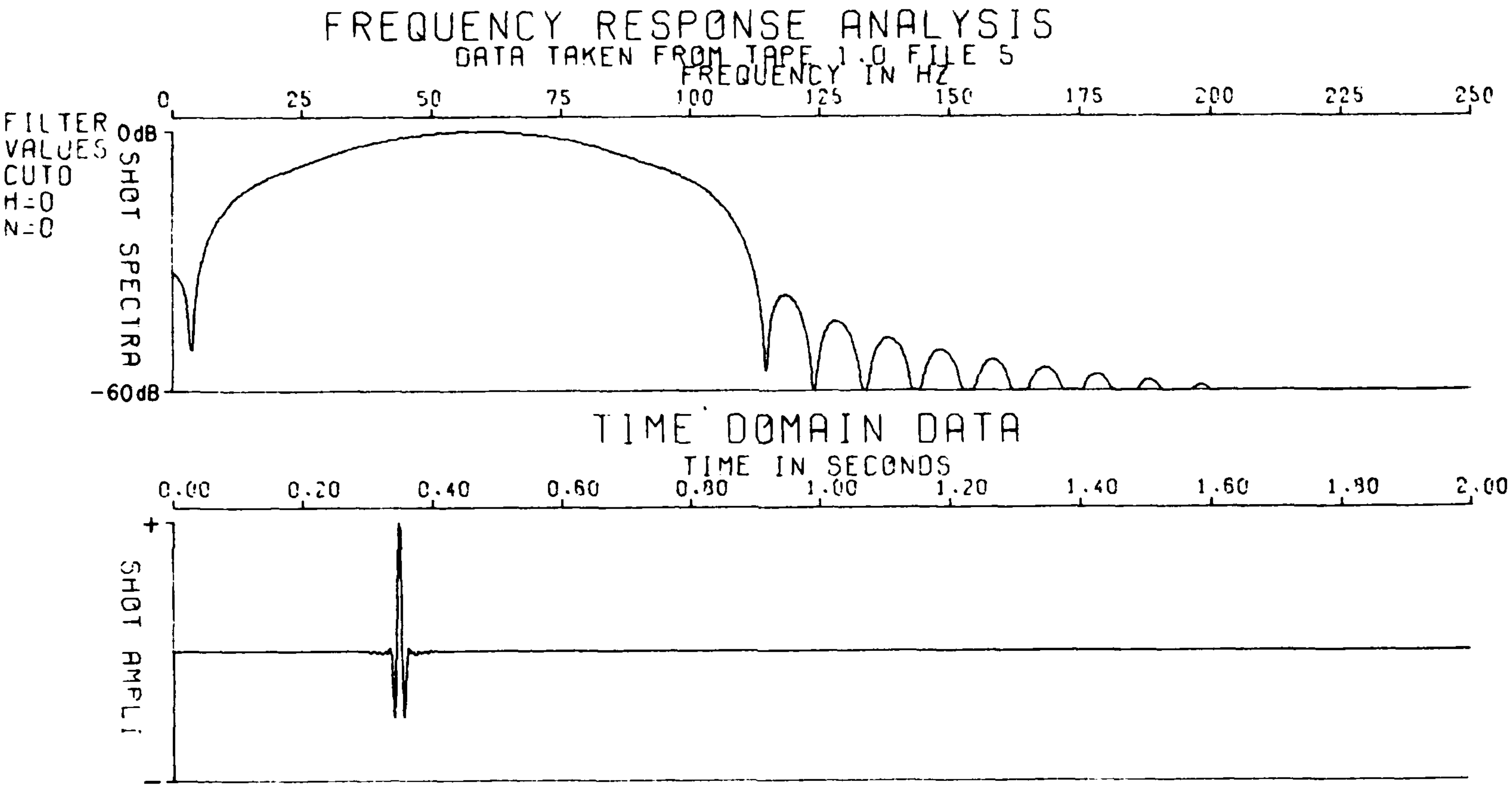


Figure 31. Impulse response. Frequency/time plot. Frequency domain filter (20 Hz to 120 Hz: Gaussian shaded)

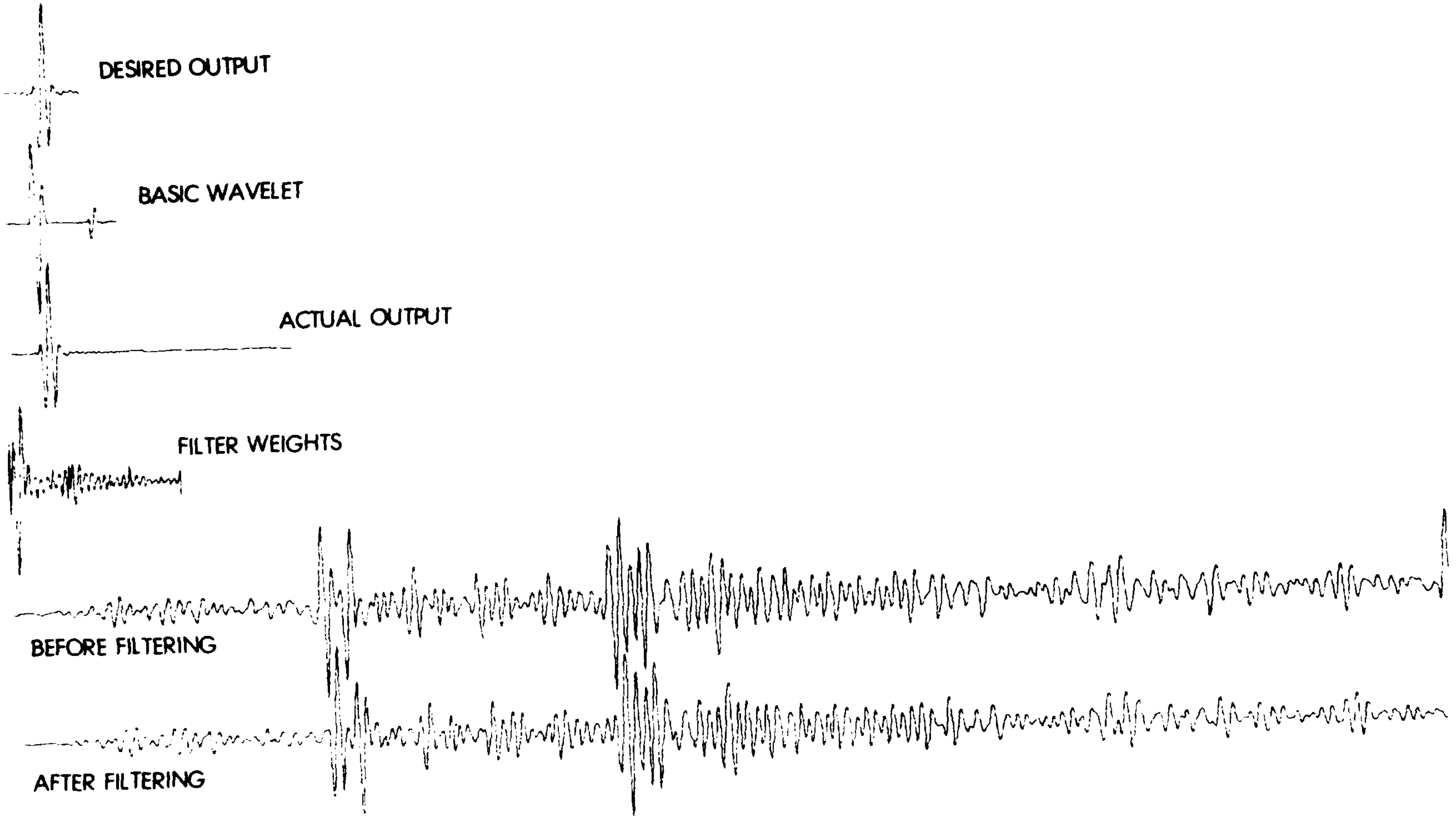


Figure 32. Line 1. Wiener filter parameters - basic wavelet - single file ocean-sediment return. Desired output - zero phase bandpassed spike (Figure 31 response: 20 Hz to 120 Hz: Gaussian shaded)

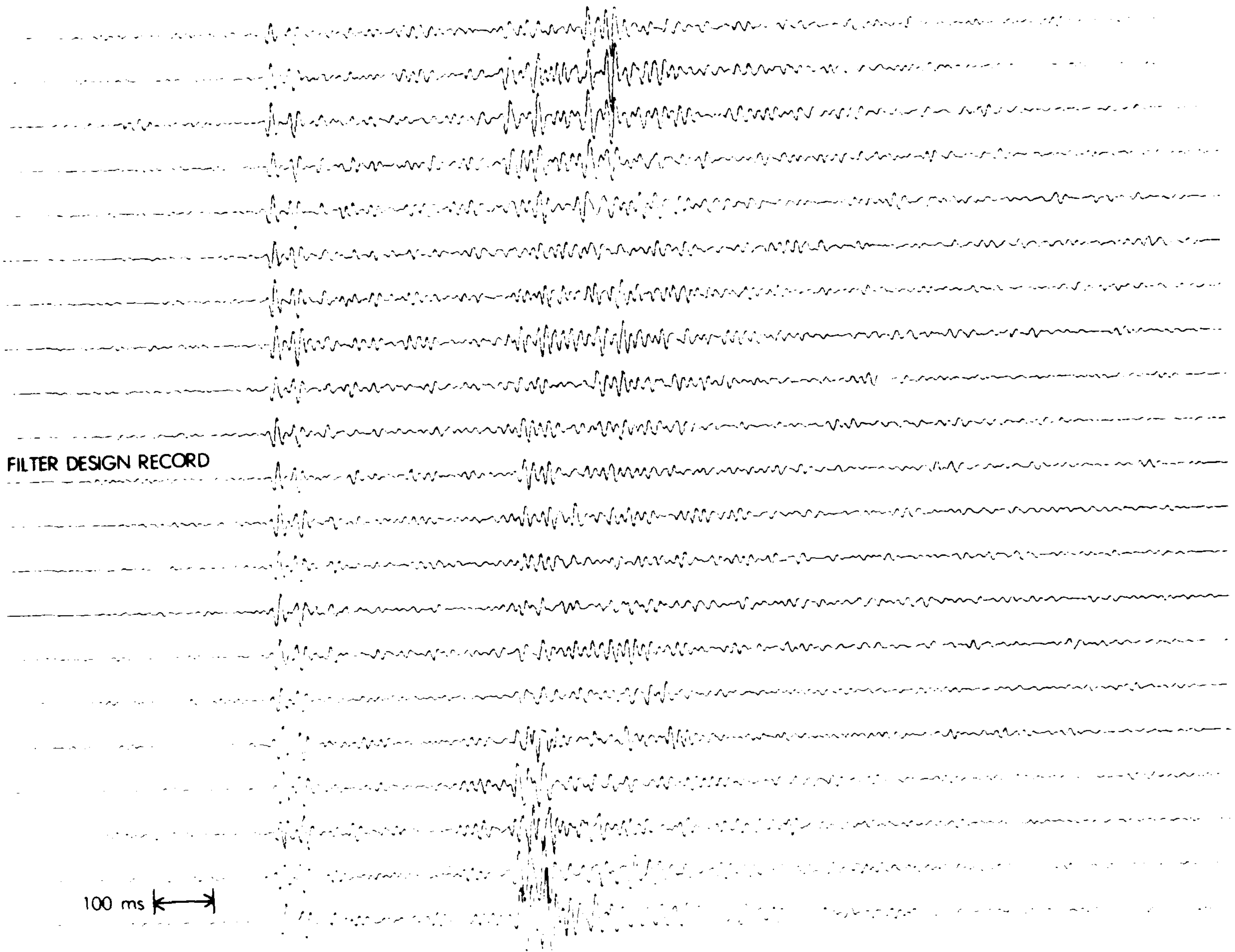


Figure 33. Line 1 Wiener filtered wiggle traces. (Figure 32 parameters)

