A DEVELOPMENTAL NEAR-VERTICAL REFLECTION SEISMIC STUDY OF THE UPPER CRUST IN THE CANADIAN SHIELD NEAR KENORA

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ABSTRACT

A developmental near-vertical reflection seismic study has been carried out in the Canadian Shield near Kenora. Numerous shots of approximately twenty pounds each were set off for each of two recording sites. A multi-channel digital processing system was subsequently developed in order to recover late arriving low amplitude signals.

The processing system which best improved the signal-to-noise ratio for late arriving events consisted of vertical stacking of all records from each recording site, followed by velocity filtering of the composite records. Frequency filtering was not found to be useful.

Original records exhibit an event arriving approximately 0.2 seconds after the first breaks. This has been interpreted to be a reflection from an interface at a depth of 1.7 kilometers. This and evidence from many other records in southeastern Manitoba and northwestern Ontario suggest that shallow crustal targets can be mapped.

The processed data exhibits possible deep crustal reflections, although it was not possible to correlate them with known deep crustal horizons. The present study suggests an operational system for the Canadian Shield but

further development is needed before the method becomes operational.

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Also I would like to thank collectively Messrs. Bates, Fansett, and Hildebrand for their help with the field work, and in addition Mr. A. Bates for his aid in digitizing the data.

Shot-to-geophone distances would not have been known accurately if it were not for the generous help of Mr. L. Homeniuk in surveying.

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CHAPTER 1

INTRODUCTION

The present study is the second project to be carried out in a program to develop the near-vertical incidence reflection technique on the Canadian Shield. This work was begun by Hajnal (1970) in 1969 as part of a continuing program run by the Department of Earth Sciences, University of Manitoba, using explosion seismology to determine the structure and constitution of the crust and upper mantle in southeastern Manitoba and northwestern Ontario.

The specific purpose of this study is to develop the field and data processing techniques necessary to the success of the reflection method in the Canadian Shield. The program was not designed for extensive mapping of deep crustal reflectors. Such a program requires an order of magnitude greater financing than was available.

During the past decade considerable evidence has been building up to support the existence of coherent arrivals of energy reflected from interfaces deep within the crust. Steinhart and Meyer (1961) have reviewed results from work done prior to 1961 and have pointed out that events rarely correlate over significant distances. These authors state also that often convenient events were picked to the neglect of other events of similar character. They concluded, therefore, that there was considerable doubt regarding deep crustal reflections at shallow angles of incidence. However, up to that time no study had been designed specifically to record such arrivals. In 1962 Beloussov *et al.* reported on a study designed to allow a continuous correlation of near-vertical incidence reflection events. They reported a number of reflecting horizons in the lower crust and upper mantle but noted that individual phases could not be continuously correlated over more than ten kilometers. Similar results have been reported by the German Research Group for Explosion Seismology (1964). Dix (1965) also conducted an experiment specifically designed to record near-vertical incidence reflections in the United States and has reported many good quality reflections, but has mentioned some difficulties in their interpretation. James and Steinhart (1966) published an updated review of previous work. In this review previously expressed doubts were tempered in light of results obtained between 1961 and 1966 but again they considered that the evidence was not completely convincing. In 1964 the University of Alberta began using the near-vertical incidence reflection technique and preliminary results were reported by Kanasewich and Cumming in 1965.

These results showed promise and further work was carried out by Clowes *et al.* (1968) who reported on a continuous profile run in Alberta. They have reported good reflections from the Intermediate discontinuity as well as the Mohorovicic discontinuity. However, it is sometimes difficult to distinguish these reflections from the numerous other events observed on their records. They are presently carrying out synthetic seismogram studies incorporating all possible multiples in an attempt to explain these other events. Of all the studies conducted up to 1970 Hajnal's (1970) was the only one done in a shield area. His study exhibited reflections from near-surface geologic features and possible arrivals from the Intermediate discontinuity. In summary then, results to date indicate the possibility of near-vertical incidence deep crustal reflections but as yet results are inconclusive. The present study hopes to resolve the difficulties in part.

A question of primary consideration should be: Why carry out a reflection survey in the Canadian Shield when the refraction method has already proven so successful? The reasons are as follows. Firstly, near-vertical incidence reflections can be obtained only from relatively sharp boundaries and therefore the reflection method can be used to test the hypothesis of the layered nature of the crust in this area. This is in contrast to refractions and wide angle reflections which can be obtained from velocity gradients. Secondly, this method can be used to gain a detailed knowledge of the crust which would otherwise be unobtainable. The subsurface area from which a recorded near-vertical reflection is obtained is small enough that in practice it may be considered to be a point. Due to suspected inhomogeneities along the travel path, uncertainty in the calculated location of the reflection point for wide angle reflections or the refraction point for refractions has in many cases made mapping impossible. Effects of such inhomogeneities are minimized for near-vertical reflections because of the shorter travel path. Therefore, by using near-vertical reflections, it is possible to map structure with greater resolution than may be obtained by using wide angle reflections or refractions. Thirdly, this is the best method by which the bottom of greenstone belts, which are of considerable economic importance, can be mapped. In general, rocks of a greenstone belt are more dense and have an equal or higher seismic velocity than surrounding rocks. Therefore, of the possible seismic methods, only the reflection method can be used for mapping. For greenstone belts the structural complexity and the resultant complexity of the ray path make mapping difficult. Again the near-vertical reflection method minimizes these effects. Also, results obtained in petroleum exploration show that mapping can be done by the near vertical method in areas of complex structure. Therefore, the near-vertical reflection method provides the best resolution for mapping.

The location of this study, which is shown in Figure 1, was chosen for the following reasons. Riley (1965) has completed a regional gravity survey of the area around the Kenora airport and has suggested a depth of about 6 kilometers to the bottom of the local greenstone belt. It was hoped that the present study would aid in the corroboration of his interpretation. Secondly, refraction studies have been carried out in this area by Hall and Hajnal (1969) and by Gurbuz (1969, 1970). The interpreted depths to the intermediate discontinuity provide a check to the results of this study. Thirdly, the area provides a known shotpoint and recording sites. The road on which the seismometer spreads were laid out is little used at the time of year the field work was done, therefore, cultural noise is known to be no problem. Shotpoint to recording site distances were determined by a stadia traverse survey along the Jones Road using instrument to rod distances varying between 400 feet and 900 feet. The accuracy of the determined distances is ±2 feet. Lastly, a regional geologic study of the area has been done by Hodgkinson (1968). The contact between fine-grained amphibolites and quartz-diorite rocks crosses the Jones Road at an angle of about 30°, approximately midway between the two recording sites. Dips and gravity

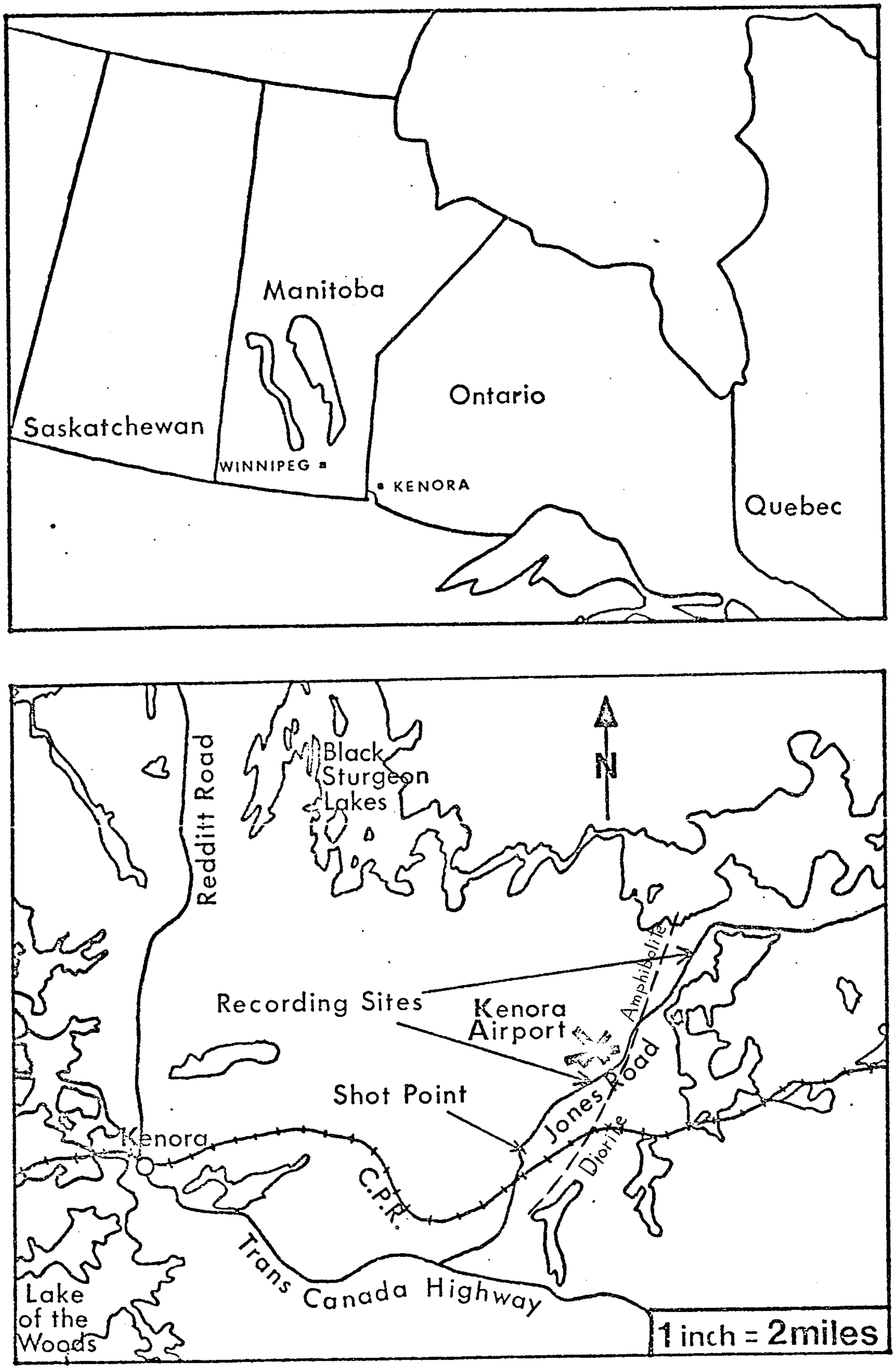

Figure 1. Location map of study area.

results indicate that the contact is nearly vertical, possibly dipping steeply under the dioritic rocks. Glacial drift cover in the area is of the order of ten feet.

CHAPTER 2

ANALYSIS OF DESIGN CRITERIA

As was mentioned in the introduction, the main purpose of this study is to develop the field and data processing techniques necessary to the success of the reflection method in the Canadian Shield. To the best of the author's knowledge all previous work except for that done by Hajnal (1970) was done in areas where there is a sedimentary section overlying Precambrian rocks. Hajnal has suggested that the reflection method is applicable on the Precambrian Shield but that further work was needed. The present study was undertaken to fulfill this need.

The theory of the reflection of an incident P wave which is treated by Grant and West (1965), shows that for small angles of incidence the reflection coefficient is quite small for a solid-solid interface with the expected velocity contrast. Therefore, charge sizes of the order of a few hundred pounds should be required to obtain near-vertical incidence reflections. Also, the method must be made logistically versatile to obtain detailed knowledge of structure in many different areas of interest under varying operational conditions: it should be possible to conduct a survey in any area of the Precambrian Shield without being restricted by surface conditions. The use of shot holes is consistent with the above. In order to set off charges of the required size in a single shot with efficient production of seismic energy a very deep hole is required. The use of small charges in shallow holes was considered, because large shots create long wave trains of high amplitude surface waves that overlap expected arrival times for deep near-vertical crustal reflections, and because of high drilling costs. Consequently, many shots can be made for each recording site and subsequent multi-channel digital filtering should permit recovery of a recognizable signal. The present study was designed to test this method.

However, suitable lakes or rivers should be used whenever possible. O'Brien (1967) has shown that in general, shots fired in water are considerably more efficient for the production of seismic energy than shots fired in boreholes. A water-filled abandoned mine shaft was used in the present study because of its availability and because of cost considerations. Further studies will be required to obtain more direct information regarding the practicability of using boreholes.

The question now arises: How many such small shots are needed to produce a recognizable signal? O'Brien (1967) states with supporting evidence that for shots in water the seismic amplitude is proportional to the two-thirds power of the charge weight and that, therefore, the maximum seismic amplitude will be obtained by splitting the charge into a number of smaller units. These can be shot at one time or successively if stacking can be done.

The result of vertically stacking "r" records to form one composite record and velocity filtering "t" traces from this record to form one trace must now be determined.

First, assume that noise has the same level "η" on all channels and is random Gaussian. For one trace from one record for a shot of charge weight W_i the signal-to-noise ratio is

$$\frac{s}{n} = \frac{k\, W_i^{2/3}}{\eta}$$

where k is a constant of proportionality. Now, consider what happens to the signal-to-noise ratio when "r" records are stacked to form a composite record. Considering one trace from this record the signal has been added in phase and can be written as

$$s = k \sum_{i=1}^{r} W_i^{2/3}$$

The noise has been added with random phase and can be written as

$$n = \sqrt{r}\,\eta$$

Therefore, the signal-to-noise ratio can be written as

$$\frac{s}{n} = \frac{k\sum_{i=1}^{r} W_i^{2/3}}{\sqrt{r}\,\eta}$$

The proof for the signal-to-noise ratio improvement may be found in Appendix 1. Now, velocity filtering t traces to obtain one trace, a signal-to-noise ratio improvement is again obtained. The signal-to-noise ratio of this trace can be written as

$$\frac{S}{N} = \sqrt{t}\,\frac{s}{n} = \sqrt{\frac{t}{r}}\,\frac{k}{\eta}\sum_{i=1}^{r} W_i^{2/3} \qquad 2.1$$

For a large shot of weight W a record of good signal-to-noise ratio for deep crustal reflections can be obtained. The purpose here is to calculate how many small shots will be required to produce a comparable composite trace by means of multichannel digital processing. Assume that the noise level for the large shot is the same as for the small shots. The signal to noise ratio of a trace from the large shot record is

$$\frac{S}{N} = \frac{k\,W^{2/3}}{\eta} \qquad 2.2$$

Because this same signal-to-noise ratio is required for the composite trace equations 2.1 and 2.2 are equated.

$$\frac{k\ W^{2/3}}{\eta} = \sqrt{\frac{t}{r}}\,\frac{k}{\eta}\sum_{i=1}^{r} W_i^{2/3}$$

Thus, the following charge weight relationship is obtained.

$$W^{2/3} = \sqrt{\frac{t}{r}}\sum_{i=1}^{r} W_i^{2/3} \qquad 2.3$$

This equation may now be used in the design process.

As discussed earlier, it was decided to use relatively small charges a number of times for each recording site and to use multichannel digital processing to improve the signal-to-noise ratio. It has now to be decided how many shots to use for each recording site. If a shot of weight W has produced a good reflection record, then a shot of one-tenth this weight should produce enough energy to obtain some reflected energy. Through the use of multichannel digital processing it should be possible to obtain a good signal-to-noise ratio. Hajnal (1970) used a charge weight of 100 lb to obtain a record on which there was a possible intermediate reflection. Velocity stacking six traces into one provided an improved trace but again there was no strong signal. By using equation 2.3 with values of W_i equal to

100, t equal to 6, and r equal to 1, the equivalent charge weight, *W*, for Hajnal's stacked traces is found to be about 380 lb. Therefore, it is apparent that equivalent charge weights of at least 400 lb are required to obtain an intermediate reflection. If charge weights of 10 lb are used to obtain twelve trace records, followed by a vertical stack of r records into one record, and then a velocity stack of the twelve traces into one trace, equation 2.3 indicates that r must be at least eleven. If charge weights of 20 lb are used, then r must be at least five. In the present study charge weights varying from 11.1 to 27.8 lb were used. Nine shots were fired for recording site one, and seven for recording site two.

In addition to calculations based on Hajnal's near-vertical reflection profile, records on which wide angle reflections have been observed may be used to predict required charge weights. Hall and Hajnal (1969) have observed wide-angle reflection events from the Intermediate discontinuity on a number of records. Record 32-5, which is the upper seismogram displayed in Figure 5 of their paper, exhibits good signal-to-noise ratio for this event. This recording was made with a shot weight of 500 lb at a distance of 137 kilometers. From this record a depth, d, to the Intermediate discontinuity of 20.5 kilometers was calculated. Therefore, the total ray path length, $2l$, for the wide-angle reflection is 71.5 kilometers. By taking into account the differences in ray path length, (that is: spherical spreading) and in reflection coefficient, it is possible to predict the charge weight necessary to obtain near-vertical reflections.

Hall and Hajnal (1969) have found the P wave velocity for the upper crust to be 6.05 kilometers/second and for the lower crust 6.85 kilometers/second. These values yield a ratio of 0.88 for upper to lower crustal velocities. By using this ratio value and referring to Grant and West (1965) the approximate reflection coefficients may be found. These are: for the near-vertical incidence reflection 0.1 (r_v) and for a wide angle reflection 0.95 (r_w).

Dobrin (1960) states that the amplitude of a wave varies as the inverse proportion of the distance the wave has travelled. Therefore, taking into consideration only spherical spreading, for a given shot size the ratio of the amplitude of the near-vertical reflection to that of the wide angle reflection is given by

$$\frac{\text{near-vertical amplitude}}{\text{wide angle amplitude}} \quad \frac{2l}{2d} = \frac{l}{d}$$

where $2l$ is the length of the wide angle reflection ray path and d is the depth to the reflector. Now, by taking into consideration the reflection coefficients, a final expression for the amplitude of the near-vertical incidence reflection in terms of the amplitude of the wide angle reflection will be

$$\text{near-vertical amplitude} \simeq \left(\frac{l}{d}\right)\left(\frac{r_v}{r_w}\right)(\text{wide angle amplitude})$$

Substituting the previously mentioned values into this equation yields the following result.

$$\text{near-vertical amplitude} \simeq 0.38 \text{ wide angle amplitude}$$

From this it may be said that the shot weight must be increased in such a manner that the amplitudes would be increased by a factor of $1 \div 0.38 \simeq 2.6$ in order to obtain a good reflection record at the near recording site. This assumes that the noise conditions are the same.

It has previously been stated that for water shots the amplitude of seismic waves is proportional to the two-thirds power of the charge weight. Now, because it is required to obtain the same amplitude for vertical reflections as has been obtained for wide angle reflections the following relation holds.

$$(\text{required charge weight})^{2/3} \simeq 2.6(\text{wide angle charge weight})^{2/3}$$

Therefore

required charge weight ≃ 4(wide angle charge weight)

This result indicates that a charge weight of the order of 4 x 500 ≃ 2,000 lb is required to obtain near-vertical reflections on a recording which has been made from only one shot and with single geophones. This also indicates that charge equivalent for a stacked trace must be of the same order of magnitude.

The charge weights used in this study were designed according to the calculations based on Hajnal's near-vertical reflection profile and were not equal to weights computed by the above analysis. The above analysis, based on wide angle reflection records, indicates that the original calculations may have underestimated the required charge weight. However, a study of Hajnal's records indicates that the maximum charge weight he used is approaching the required charge weight. Therefore, it is quite possible that the true required charge weight is somewhere between the two estimates of 400 pounds and 2,000 pounds. The results of this study hope to clarify this point.

CHAPTER 3

DATA ACQUISITION

3.1 Instrumentation

The recording equipment consists basically of the Texas Instruments Incorporated VLF-2 refraction system, which, as used by the University of Manitoba Department of Earth Sciences, records twelve seismic channels. Figure 2 shows the frequency response of the system. The recording units have twenty-five galvanometers, twelve for high level gain, twelve for low level gain and one for time information. A more detailed description may be found in Hajnal (1970). In the present study this system was modified to record a shot time tone on galvanometer twenty-four and not to use galvanometer twenty-five. The 500 Hz time tone, which was transmitted to the recording unit by radio, was cut off electrically at the shot instant to provide a timing reference.

One limitation of this configuration is that radio reception must be quite good in order to obtain a good quality time break on the recording. Also it was found that camera-generated electrical noise made the time break almost unrecognizable and therefore most of the recordings

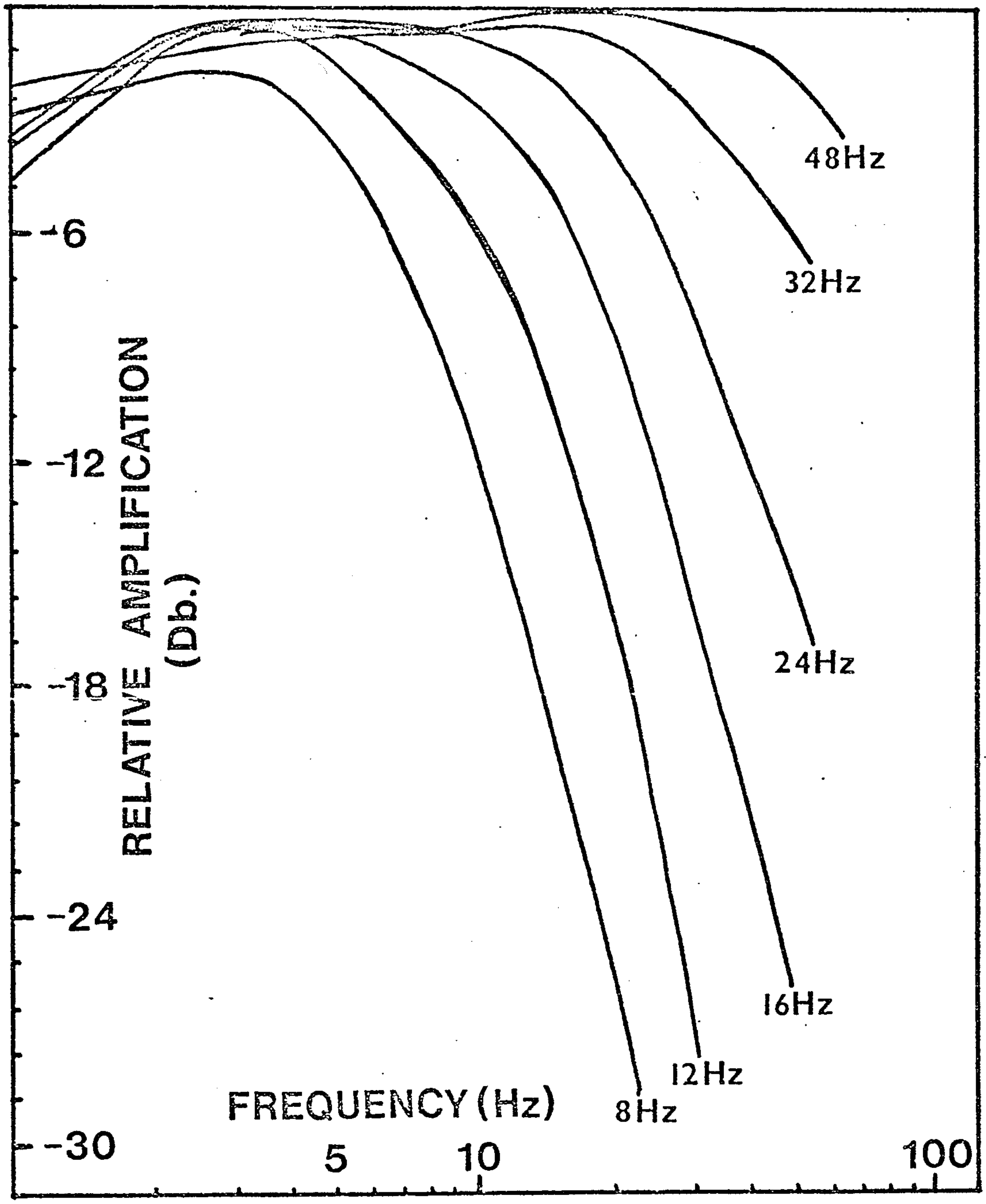

Figure 2. VLF-2 frequency response.

were done with the camera off. This necessitated playing back to obtain photographic records. The problem might be solved by having a filter installed in the time tone recording system. However, it would be even more useful to incorporate a high amplitude spike time break into one of the active seismic channels for reasons which will be apparent later.