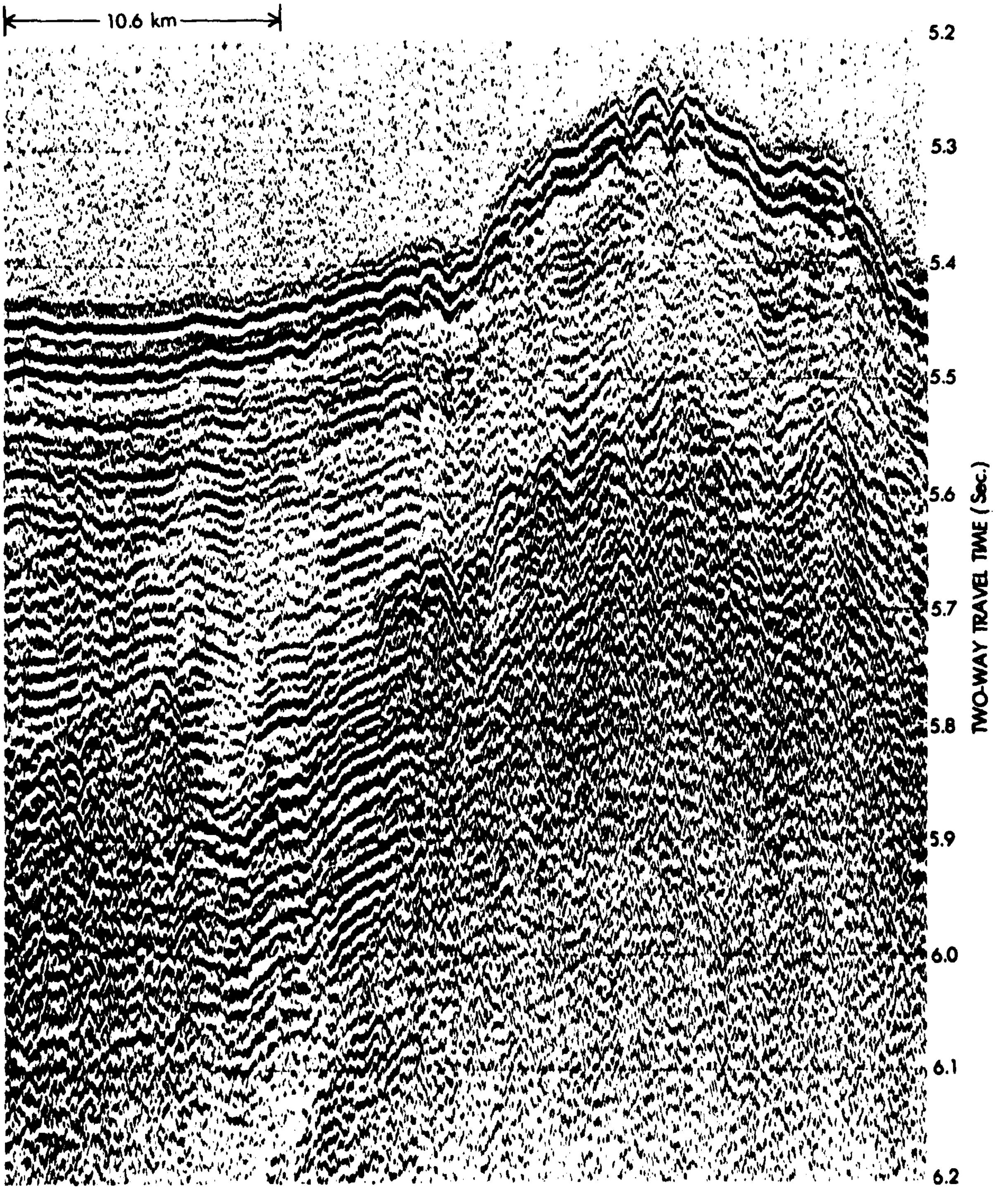


Figure 34. Line 1 Wiener filtered seismic record. (Figure 32 parameters)

Figure 35. Line 1 X-Y recorder wiggle traces

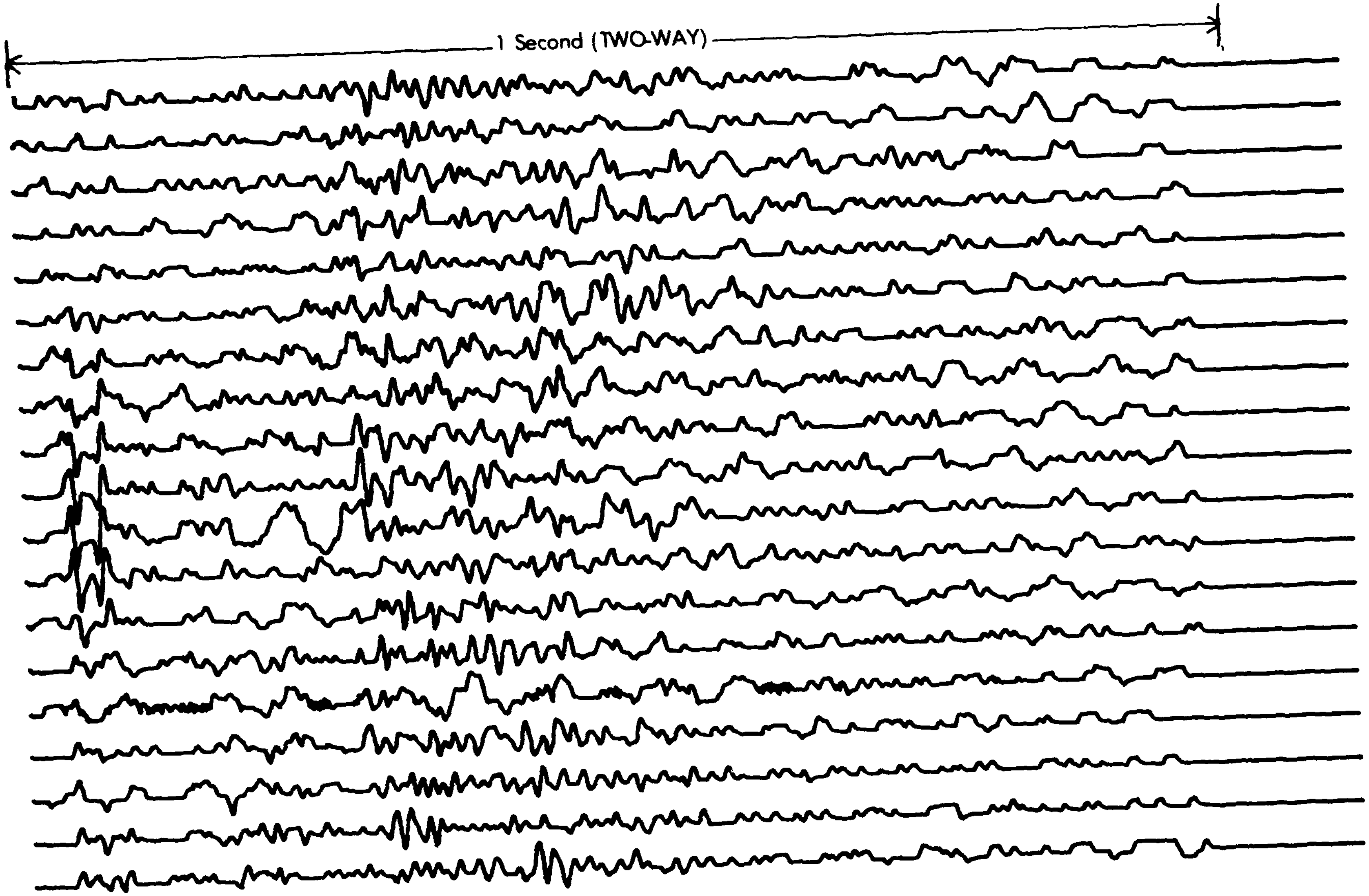


Figure 36. Line 2 X-Y recorder wiggle traces

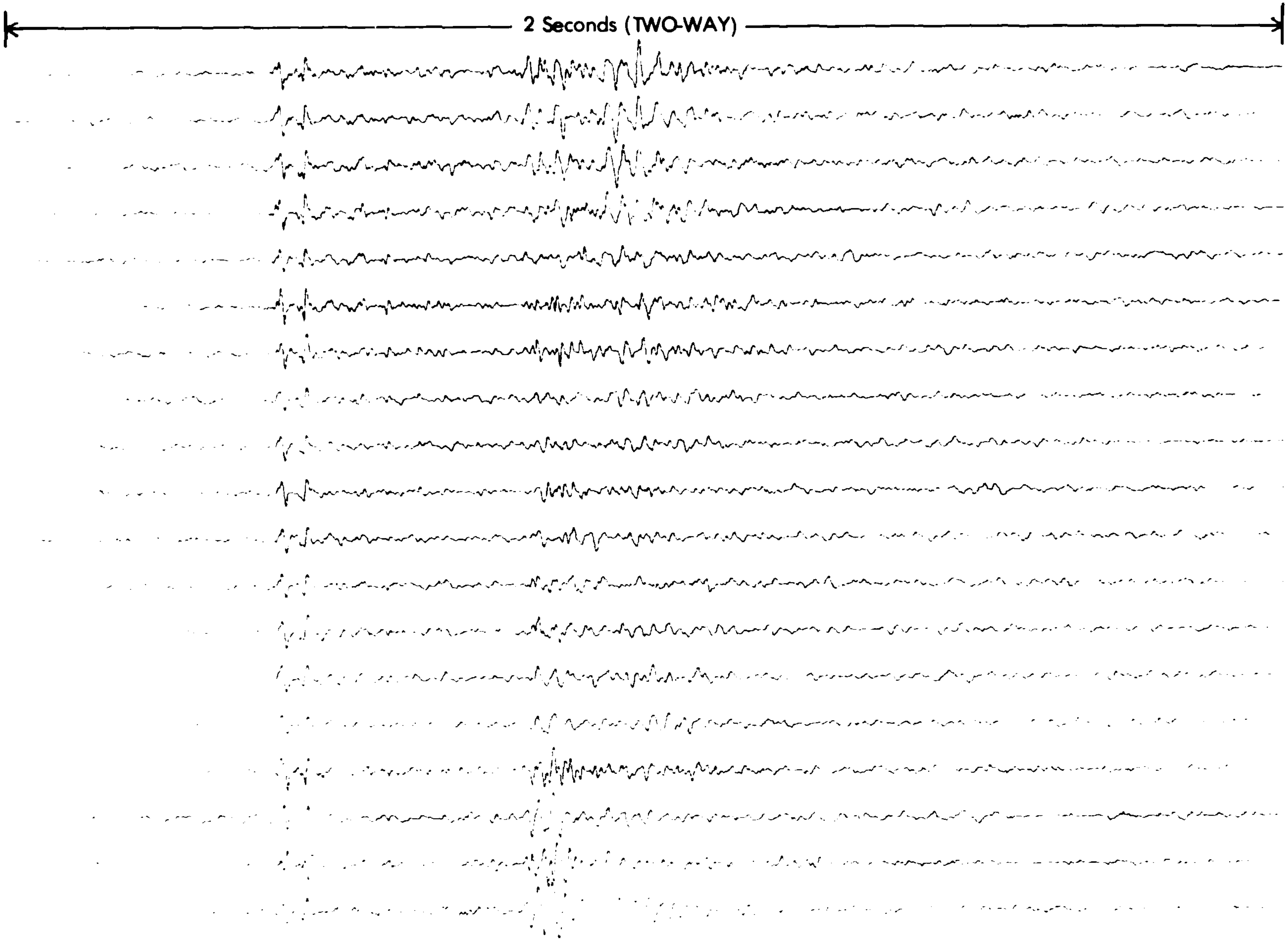


Figure 37. Line 1 CALCOMP wiggle traces

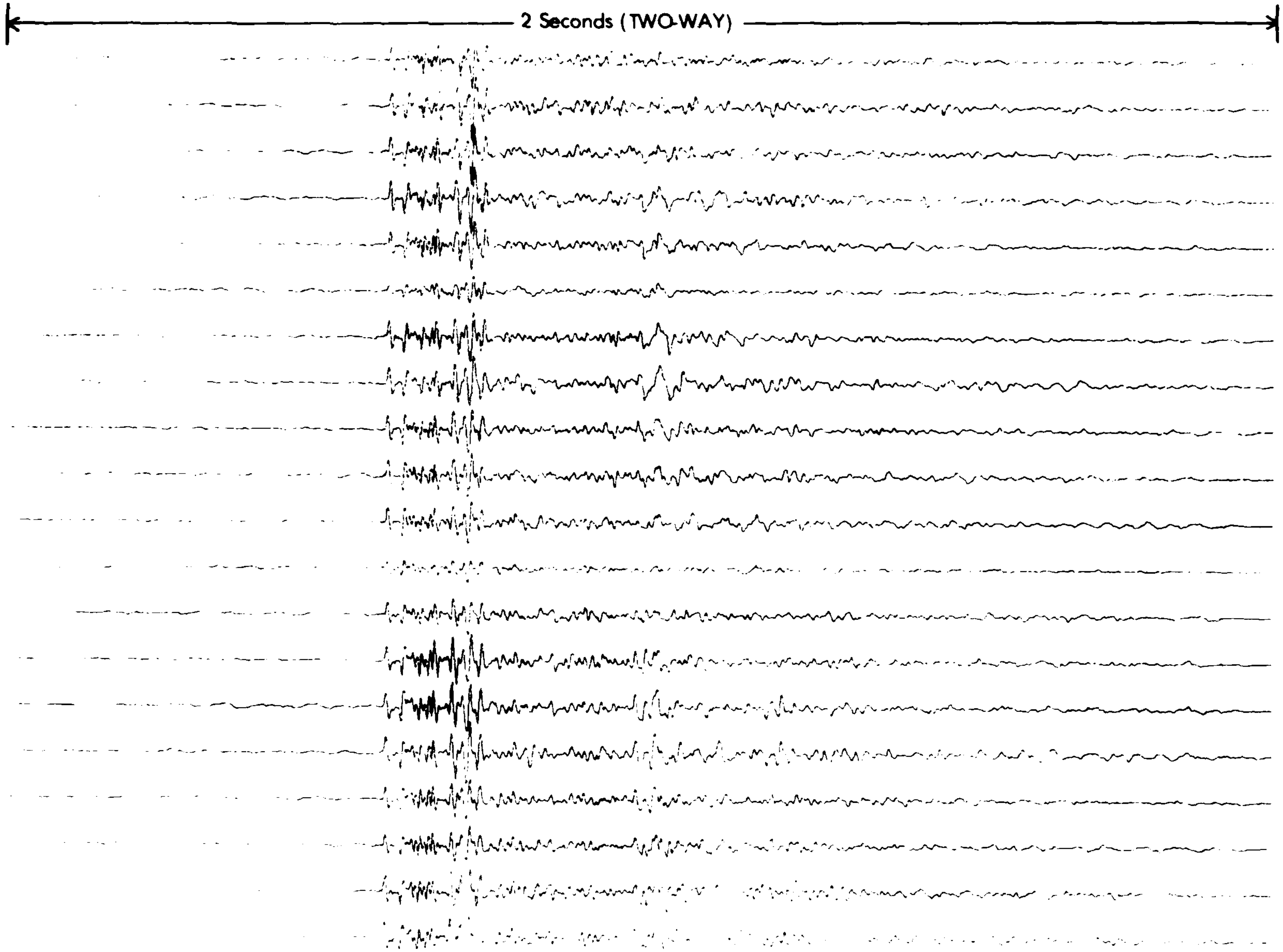


Figure 38. Line 2 CALCOMP wiggle traces

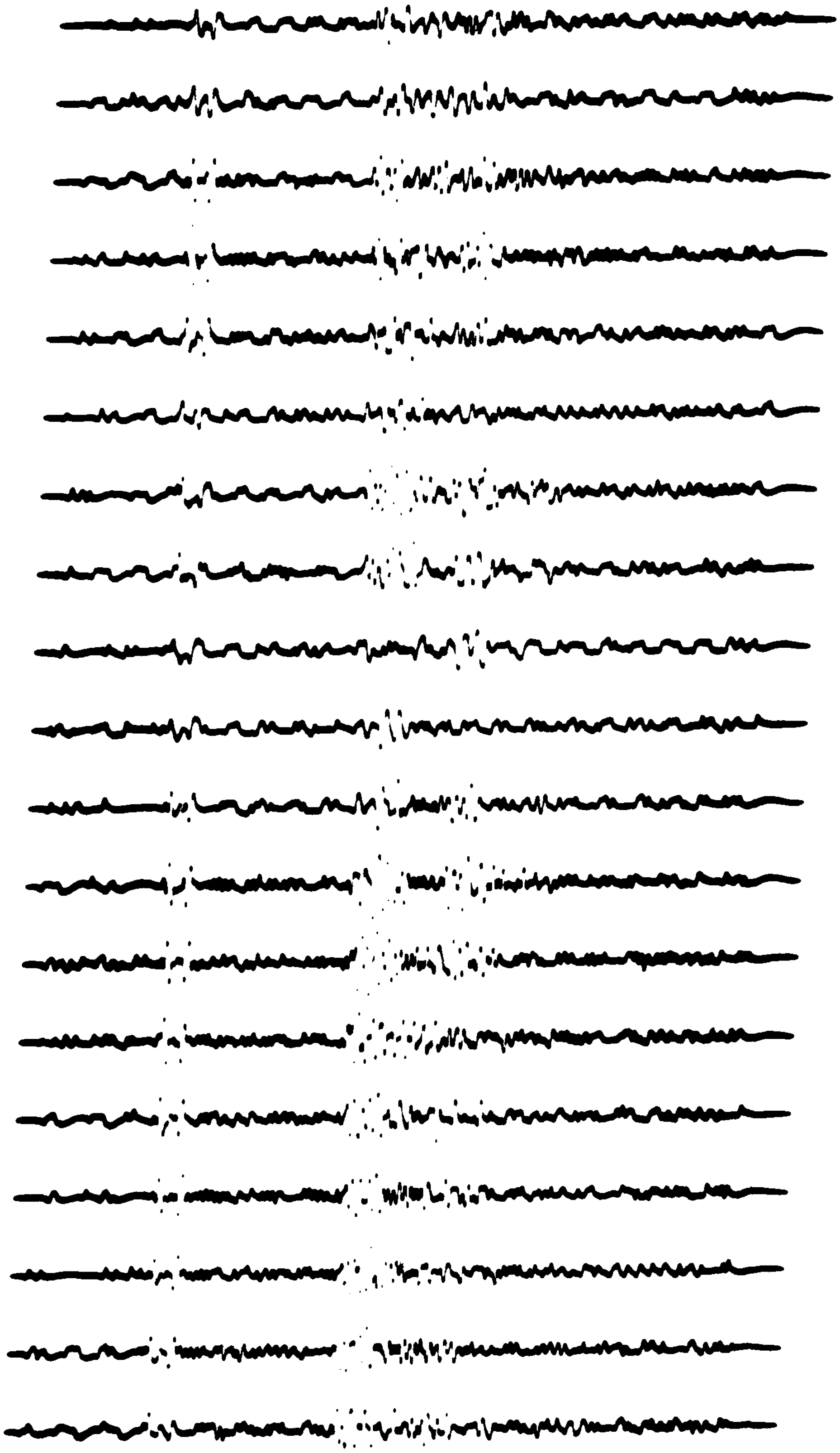


Figure 39. Line 1 fiber optic recorder wiggle traces

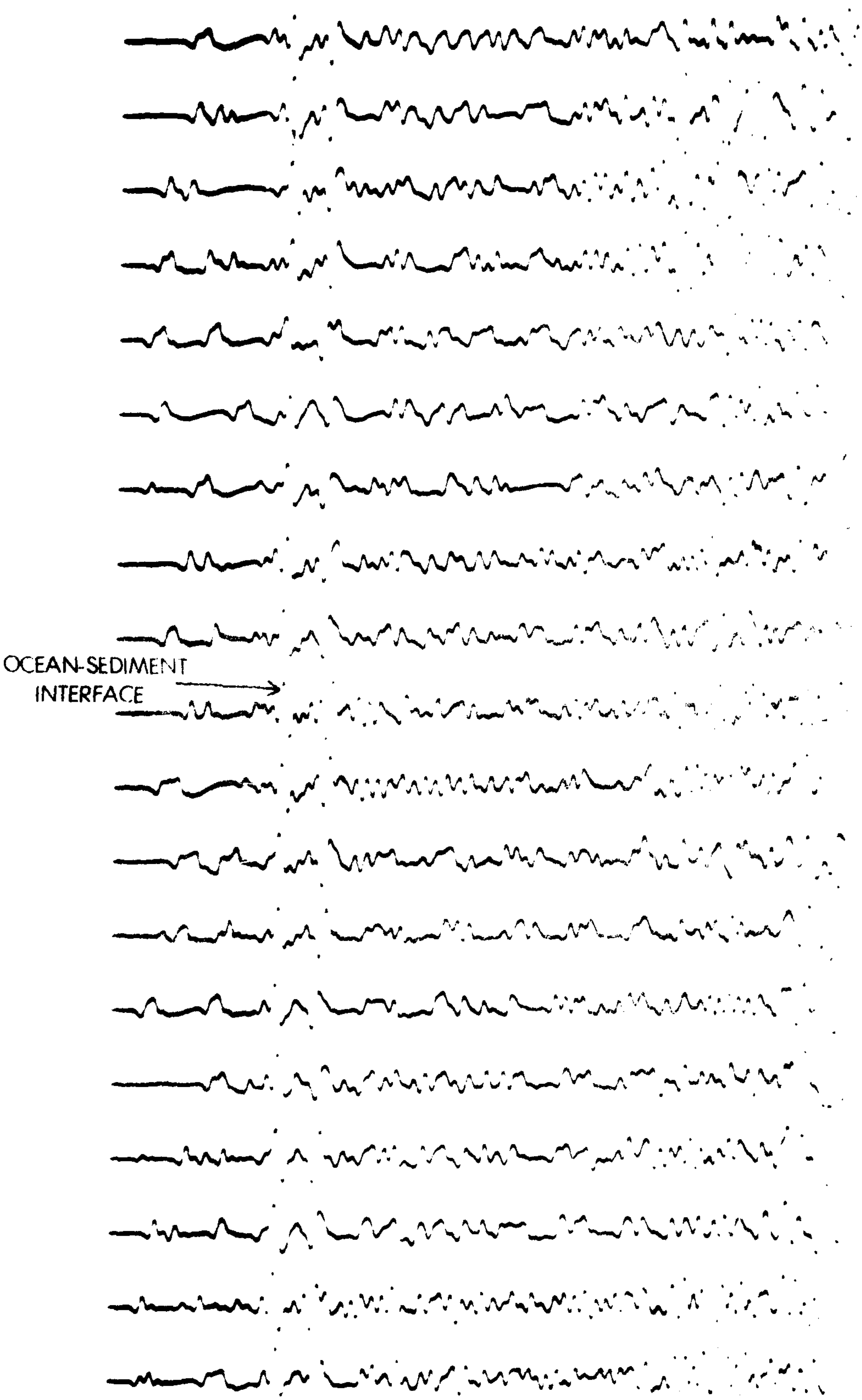


Figure 40. Line 1 fiber optic recorder expanded wiggle traces

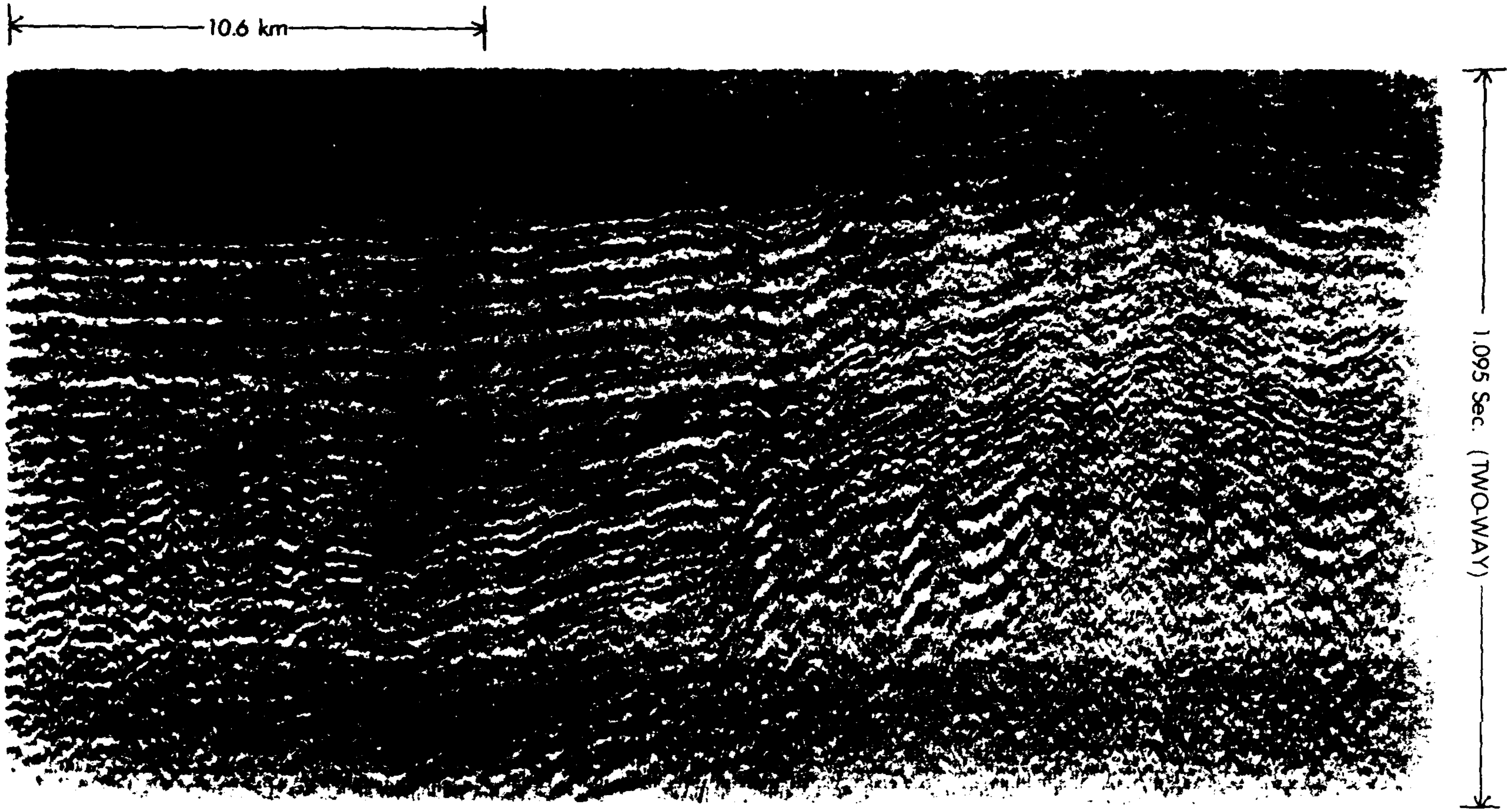


Figure 41. Line 1 fiber optic recorder intensity modulated seismic record

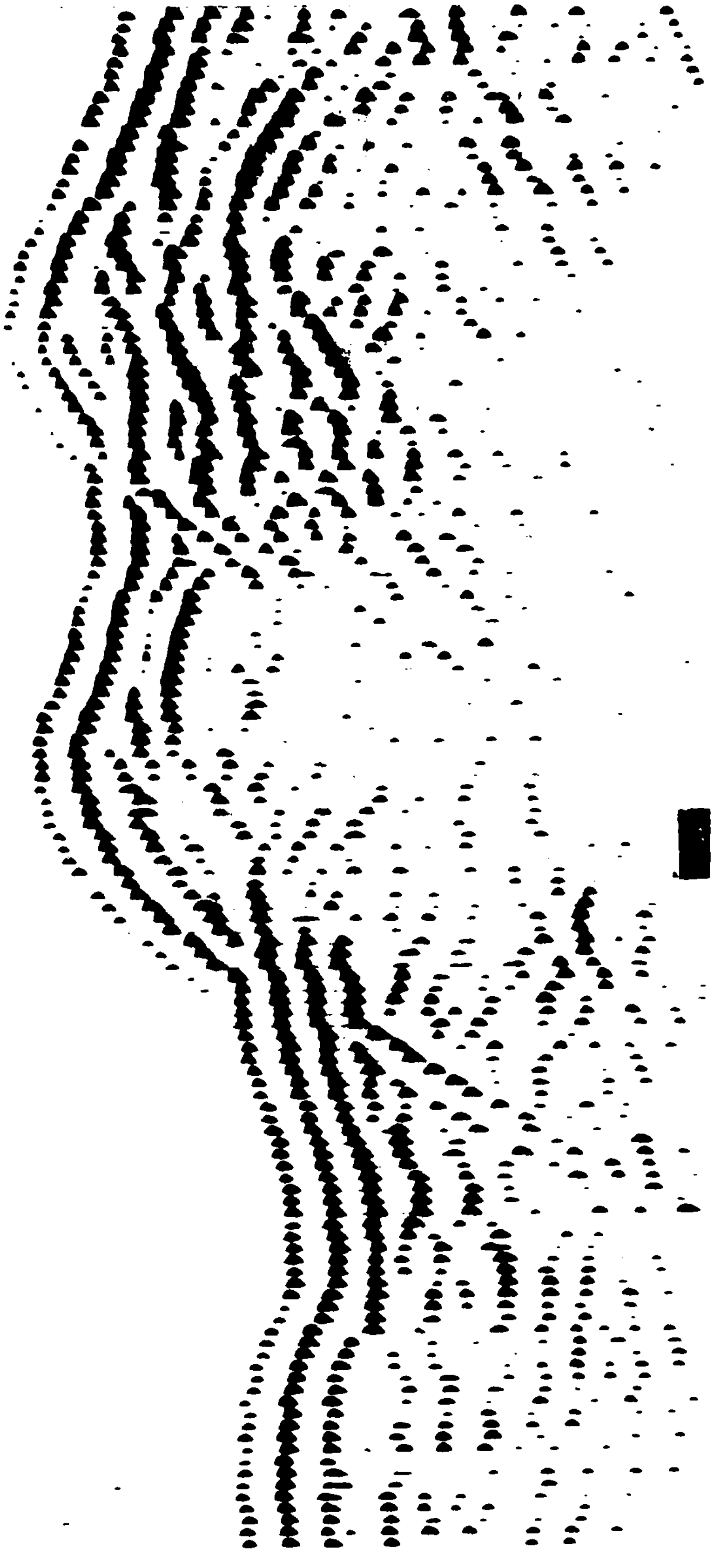


Figure 42. Fiber optic recorder half-wave wiggle traces with experimental interface