All twelve seismometers were vertically-sensing L-1B type with a natural frequency of 8 Hz. The response curves are shown in Figure 3.

3.2 Field Procedure

The recording truck was parked at the side of the road and two cables run out, one in each direction along the road from the truck. Takeouts on the cables were 220 feet (67.1 meters) apart except for numbers 6 and 7 which were 210 feet (64 meters) on either side of the truck. Figure 4 shows the configuration. The geophones, which were connected one to each takeout, were planted solidly in the gravel at the side of the road. They were partly covered and packed to provide good coupling as well as to decrease wind noise. All takeout connections were elevated to minimize leakage. After the cable and geophones were laid out a noise test record was run to see if the system was functioning correctly. Then, radio contact was established with the shot-point crew and a time set for a shot to be

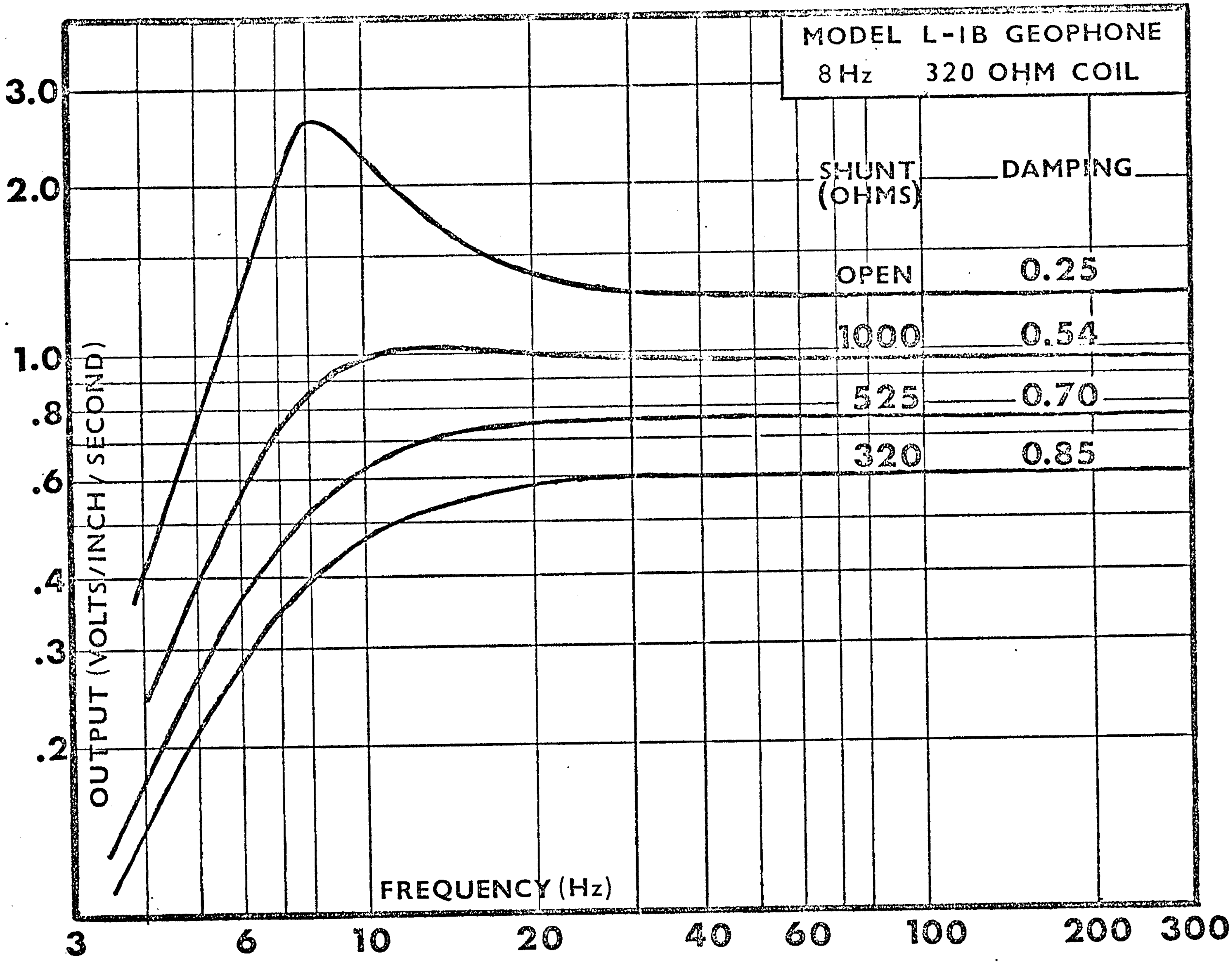

Figure 3. Geophone frequency response.

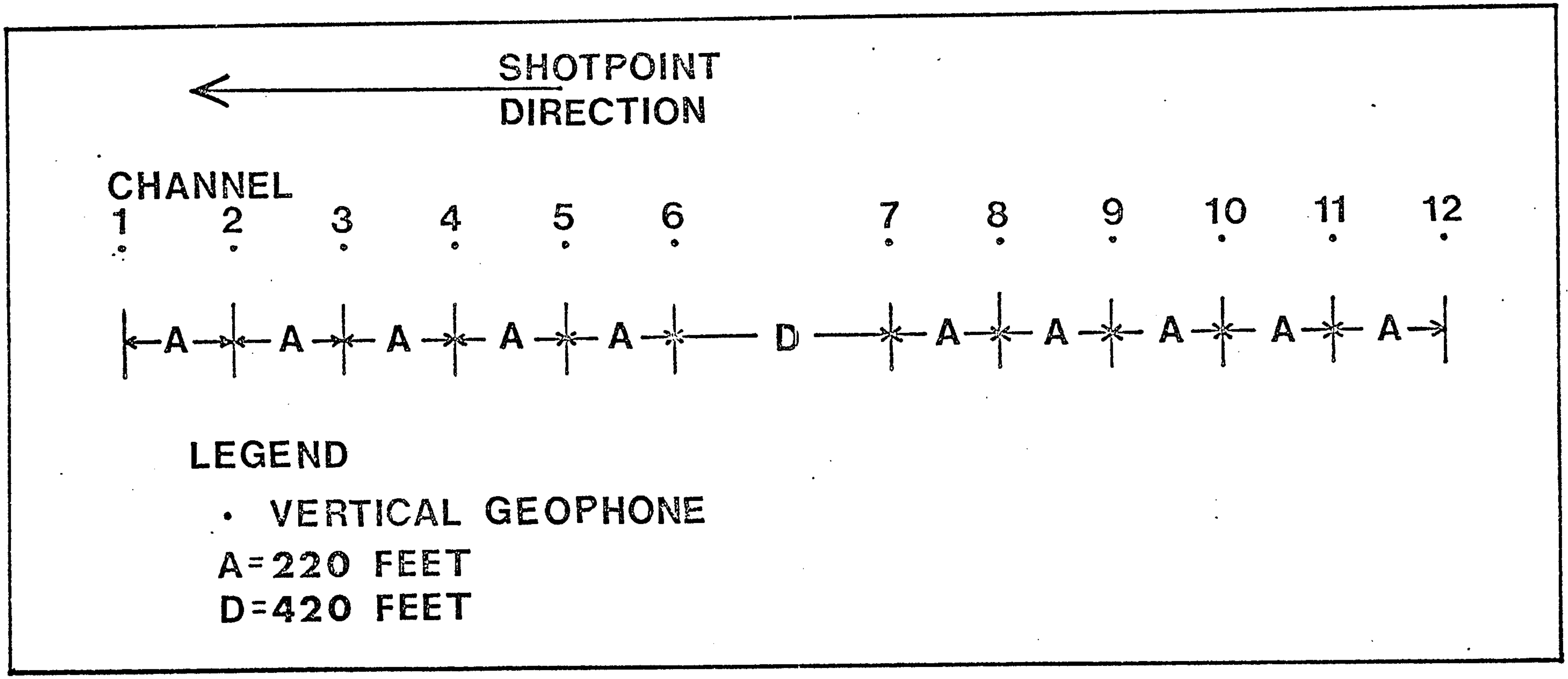

Figure 4. Recording site geometry.

fired. Recording commenced about 10 seconds before shot time and continued for about 30 seconds. As was mentioned previously, the camera was not running during the recording and therefore immediately after recording, a playback was run to check the recording system and to provide records with which to do a preliminary interpretation.

The field work, which was done in late May, took three working days to complete. On the first day of recording, recording site one, farthest from the shotpoint was occupied and three records obtained. The distance from the shotpoint to the truck was 5.39 kilometers. The same recording site was occupied on the second day and six records were obtained. On the last day the closer site (site number two, 1.95 kilometers from the shotpoint) was occupied and seven recordings were made.

All of the shots were fired in an abandoned mine shaft which was 12 feet by 8 feet in plan view and about 50 feet deep. The shaft was filled with about 30 feet of water. The charges, which varied from 11 pounds to 28 pounds, were lowered into the shaft by a rope and were suspended about one foot from the bottom. As an explosive agent, 60% Forcite was used because of its high velocity and ability to be detonated under water. Having tested the cap resistance, the shotpoint crew waited for communication from the recording site. About 30 seconds

Table 1

Shot Point and Recording Site Information

Recording Station	Shot Number	Charge Weight (lb)
1	1	16.6
1	2	16.6
1	3	16.6
1	4	16.6
1	5	22.3
1	6	11.1
1	7	11.1
1	8	11.1
1	9	27.8

Instrument Settings For All Recordings at Site One

Channel	1	2	3	4	5	6	7	8	9	10	11	12
Attenuation	36	36	36	36	36	36	30	30	30	36	30	30
High Cut Frequency	48	48	48	48	48	48	48	48	48	48	48	48

Table 1. (Continued)

Recording Station	Shot Number	Charge Weight (lb)	Attenuation (All channels)	H.C.F.
2	1	16.6	36	48
2	2	16.6	36	48
2	3	16.6	36	48
2	4	16.6	42	48
2	5	11.1	36	48
2	6	11.1	42	48
2	7	11.1	42	48

before shot time the time tone was started. Table 1 lists the pertinent field data.

CHAPTER 4

PREPARATION OF DATA

4.1 Analog to Digital Conversion

Analog to digital conversion was accomplished with the use of a Radiation Corporation analog to digital converter which will accept up to sixteen analog channels. The output from this equipment is a seven track IBM compatable tape. However, this tape is not FORTRAN readable and therefore an existing COBOL program was used to convert the data format and translate it onto a mine track FORTRAN readable tape. The equipment and procedure is given in detail by Hajnal (1970).

For the purpose of this work only the twelve seismic channels were digitized using a digitizing interval of 0.002448 seconds. The time tone channel was not digitized because the existing programs were written to handle twelve channels and it was decided that the modification of the programs to handle thirteen channels would be too time consuming. Also, it was decided that timing could be accomplished with sufficient accuracy by plotting the digitized data and comparing them to the analog records. Plotting of the raw data also provided a check on the digitizing.

4.2 Digital Processing

4.21 General Discussion

Without the capability of multichannel digital processing techniques the practical use of near-vertical reflection seismology would not be feasible. The methods used in this study were frequency filtering, velocity filtering and vertical stacking. Both Clowes (1968) and Hajnal (1970) have used bandpass filtering and velocity filtering to achieve a marked improvement in record quality and signal-to-noise ratio. The author has applied both of these techniques by using a development of programs written by Hajnal, one of which was modified by Bates, Homeniuk and the author at the University of Manitoba. In addition the author has written a program to effect vertical stacking of traces.

The purpose of digital processing of seismic data is to enhance the signal with respect to the noise. In order to decide what kind of processing to do, it is necessary to define what constitutes signal and what constitutes noise. A good discussion on the noise component of a seismogram has been written by Olhovich (1964). For the purpose of this study, signal is defined as reflections and noise is anything else including Rayleigh waves, direct S waves, reflection multiples, random noise, and signal generated noise. Direct P waves may also be considered noise when shallow reflections are considered as signal.

4.22 Frequency Filtering

Frequency filters are useful only when signal and noise are separated on the frequency spectrum. The expected frequency for deep reflections is in the range from 12 to 25 Hz (Dix, 1965) and the measured dominant frequency of a shallow reflection is about 30 Hz. Only electronic noise, wind noise, 60 Hz pickup and the low frequency components of Rayleigh waves differ significantly in frequency from the signal and these may be attenuated with a frequency filter before further processing. It was decided that a 10 to 45 Hz passband would best improve the record quality. Figure 5(a) and (b) give a comparison of record 1-1 raw and filtered. On the filtered record there has been good attenuation of high frequency noise but the Rayleigh waves are still present. Displayed in Figure 5(c) is record 1-1 filtered with a 20 to 30 Hz passband. This filtering provides a very ringy appearing record which is often the case when such a narrow passband is used.

4.23 Velocity Filtering

Velocity filtering makes use of the differential moveout of events on a record. It is useful for enhancing signal and attenuating coherent noise with a

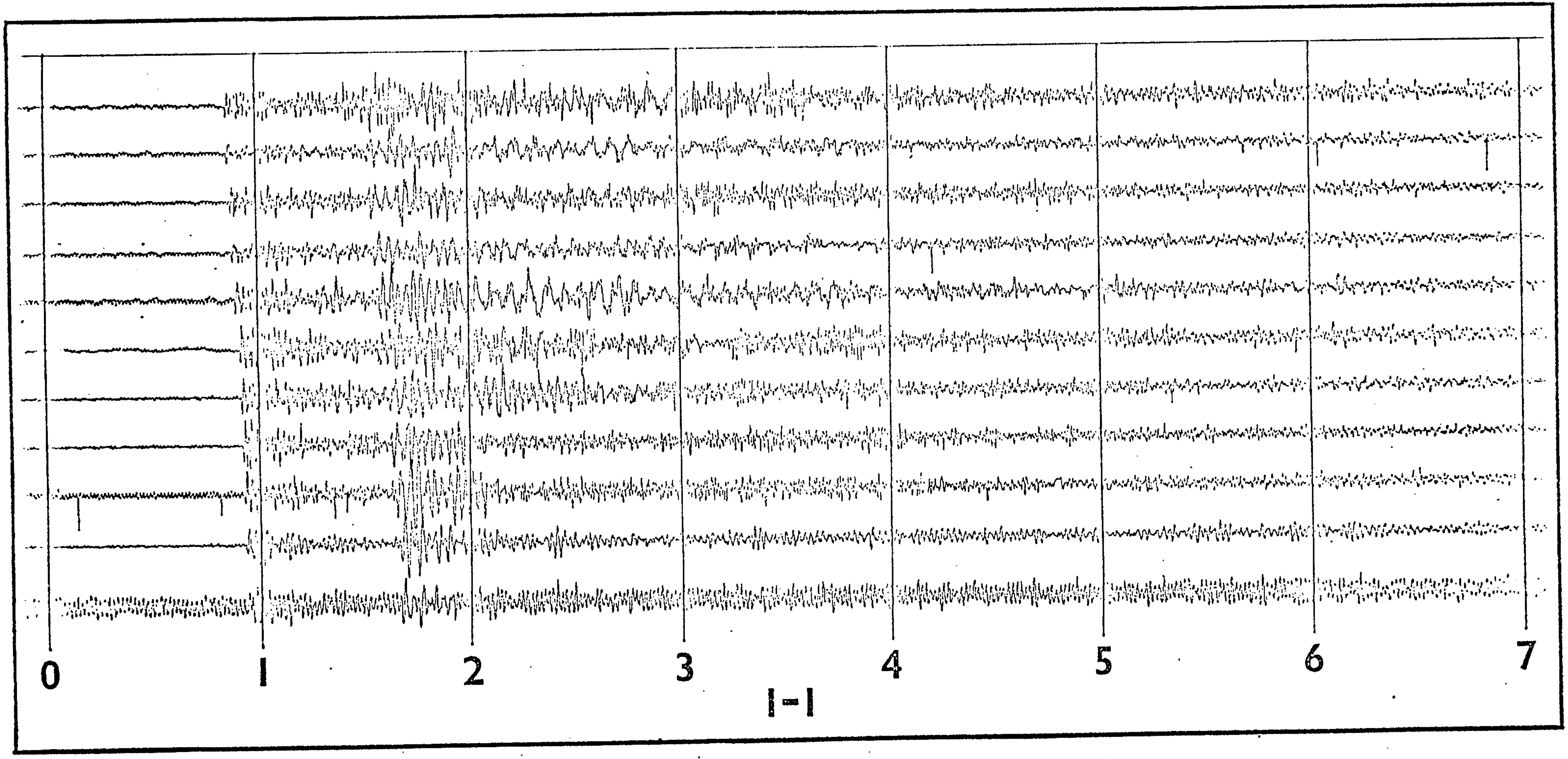

Figure 5(a) Original record 1-1.

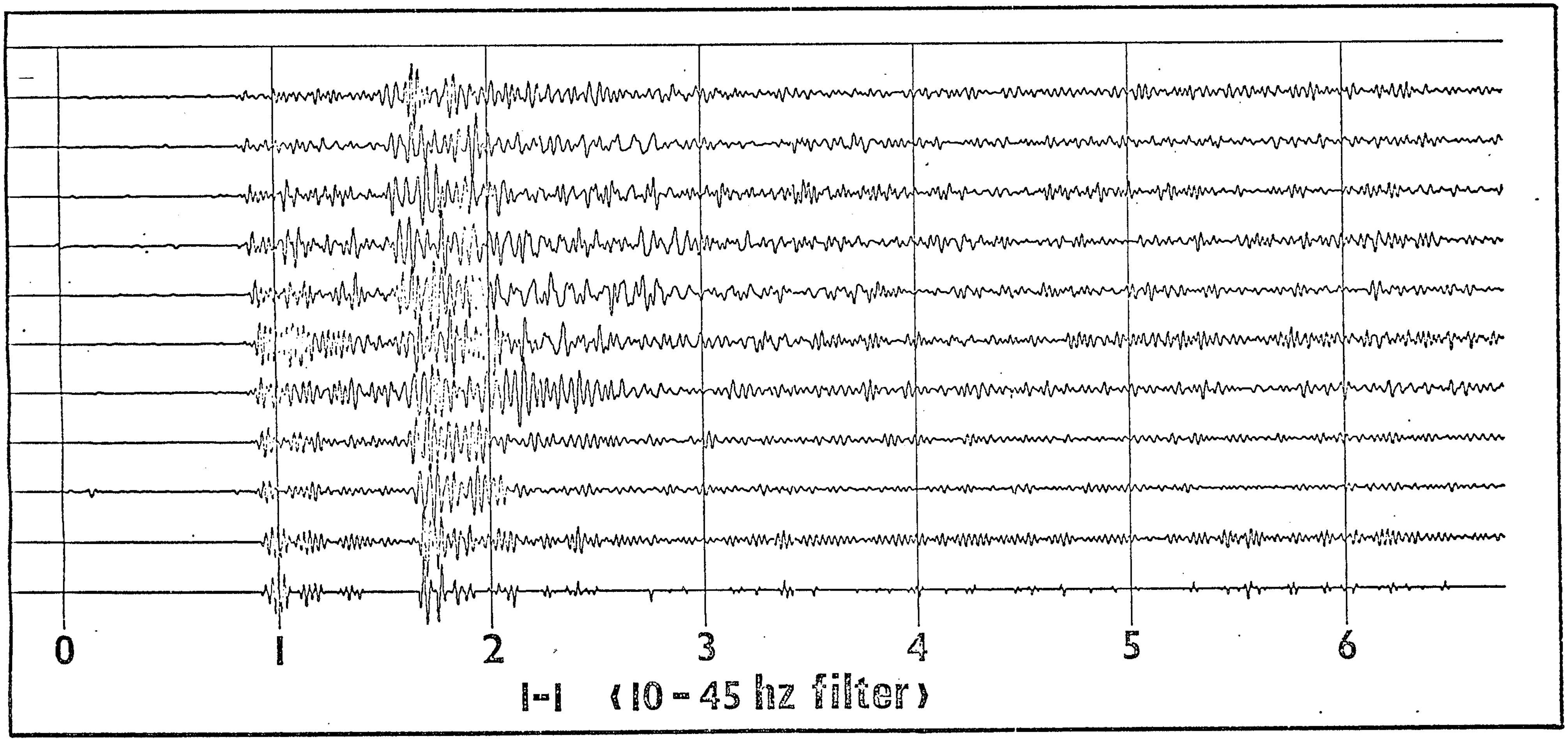

Figure 5(b) 10-45 Hz filtered version of 1-1.