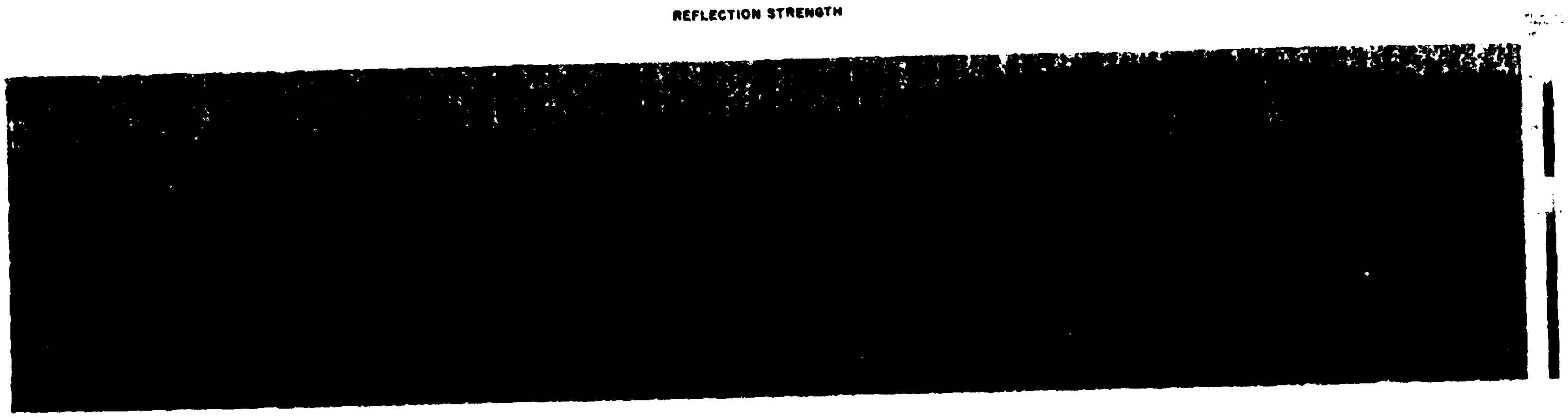


Figure 43. Line 1 color seismic record. Relative reflection strength (processed by Seiscom Delta, Inc.)

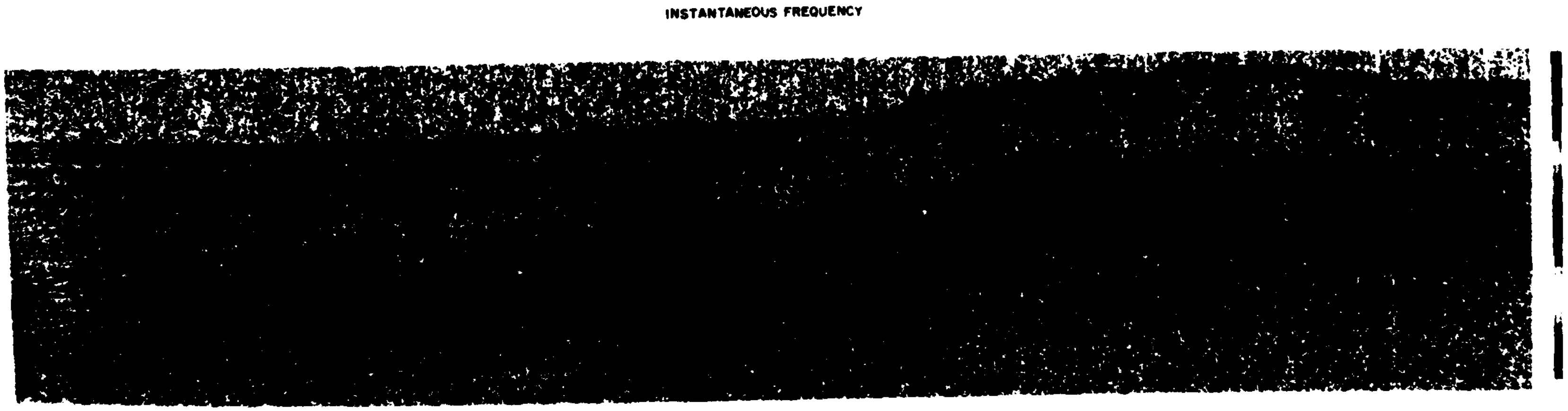


Figure 44. Line 1 color seismic record. Instantaneous frequency (processed by Seiscom Delta, Inc.)

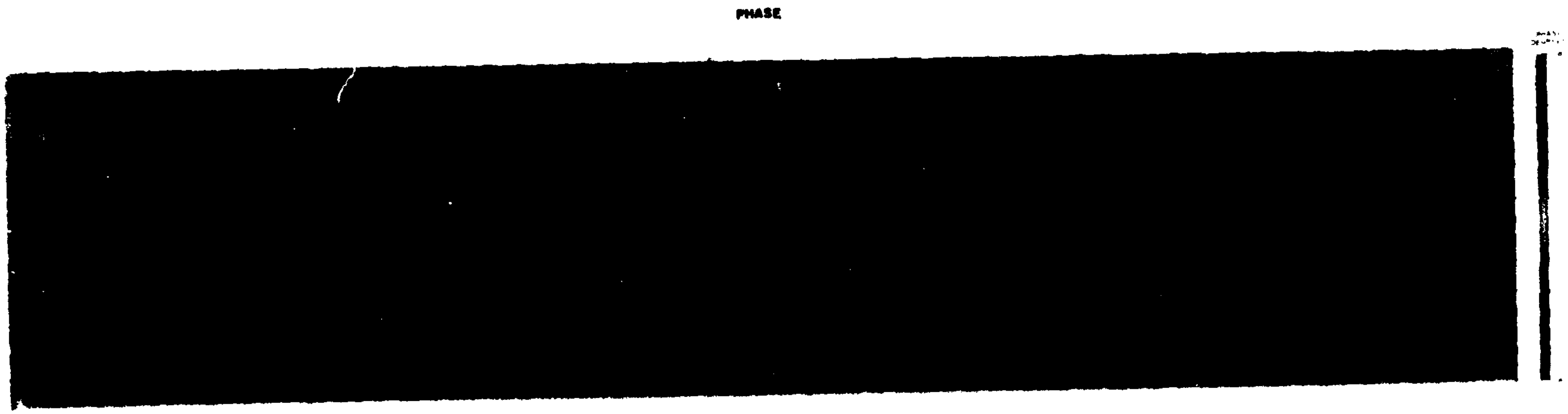


Figure 45. Line 1 color seismic record. Phase (processed by Seiscom Delta, Inc.)

Figure 46. Line 2 color seismic record. Relative reflection strength (processed by Seiscom Delta, Inc.)

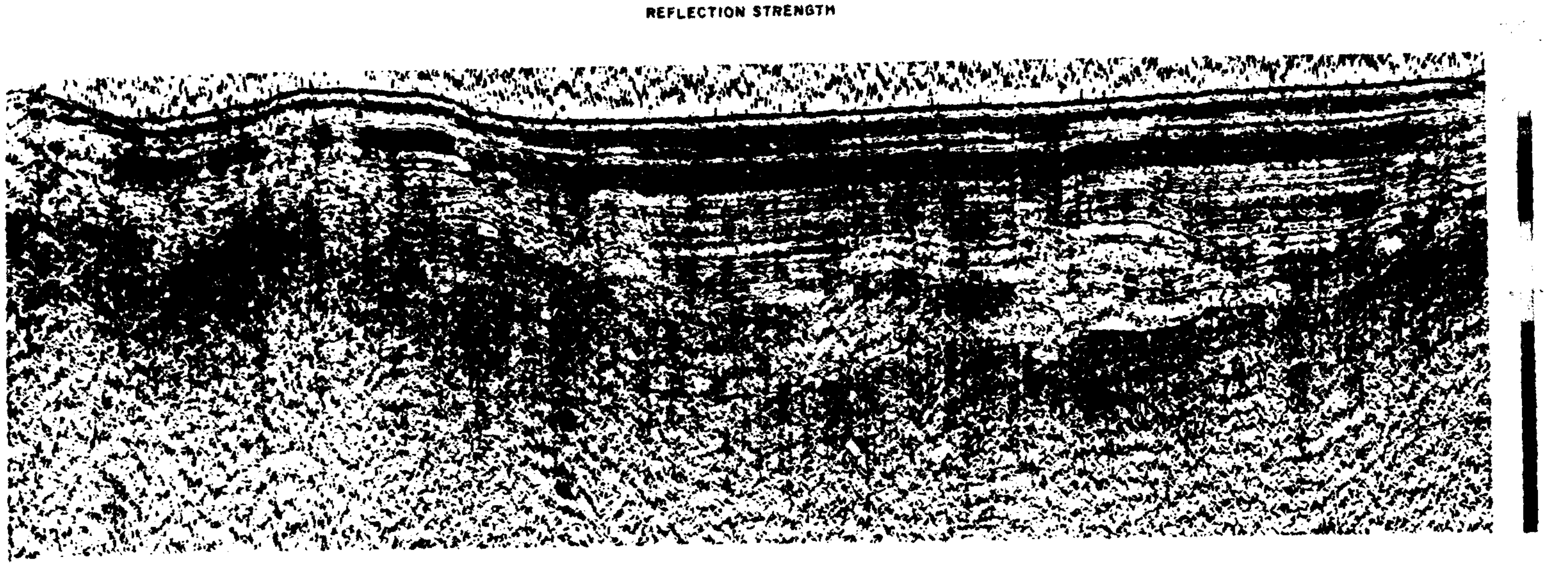
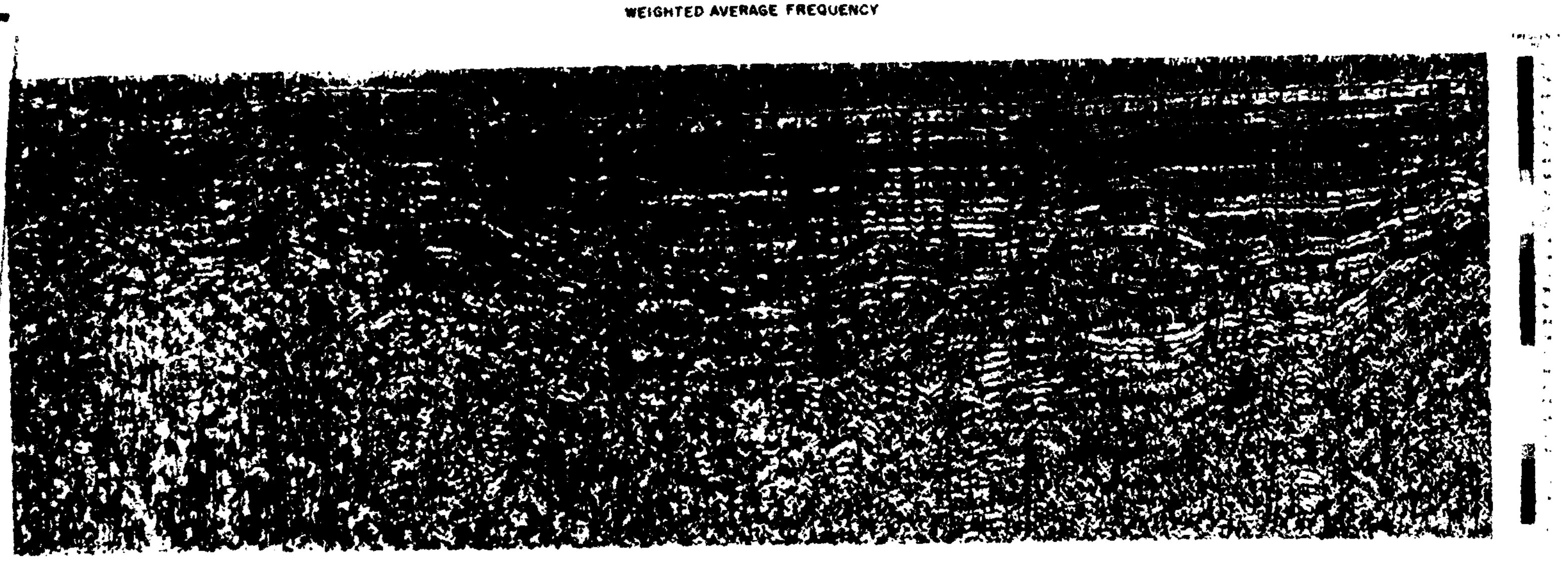


Figure 47. Line 2 color seismic record. Weighted average frequency (processed by Seiscom Delta, Inc.)