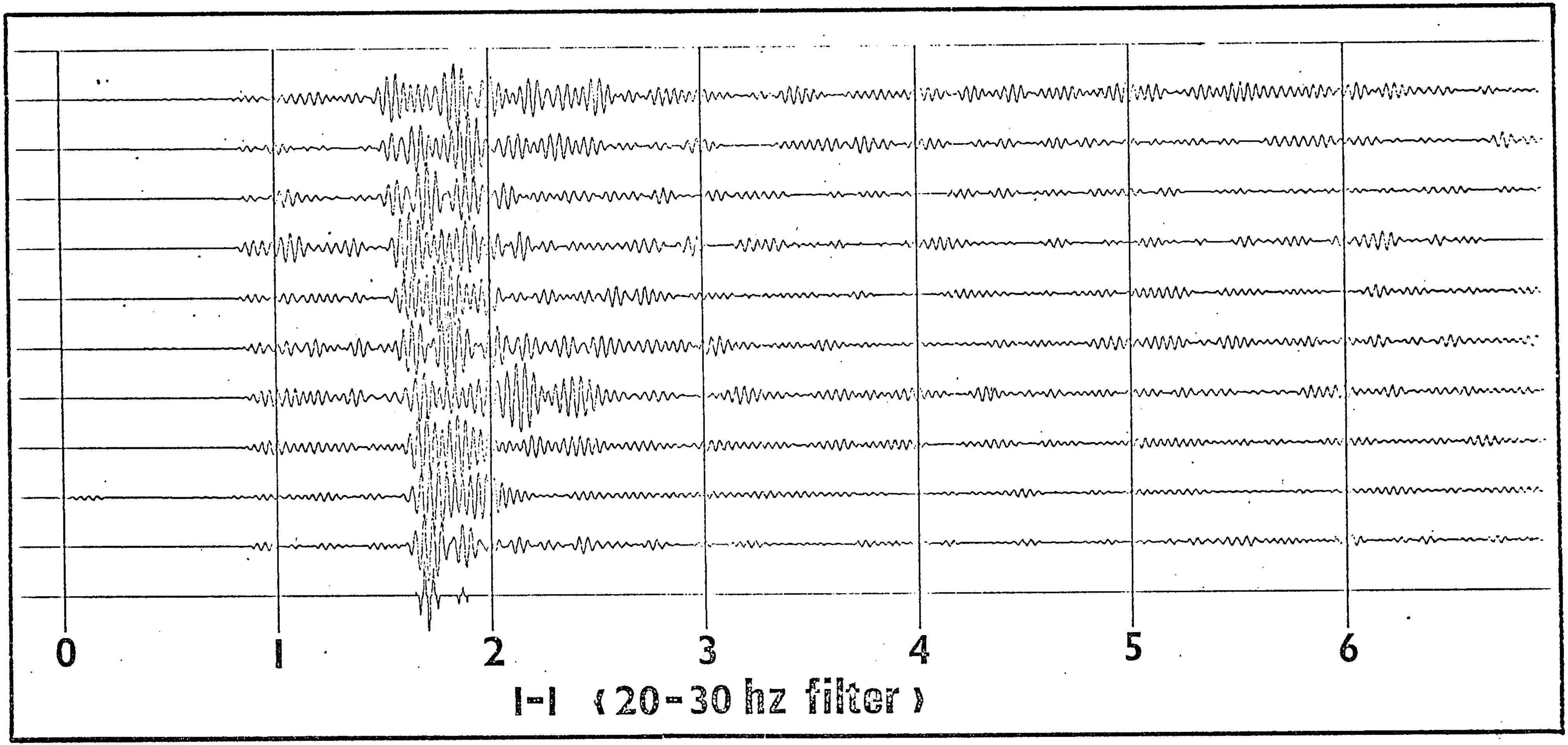

Figure 5(c) 20-30 Hz filtered version of 1-1.

moveout that is significantly different from the event of interest. The program used was written by Hajnal (1970) and modified by Bates, Homeniuk and the author. The program sums the specified traces of one record with a specified time lag between successive traces, the lags being defined by the moveout for the event of interest. It can be seen that the signal will be added in phase and therefore enhanced, and the incoherent noise and coherent noise with significantly different moveout will be added out of phase and therefore attenuated. This technique is used in this study predominantly to attenuate surface waves although it is useful for the attenuation of incoherent noise. In future it would be useful to employ seismometer arrays to discriminate against surface waves.

4.24 Vertical Stacking

In the present study numerous shots were fired into each spread with the intention of stacking output records. This form of stacking will attenuate only random noise. If for one spread and shot location "r" records of "t" traces each are obtained, then vertical stacking will produce one composite record of "t" traces. The signal-to-noise ratio of one trace of the stacked record will be approximately $\sqrt{r}$ times the signal-to-noise ratio of an average trace of one of the original records as is shown theoretically in Appendix 1. The program which was written by the author is designed to stack all trace ones of the original records into one output trace, then all trace twos and so on for all twelve traces. A listing of the programs VERTS is to be found in Appendix 2.

The major difficulty to overcome in this procedure involves the alignment of the records. At present this is done manually by providing alignment timing information to the program as input parameters. The difficulty could be solved by having a high amplitude spike recorded on an active seismic trace to indicate the shot instant. This would provide a timing reference for each record that the program could search for and the records would then be aligned automatically by the program. Of more value might be a header label for each record which would give timing information and other pertinent recording and geometry information in addition to the record number. Such a system would necessitate writing one new program and revising all the existing ones, but it would simplify processing.

4.25 Discussion

In the preceeding sections we have considered three possible processing techniques and it is now necessary to evaluate the usefulness of these techniques. The value of vertical stacking has already been discussed in Chapter 2.

If such processing alone provides good quality reflection events, then the need for further processing would be precluded. Otherwise, further processing must be carried out. Because of the problem posed by surface waves and other coherent noise, velocity filtering immediately suggests itself as the processing technique to use. Some question now arises regarding the usefulness of frequency filtering. Apparently only high frequency noise can be removed from the records using this technique. In general all high frequency noise on the records is random noise although there is some 60 Hz pickup. The stacking techniques quite effectively attenuate random noise and therefore only 60 Hz noise need be frequency filtered from the records whenever it poses a problem. Bearing in mind cost in addition to these considerations, it is better not to use frequency filtering as a production processing technique except where it is deemed necessary. For these reasons vertical stacking and velocity filtering were the predominant processing techniques applied. Further results will indicate the validity of this decision.

CHAPTER 5

INTERPRETATION

5.1 Velocity Determination

Crustal velocities in southeastern Manitoba and part of northwestern Ontario have been determined by Hall and Hajnal (1960) and by Gurbuz (1960). The velocity range for compressional waves in the upper crust is from 5.8 to 6.2 kilometers/second and for shear waves it is about 3.5 kilometers/second.

In the present study upper crustal compressional and shear wave velocities were determined from direct wave arrivals for which the arrival times are listed in Table 2 and plotted in Figure 6. A linear least squares fit was applied to both Pg and Sg arrival times. For the compressional wave the slope is 0.1653 with a standard deviation of 0.0011 which corresponds to a velocity of 6.05±0.04 kilometers/second. The intercept of the best fit line is 0.0058 seconds which is within the error involved. This indicates that the glacial drift cover is negligible. For the shear wave the slope is 0.2859 with a standard deviation of 0.0011 which corresponds to a velocity of 3.50 ±0.02 kilometers/second. The intercept is 0.058

Table 2

Time-Distance Information

Distance (km)	Pg (sec)	Shallow Reflection	Sg (sec)	GR (sec)
1.58	0.251		0.495	0.618
1.64	0.272		0.522	0.656
1.71	0.292		0.544	0.678
1.76	0.292		0.558	0.690
1.83	0.305		0.579	0.717
1.89	0.310		0.598	0.738
2.01	0.338		0.637	0.776
2.07	0.355		0.659	0.799
2.14	0.365		0.676	0.807
2.20	0.375		0.696	0.854
2.27	0.375		0.707	
2.33	0.410			0.913
4.98	0.835	1.011	1.483	1.866
5.05	0.853	1.019	1.511	1.911
5.12	0.855	1.024	1.530	1.940
5.19	0.872	1.045	1.554	1.967
5.25	0.879	1.050	1.570	1.981
5.32	0.890	1.060	1.587	2.006
5.45	0.910	1.073	1.620	2.034
5.52	0.912	1.074	1.628	2.072
5.58	0.921	1.072	1.644	2.081
5.65	0.924	1.082	1.656	2.088
5.71	0.933	1.090	1.675	2.120
5.78	poor	trace		

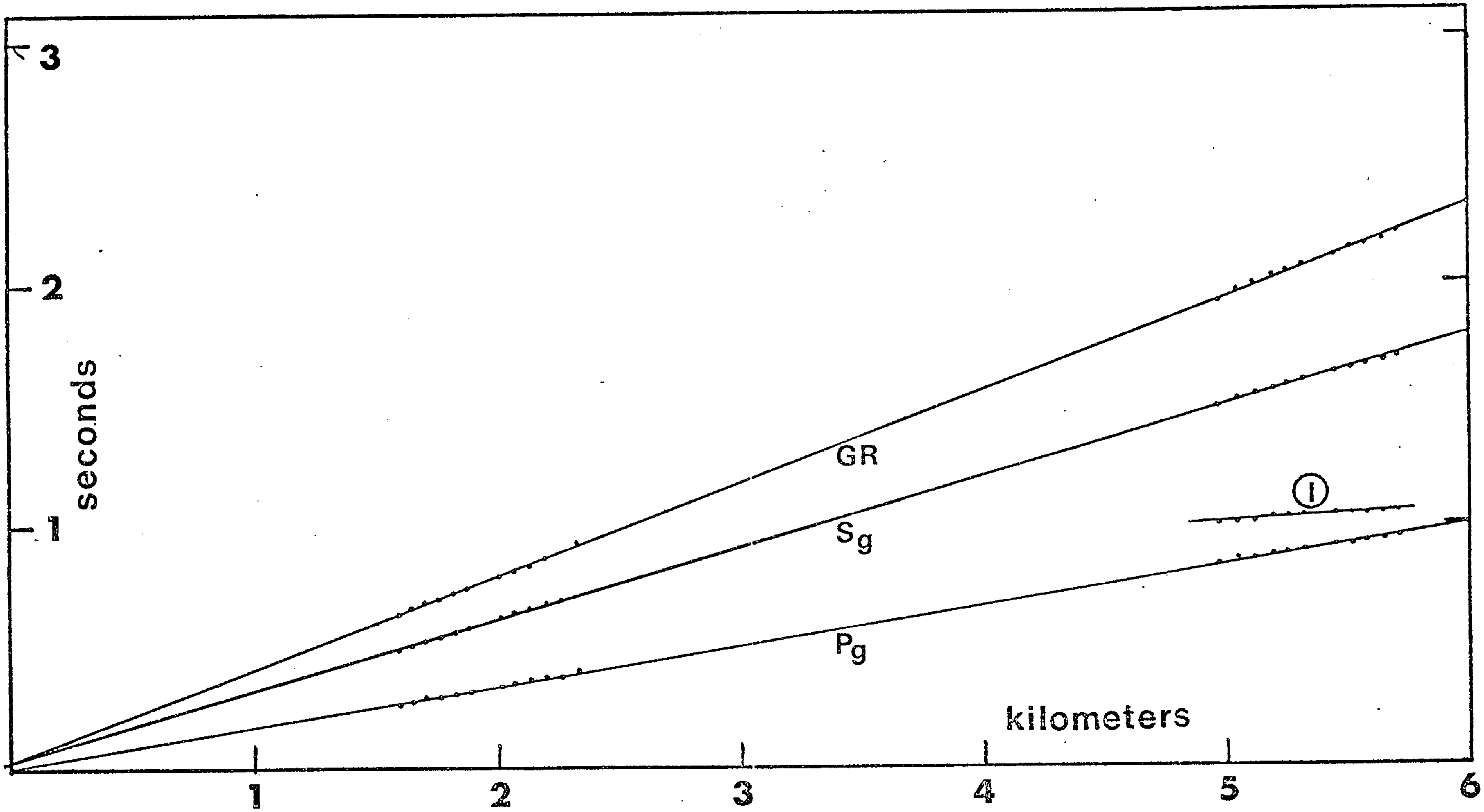

Figure 6. Time-distance graph of arrivals.

seconds, part of which may be accounted for by the fact that the first trough was picked rather than the first arrival of direct shear wave energy.

5.2 Shallow Reflection

An event has been noted on the records from recording site one with an arrival time approximately 0.2 seconds after the first breaks. The arrival times, which are listed in Table 2 and plotted in Figure 6, were taken from record 1-9 and the event is marked with an arrow in Figure 8(h). This event has been interpreted as being a reflection from an interface at a depth of about 1.7 kilometers. The straight line segment which best fits the arrival times for this event is $T = 0.105X + 0.4928$ with a standard deviation for the slope of 0.0082. Using this fitted line for mean arrival times a depth to the reflecting interface of 1.7 kilometers was calculated assuming plane horizontal layering. Using a depth of 1.7 kilometers and subject to the previous assumptions it was found that predicted arrival times for distances ranging from 1.58 to 2.33 kilometers fell between the observed Sg arrivals and surface wave arrivals. This would explain why this event is not visible on the records from recording site two.

A comparison was made with records obtained in past years to test this interpretation. One record, displayed in Figure 7, from a recording site about 15 kilometers

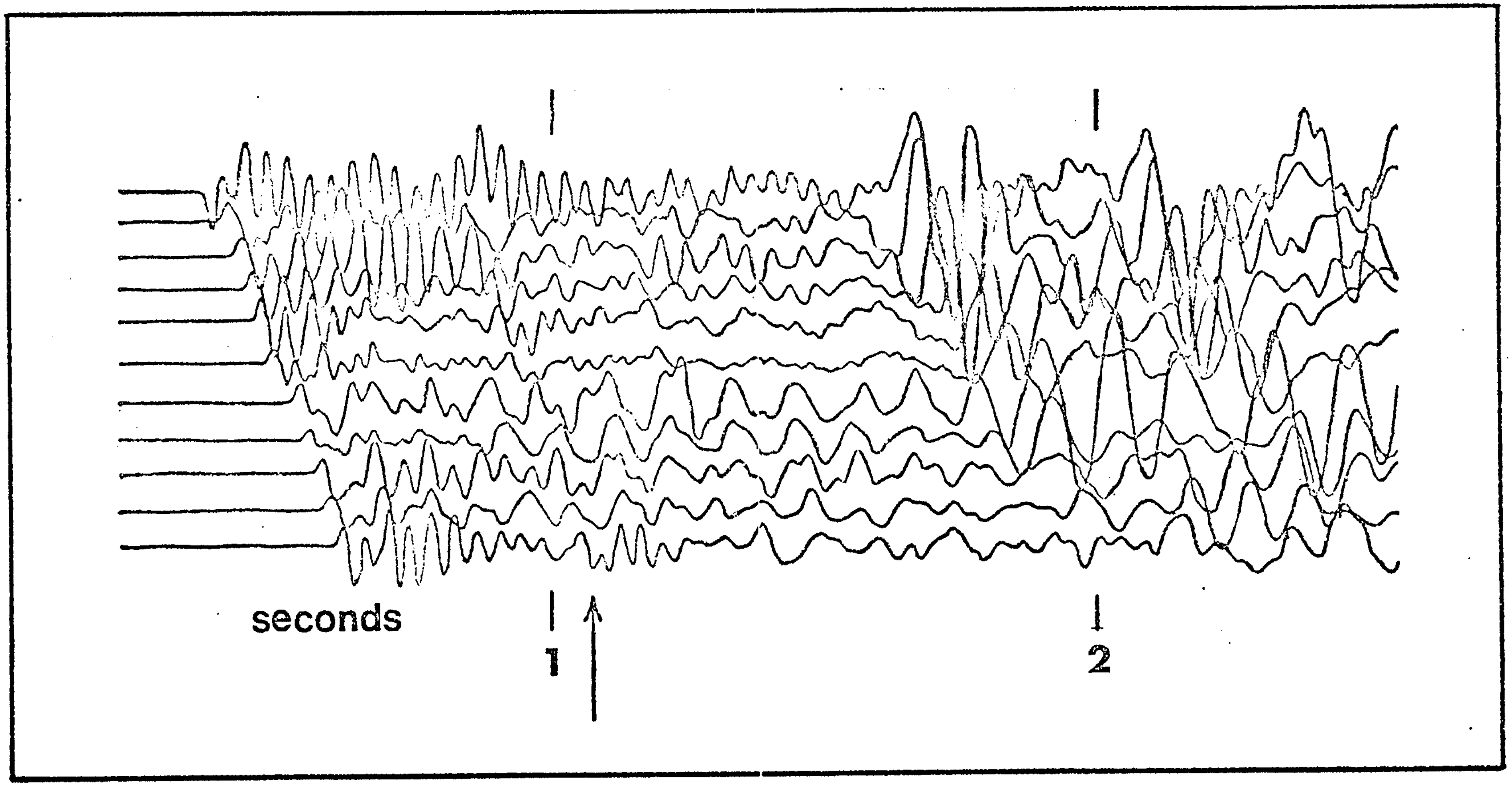

Figure 7. Old Jones Road record

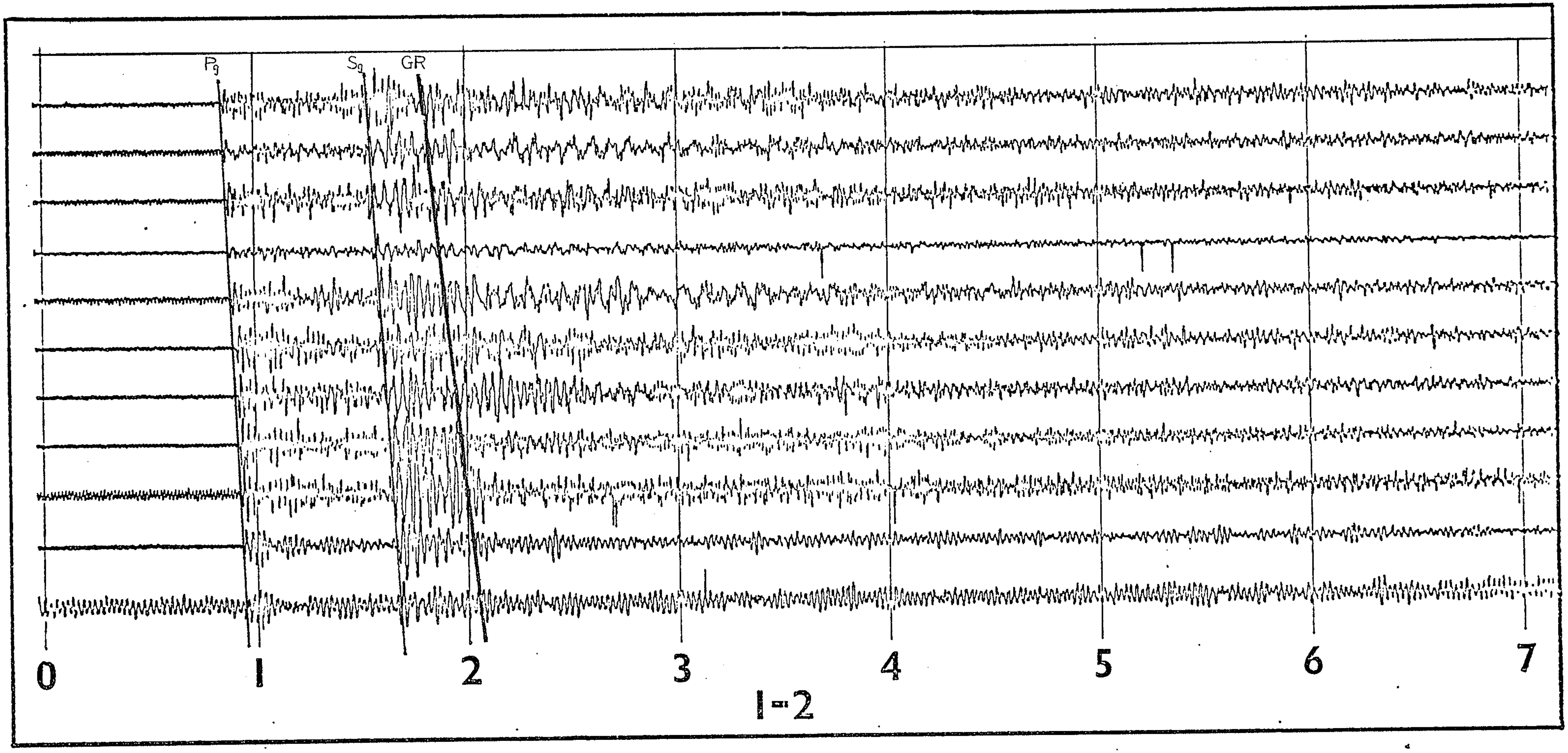

Figure 8(a) Original record 1-2.

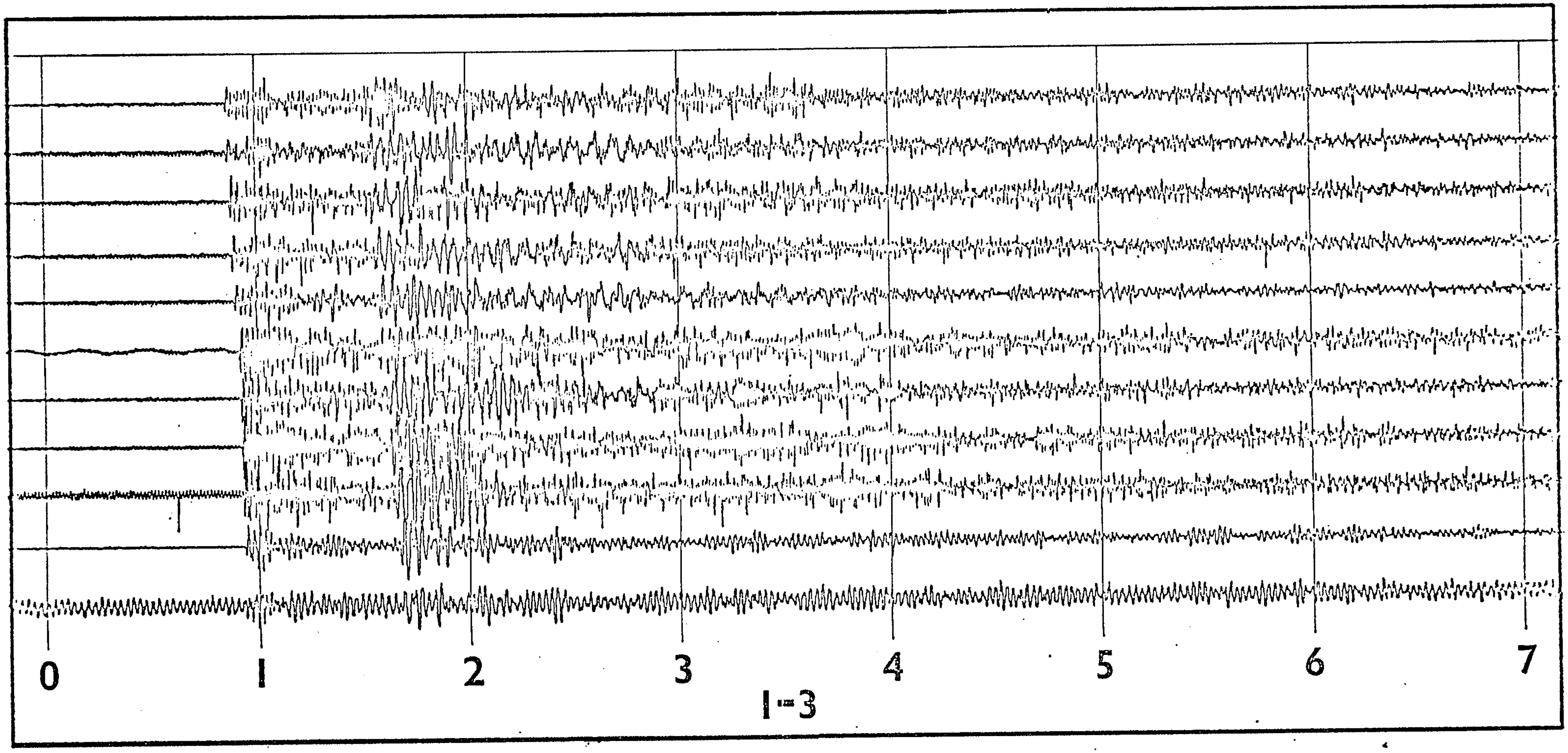

Figure 8(b) Original record 1-3.

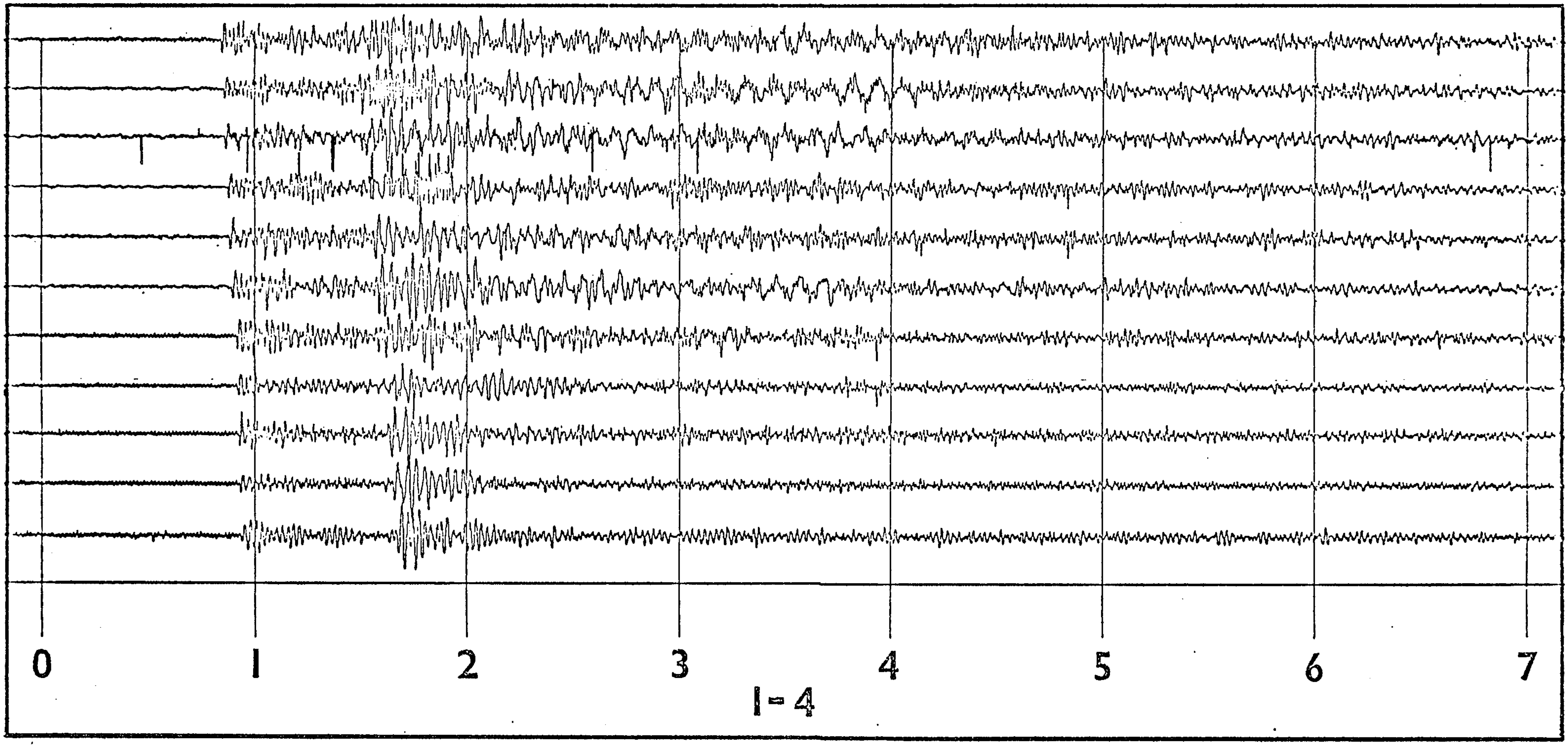

Figure 8(c) Original record 1-4.

Figure 8(d) Original record 1-5.

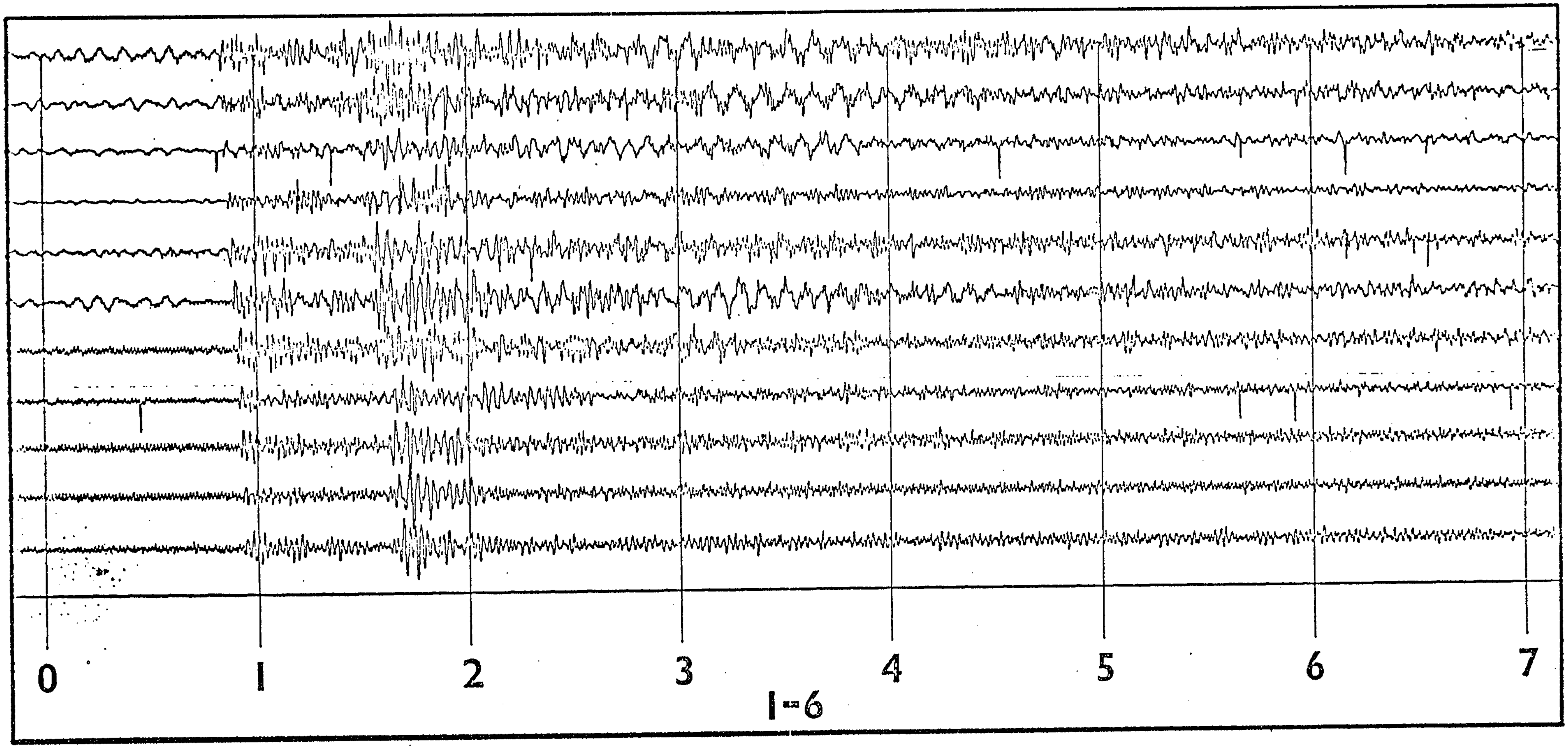

Figure 8(e) Original record 1-6.

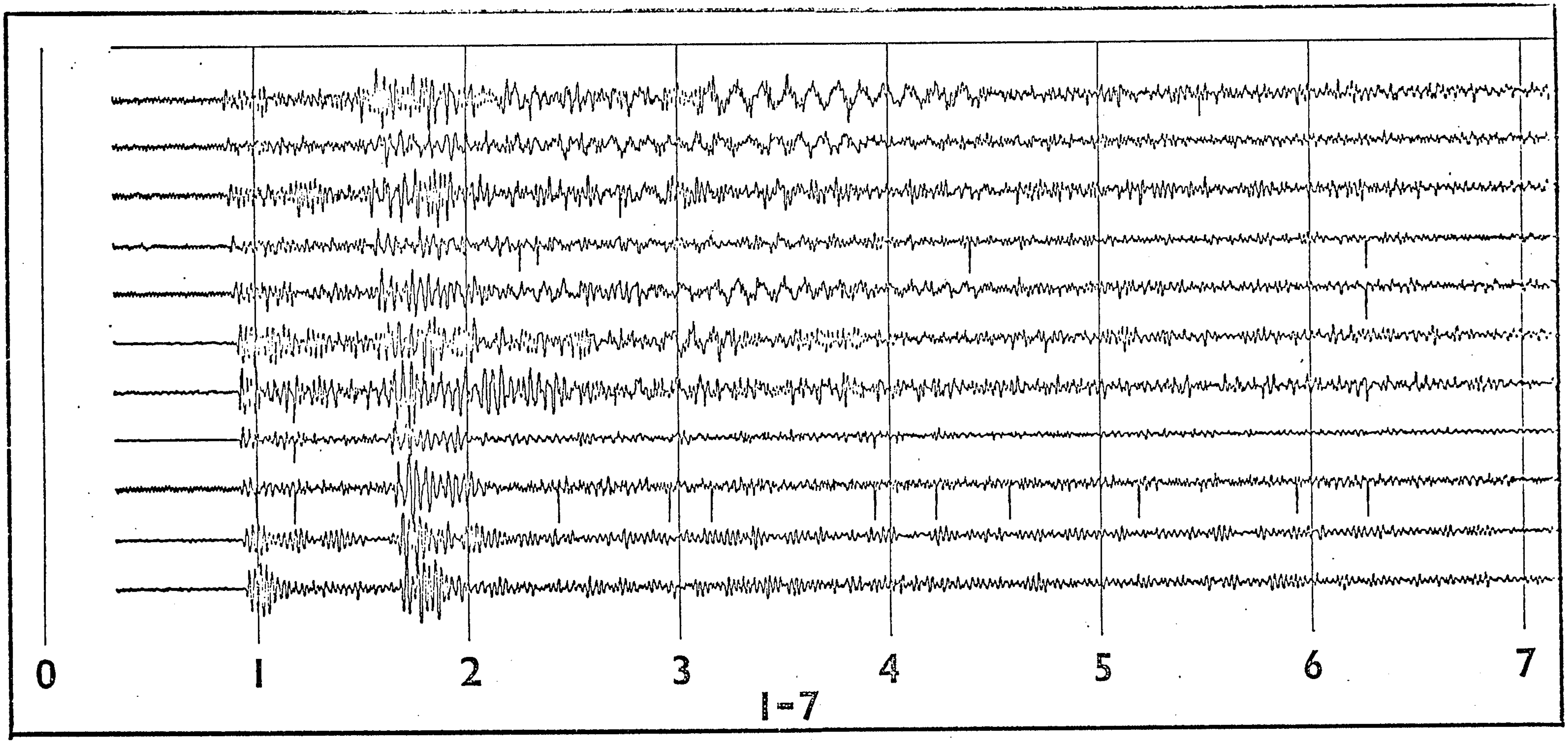

Figure 8(f) Original record 1-7.

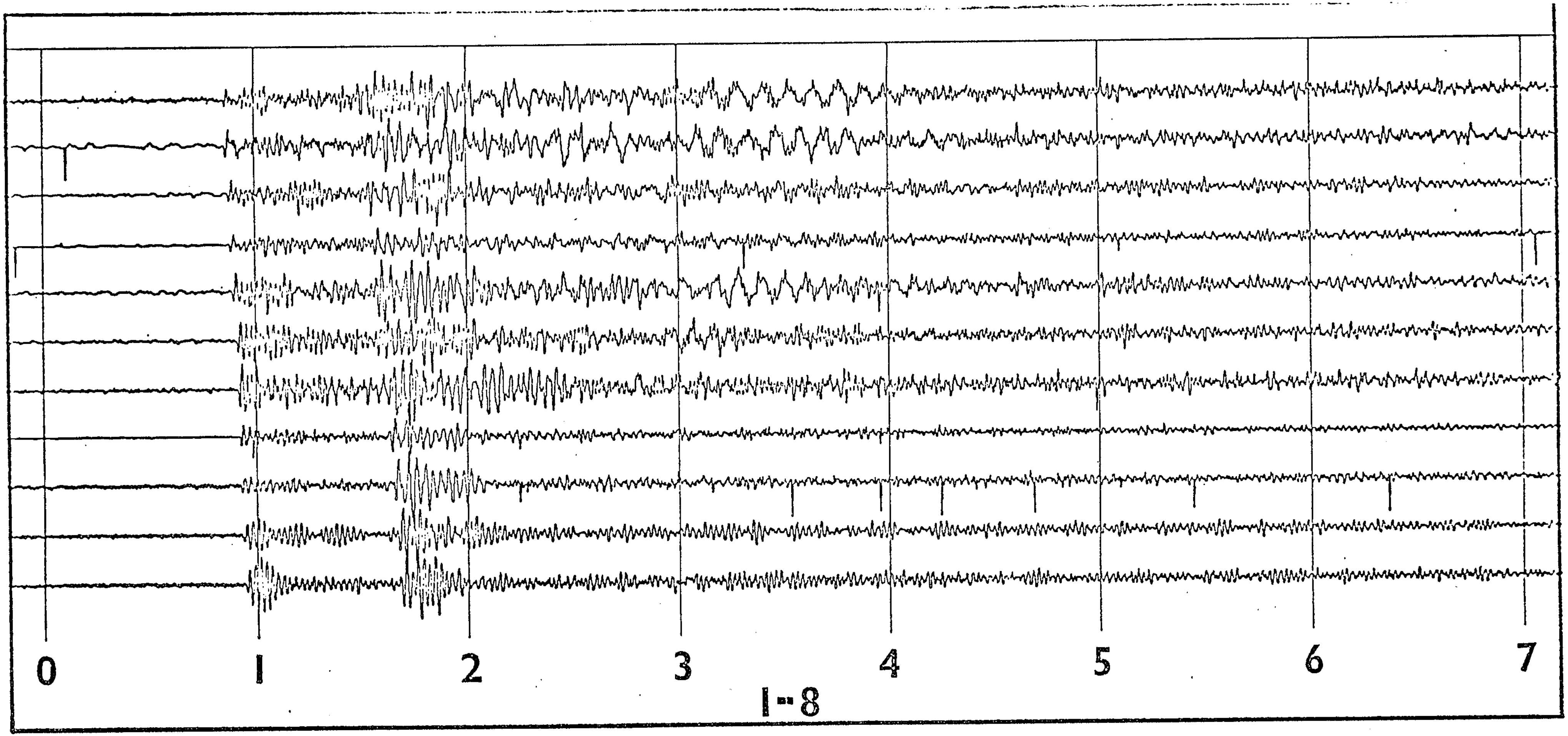

Figure 8(g) Original record 1-8.

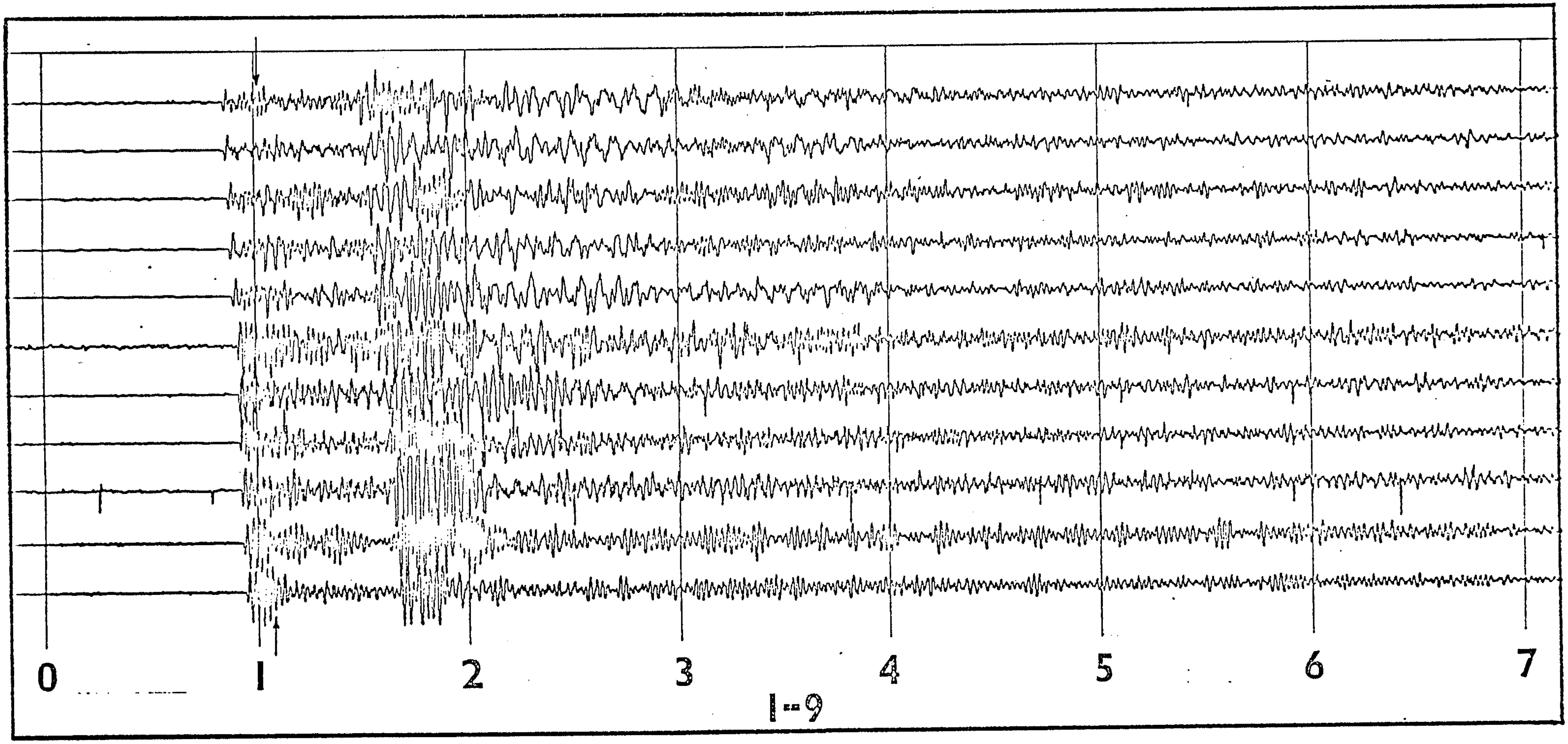

Figure 8(h) Original record 1-9.

farther along the Jones Road also shows an arrival between Pg and Sg. The shot to receiver distance was 4.18 kilometers and the shot was located northeast of the spread in Silver Lake. The arrival times correspond quite well to the model although the moveout of the event is too great by approximately 0.04 seconds. It is likely that the model is too simplified and that the interface is probably neither horizontal nor planar. Upon examining other records obtained in southeastern Manitoba it was noted that in general there were distinct arrivals between Pg and Sg. Hajnal (1970) has interpreted one set of arrivals from his records to be a reflection from a shallow crustal layer. As he has pointed out, a well designed reflection survey could be used for exploration purposes on the Canadian Shield. This method would lend itself particularly well to determining the depth to the bottom of greenstone belts.

Other models have been tested in the attempt to explain this early arrival. Consider this event to be a refraction from a shallow interface. The best fit straight line yields a velocity of 9.52 kilometers/second which is unreasonably high. It is possible that the interface is dipping which might account for this high velocity but the dip would have to be extreme for any reasonable combination of velocities. Since a reversed profile is not available no definite decision can be made. However, if a horizontal layer with a reasonable velocity were considered the critical distance would be at least twice the distances at which this event is observed. Therefore the refraction hypothesis may be discarded.

Having accepted this event as a shallow reflection it was decided to do a $T^2 - X^2$ analysis on the data. This yielded a velocity of 6.98 kilometers/second with a standard deviation of 0.27. If we consider that the interface may be dipping this velocity provides quite good agreement with the previously obtained upper crustal compressional wave velocity of 6.05 kilometers/second. A dip of the order of 15° to 20° would be sufficient to explain this difference of velocity.

5.3 Low Apparent Velocity Event

The records from recording site two display a prominent low frequency, low apparent velocity event. A least squares linear fit yields a velocity of 2.7±0.1 kilometers/second. This very low velocity rules out the possibility of a refraction or a reflection except for the case of an extreme dip. This of course cannot be checked because the profiles are not reversed.

However, the above mentioned velocity is very near to that of surface waves in the area although the intercept time is 0.9±0.1 seconds. Also this event seems to be repeated on the records as can be seen best in Figure 9(e).

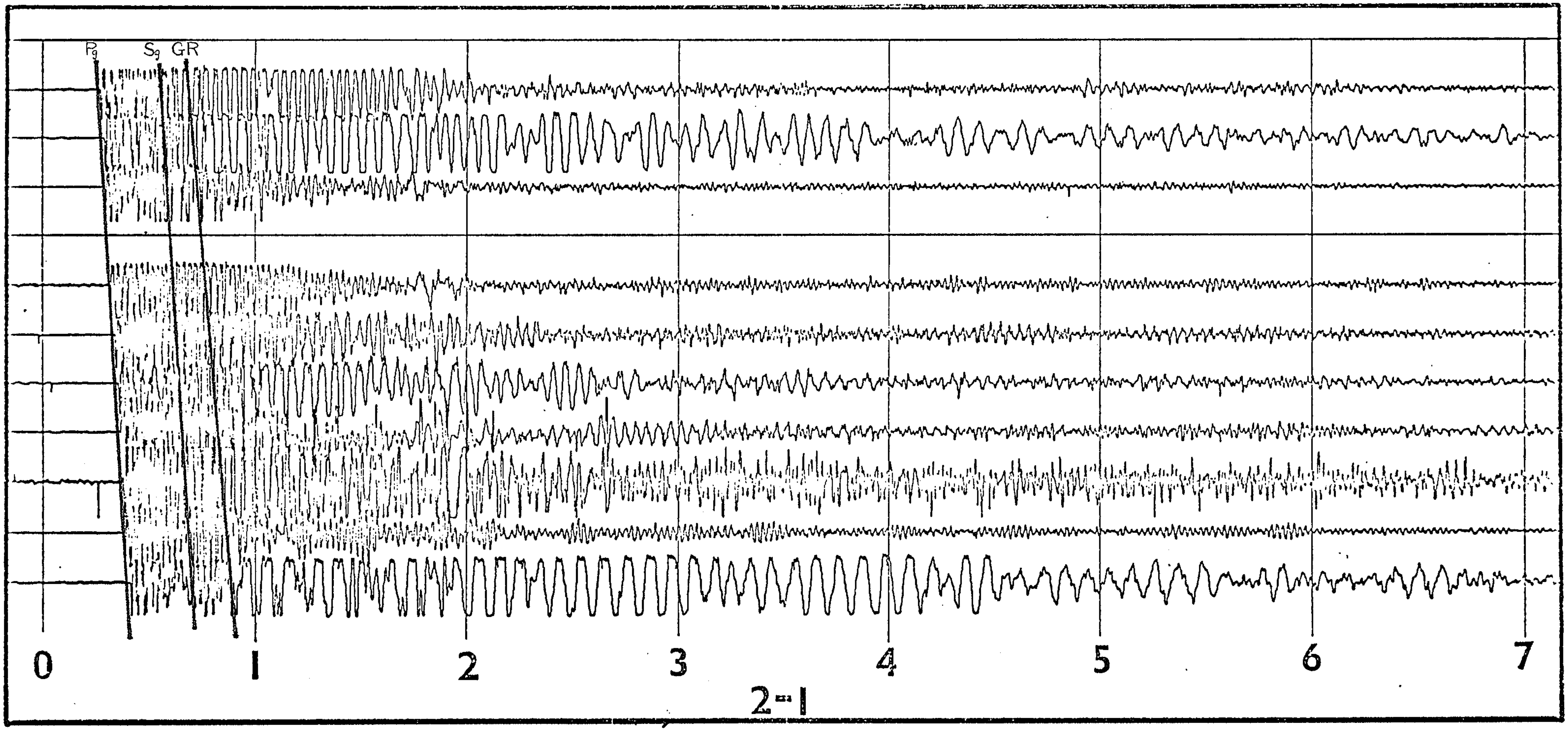

Figure 9(a) Original record 2-1.