INSTANTANEOUS FREQUENCY

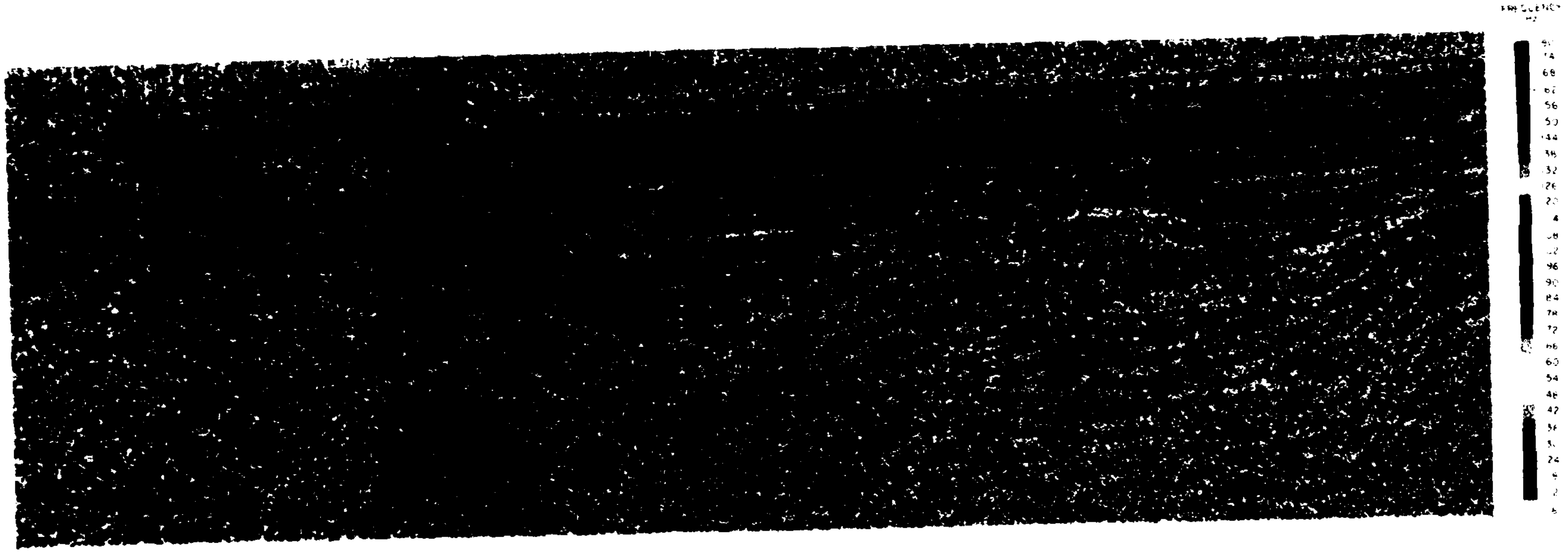


Figure 48. Line 2 color seismic record. Instantaneous frequency (processed by Seiscom Delta, Inc.)

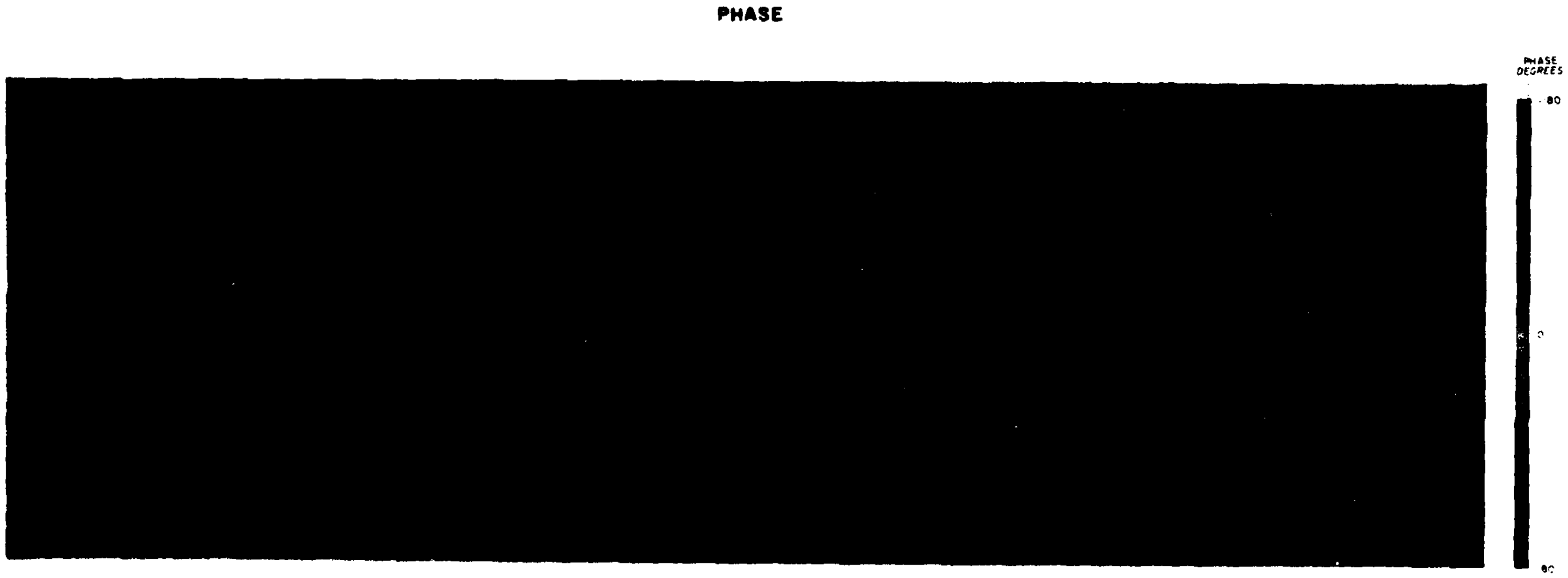


Figure 49. Line 2 color seismic record. Phase (processed by Seiscom Delta, Inc.)

APPARENT POLARITY

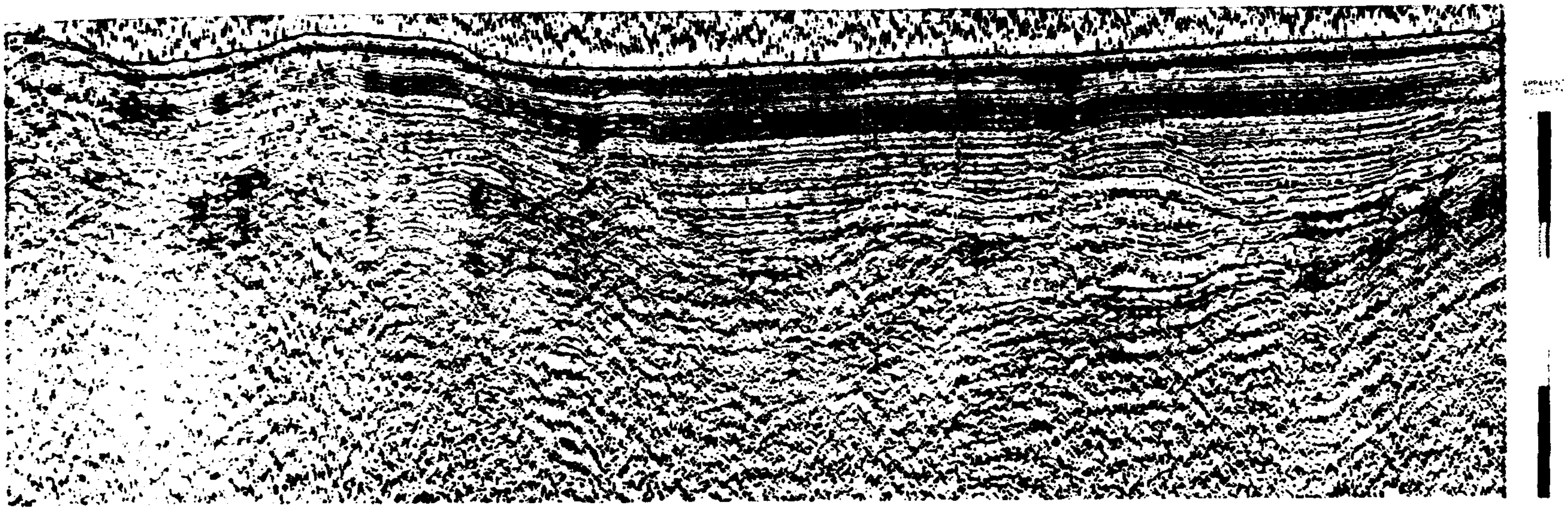


Figure 50. Line 2 color seismic record. Apparent polarity (processed by Seiscom Delta, Inc.)

TABLE 1

SEISMIC DATA ACQUISITION SYSTEM (SDAS) MAXIMUM SAMPLE RATES PER DATA CHANNEL FOR 12 AND 6 BIT RESOLUTION

Dynamic Range 72 DB (12 Bit Resolution)		Dynamic Range 36 DB (6 Bit Resolution)	
Number of Channels Recorded	SDAS Maximum Sample Rate /Channel (Hz)	Number of Channels Recorded	SDAS Maximum Sample Rate/Channel (Hz)
1	10,000	1	20,000
2	5,000	2	10,000
3	2,500	3	6,250
4	2,500	4	5,000
5	2,000	5	4,000
6	1,000	6	2,500
7	1,000	7	2,500
8	1,000	8	2,500
9	1,000	9	2,000
10	1,000	10	2,000
11	500	11	1,000
12	500	12	1,000
13	500	13	1,000
14	500	14	1,000
15	500	15	1,000
16	500	16	1,000

APPENDIX A

Seismic Profiling Data Acquisition Field Procedures

APPENDIX A

SEISMIC PROFILING DATA ACQUISITION FIELD PROCEDURES

I. SOURCE SIGNATURE

A. INTRODUCTION

The processing of seismic data utilizing techniques such as wavelet processing requires a good representation of the proagating source signature. Acquisition of source signatures has been obtained through (a) far field hydrophones measurement (on station/underway), (b) detecting the reflection off a high salinity layer within the water column, (c) near field hydrophone measurement, and (d) detecting strong reflection off a sub-bottom interface. If the system configuration (streamer depth, source depth, source type, source volume, source pressure, and signal conditioning) remains constant, the measured source signature obtained by these techniques can be utilized for other survey locations. Maintaining constant system configuration, data acquisition quality control, cannot be overemphasized.

The approach discussed here is to constantly record nearfield (pressure not in phase with particle velocity) source signature and then software correct these signatures for source and streamer ghosts prior to wavelet processing. The software technique has been successfully utilized by other investigators and is documented in the literature (Watters, 1977: Shugart, 1977). In addition, the near-field phone will allow monitoring the source depth and performance.

Measurements of near/far field pressure source signature must duplicate as close as possible the operating conditions/parameter to be employed during the field survey. Measurements on station of source signatures and the subsequent frequency analysis provides a basic understanding of the source characteristics. The source level, bubble period, and spectra content are a function of source depth, source volume, and source pressure. For a fixed gun volume and with a pressure level maintained between 1800 to 2000 psi the prime factor effecting spectral content is source depth. This was demonstrated by Mero (1974) which showed the variability of source output characteristics as a function of source parameters (volume, pressure and depth).

Kramer (1968) presented a discussion of near field measurements with comparative examples of far and near field pressure source signatures. The prime difference between the two measurements is the near field bubble pulse will be emphasized and the surface reflection will be weak.

Figure A 1 presents a near field idealized source pressure signature and amplitude frequency spectrum for an airgun. Noted on the figure are the time domain characteristics that control the frequency spectrum. Figure A2 is a far field time domain pressure signature and its resulting frequency spectrum (after Mero, 1974). Computations are included which describe the major characteristics of the frequency spectrum. The major high frequency null is controlled by the travel time of the initial pulse to the surface ghost ($F_{null} = \frac{c}{2d}$ Hz where c=sound speed and d=tow depth). The low frequency peak in the spectrum is controlled by the bubble pulse period T. The standard equation to compute T for an airgun is given by:

$$T = \frac{[(Pc)\ (Vc)\ ]^{1/3}}{46.1\ (Po)^{5/6}} \text{ second}$$

where Pc = gun pressure, PSI
Vc = gun volume, in^3
Po = pressure depth of gun, PSI
= 14.7 + (0.434) (d)
d = gun depth, ft.

B. MEASUREMENT PROCEDURE

1. General

The guidelines presented are general in nature and apply to the airgun sound source. The objectives in performing on station source pressure signature far/near field measurements are to:

(a) *determine source levels and spectral content as a function of* variable source parameters thus allowing adjustment of source parameters to control source spectral content,

(b) allow correlation between near field and far field signatures for wavelet processing, and

(c) provide source tow depth calibration data to be used while monitoring near field signatures underway.

These procedures only discuss the field operation and do not address the computer processing software required to analyze the data. Volume II of this Final Report series presents a spectral analyses routine.

The operating parameters, instrumentation, and recording techniques employed during normal survey operations should be duplicated as close as possible for these measurements.

Figure A3 presents an over-the-side configuration depicting placement of the source/hydrophones. The near field phone should be mounted in the position that will be employed during the survey operation. The far field phone should be placed a minimum of 100 meters and preferably 300 meters from the source. It is also recommended that the source be at a distance from the stern equal to that planned for the normal underway survey condition. Distortion in the source signature caused by reflecting from the ship has been observed in the past when the source is near the hull. The use of a small buoy tethered near the source is recommended. Although the buoy will reflect energy, its influence on the source signature will be minimal compared to the ship.

2. Parameters

The source parameters, volume, pressure, and depth, for the on-station measurements should duplicate those planned to be employed during the survey operation. Recommended as minimum parameter variables for each volume gun are the following:

(a) Pressure = 2000 psi (constant)
Source Depth = 1.5, 3.0, 4.5, 6.1, 7.6, & 9.2 m
(5, 10, 15, 20, 25 & 30 ft)

(b) Pressure = 1500 psi (constant)
Source Depth = 1.5, 3.0, 4.5, 6.1, 7.6, & 9.2 m
(5, 10, 15, 20, 25 & 30 ft)

(c) Pressure = planned for operation that can be maintained based on shot repetition rate and capacity of compressor.
Source Depth = 1.5, 3.0, 4.5, 6.1, 7.6, & 9.2 m
(5, 10, 15, 20, 25, & 30 ft)

3. Instrumentation

The instrumentation configuration for the source signature measurements (near field and far field) is presented in Figure A4. This configuration will allow analog and digital (with Seismic Data Acquisition System) recording of the source time domain signature for subsequent computer analysis to extract spectral information.

(a) Near Field Hydrophone - This phone should meet the minimum following specifications:

(1) Peak Pressure (withstand up to) : 230dB/ /μPam

(2) Frequency Range: 10 Hz to 1000 Hz

(3) Frequency response: ±1 dB over frequency range

The Naval Research Laboratory, Underwater Sound Reference Division (NRL/USRD), leases calibrated hydrophones. The model F36 with reduced sensitivity to eliminate saturation with high peak pressures meet the required specification.

(b) Far Field Hydrophone - This phone should meet the basic frequency range and response specified for the far field phone. A pre-amplifier at the phone will generally be necessary. The sensitivity and pre-amplifier gain should be sufficient to allow recording of sound pressure levels as low as 160 dB/ /μpa (210 dB - 20 log 300).

The capability to inject a calibration signal into the pre-amplifier circuit should be provided. The model H56 leased by NRL/USRD will meet the required specification.

(c) Hydrophone Amplifier/Attenuator - These units provide impedence matching and amplification/attenuation required to record the signals. Units with linear phase response and calibration gain should be utilized to assure distortion free data.

(d) Storage Oscilloscope - This unit is used to monitor data to assure no data distortion exists and to adjust gain level compatible with the recording devices. The storage capability is used when calibrating source depth by monitoring bubble period from the near field phone. This procedure will be discussed in more detail later.

(e) Seismic Recorders - One recorder is used to key the sound source at the rate used during normal survey operation (generally every 10 seconds). Although a signal generator at a frequency equal to desired sound source repetition rate could be used to key the source, the seismic recorder is recommended to maintain the standard operational configuration. The second recorder is used in a start-stop mode at the fastest start-stop rate of the recorder to obtain a hardcopy record of the bubble period from the near field phone. An alternate approach is to use a single recorder operating in programed mode. The recorder is operated at a fast sweep rate (say, one second) and programed to key the sound source at the selected shot rate. During the shot sweep cycle, the signal from the near field phone is programed to be recorded.

(g) Analog Recorder System - A good quality instrumentation tape recorder is required. This provides a back-up to the SDAS hardware. A recorder speed and FM record electronics compatible with the bandwidth of the hydrophone should be used. The recommended record electronics is given:

(1) Sound Source Key - Direct

(2) Time Code Generator - Direct

(3) Far Field Hydrophone - FM

(4) Near Field Hydrophone - FM

(f) Digital Recording System (SDAS) - Direct digital recording of the data provides greater dynamic range than analog recording and also provides a tape formated for computer processing. The SDAS hardware is employed for digital recording. For detailed operating procedure of SDAS, see Volume III of this Final Report series. The anti-alias filters are set at the high pass cut-off of the data band of interest. The sample rate should be 5 times the cut-off frequency. The signal level at the data sample frequency should be down 72 dB at the output of the anti-alias filter. Two channels of data are recorded, near and far field hydrophone signals. The SDAS is keyed by the seismic recorder and the Data Record Delay is set at minimum delay. The Data Record Length can be set to 0.5 sec for the far field hydrophone at the 300 m depth level.

4. Data Recording

A recommended log sheet format, Figure A5, is presented which allows recording critical information. SDAS switch annotation and analog recording voice annotation should also be used. Also, space is provided to compute in the field critical spectral information based the time domain source signature measurements.

A series of test shots are fired at the planned survey repetition rate to allow the air compressor to stabilize and to allow adjustment of the amplifiers/attenuators for levels compatible with the recording system.

For each source depth the bubble period from the near field hydrophone is measured and recorded on the log sheet. The storage scope provides the main method of measuring the bubble period. An additional method is provided by scaling the bubble period off the fast sweep rate seismic recorder. The seismic recorder is adjusted to record positive polarity and thresholded to print only the peak signal of the source signature, P and P' on Figure A1. This sesimic recorder technique is an alternate approach with the scope technique providing the more accurate approach.

II. DATA ACQUISITION

A. GENERAL

Seismic data recording allows software processing to enhance data quality. Data acquisition quality control must be maintained to achieve the full potential of the processing software available to the interpreter. Major factors that effect data quality include:

(1) pressure of air gun source

(2) depth of sound source

(3) depth of hydrophone array

(4) constant initiation of sound source firing, T_O

(5) low system self-noise

(6) constant sound source pulse waveform

Variations in pressure on the source, as noted earlier, will vary source level, high-frequency cutoff, and bubble pulse period (Mero, 1974). The pressure on the air gun source should be kept in the range of 1800 to 2000 psi to minimize the effects on record quality.

The depth of the source is a major factor controlling the period of the bubble pulse, and therefore the spectrum of the propagating source wavelet. Constant source depth or knowledge of variations is probably the single most critical factor influencing data quality.

The depth of the hydrophone array and the surface reflection acts as a tuned circuit and when variation in tow depth exists, the frequency spectrum of the received energy varies. If the depth variation is known, the effect on the frequency spectrum can be predicted. With a near-field source signature, and knowledge of source and hydrophone array depth, the effect of sub-bottom structure on varying the propagating wavelet can be determined.

The initiation of each sound source firing, T_0, for the system must remain constant to maintain data resolution. If T_0 varies, for example, the process of vertical stacking records will blur the data from each reflecting surface, resulting in loss of resolution.

Self-noise must be minimized. Causes of self-noise are: (1) tow speed, (2) radio transmission, (3) weather conditions, and (4) 60 Hz power. Limiting tow speed to 7 knots helps reduce tow noise. Radio transmissions during recording should be eliminated, because radio transmissions can be recorded as if they were data. During periods of bad weather, if possible, recording should be stopped. Proper shielding of wires, power and signal, reduces induced 60 Hz noise. Use of proper grounding techniques also helps eliminate noise.

The source signature should be monitored and recorded by employing the near-field hydrophone technique discussed earlier. In addition to providing recorded data necessary for post data processing, and to determine source depth, monitoring the source waveform during the survey operation provides a means to assure proper sound source operation. Variation in the waveform can indicate the need of sound source repair.

B. MEASUREMENT PROCEDURE

1. Establish High Pass Filter Cut-Off Frequency

The following procedure is recommended to establish the high pass filter cut-off frequency while retaining maximum recorded dynamic range. This filter reduces low frequency noise primarily caused by sea state conditions. (NOTE: High-pass filter - filter which passes all frequencies above a low cut-off frequency, F_0.) This procedure establishes a low cut-off frequency at a value where (1) the noise level measured at the output of the filter is at least 48 dB below the signal return off the ocean sediment interface, or (2) the low frequency peak of the source signature (inverse of bubble period) is attenuated by 6 dB. The value of 48 dB was selected for compatability with the dynamic range of most analog recording systems and with the slope characteristics of analog filters. The level of low frequency noise suppression resulting from this procedure is also compatable with digital recording and processing.

(a) Determine that the source and receiver systems are being towed and the source is firing.

(b) Set the filter cut-off frequency (F_0) to zero.

(c) Trigger the source and increase the gain until the maximum voltage of the signal return off the ocean-sediment (do not consider direct source to array arrival) is 6 dB below maximum recorder system input (0.5 volts RMS, 0.71 V peak, for maximum record system input of lv RMS), measured at the output of the filter. Use slightly less gain if an increase of signal strength is anticipated.

(d) Stop triggering the source and observe signal level at the output of filter. Leave air compressor running.

(e) If the signal level is greater than 48 dB below (signal level is less than 2.0 mvRMS, 2.8 mv peak referenced 1 vRMS) the signal established in step (c) use this filter setting for the high-pass filter cut-off frequency and proceed to step (f). Note this signal level and frequency on log sheets. If the signal level is less than 48 dB down (signal level greater than 2.0 mvRMS, 2.8 mv peak referenced 1 vRMS) increase F_0 (cut-off frequency) and return to step (c).

(f) Determine the low-frequency spectral peak of your source. This is established by the bubble period as is equal to $\frac{1}{T}$ where T is the bubble period.

(g) Find a second F_0 of the high pass filter such that at the low-frequency spectral peak of the source signal is 6 dB down (a factor of 0.5). To find F_0, set an oscillator at the low-frequency peak with 0 dB reference level. Increase F_0 until output signal level is 6 dB lower than for $F_0 = 0$

(h) Use the lower F_0 for the high pass filter cut-off frequency of the two values determined (steps (e) and (g)).

2. Recording Noise Records

Noise files are taken periodically to assist in the analysis of seismic data. The recommended procedure for taking noise records is:

(a) Noise records are made at the beginning of each reel.

(b) All sources of noise must be operating.

(1) Air compressor is running

(2) Receive array and sound source systems deployed in survey configuration.

(3) Ship is at tow speed.

(c) Data acquisition system's amplifiers and filters adjusted for seismic data recording.

(d) Stop firing sources for 1 minute and continue recording for at least 1 minute in length. Be sure to record sound source trigger pulses.

Also, a system noise record should be recorded on the start of each new data reel. The acquisition system is adjusted for normal data recording and then the input to the amplifier system (at hydrophone array output) is shorted and the system noise record is recorded. This record should be 10 seconds in duration (also simultaneously record trigger pulse).

3. Recorder Channel Assignments

It is recommended that a set of standard recorder channel assignments be established. The following assignment for analog and digital recording is recommended.

(a) Digital Recording (SDAS)

Channel	Information
1	Seismic data
2	Gain ranging level (for automatic gain ranging amplifier if used)
3	Near field sound source hydrophone
4	Hydrophone array depth

(b) Analog Recording

Channel	Electronics	Information
1	Direct-wideband	Trigger pulse (T_0)
2	Direct-wideband	Time code generator
3	FM-wideband	Seismic data
4	FM-wideband	Near field sound source hydrophone
5	FM-lowband	Hydrophone array depth
6	FM-lowband	Seismic data (optional)
7	FM-wideband	Non-clipping direct sound source to hydrophone array arrival (optional)

4. Data Log Sheet

The log sheet (see Figure A6 - Seismic Data Log) is designed as an aid in processing of data. Log sheets must be accurate and complete! Ship name, cruise number, operator, reel number, tape speed, shot repetition rate and position help identify the data being recorded. Sound source volume for air gun and type of each source should be listed. The depth of the source is obtained from the bubble pulse period by using the source signature bubble pulse period versus source depth calibration data previously obtained. If the actual bubble pulse period varies from the desired, it should be annotated on the log. The source offset distance is measured from the ship tow point to the sound source. The receiver offset distance is measured from the ship tow point to the beginning of the active section of the hydrophone array. Hydrophone array active section length is the length of cable over which the hydrophones are placed (fixed for each array). Also, indicate the number of hydrophones for each channel and the separation between each hydrophone. List the low-cut filter, hi-cut filter and amplifier gain to each channel. Always list the data recorded for each channel and the recorder bandwidth module (low, intermediate, wide) under "Information Recorded on this Channel". Also, the polarity of the recorded signal for positive pressure should be noted on the log sheet.

After this information is annotated in the log, information about the seismic data records is annotated. Remember each time a new reel of tape is started, a new log sheet should be started. The first record of information is always a noise record taken by the method indicated in "Recording Noise Record". The time is referenced on 24 hour GMT clock.

Hydrophone array depth and sound source air pressure are indicated at monitor readings. The counter readings (footage counter on analog recorder and file number on digital recorder) are taken at each log entry. When new reel is mounted, counter should be zeroed at the first trigger pulse recorded. Monitor readings are taken every 10 minutes. Please carefully observe, on the monitoring scope and line scan recorder, the seismic data at each monitor and note on the log sheet any unique characteristic of the data. Do not forget to number pages.

III. REFERENCES

Kramer, F. S. (1968), R. A. Peterson, and W. C. Walter (editors). Seismic Energy Sources 1968 Handbook. Presented at the 38th Annual Meeting of the Society of Exploration Geophysicists. Denver, Colorado. October.

Metro, T. N. (1974), and J. Freitag. Seismic Source Signature Analysis. U. S. Naval Oceanographic Office, Technical Note 6222-5-74, 29 p., (Unpub.)