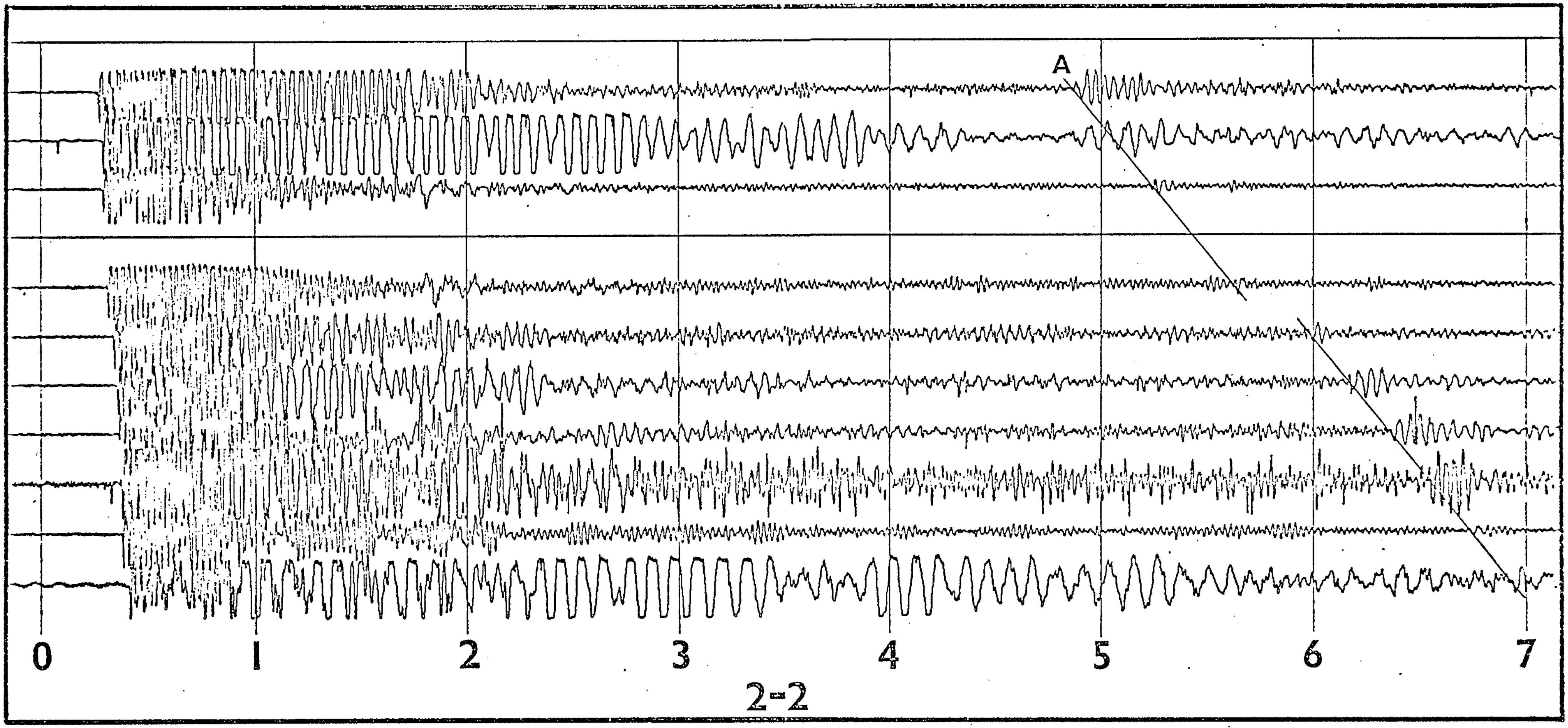

Figure 9(b) Original record 2-2

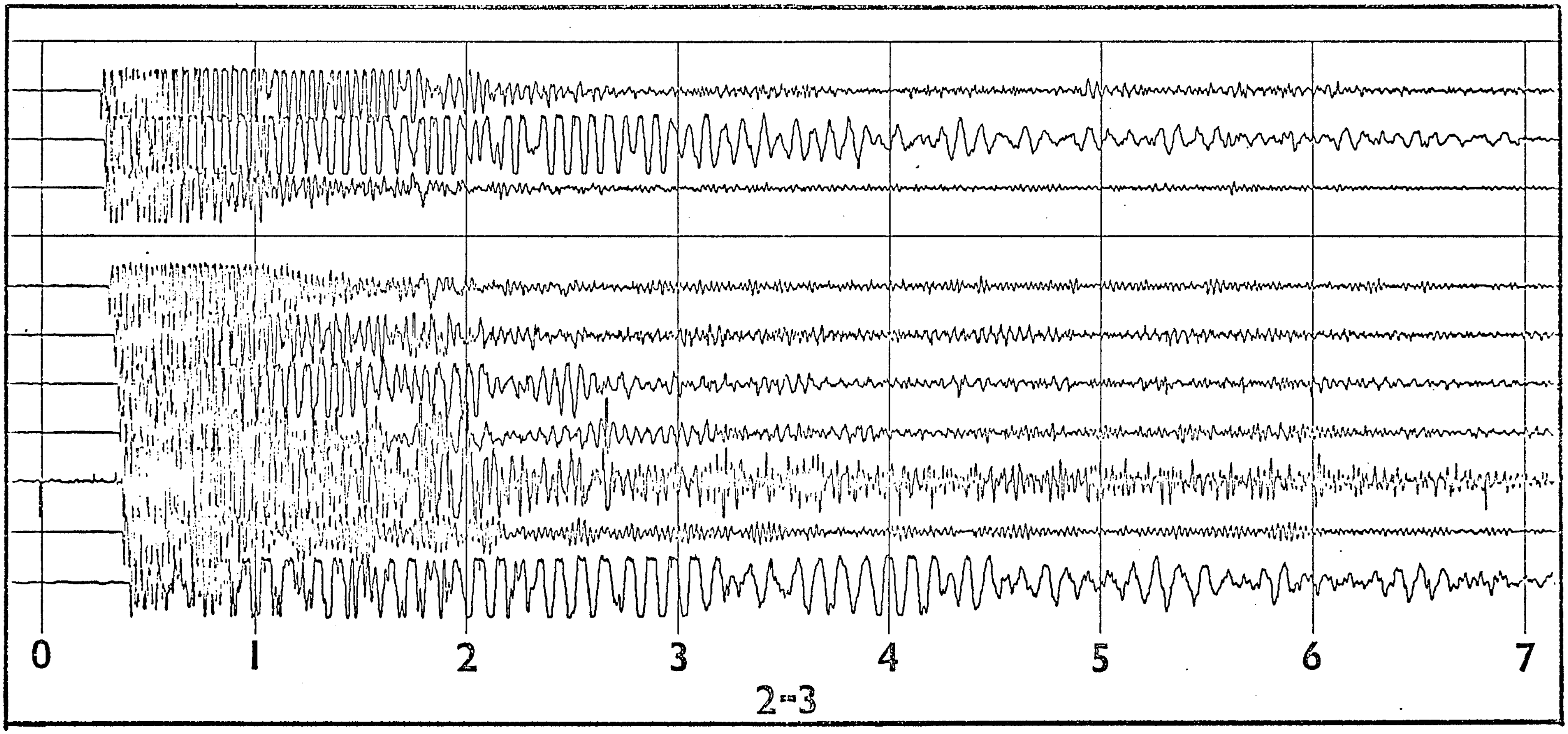

Figure 9(c) Original record 2-3.

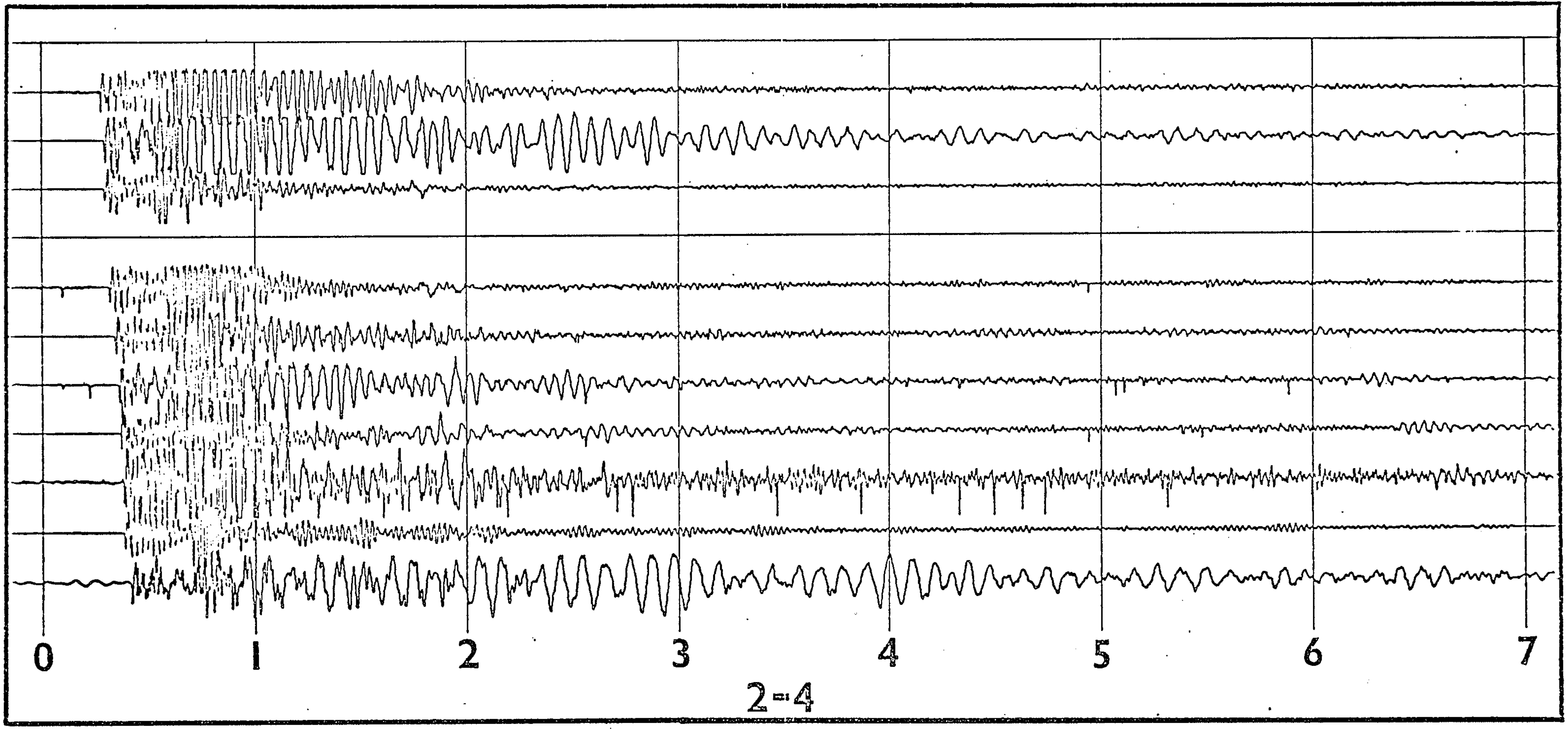

Figure 9(d) Original record 2-4.

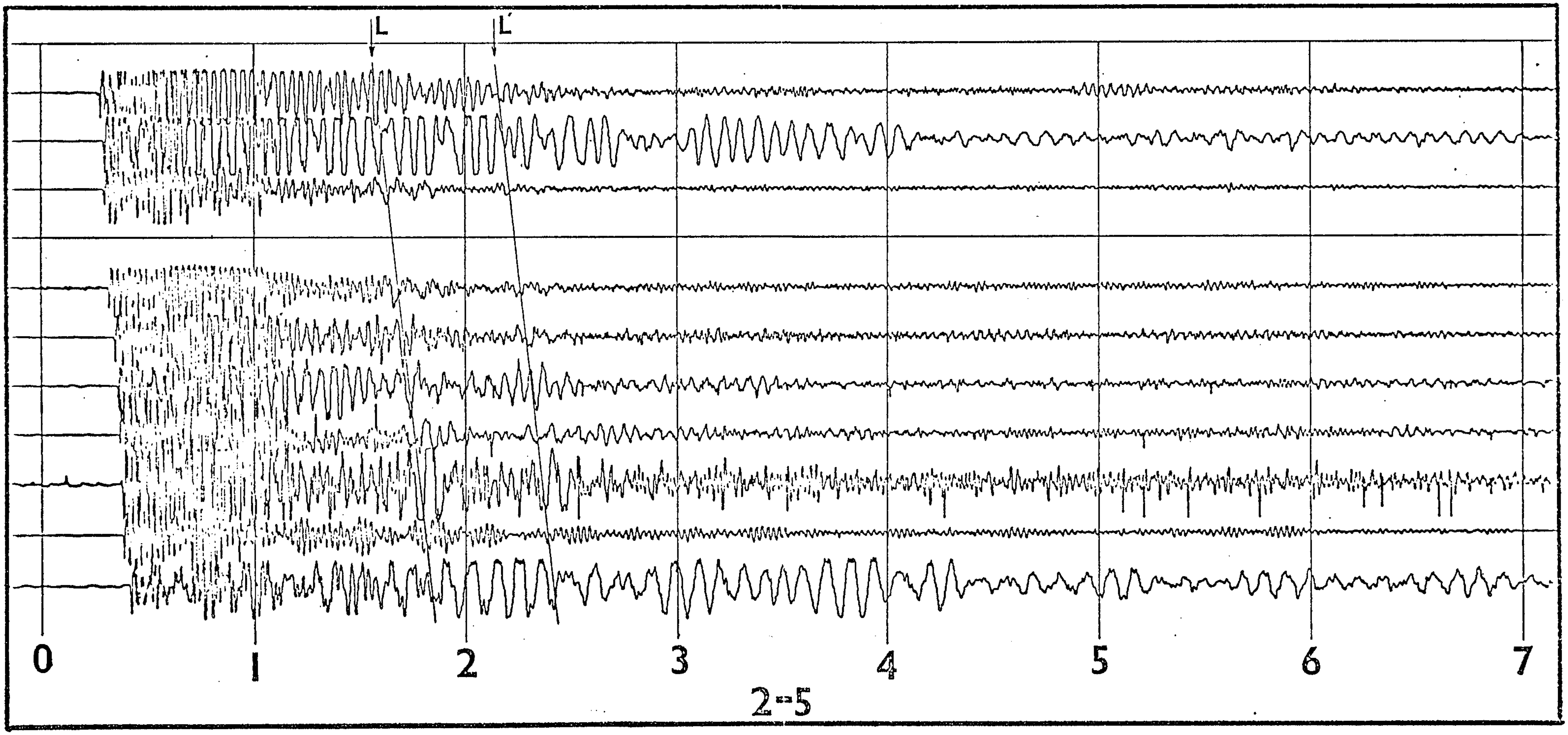

Figure 9(e) Original record 2-5.

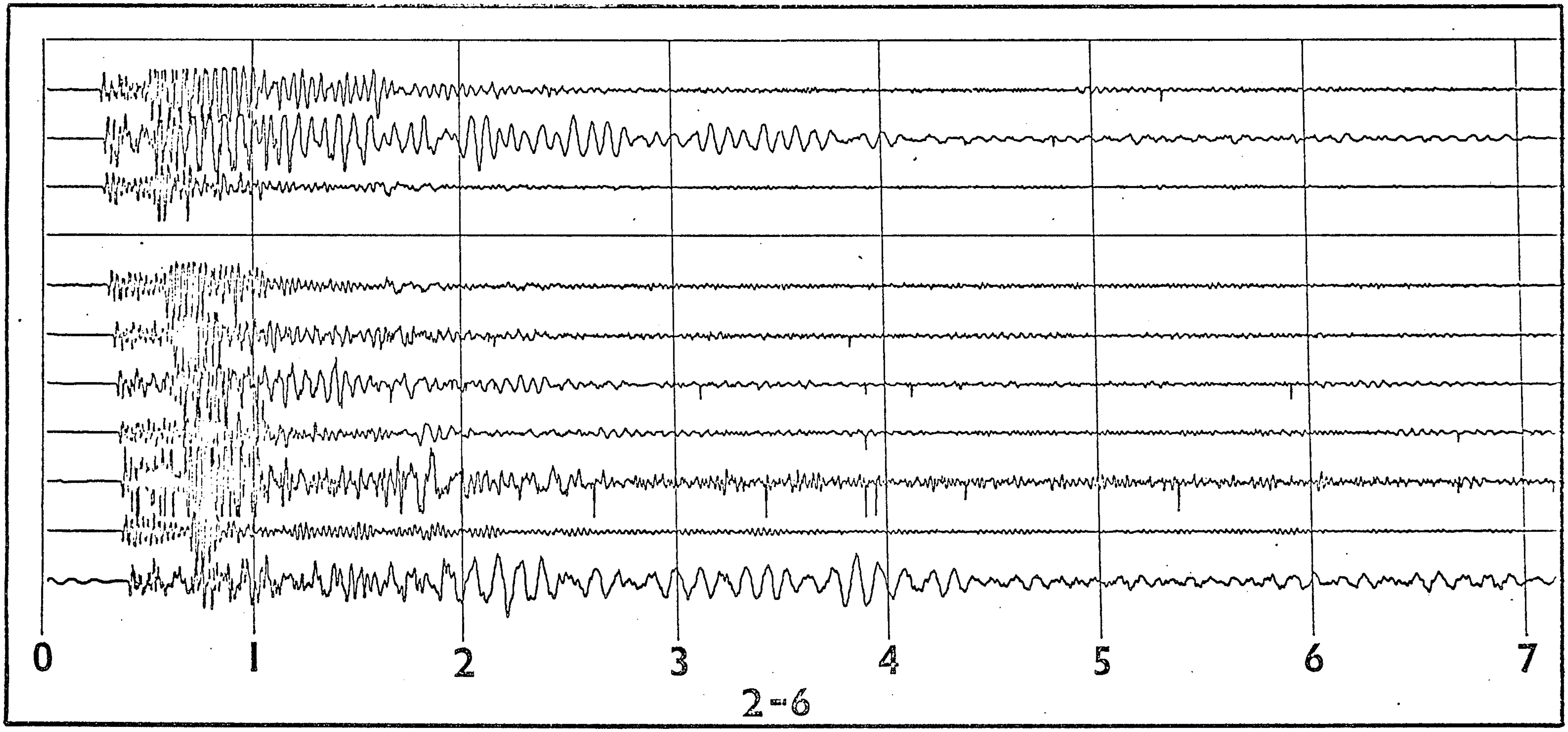

Figure 9(f) Original record 2-6.

And finally the arrival time for a 16.6 pound charge is delayed about 0.2 seconds compared to the arrival time for an 11.1 pound charge. This evidence suggests that the event may be a surface wave generated by later pulsations of a gas bubble. Secondary and further direct P and A events due to bubble pulsing would not be visible because they would be masked by the first set of surface waves.

The theory of pulsing bubbles (O'Brien, 1967) predicts a maximum bubble radius of about 7 feet for an 11.1 pound charge at a depth of 30 feet and the predicted first bubble pulse time is about 0.31 seconds. For a shot of 16.6 pounds at the same depth the predicted radius is 8 feet with a first bubble pulse time of 0.36 seconds. Therefore the observed sense of arrival time variation with charge weight agrees with theory but the magnitude is significantly different.

From the predicted radii we can see that the walls of the shaft would very definitely affect the bubble pulsing. Cole (1948) shows that the bubble will have an affinity for a rigid wall and we would expect this to be true especially in this case because the predicted maximum size of the bubble exceeds the available space. Probably therefore, the bubble is destroyed on its first expansion. Thus there is really no support for bubble pulsing in this case. In summary then the frequency and apparent velocity of this event suggests a surface wave phenomena but as yet there is no mechanism to explain the observed time delay of the intercept.

To eliminate any question about bubble pulsing it is suggested that in the future shots be fired at a shallow enough depth such that bubble pulsing cannot occur. The necessary equation to calculate the best shot depth is given by O'Brien (1967), although these apply to open water only.

5.4 Deep Crustal Reflections

The use of small charge weights theoretically precludes the observation of deep crustal reflections on the original records. An examination of these records indicates that the only late arrival in the time range of interest is the air wave which is marked on record 2-2, Figure 9(b). Therefore, in order to draw any conclusions regarding deep crustal reflections the data must be processed by the techniques previously mentioned.

The primary target reflecting horizon for this study is the Intermediate discontinuity. For a reflector at this depth the expected moveout of the associated reflection event for the offset distances involved would be very nearly zero. Therefore, initial processing involved velocity filtering all of the original records with an infinite apparent velocity and the resulting traces are displayed in Figure 10(a) and (b). A cursory examination yields no obvious events after 3.5 seconds but upon closer examination there appears to be an

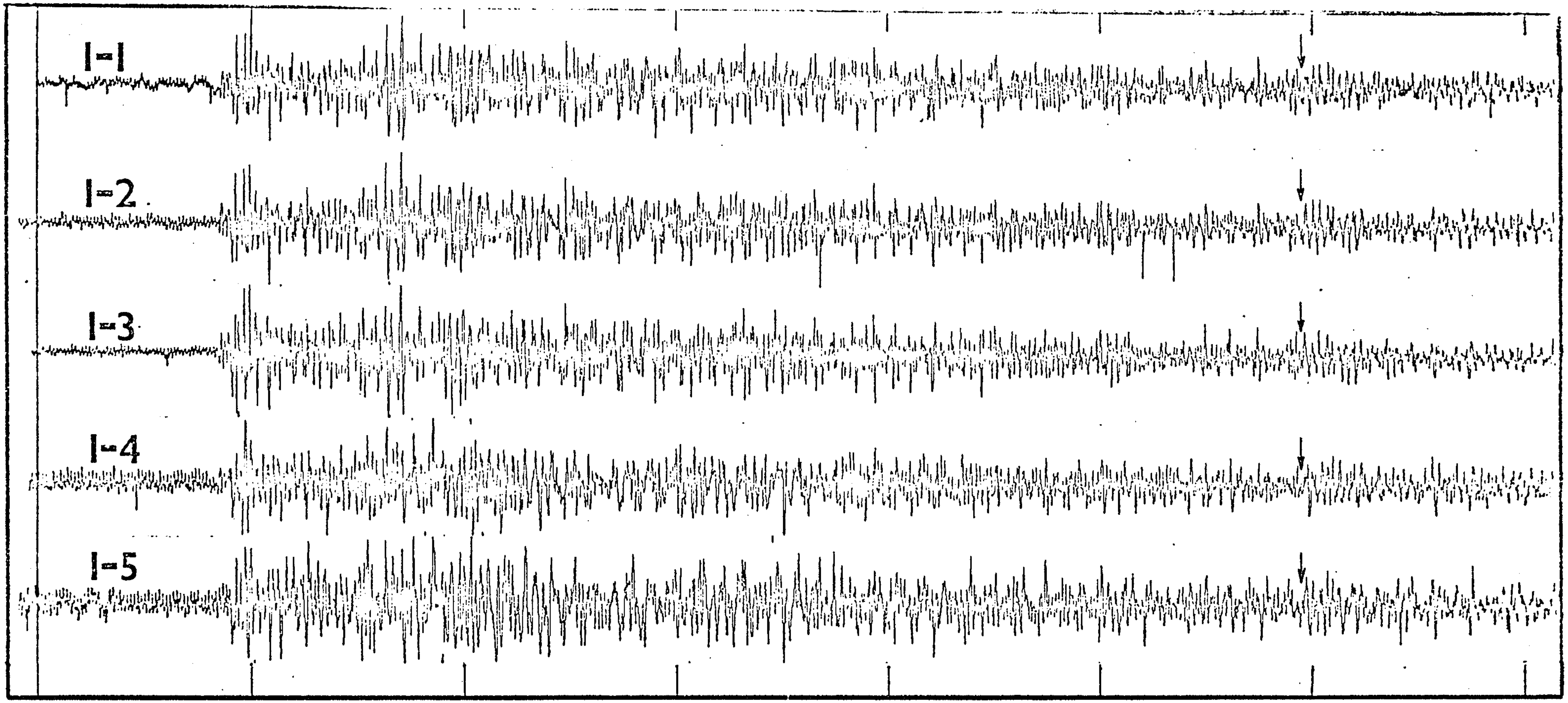

Figure 10(a) Part I. Zero moveout velocity filter of recording site one records.

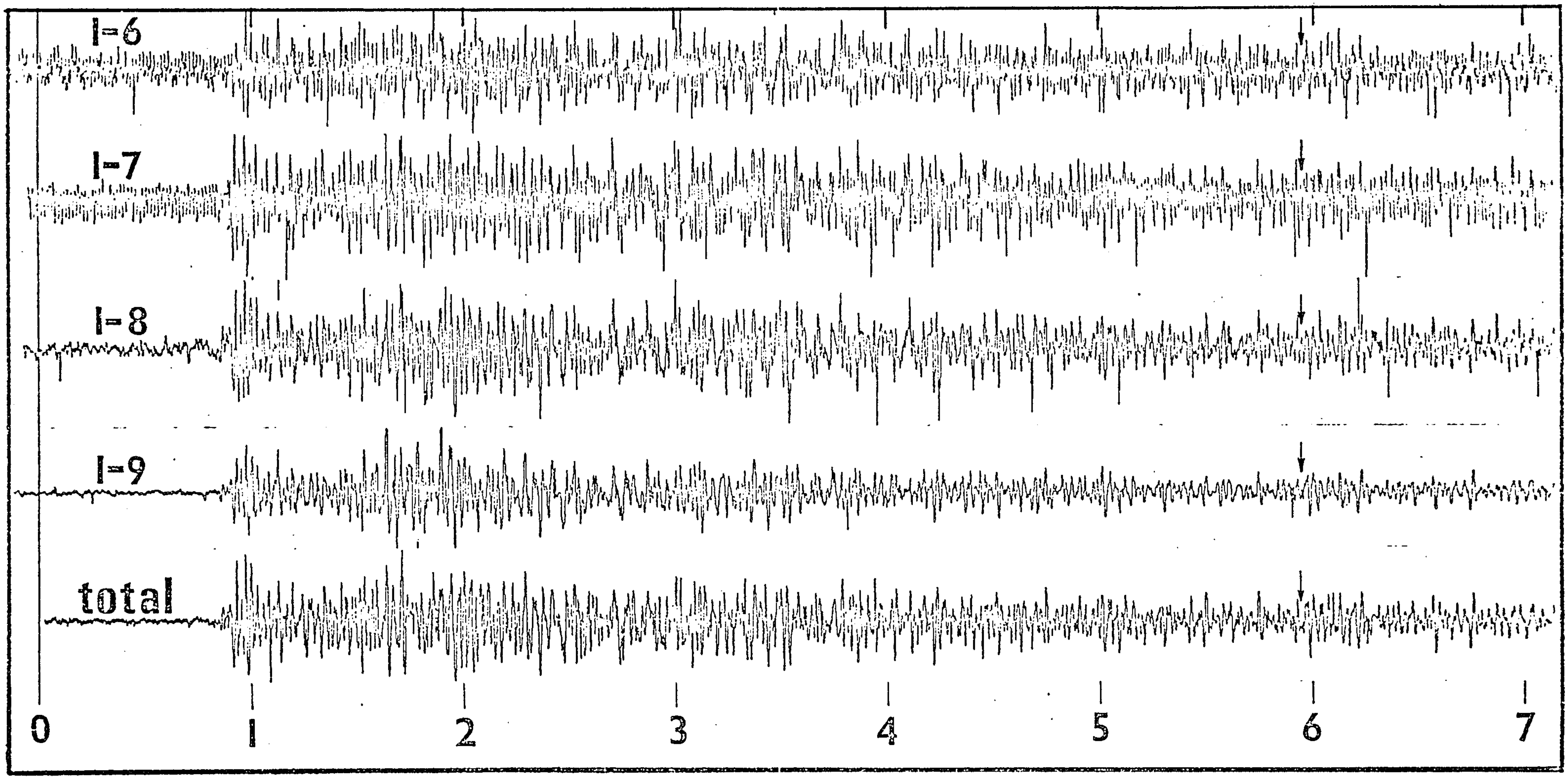

Figure 10(a) Part 2. Zero moveout velocity filter of recording site one records.

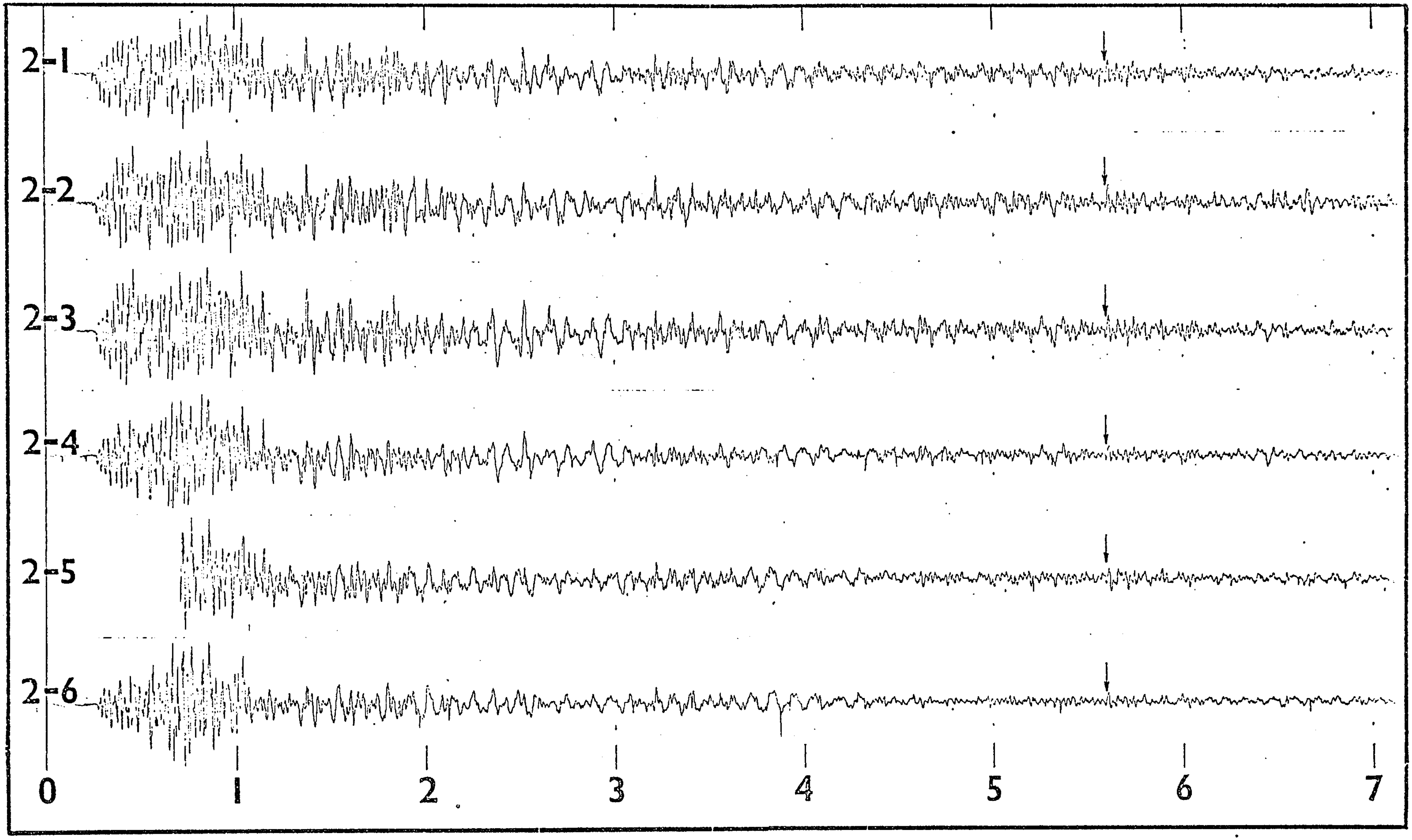

Figure 10(b) Zero moveout velocity filter of recording site two records.

increase in amplitude as well as a periodic wave train at 5.7 seconds on the composite traces for recording site two. This event is most noticeable on the composite traces associated with records 1-5 and 1-6, probably because of the shorter duration of the surface wave train due to the smaller charge weight used. From the charge weight relationship developed in Chapter 2, setting t equal to ten and r equal to one, the equivalent charge weight for composite traces 2-1 through 2-4 is about 93 pounds and for composite traces 2-5 and 2-6 it is about 62 pounds. These values are approaching the maximum charge size Hajnal (1970) used.

In addition to this event there appears to be increased periodicity starting at 5.95 seconds on the composite traces for recording site one. The traces for records 1-2 and 1-9 best display this periodicity as well as displaying some increase in amplitude. For these composite traces the equivalent charge weights may be found by setting t equal to 10 for records 1-1 to 1-3 and 11 for records 1-4 to 1-9 and by setting r equal to one for all records. The resultant equivalent charge weights are 93 pounds for traces 1-1 to 1-3, 100 pounds for trace 1-4, 135 pounds for trace 1-5, 67 pounds for traces 1-6 to 1-8, and 167 pounds for trace 1-9. Trace 1-9 appears to have the best signal-to-noise ratio and traces 1-6 and 1-7 the worst. In general, therefore it appears that the higher the equivalent charge weight is, the better the composite trace further by the organisms at this phase of growth. The organisms lack enzymes for the degradation of aniline and the amount of aniline is not yet high enough to cause any induction of enzymes; we have already established that a high concentration of aniline is required for growth. As the culture reaches 6 days growth period, the major portion of acetanilide is utilized and the induction of deacylase enzyme cannot be maintained further. Therefore, the growth ceases as the deacylation reaction is the main reaction providing energy in the form of acetate.

At this phase of growth the concentration of aniline is now high enough, and as a result it causes induction of enzymes for its own degradation. This induction is a slow process and so, a second lag period appears in the growth curve. The organisms start growing again rapidly because the energy and carbon for growth is now being provided by aniline, which is broken down to simpler readily utilizable compounds, by ring fission.

This growth study shows that the adaption to utilize acetanilide as sole carbon and energy source is not alone responsible for simultaneous adaptation to aniline. On the contrary, aniline induces enzymes for its own degradation. Thus, we may say that there are two main energy providing steps in the metabolism of acetanilide by *Pseudomonas sp*.

(a) Deacylation: Which releases acetate, readily used by the organism for the first phase of growth.

(b) Fission of aniline ring after dihydroxylation and formation of simple aliphatic compounds, which provide energy for growth in the second phase.

Our present work does not reveal the mode of cleavage of the aromatic nucleus after dihydroxylation of aniline, by *Pseudomonas sp*.

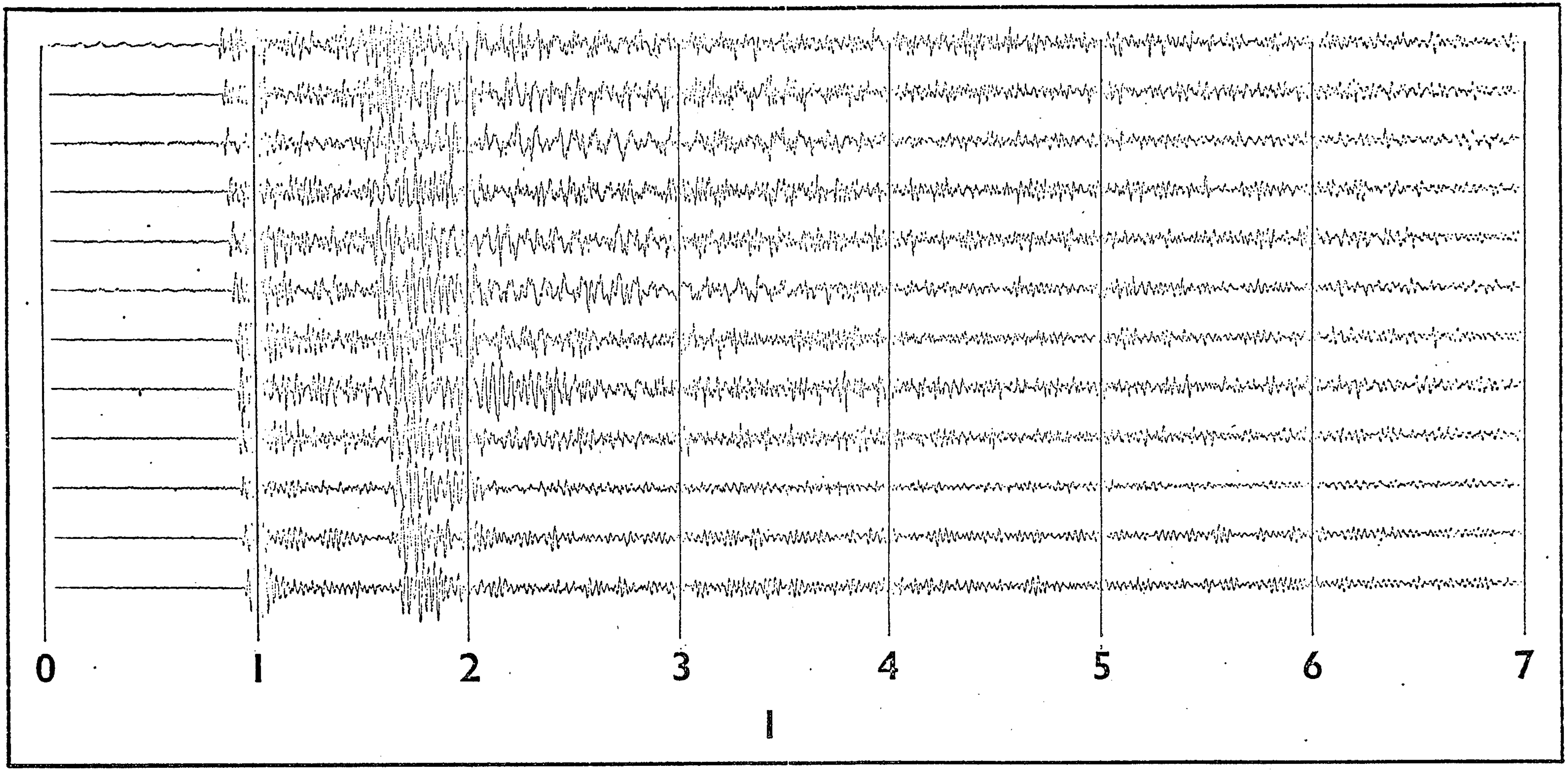

Figure 11(a) Recording site one vertical stack record.

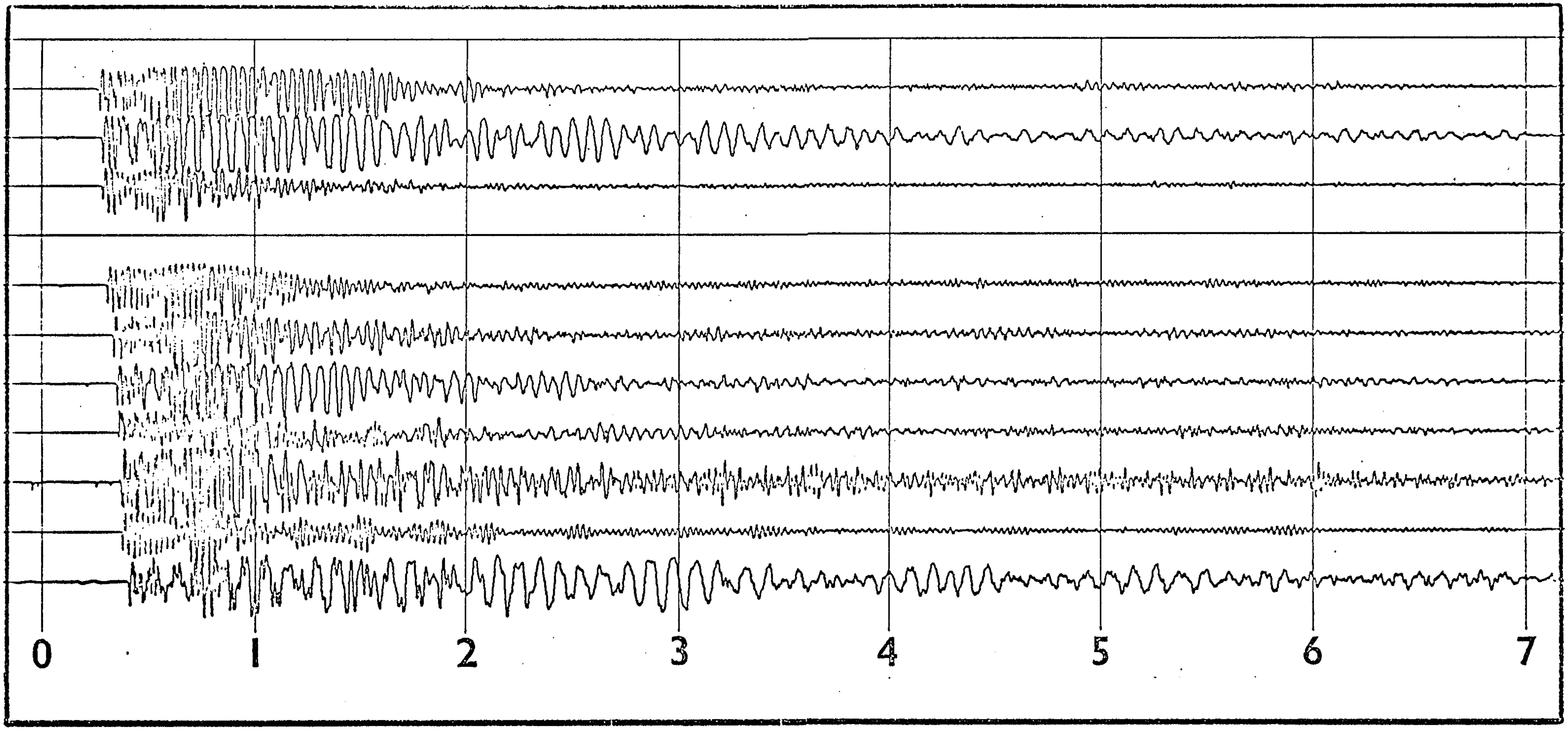

Figure 11(b) Recording site two vertical stack record.

charge weights for these composite records are about 80 pounds for recording site one and about 50 pounds for recording site two. These are notably less than the expected minimum required charge weight.

The composite records are now useful in applying the velocity filtering technique to obtain total stacked traces for each recording site. Both composite records were filtered with a range of apparent velocities to obtain the display in Figure 12 (a) and (b). The equivalent charge weights are 500 pounds for recording site one and 280 pounds for recording site two.

Considering first the traces for recording site two, the previously noted event at 5.7 seconds appears with highest amplitude on the trace which was stacked with an 8 millisecond total moveout. It is difficult to be certain that an event which is visible on such a display is valid because it must be borne in mind that such a display is not a section and that correlations from trace to trace have little meaning. Almost any event for which the signal-to-noise ratio is nearly one are suspect because they may have been formed by appropriate stacking of noise. In this particular case the event at 5.7 seconds could have been formed by appropriate stacking of air waves. To test this possibility a zero moveout stack was made with trace six, the possible contributing trace, omitted in addition to traces one and five (Figure 13). A comparison

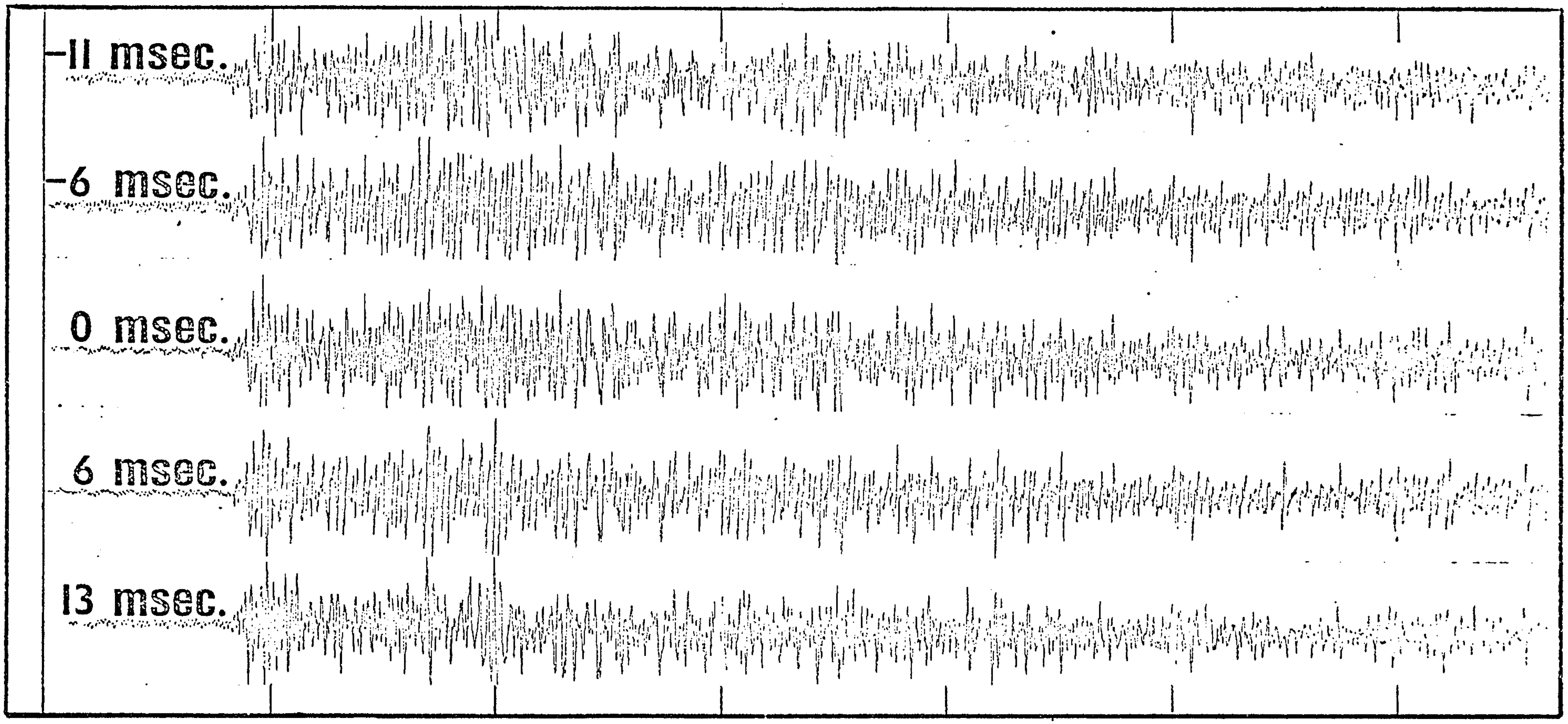

Figure 12(a) Part 1. Velocity filter traces of composite record one.