Shugart, T. R. (1977), and J. D. Matthews. A Marine Seismic Wavelet and Its Component Parts. Presented at the 47th Annual Meeting of the Society of Exploration Geophysicists, Calgary, Alberta, Canada.

Watters, B. G. (1977), R. Harter, and J. C. Hough. Wavelet Control - The Key to High Resolution Sparker Data and Interpretation. Presented at the 9th Annual Offshore Technology Conference, Houston, Texas, Paper OTC 2987.

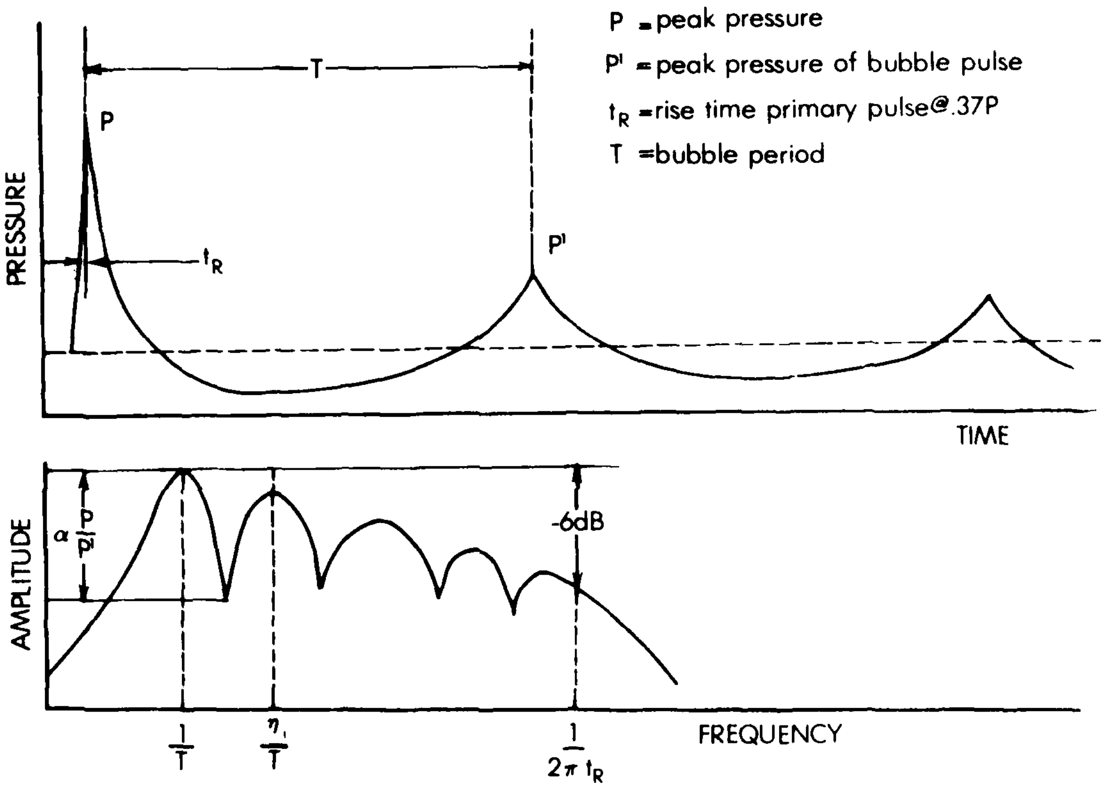


Figure A1. Idealized near field air gun source signature

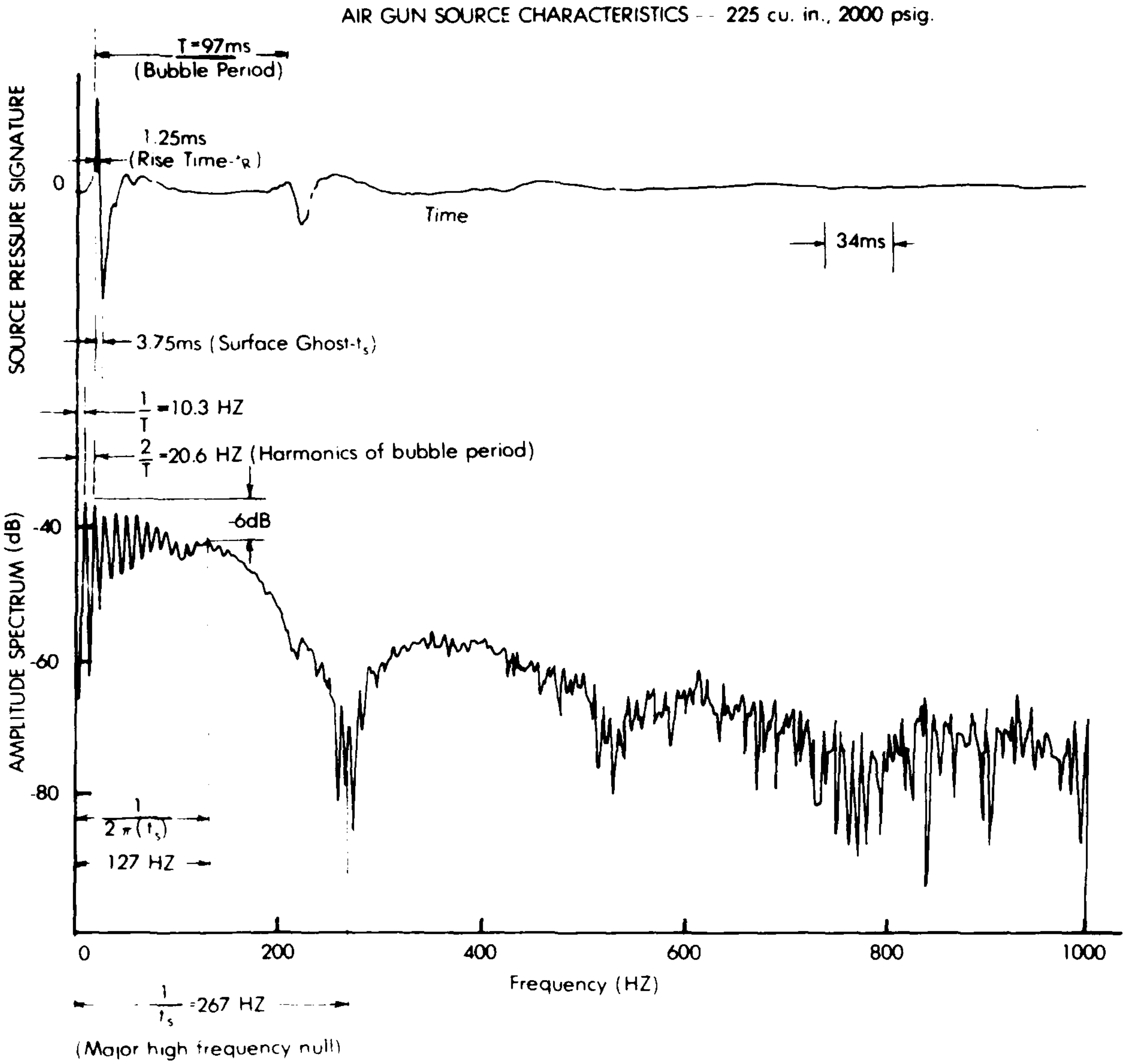


Figure A2. Far field source signature and amplitude spectrum for air gun source

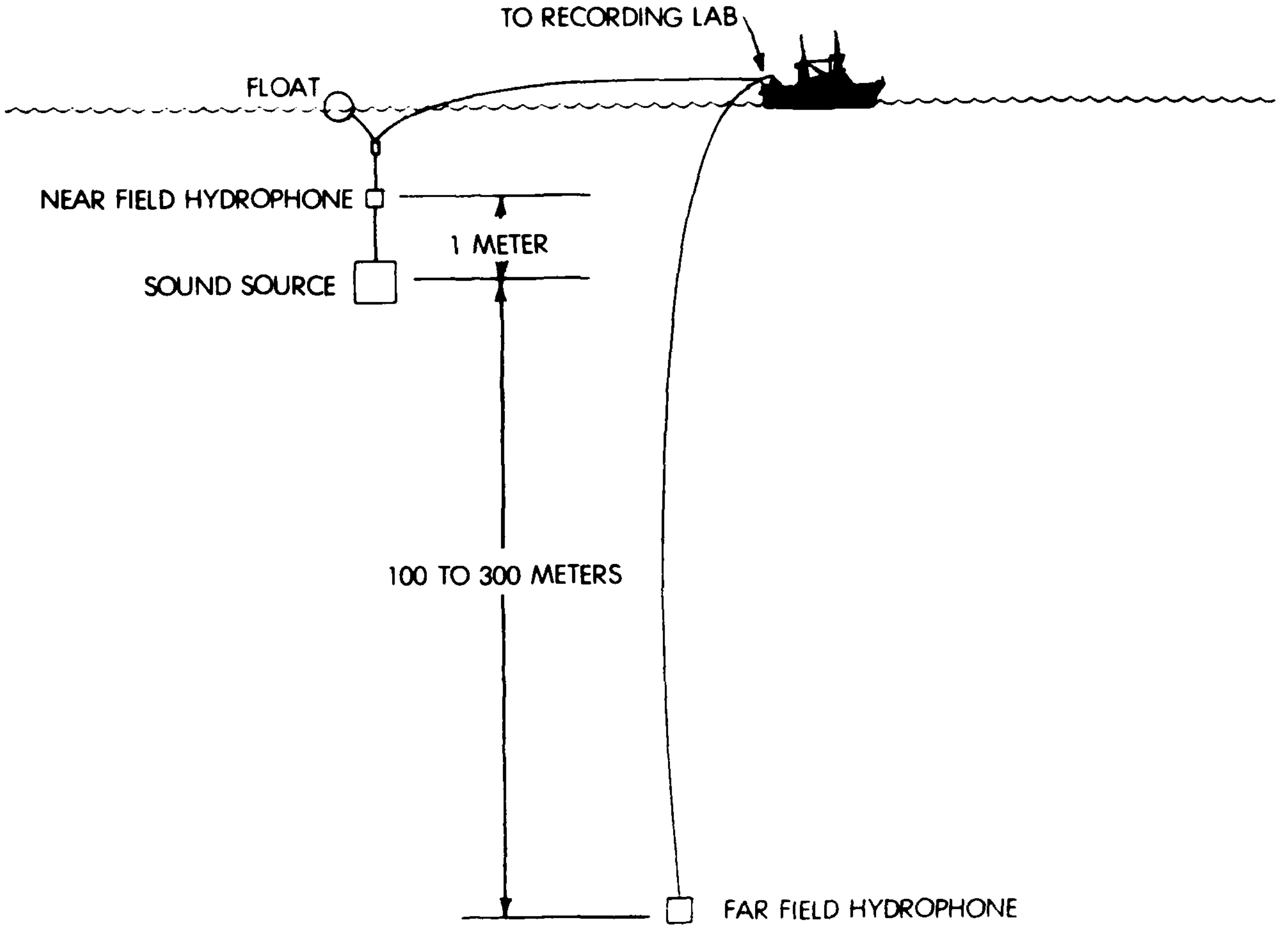


Figure A3. Source signature measurement configuration

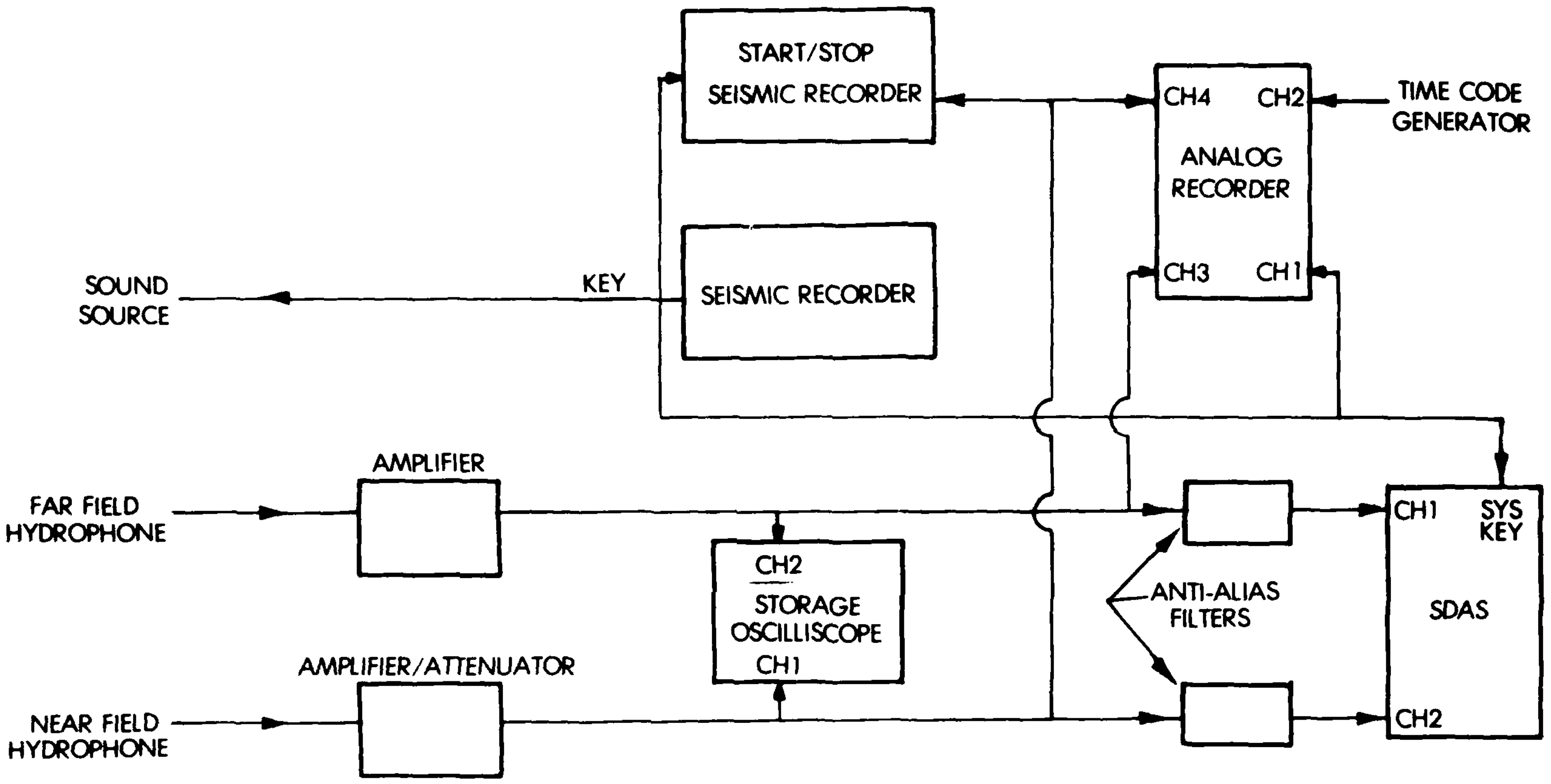
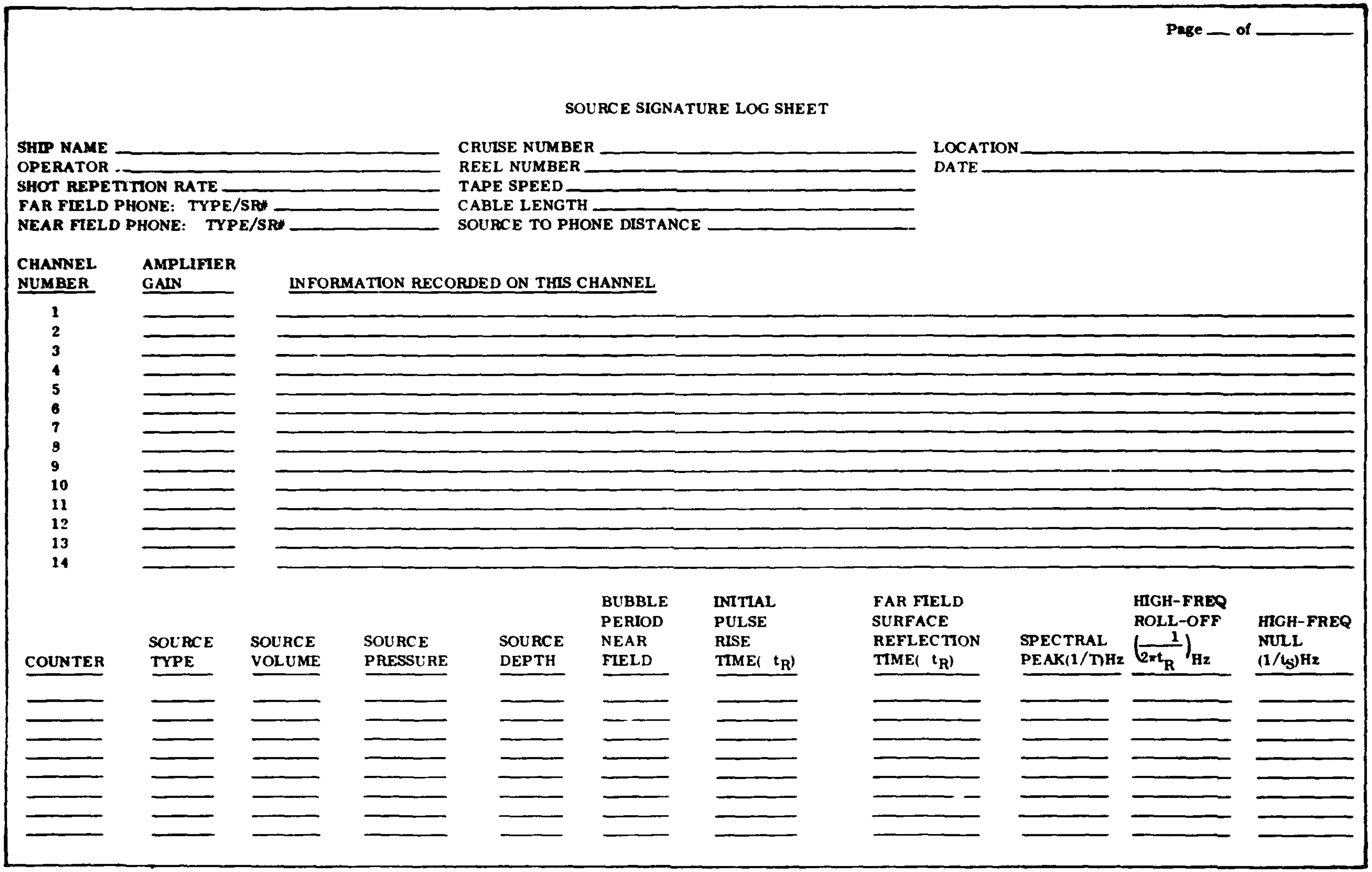


Figure A4. Instrumentation configuration for source signature measurement



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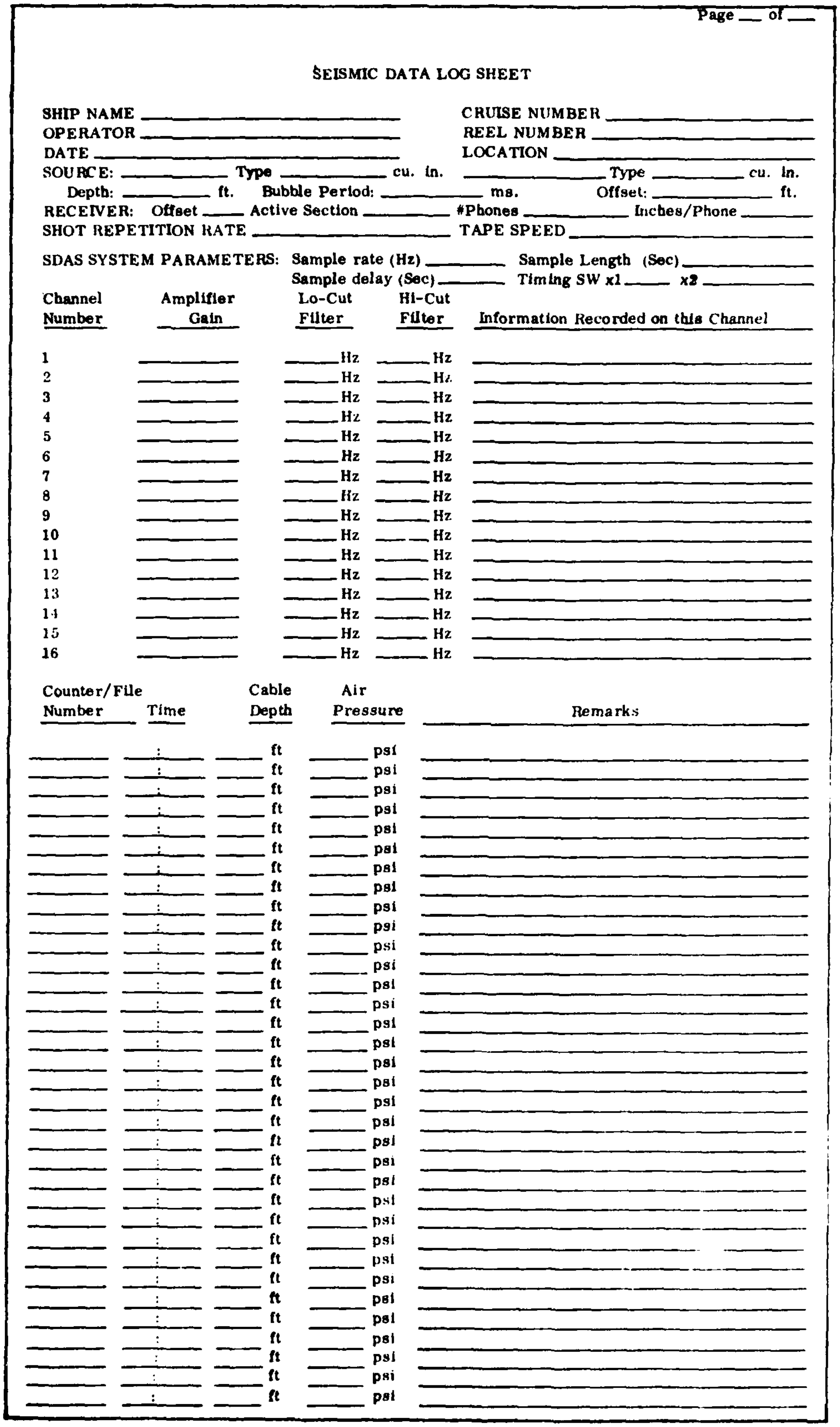
SOURCE SIGNATURE LOG SHEET

SHIP NAME ______ CRUISE NUMBER ______ LOCATION ______
OPERATOR ______ REEL NUMBER ______ DATE ______
SHOT REPETITION RATE ______ TAPE SPEED ______
FAR FIELD PHONE: TYPE/SR# ______ CABLE LENGTH ______
NEAR FIELD PHONE: TYPE/SR# ______ SOURCE TO PHONE DISTANCE ______

CHANNEL NUMBER	AMPLIFIER GAIN	INFORMATION RECORDED ON THIS CHANNEL
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

COUNTER	SOURCE TYPE	SOURCE VOLUME	SOURCE PRESSURE	SOURCE DEPTH	BUBBLE PERIOD NEAR FIELD	INITIAL PULSE RISE TIME(t_R)	FAR FIELD SURFACE REFLECTION TIME(t_R)	SPECTRAL PEAK(1/T)Hz	HIGH-FREQ ROLL-OFF $\left(\frac{1}{2\pi t_R}\right)$Hz	HIGH-FREQ NULL $(1/t_S)$Hz

Figure A5. Source signature log sheet



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SEISMIC DATA LOG SHEET

SHIP NAME ______________________ CRUISE NUMBER ______________________
OPERATOR ______________________ REEL NUMBER ______________________
DATE ______________________ LOCATION ______________________
SOURCE: __________ Type __________ cu. in. __________ Type __________ cu. in.
Depth: __________ ft. Bubble Period: __________ ms. Offset: __________ ft.
RECEIVER: Offset _____ Active Section __________ #Phones __________ Inches/Phone __________
SHOT REPETITION RATE ______________________ TAPE SPEED ______________________

SDAS SYSTEM PARAMETERS: Sample rate (Hz) ________ Sample Length (Sec) ________
Sample delay (Sec) ________ Timing SW x1 ______ x2 ________

Channel Number	Amplifier Gain	Lo-Cut Filter	Hi-Cut Filter	Information Recorded on this Channel
1		Hz	Hz	
2		Hz	Hz	
3		Hz	Hz	
4		Hz	Hz	
5		Hz	Hz	
6		Hz	Hz	
7		Hz	Hz	
8		Hz	Hz	
9		Hz	Hz	
10		Hz	Hz	
11		Hz	Hz	
12		Hz	Hz	
13		Hz	Hz	