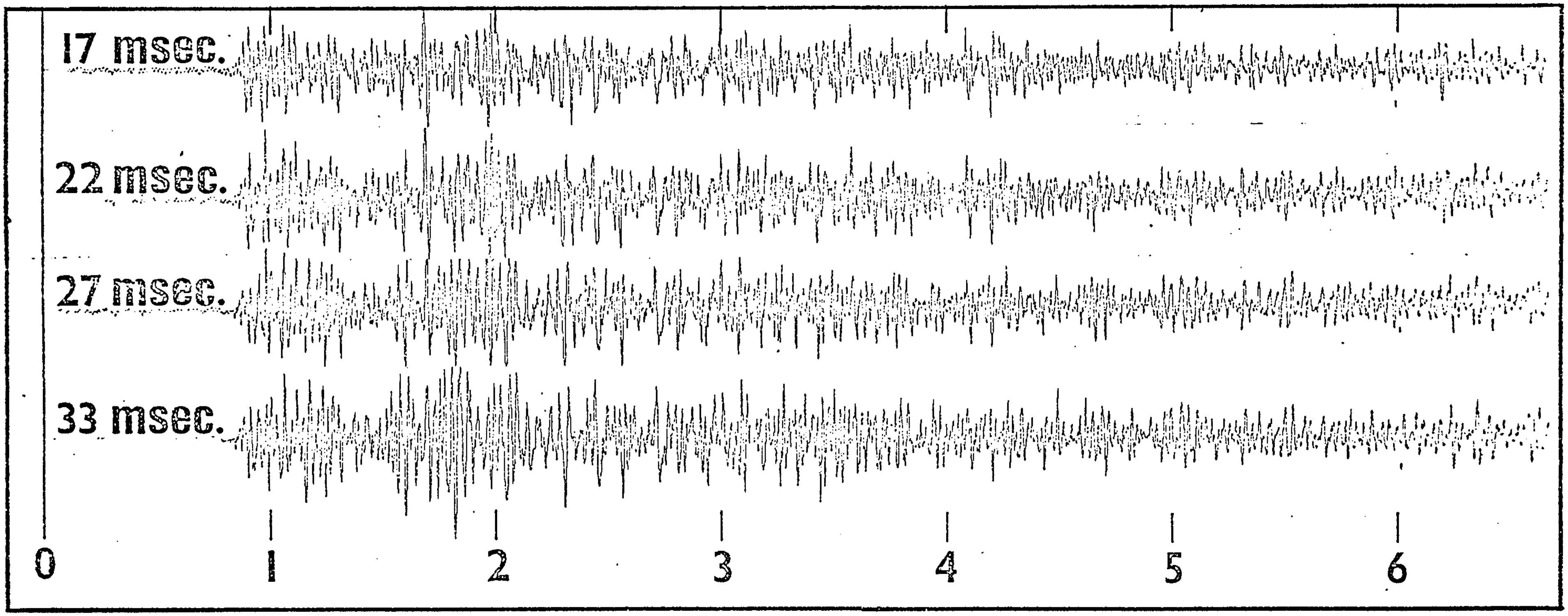

Figure 12(a) Part 2. Velocity filter traces of composite record one.

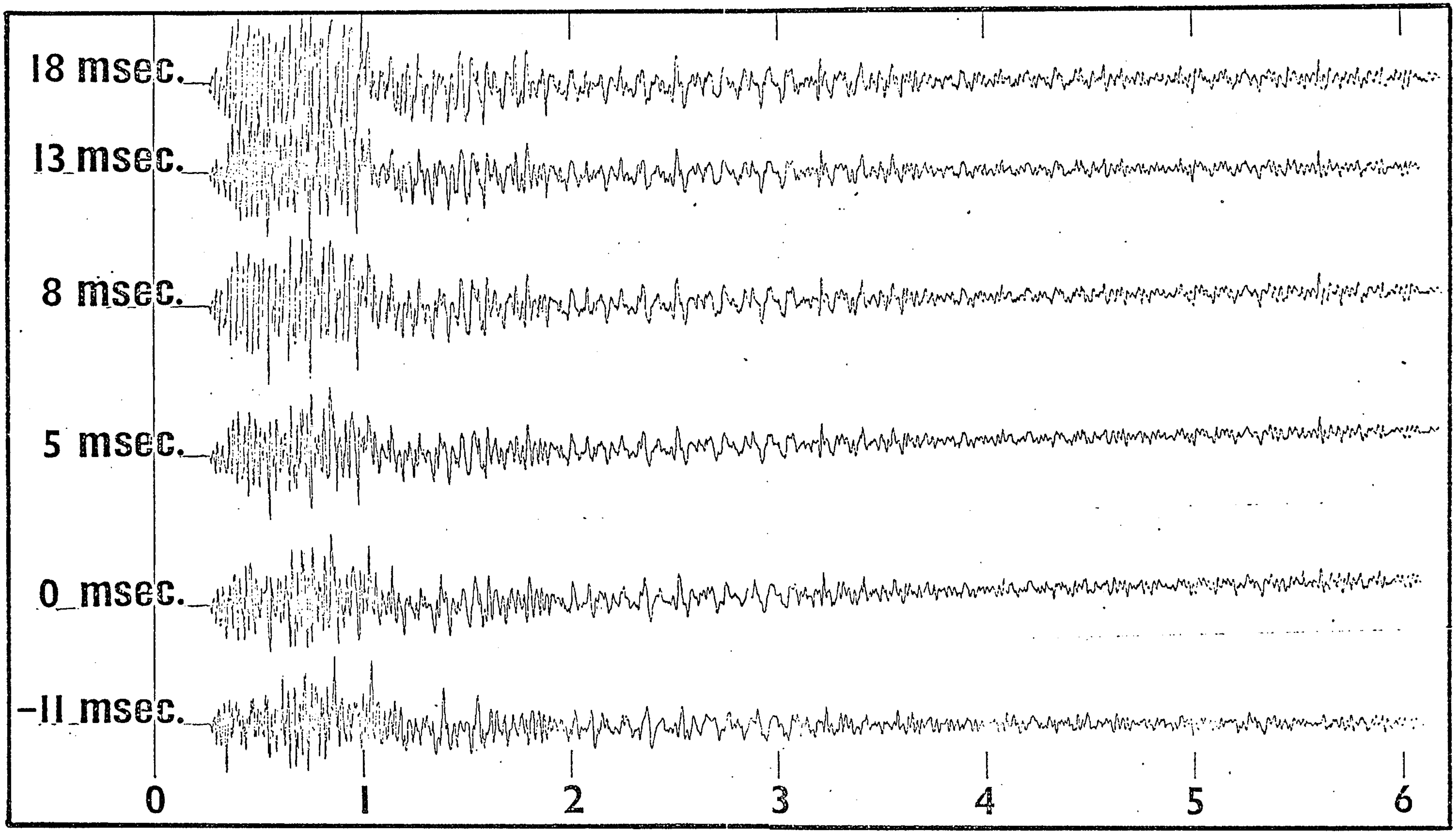

Figure 12(b) Velocity filter traces of composite record two.

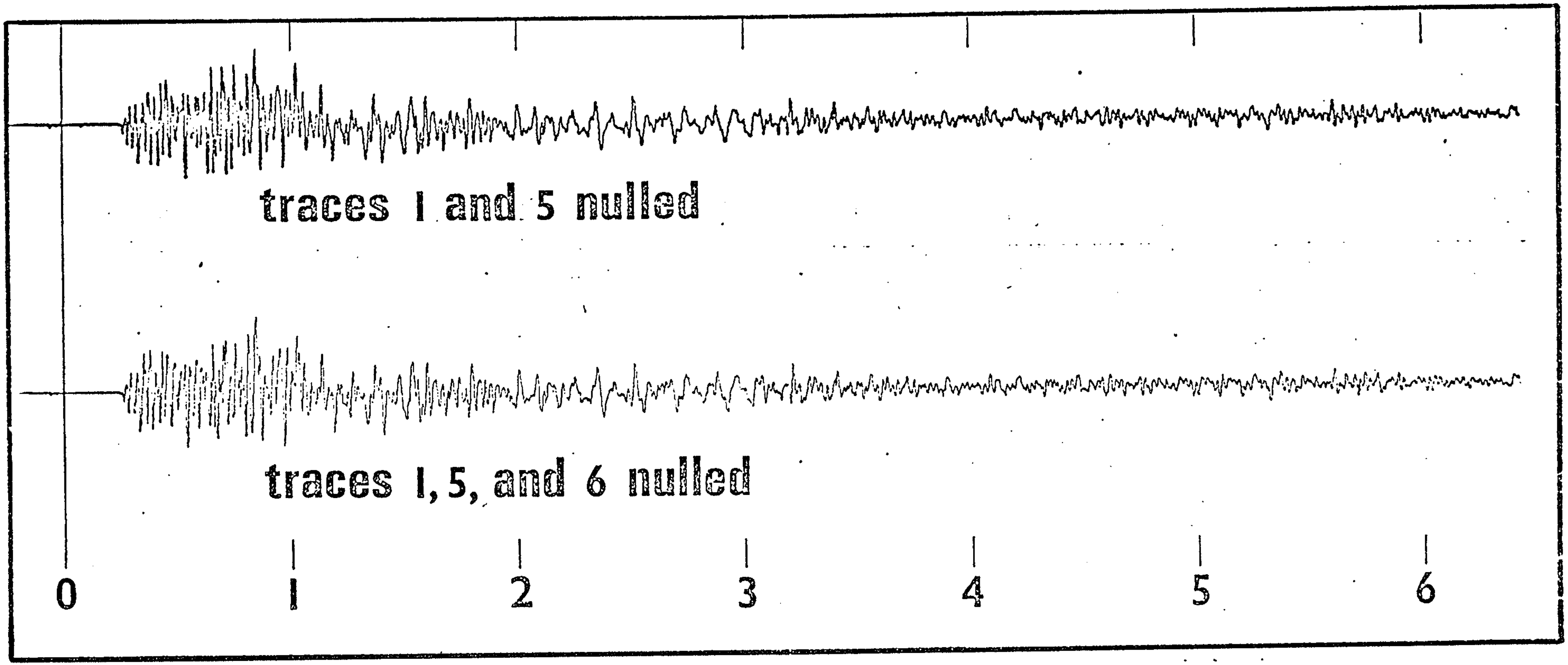

Figure 13. Stack of record 2-1 with traces 1, 5 and 6 omitted.

between this output trace and one which includes trace six shows no significant difference and therefore this event cannot be due to inconvenient stacking of air waves.

Considering the display for recording site one the previously noted event at 5.95 seconds appears most noticeable on the trace stacked with zero moveout. However, the signal-to-noise ratio is very low and there is considerable question regarding the validity of this event. In fact, evidence to support either of these events is poor. Neither event can be correlated with any other possible event. In both cases the signal-to-noise ratio is low and the length of the surface wave train is a problem because velocity filtering has not succeeded in completely attenuating them. And finally, neither event fits the present crustal model. Arrival times for both events yield depth values between known depths for the Intermediate and Mohorovicic discontinuities. For the area in which this study was conducted, Gurbuz (1969) has suggested a crust composed of more than two layers. Continuing work is investigating the possibility that the arrivals which Gurbuz has attributed to a sub-Intermediate interface may be explained by a velocity gradient below the Intermediate discontinuity. It must be concluded therefore, that the two aforementioned events at best may be real events but nothing further can be said regarding a geologic interpretation.

5.5 Effectiveness of Digital Processing

The digital processing techniques employed in this study have previously been discussed in Chapter 4. There it was decided not to use frequency filtering in the main stream of processing. Examples of filtered records in that chapter demonstrated that frequency filtering of the present records was helpful in eliminating high frequency noise but an examination of the vertical stack records indicates that similar good attenuation of such noise may be obtained by this technique. Also, because of the necessity of vertical stacking due to field problems it has been decided that in general frequency filtering is not necessary. However, further study will be required in order to make a final decision because it must be remembered that no deep crustal reflections were positively identified in this study and therefore knowledge of near-vertical reflection frequencies in shield areas is limited.

The necessity of vertical stacking has been discussed in Chapters 2 and 4 and the effectiveness of this method for the elimination of high frequency noise has been mentioned in the previous paragraph. For completeness it should be mentioned again that the vertical stack record provides a composite record on which subsequent velocity filtering can be effected most efficiently. In the present study this was necessary because the equivalent charge weight of the two vertically stacked records was insufficient to yield deep reflection events. In future studies such events may be visible on these composite records. However, it is doubtful that vertical stacking of original records alone would yield good signal-to-noise ratio for deep reflections because of the length of the surface wave train. Also, a comparison of the composite records with the original records indicates that there is considerable non-random noise on the seismograms. Therefore it is suggested that any practical field techniques such as shot and/or geophone arrays should be employed to minimize the non-random noise.

In the present study it was necessary to carry out velocity filtering of the two composite records in order to obtain a trace with high enough equivalent charge weight theoretically to allow identification of deep reflection events. In practice, events were found on velocity filtered original records but by comparing these filtered traces to velocity filtered traces from composite records it is found that the latter system has accomplished additional low frequency noise attenuation. Therefore it is suggested that the processing combination of vertical stacking followed by velocity filtering provides the best traces for interpretation. However, in future it is suggested that the velocity filtering program be modified to allow filtering any number of traces at one time. Also, for a continuous profile type of survey it would be useful to be able to filter traces from adjacent records at one time. This would allow a continuous profile of velocity filtered traces to be produced

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

As was expected, deep crustal reflections were not visible on original records. However, the low charge weights used provide sufficient amplitude of late arriving events for stacking techniques to be successful in improving the signal-to-noise ratio. Therefore, similar charge weights should be used in future work.

Surface waves and other non-random noise have proven to be a problem. Observed frequencies of this noise are too near to the expected frequencies of reflections to use frequency filtering. Velocity filtering has helped to eliminate this noise but it is suggested that in future, arrays of shots and/or geophones be used to best advantage.

The processing system established in this study has proven very useful and workable but the program modifications mentioned earlier would improve its flexibility and would facilitate ease of processing. Vertical stacking followed by velocity filtering has provided the best processed traces because vertical stacking has accomplished good attenuation of random noise and velocity filtering has successfully attenuated non-random noise.

This study has demonstrated that reflections may be obtained from near-surface geologic features with relatively low charge weights. An interface at a depth of 1.7 kilometers with probable dip to the south-west was found based on an event arriving about 0.2 seconds after the first breaks. These results indicate the usefulness of the reflection method in studies of the near-surface for prospecting purposes in the Canadian Shield.

No strong deep crustal reflections were observed in this study. This is apparently due to insufficient charge weight. In future, more shots should be fired for each recording site in order to raise the equivalent charge weight to at least 1,000 pounds. Also it would be adviseable to run continuous profiles in order to provide a section on which to observe correlations of events. In addition to this, a continuous profile would allow mapping of a reflecting interface. Therefore, it is suggested that with modifications the reflection method may be used successfully on the Canadian Shield for near-surface and for crustal studies.

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APPENDICES

APPENDIX 1

THEORY FOR SIGNAL TO NOISE RATIO IMPROVEMENT OF STACKING

APPENDIX 2

PROGRAM *VERTS* DESCRIPTION AND LISTING

APPENDIX 1

THEORY FOR SIGNAL-TO-NOISE RATIO IMPROVEMENT OF STACKING

It can be seen intuitively that by summing a number of seismic traces in a manner such that the signal components are in phase and the noise components out of phase, that the signal-to-noise ratio of the sum traces will be improved compared to that of the individual traces. It is useful to know quantitatively what the improvement should be.

Consider a seismic trace $X_i(t)$ which is composed of a signal component and a noise component.

$$X_i(t) = s_i(t) + n_i(t)$$

We may define the signal-to-noise ratio, s/n, as

$$\frac{\sigma_s}{\sigma_n} = \frac{\text{RMS signal level}}{\text{RMS noise level}}$$

Now let us consider only the noise component and let it be statistically Gaussian random noise. Consider the second moment about the mean for this distribution (Hoel, 1971, p. 103)

$$m_2 = \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2$$

for an n point digitized noise trace where the x_i are the digitized amplitudes and $\bar{x}$ is the mean value of the amplitude. Now the second moment is the variance, σ^2, from which we obtain the standard deviation, σ, by taking the square root

$$\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2}$$

Thus we can see that the standard deviation is equivalent to the root-mean-square of the trace about the average value. That is

$$\sigma_n = \sigma$$

Let us now see what happens when m such seismic noise traces are added together (Hoel, 1971, p. 121). Consider a seismic noise trace n_i to be a sample from a population n which is normally distributed with mean μ and variance σ^2. Consider a random sample of size m from this normal population. The mean of such a sample,

$$\bar{n} = \frac{1}{m}(n_1 + \ldots + n_m) = \frac{1}{m} \sum_{i=1}^{m} n_i$$

will be a random variable because $n_1, \ldots, n_m$ corresponding to the m traces of the sample are random variables. To find the density function of $\bar{n}$ let us consider its moment generating function

$$M_{\bar{n}}(\theta) = M_{\frac{1}{m}(n_1 + \ldots + n_m)}(\theta) = M_{(n_1 + \ldots + n_m)}(\frac{\theta}{m})$$

Since the sampling is random the variables $n_1, \ldots, n_m$ are independent and therefore

$$M_{\bar{n}}(\theta) = M_{n_1}(\frac{\theta}{m}) \ldots M_{n_m}(\frac{\theta}{m})$$

But random sampling implies that all of $n_1, \ldots, n_m$ have the same density function, namely that of n, and hence the same moment generating function. Therefore

$$M_{\bar{n}}(\theta) = M_{n}^{m}(\frac{\theta}{m})$$

Because n is normally distributed it is known that

$$M_{n}(\theta) = e^{\mu\theta + \frac{1}{2}\sigma^2\theta^2}$$

Therefore

$$M_{\bar{n}}(\theta) = [e^{\mu\frac{\theta}{m} + \frac{1}{2}\sigma^2(\frac{\theta}{m})^2}]^m = e^{\mu\theta + \frac{1}{2}\frac{\sigma^2}{m}\theta^2}$$

This is the moment generating function of a normal variable $\bar{n}$ with mean μ and variance $\frac{\sigma^2}{m}$. The standard deviation is thus $\frac{\sigma}{\sqrt{m}}$ which means that taking a random sample of size m will reduce the standard deviation by a factor of $\frac{1}{\sqrt{m}}$. That is

$$\sigma_{\bar{n}} = \frac{\sigma_n}{\sqrt{m}} \tag{1}$$

Consider now the mean signal function $\bar{s}$ of the sum trace.

$$\bar{s} = \frac{1}{m}(s_1 + \ldots + s_m) = \frac{1}{m}\sum_{i=1}^{m} s_i$$

We know that the signal component of each of the m traces is equal and therefore we have

$$\bar{s} = s_i = s$$

Therefore the root-mean-square average signal remains unaltered.

$$\sigma_{\bar{s}} = \sigma_{s} \tag{2}$$

We have already written the signal-to-noise ratio for a single trace as

$$\frac{s}{n} = \frac{\sigma_s}{\sigma_n}$$

After summing and averaging m traces the signal-to-noise ratio is

$$\left(\frac{s}{n}\right)_{\bar{x}} = \frac{\sigma_{\bar{s}}}{\sigma_{\bar{n}}} \tag{3}$$

Substituting (1) and (2) into (3) we obtain therefore

$$\left(\frac{s}{n}\right)_{\bar{x}} = \frac{\sigma_s}{\sigma_n/\sqrt{m}} = \sqrt{m}\,\frac{\sigma_s}{\sigma_n} = \sqrt{m}\left(\frac{s}{n}\right)$$

APPENDIX 2

PROGRAM: *VERTS*

A. Identification

Title: Vertical Stack

Programmer: D.W. Baer

Date: December, 1971

Language: FORTRAN IV

B. Purpose

To sum up seismic records vertically in order to improve the signal-to-noise ratio.

C. Usage

1. *Operational Procedure:* Subroutines ENT, BLOCK, INI, STAND, SAV and NORMAL, which are called by the main program, read and prepare the input data for stacking. Also, NORMAL stores the data on a direct access disk. The main program then completes the vertical stacking, outputs the stacked record on tape, and may or may not plot it as requested.
2. *Parameters:* R = number of records to be stacked
   N = number of traces in each record
   DI = digitizing interval
   STP = start time in seconds before first breaks

EDTP = end time in seconds after first break

PLOT = "T" for plot, "F" for no plot

A = record number of output record (arbitrary)

PROF = input record number

FBB = block containing first breaks

NST = number of samples up to first breaks (within FBB)

KILL = "1" to include the trace, "0" to omit it

BLK = number of data points per trace on tape (presently 70)

NDPT = number of data points per trace (integer multiple of BLK; presently 1050)

N3 = blocking factor (N3=NDPT/BLK) gives N3 x 0.171 seconds of data per block

FBT = first break time

TT = number of seconds of data to stack (TT=STP + EDTP)

TB = number of tape blocks of data to stack

STB = number of tape blocks before first breaks

SEC = number of seconds before start point in block containing start point

SST = number of samples before start point in block containing start point

MB = block number before block of interest

ZHT = number of seconds of data to plot

MSW = number of blocks to skip before plotting

3. *Input Formats:*

R, N, DI, STP, EDTP, PLOT, A, according to FORMAT (I2, 1X, I2, 1X, F8.6, 2F6.3, L1, 1X, I3)

PROF(I), FBB(I), NST(I), (KILL(I,J),J=1,N) according to FORMAT (2I4, I3, 1X, 12I1) one card for each record

4. *Printout:*

(a) Number of records stacked and time length of data to be stacked.

(b) Input record number, first break time, kill trace information, trace average values and trace standard deviations. This data is listed for each input record in the order in which it is read.

(c) Output record number, number of traces going into each output trace, trace average values and trace standard deviations.

(d) Plotting information if plotting is requested.

5. *Input Tape:* 9 track unprocessed data
6. *Output Tape:* 9 track processed data
7. *Plot Tape:* track processed data. A tape must be mounted whether or not plotting is requested.
8. *Temporary Storage Required:* 2 disks, one of which must be random access. (See note on DEFINE FILE statement in listing)
9. *Time:* 3 seconds per block record input (12 x 70 block size)
10. *Space Requirements:* 170K
11. *Reference:* None

VERTS PROGRAM DESCRIPTION

This program was written to stack records which have a common recording site and shotpoint. Stacking is accomplished by gathering all trace ones to form one output trace, all trace twos, etc. for N traces. Because gain settings, effects of ground to geophone coupling and shot sizes vary from record to record the data must be normalized before stacking. Each trace is normalized by dividing by the standard deviation of the trace. This is computed from the formula

$$\sigma = [\frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2]^{\frac{1}{2}}$$

where n = total number of samples used per trace
$\bar{x}$ = average value of the trace

First the main program reads the initializing parameters and converts STP and EDTP to number of sample intervals. Then the main program, by calling a succession of subroutines, prepares the data for stacking and stores it temporarily on disk. The data is processed record by record. The following six paragraphs briefly describe the subroutines used.

Subroutine ENT reads down the input tape to find the required input record.

Subroutine BLOCK searches for the appropriate starting block, MB, within this record.

Subroutine INI computes the trace average values for this record.

Subroutine STAND computes the trace standard deviations for this record.

Subroutine SAV subtracts the average values from the traces.

Subroutine NORMAL divides the traces by the standard deviations and outputs the record on the direct access disk.

At this point all the input records have been prepared for stacking. Now the main program stacks these records trace by trace to form one output record of N traces. Output traces are also normalized at this time. The output record is stored temporarily on the direct access disk.

The main program then reads the output records, rearranges the samples and outputs the record in 12 x 70 blocked form onto the output tape. The output record is also plotted if a plot is requested. Plotting is accomplished through the use of subroutines DAVE and TPPLT.

```
C *****************************************************************************
C *                                                                           *
C *    THIS PROGRAM STACKS RECORDS SUCH THAT ALL TRACE ONES ARE SUMMED TO FORM *
C * ONE OUTPUT TRACE, ALL TRACE TWOS TO FORM A SECOND OUTPUT TRACE, ETC UP TO  *
C * N - THE NUMBER OF TRACES IN A RECORD.                                      *
C * PROFILES MUST BE READ IN THE SAME ORDER AS THEY ARE RECORDED ON THE INPUT  *
C * TAPE.                                                                      *
C *                                                                           *
C * OUTPUT DATA                                                                *
C * -----------                                                                *
C * OUTPUT PROFILE ON TAPE 13.                                                 *
C * PLOT OF OUTPUT PROFILE IF REQUIRED ( SEE INPUT PARAMETERS ).               *
C *                                                                           *
C * INPUT PARAMETERS (SEE FORMAT STATEMENTS 3 AND 1)                           *
C * ----------------                                                           *
C * R = NO. OF PROFILES TO BE STACKED.                                         *
C * N = NO. OF TRACES IN EACH RECORD.                                          *
C * DI = DIGITIZING INTERVAL.                                                  *
C * STP = START TIME IN SEC. BEFORE FIRST BREAKS.                              *
C * EDTP = END TIME IN SEC. AFTER FIRST BREAKS.                                *
C * PLOT = 'T' FOR PLOT , 'F' FOR NO PLOT.                                     *
C * A = RECORD NO. OF OUTPUT RECORD (ARBITRARY).                               *
C * PROF = INPUT PROFILE NO.                                                   *
C * FBB = BLOCK NO. CONTAINING FIRST BREAKS.                                   *
C * NST = NO. OF SAMPLES UP TO FB ( WITHIN FBB).                               *
C * KILL = '1' TO INCLUDE THE TRACE , '0' TO OMIT IT.                          *
C *                                                                           *
C * OTHER PARAMETERS                                                           *
C * ----------------                                                           *
C * BLK = NO. OF DATA POINTS PER TRACE ON TAPE. ( PRESENTLY 70 )               *
C * NDPT = NO. OF DATA POINTS PER TRACE (INTEGER MULTIPLE OF BLK;PRESENTLY 1050*
C * N3 = BLOCKING FACTOR. (N3 = NDPT/BLK) GIVES N3*0.171 SEC. OF DATA PER BLOCK*
C * FBT = FB TIME.                                                             *
C * TT = NO. OF SEC. OF DATA TO STACK. ( TT = STP+EDTP)                        *
C * TB = NO. OF TAPE BLOCKS OF DATA TO STACK.                                  *
C * STB = NO. OF TAPE BLOCKS BEFORE FB.                                        *
C * SEC = NO. OF SEC. BEFORE START PT IN BLOCK CONTAINING START PT.            *
C * SST = NO. OF SAMPLES BEFORE START PT IN BLOCK CONTAINING START PT.         *
C * MB = BLOCK NO. BEFORE BLOCK OF INTEREST.                                   *
C * ZHT = NO. OF SEC OF DATA TO PLOT.                                          *
C * MSW = NO. OF BLOCKS TO SKIP BEFORE PLOTTING.                               *
C *                                                                           *
C *     IT IS REQUIRED TO CHANGE THE NO. OF 2100 BYTE RECORDS OF DISK STORAGE  *
C * FOR EACH RUN .THIS NUMBER (NO) IS ENTERED IN THE 'DEFINE FILE 14(NO,2100,  *
C * E,INDEX2)' STATEMENT AND IN THE 'SPACE=(2100(NO,10),RLSE)' PARAMETER IN    *
C * JCL . THIS NUMBER IS COMPUTED AS FOLLOWS: NO = N3*N*R+N3. THIS NUMBER MAY  *
C * BE A 3 OR 4 DIGIT NUMBER.                                                  *
C *                                                                           *
C *****************************************************************************
      INTEGER*2 A,B,DATA(12,70),FBB(25),NST(25),TR(12,1050),SUMT(1120),
     1TR1(1050),MB,STB,SST,A1
      INTEGER PROF(25),KILL(25,12),R,N3,BLK,NDPT,TB,NULL(12)
      REAL FBT(25),AVR1(12),AV(12,12),AVR(12),STD(12),STP,EDTP,DI,HDI
      LOGICAL PLOT
      DEFINE FILE 14(292,2100,E,INDEX2)
      BLK=70
      NDPT=1050
      MSW=0
```

```
      CALL TPST
C READ AND CALCULATE INITIAL PARAMETERS.
      READ(5,3)R,N,DI,STP,EDTP,PLOT,A
    3 FORMAT(I2,1X,I2,1X,F8.6,2F6.3,L1,1X,I3)
      WRITE(6,2)R,STP,EDTP,N,DI
    2 FORMAT(1H1,40X,///,' STACK OF',I4,' PROFILES',//,10X,'START',F8.3,
     1' SEC. BEFORE FB,  END',F8.3,' SEC. AFTER FB',' (',I3,' TRACE RE',
     1'CORD.  DIGITIZING INTERVAL=',F10.6,' )',///,' PROFILE NO.',5X,
     1'FB TIME',10X,'KILLED TRACES',31X,'TT',4X,'TB',3X,'N3',2X,'STB',
     15X,'SEC',3X,'SST',/)
      HDI=BLK*DI
      TT=STP+EDTP
      TB=TT/HDI
      TBT=TT-TB*HDI
      IF(TBT.EQ.0.)GO TO 30
      TB=TB+1
   30 M=NDPT/BLK
      N3=TB/M
      M=TB-N3*M
      IF(M.EQ.0)GO TO 31
      N3=N3+1
   31 STB=STP/HDI
      SEC=(STB+1)*HDI-STP
      M=SEC/DI
      IF(M.LT.BLK)GO TO 32
      M=M-BLK
      MSW=1
   32 SST=M
      WRITE(6,900)TT,TB,N3,STB,SEC,SST
  900 FORMAT(72X,F9.3,3I5,F9.3,I5)
C PREPARE DATA FOR STACKING  (DATA TEMPORARILY STORED ON DISK) DATA IS
C PROCESSED RECORD BY RECORD. KILLED TRACES ARE NOT PROCESSED BUT ARE ZEROED.
C READ ONE CARD FOR EACH PROFILE TO BE STACKED. N3*NDPT*DI SEC. OF DATA
C ARE PROCESSED STARTING 'STP' SEC. BEFORE FB.
      DO 10 I=1,R
      READ(5,1,END=99)PROF(I),FBB(I),NST(I),(KILL(I,J),J=1,N)
    1 FORMAT(2I4,I3,1X,12I1)
      FBT(I)=((FBB(I)-1.)*BLK+NST(I))*DI
      WRITE(6,4)PROF(I),FBT(I),(KILL(I,J),J=1,N)
    4 FORMAT(I7,10X,F6.3,5X,12I2)
      WRITE(6,901)FBB(I),NST(I)
  901 FORMAT(15X,2I4)
      DO 600 J=1,N
  600 NULL(J)=KILL(I,J)
      A1=PROF(I)
      CALL ENT(DATA,A1,N,BLK)
      MB=FBB(I)-STB
      IF(MB)20,21,22
   22 CALL BLOCK(DATA,MB,N,BLK)
   21 CALL INI(TR,N,NDPT,AVR1,AV,AVR,N3,BLK,A1,NULL)
      IF(BLK.EQ.1)GO TO 118
      CALL STAND(TR,AVR1,STD,N,NDPT,N3,BLK,NULL)
      INDEX=N3*(I-1)
      WRITE(6,904)
  904 FORMAT(///)
      DO 55 J=1,N3
      CALL SAV(TR,N,NDPT,AVR1,BLK,NULL)
      CALL NORMAL(TR,N,NDPT,STD,J,N3,INDEX,R,NULL)
```

```
   55 CONTINUE
      REWIND 13
   10 CONTINUE
C STACKING ROUTINE. DATA IS PROCESSED TRACE BY TRACE. KILLED TRACES ARE NOT
C PROCESSED.
      M=NDPT+BLK
      DO 64 I=1,M
   64 SUMT(I)=0
      INDEX3=1
      INDEX2=1
      DO 65 I=1,N
      AVR(I)=0
      INDEX=R*N3*(I-1)
      DO 70 J=1,N3
      INDEX1=INDEX+J
      FIND(14'INDEX1)
      DO 75 K=1,R
      IF(KILL(K,I).EQ.1)GO TO 60
      INDEX1=INDEX1+N3
      FIND(14'INDEX1)
      GO TO 75
   60 READ(14'INDEX1,11)(TR1(L),L=1,NDPT)
   11 FORMAT(250A2,250A2,250A2,250A2,50A2)
      INDEX1=INDEX1+N3
   61 FIND(14'INDEX1)
      DO 80 L=1,NDPT
      M=L+BLK-NST(K)
   80 SUMT(M)=SUMT(M)+TR1(L)
   75 CONTINUE
      WRITE(14'INDEX3,11)(SUMT(L),L=1,NDPT)
      INDEX3=INDEX3+1
      DO 76 L=1,NDPT
   76 AVR(I)=AVR(I)+SUMT(L)
      DO 85 L=1,BLK
   85 SUMT(L)=SUMT(NDPT+L)
      DO 90 L=1,NDPT
   90 SUMT(BLK+L)=0
   70 CONTINUE
      DO 95 L=1,BLK
   95 SUMT(L)=0
      AVR(I)=AVR(I)/(N3*NDPT)
   65 CONTINUE
C PREPARE STACKED DATA FOR OUTPUT TAPE . KILLED TRACES ARE NOT PROCESSED BUT
C ARE SIMPLY OUTPUT IN ZEROED FORM.
      WRITE(6,5)A
    5 FORMAT(//,3X,'STACKED RECORD',2X,I3)
      REWIND 13
      DO 135 J=1,N
      DO 125 I=2,R
      KILL(1,J)=KILL(1,J)+KILL(I,J)
  125 CONTINUE
  135 CONTINUE
      WRITE(6,7)(KILL(1,J),J=1,N)
    7 FORMAT(10X,12I3)
      INDEX2=1
      FIND(14'INDEX2)
      DO 100 I=1,N
      STD(I)=0.
```

```
      IF(KILL(1,I).NE.0)GO TO 602
      INDEX2=INDEX2+N3
      GO TO 601
  602 DO 105 J=1,N3
      READ(14'INDEX2,11)(TR1(K),K=1,NDPT)
      DO 110 K=1,NDPT
  110 STD(I)=STD(I)+(TR1(K)-AVR(I))*(TR1(K)-AVR(I))
  105 CONTINUE
      STD(I)=SQRT(STD(I)/(N3*NDPT))*.01
  601 WRITE(6,6)I,AVR(I),STD(I)
    6 FORMAT(20X,'TRACE',I3,5X,'AVE. VAL. =',F11.4,10X,'STD. DEV. =',
     1E15.5)
  100 CONTINUE
      B=1
      DO 115 I=1,N3
      INDEX1=I
      FIND(14'INDEX1)
      DO 120 J=1,N
      READ(14'INDEX1,11)(TR(J,K),K=1,NDPT)
      INDEX1=INDEX1+N3
      FIND(14'INDEX1)
      IF(KILL(1,J).EQ.0)GO TO 120
      DO 121 K=1,NDPT
      TR(J,K)=TR(J,K)-AVR(J)
      TR(J,K)=TR(J,K)/STD(J)
  121 CONTINUE
  120 CONTINUE
C OUTPUT OF STACKED DATA ( AND PLOT IF REQUIRED )
      DO 130 K=1,NDPT,BLK
      L=K+BLK-1
      WRITE(9,8)A,B,((TR(J,M),J=1,N),M=K,L)
    8 FORMAT(2A2,250A2,250A2,250A2,90A2)
      B=B+1
      IF(PLOT)WRITE(13)((TR(J,M),J=1,N),M=K,L)
  130 CONTINUE
  115 CONTINUE
      REWIND 13
      IF(PLOT)GO TO 117
      GO TO 118
  117 CALL DAVE(DATA,N,BLK,SST,EDTP,STP,MSW,DI,KILL)
  118 REWIND 8
      REWIND 9
      REWIND 13
      CALL TPFIN
      GO TO 116
   99 WRITE(6,98)
   98 FORMAT(////,10X,'TOO FEW PROFILE CARDS')
      GO TO 118
   20 WRITE(6,97)
   97 FORMAT(////,10X,'CHECK START TIME DATA')
      GO TO 118
  116 CALL EXIT
      END
```

```
      SUBROUTINE ENT(LOT,A1,N,BLK)
C ENT SEARCHES FOR RECORD 'A1'.
      INTEGER BLK
      INTEGER*2 A,B,A1
      INTEGER*2 LOT(N,BLK)
      DO 58 MS=1,6000
      READ(8,12)A,B,((LOT(I,J),I=1,N),J=1,BLK)
   12 FORMAT(2A2,250A2,250A2,250A2,90A2)
      IF(A.EQ.A1)GO TO 65
   58 CONTINUE
   65 BACKSPACE 8
      RETURN
      END
```

```
          SUBROUTINE BLOCK(DATA,MB,N,BLK)
    C BLOCK SEARCHES FOR THE APPROPRIATE BLOCK 'MB' WITHIN THE RECORD TO BE
    C PROCESSED.
          INTEGER BLK
          INTEGER*2 A,B,MB
          INTEGER*2 DATA(N,BLK)
          II=0
          DO 42 K=1,1000
          READ(8,5)A,B,((DATA(I,J),I=1,N),J=1,BLK)
        5 FORMAT(2A2,250A2,250A2,250A2,90A2)
          II=II+1
          IF(II.EQ.MB)GO TO 45
       42 CONTINUE
       45 RETURN
          END
```

```
      SUBROUTINE INI(T,N,NDPT,AVR1,AV,AVR,N3,BLK,A1,NULL)
C INI COMPUTES AVERAGE TRACE VALUES.
      INTEGER BLK,NULL(12)
      INTEGER*2 A,B,A1
      INTEGER*2 T(N,NDPT)
      DIMENSION AV(N3,12),AVR(N),AVR1(N)
      DO 99 LS=1,N3
      DO 18 K=1,NDPT,BLK
      L=K+BLK-1
      READ(8,2)A,B,((T(I,J),I=1,N),J=K,L)
    2 FORMAT(2A2,250A2,250A2,250A2,90A2)
      IF(A.EQ.A1)GO TO 17
      BLK=1
      WRITE(6,16)
   16 FORMAT(1H1,'     DATA LENGTH TOO SHORT')
      GO TO 90
   17 WRITE(13)((T(I,J),I=1,N),J=K,L)
   18 CONTINUE
      DO 76 I1=1,N
      AV(LS,I1)=0.
      IF(NULL(I1).EQ.1)GO TO 3
      GO TO 76
    3 DO 77 J1=1,NDPT
   77 AV(LS,I1)=AV(LS,I1)+T(I1,J1)
   76 CONTINUE
   99 CONTINUE
      DO 78 NS=1,N
      AVR(NS)=0.
      DO 79 MS=1,N3
   79 AVR(NS)=AVR(NS)+AV(MS,NS)
      AVR1(NS)=AVR(NS)/(NDPT*N3)
   78 CONTINUE
   90 REWIND 13
      RETURN
      END
```

```
      SUBROUTINE STAND(TR,AVR1,STD,N,NDPT,N3,BLK,NULL)
C STAND COMPUTES STANDARD DEVIATION OF TRACES.
      INTEGER BLK,NULL(12)
      DIMENSION E(12,12),STD(N),AVR1(N),E2(12)
      INTEGER*2 TR(N,NDPT)
      DO 29 I3=1,N3
      DO 17 K=1,NDPT,BLK
      L=K+BLK-1
      READ(13)((TR(I,J),I=1,N),J=K,L)
   17 CONTINUE
      DO 30 L3=1,N
      E(I3,L3)=0.
      IF(NULL(L3).EQ.1)GO TO 18
      GO TO 30
   18 DO 31 KT=1,NDPT
   31 E(I3,L3)=E(I3,L3)+(TR(L3,KT)-AVR1(L3))*(TR(L3,KT)-AVR1(L3))
   30 CONTINUE
   29 CONTINUE
      DO 32 IS=1,N
      E2(IS)=0.
      DO 33 LS=1,N3
   33 E2(IS)=E2(IS)+E(LS,IS)
      STD(IS)=SQRT(E2(IS)/(NDPT*N3))*.01
      WRITE(6,34)IS,AVR1(IS),STD(IS)
   34 FORMAT(20X,'TRACE',I3,5X,'AVE. VAL. =',F11.4,10X,'STD. DEV. =',
     1E15.5)
   32 CONTINUE
      REWIND 13
      RETURN
      END
```

```
G LEVEL  20.1                  SAV                    DATE = 71363           21/06/50

      SUBROUTINE SAV(TR,N,NDPT,AVR1,BLK,NULL)
C SAV SUBTRACTS AVERAGE VALUES FROM TRACES.
      INTEGER BLK,NULL(12)
      INTEGER*2 TR(N,NDPT)
      DIMENSION AVR1(N)
      DO 18 K=1,NDPT,BLK
      L=K+BLK-1
      READ(13)((TR(I,J),I=1,N),J=K,L)
   18 CONTINUE
      DO 36 LL=1,N
      IF(NULL(LL).EQ.0)GO TO 19
      DO 37 KK=1,NDPT
   37 TR(LL,KK)=TR(LL,KK)-AVR1(LL)
      GO TO 36
   19 DO 20 KK=1,NDPT
   20 TR(LL,KK)=0
   36 CONTINUE
      RETURN
      END
```

```
G LEVEL  20.1                 NORMAL              DATE = 71363          21/06/50

      SUBROUTINE NORMAL(TR,N,NDPT,STD,J,N3,INDEX,R,NULL)
C NORMAL NORMALIZES TRACES BY DIVIDING BY STANDARD DEVIATION AND OUTPUTS ON
C DIRECT ACCESS DEVICE.
      INTEGER R,NULL(12)
      INTEGER*2 TR(N,NDPT)
      DIMENSION STD(N)
      DO 30 I=1,N
      IF(NULL(I).EQ.0)GO TO 30
      DO 40 K=1,NDPT
   40 TR(I,K)=TR(I,K)/STD(I)
   30 CONTINUE
      DO 50 I=1,N
      INDEX1=INDEX+R*N3*(I-1)+J
      WRITE(14'INDEX1,10)(TR(I,K),K=1,NDPT)
   10 FORMAT(250A2,250A2,250A2,250A2,50A2)
   50 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DAVE(DATA,N,BLK,SST,EDTP,STP,MSW,DI,KILL)
C DAVE SETS UP DATA FOR PLOTTING.
      INTEGER BLK,KILL(25,12)
      INTEGER*2 DATA(N,BLK)
      INTEGER*2 Y(12000),SST,YMAX
      REAL EDTP,STP
      LOGICAL PRNT
      WRITE(6,97)
   97 FORMAT(///,' PLOT DETAILS')
      HDI=BLK*DI
      ZCH=EDTP+STP
      N33=ZCH/HDI
      EKD=HDI*N33
      EFT=ZCH-EKD
      IF(EFT.EQ.0.)GO TO 21
      N33=N33+1
   21 DO 9 IB=1,N
      IF(MSW.NE.1)GO TO 33
      READ(13)((DATA(I,J),I=1,N),J=1,BLK)
   33 II=0
      M1=SST
      IF(M1)8,8,14
    8 M1=1
   14 DO 10 KB=1,N33
      READ(13)((DATA(I,J),I=1,N),J=1,BLK)
      KT=BLK
      IF(KB.NE.N33)GO TO 18
      KT=EFT/DI
   18 DO 11 K=M1,KT
      II=II+1
   11 Y(II)=DATA(IB,K)
      M1=1
   10 CONTINUE
      INDEX=1
      IF(KILL(1,IB).NE.0)GO TO 99
      YMAX=0
      GO TO 98
   99 DO 1 I=1,II
      IY=Y(INDEX)
      IZ=Y(I)
      IF(IABS(IY).LT.IABS(IZ))INDEX=I
    1 CONTINUE
      IY=Y(INDEX)
      YMAX=IABS(IY)
      C=2000./YMAX
      DO 2 J=1,II
      Y(J)=Y(J)*C
    2 CONTINUE
   98 WRITE(6,15)YMAX
   15 FORMAT(' ','YMAX=',I5)
      Y(II)=0
      PRNT=.FALSE.
      CALL TPPLT(Y,1,II,3*DI,1./4000.,.7,PRNT,IB)
    9 REWIND 13
      RETURN
      END
```

```
       SUBROUTINE TPPLT(Y,NO1,NO2,XSL,YSL,DIST,PRNT,IB)
C
C---   DEPARTMENT OF GEOLOGY
C---   UNIVERSITY OF MANITOBA
C
C
C---   INPUT PARAMETERS
C---   INPUT VECTOR Y IN ARGUMENT OF SUBROUTINE
C---   INPUT VECTOR INTEGER*2
C---   NO1 IS FIRST ELEMENT OF VECTOR TO BE PLOTTED
C---   NO2 IS LAST ELEMENT OF VECTOR TO BE PLOTTED
C---   XSL IS XSCALE IN INCHES PER UNIT
C---   YSL IS Y-SCALE IN INCHES PER INTERVAL
C---   DIST IS DISTANCE IN INCHES BETWEEN AJACIENT TRACES
C---   MAX SIZE OF Y .GT. NO1 .GT. 1
C---   MAX SIZE OF Y .GT. NO2 .GT. NO1
       LOGICAL PRNT
       INTEGER*2 Y(1)
       DIMENSION IBUF(5000)
       IF(IB.GT.1)GO TO 7
       CALL PLOT(3.,9.,-3)
     7 IF ( PRNT ) PRINT 1,NO1,NO2,XSL,YSL,DIST
 1     FORMAT (1H1///' PLOTTING BEGINS AT ELEMENT',I4,' OF Y AND ENDS AT       0
      XELEMENT',I5,' X-SCALE IS 1 UNIT EQUALS',F7.5,' INCHES',/,'Y-SCALE
      XIS 1 INTERVAL EQUALS',F7.5,' INCHES',/,'DISTANCE BETWEEN TRACES IS      0
      X',F7.2,' INCHES',/,'PLOTTED POINTS ARE '////)
 2     FORMAT (1H  26I5)
       IF ( PRNT )  PRINT 2,(Y(I),I=NO1,NO2)
       DO 3 I=NO1,NO2
       XD=(I-1)*XSL
       YD=Y(I)*YSL
 3     CALL PLOT(XD,YD,2)
       CALL PLOT(0.,-DIST,-3)
       RETURN
       ENTRY TPST
       CALL PLOTS(IBUF,5000,2)
       RETURN
       ENTRY TPFIN
       CALL PLOT(0.,-DIST,999)
       RETURN
       END
```