14		Hz	Hz	
15		Hz	Hz	
16		Hz	Hz	

Counter/File Number	Time	Cable Depth	Air Pressure	Remarks
	:	ft	psi	
	:	ft	psi	
	:	ft	psi	
	:	ft	psi	
	:	ft	psi	
	:	ft	psi	
	:	ft	psi	
	:	ft	psi	
	:	ft	psi	
	:	ft	psi	
	:	ft	psi	
	:	ft	psi	
	:	ft	psi	
	:	ft	psi	
	:	ft	psi	
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Figure A6. Seismic data log sheet

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18. SUPPLEMENTARY NOTES

This report is Volume I of a three volume series for the final report on Marine Seismic Display Enhancement Program.

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Marine seismic profiling, filtering, Wiener filtering, marine seismic data, airgun source signature, marine seismic data processing, seismic data acquisition, color seismic data

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The quality of marine seismic profiling data governs the geophysicist's ability to interpret the geological character of the ocean sub-bottom structure. This report presents the results of a development program in the areas of data acquisition, processing and display to enhance single channel deep water marine seismic profiling data.

A digital data acquisition system with a multi-channel (16) analog input capability has been developed. The system has a sampling rate up to 10 kHz with 72 dB dynamic range. The digitally recorded data is compatible with either the UNIVAC 1108 or CDC 6600 computer systems.

Basic processing software has been implemented for the UNIVAC 1108 or CDC 6600 computers to enhance data quality through signal-to-noise improvement and increased resolution. The software includes time domain filtering, frequency domain filtering, Wiener filtering, spectral analysis and trace stacking. Wiggle traces can be generated through a CalComp or Zeta software routine.

A display playback system for the processed data with multi-format capability has been developed. The system generates outputs for the conventional line scan recorder, an X-Y plotter and a fiber optic recorder. Display formats include intensity modulated line scan, wiggle traces and variable area half-wave rectified wiggle traces. Playback rates up to 40 times real time acquisition are possible.

Processed and displayed field data acquired over the magnetic "J" anomaly in the Northeastern Atlantic Basin off the coast of Spain is presented. Selected sections of the field data are, also, presented in a color format. The color presentations were generated by Seiscom Delta, Inc., employing their SEIS-CHROME(R) technique.

Recommended field procedures for acquisition of single channel marine seismic profiling data optimized for subsequent data processing are presented.