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THE SARNIA VIBROSEIS PROJECT

by

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The Sarnia Vibroseis Project

1. Introduction

Vibroseis* is a repetitive source technique wherein truck-mounted hydraulic vibrators, phase-locked to a long duration, frequency modulated pilot signal, exert a quasi-sinusoidal force of many tons on the ground surface, generating seismic waves. The recorded signal consists of a superposition of long wave trains arriving at different times corresponding to the two-way travel time of seismic energy to the various reflecting interfaces. Match filtering (cross-correlation) of the field seismogram with the pilot signal compresses the long wavetrains into short pulses, producing a record that resembles a conventional explosion seismogram.

The potentiality of applying the Vibroseis technique to deep crustal sounding has been of recent interest. Fowler and Waters (1975) have reported refractions and probable reflections to Moho depths in experiments conducted near Kildare, Oklahoma, and Mateker and Ibrahim (1973) observed correlatable events, attributed to deep reflectors, at vertical two-way times of up to 13 s in the vicinity of Beach, North Dakota. A Vibroseis survey at Ahbau Lake, B.C., conducted under contract for the Division of Seismology and Geothermal Studies, produced convincing evidence for a Moho reflector at about 11 s, corroborated by explosion data (Mair and Lyons, 1976).

In August 1974, the Division of Seismology and Geothermal Studies undertook a Vibroseis experiment in the Sarnia - Chatham area of southwestern Ontario. The purpose of this experiment was twofold:

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*Trademark of Continental Oil Company

firstly, to determine the suitability of the technique for crustal studies in a sedimentary basin, and, secondly, to evaluate the feasibility of a non-specialist group "piggybacking" on a Vibroseis survey, using their own facilities for recording and processing the data. Initial estimates of the resources required were $3K for field expenses, $10K (½ manyear) for an analyst and $2K for computer charges.

The project was terminated before the interpretation stage when it became apparent that the initial estimates of manpower and computer resources required would be greatly exceeded. This report outlines the field work, data processing and early results obtained and makes some recommendations for future high-resolution experiments conducted by the Division.

2. Field Work

Two orthogonal lines, each consisting of 24 vibrator positions (VP's) over 4 miles and 12 geophone group positions (GP's) over 2 miles, were shot along intersecting rural roads. The lines intersected at the village of Rutherford, some 7 miles northeast of the town of Dresden, southwestern Ontario, along Highway 21. Figure 1 shows a map of the survey area, with the vibrator positions and group positions indicated by arrows and crosses, respectively.

Each group position consisted of 16 Mark Products 8-Hz geophones in a quasi-tapered array, with an 880 ft. (268.2 m) separation between adjacent takeouts. Initial plans to expand the spreads were abandoned after the loss of several days due to inclement weather and equipment problems.

Vibro-X Explorations Ltd. of Calgary, who were then working in the Sarnia - Chatham area, were contracted to provide the Vibroseis source. Their fee for three V.H.S. Model 11 (15-ton) vibrators with operators, one instrument truck with technician, and a support vehicle with party manager and observer, was $250.00 per hour. This favourable rate assumed the work was done outside of their normal hours of operation.

The source parameters employed were a linear upsweep from 8-32 Hz over 14 s (shown in Fig. 2), with a recording period of about 28 s. This bandwidth was considered to encompass the range of frequencies over which crustal reflections would be observed (Mair and Lyons, 1976), and the sweep direction from low to high frequencies was selected to avoid the effect of interference between late reflections and the harmonic distortion signals from strong early events (Seriff and Kim, 1970). A total of 32 sweeps were made at each vibrator point, between which the vibrators moved ahead slightly to avoid damage to the roadbed.

The recording equipment comprised two Divisional "High Speed" tape systems mounted in the back of an Econoline truck. Each system consisted of a bank of six Geotech AS 330 seismic amplifiers (fixed gain) and a 7-track Precision Instrument 5100 FM tape recorder, modified to operate at 15/16 IPS. Six broadband analogue filtered seismic channels (i.e., half the spread) and an internal chronometer were recorded by each system. During recording the line balance of the amplifiers was continually adjusted in an effort to reduce the ever-present 60 Hz pickup from powerlines along the roadway. Since the anticipated signal-to-noise ratio for a single sweep was considerably less than unity, the amplifier gains were set so that the background noise was just below the level of saturation of the tape. A hard-wired connection from the sweep generator in the instrument truck to our recording truck provided a trigger signal which was passed through a pulse detector circuit and then recorded on top of the time track of each recorder as a time break.

3. Data Processing

Table 1 shows the sequence of data processing stages, including the programs used, their operation, and, for the Cyber, some indication of costs involved. Generally, the early stages of digitization, editing and graphic verification, which required a "hands-on" approach, were performed using the PDP 11/40 minicomputer and peripherals in the Datalab. The heavier computation associated with later processing was relegated to the Departmental CDC Cyber 74. The data from VP 4 N/S (from the first good day of recording) was worked up, with software development and testing proceeding concurrently, to a point just prior to CRP stack.

3.1 Datalab Processing

The field tapes were played back in real time on the Sanborn 3907B tape drive and digitized at 200 Hz using the A/D facility of the PDP 11/40. A simultaneous analogue monitor was produced on the Beckman 8-channel chart recorder. Finding the desired position on the field tape consisted of first getting in the vicinity using a rough footage count and then visually matching the current analogue monitor with a previous chart recording. Since there was insufficient disk storage available to handle 32 sweeps, each vibrating point was digitized in two portions of 16 sweeps each.

Editing the digitized data amounted to breaking it up into records corresponding to a sweep. Trigger pulses on the time track were detected and the sweeps were pared to begin precisely on a trigger pulse and run for a fixed number of seconds. The data, heretofore in standard 252-word blocks, were re-formated, i.e., block-demultiplexed and converted to more efficient 1260-word blocks and written to tape. It transpired that, for purposes of transferring data on magnetic tape from the PDP 11/40 to the Cyber, binary output tapes provided both the best rates of data transfer and compactness.

As shown in part (a) of Table 1, no attempt was made to assess costs for that part of the processing performed in the Datalab. It was found, however, that a typical digitizing session for 6 traces of a single VP, from interconnection and warmup of the machines to verification of the edited output tape, would take the best part of an afternoon. Simple extrapolation of this value for all 12 traces of 48 VP's gives a total time requirement of 48 days! Now, a considerable saving of overhead in terms of set-up, tape handling, etc., could be realized by scheduling longer continuous sessions, but the total amount of time during which the Datalab would be essentially tied up is still formidable. Not included in the above estimate are the many hours actually spent on program development.

3.2 Cyber Processing

Part (b) of Table 1 outlines the processing performed on the Departmental CDC Cyber 74 computer system. The costs indicated are representative of those assessed by the Computer Science Centre, which attempts to run on a cost recovery basis. By far the most expensive processing step (almost 70% of the total) is match filtering (cross-correlation). In this early work, the traditional time domain method, for which programs were already at hand, was used. In principle, a considerable saving could be achieved by implementing a more efficient correlation algorithm such as cyclical convolution (FFT) or the "Fast Correlation" method of Robinson (1975), for high-volume production. Simple extrapolation of the costs shown in Table 1 for all 12 traces of 48 VP's yields a value of $7152. An estimate of the additional costs of CRP stacking and display of final sections required to complete the project would be around $150-$200. Allowing $150 for program testing and development, we arrive at a total projected cost for Cyber processing of about $7500. Even considering the efficiencies inherent in volume production, including a faster correlation procedure, it is unlikely that this figure could be reduced by more than 10-15%.

4. Results and Discussion

Analogue playback of the field tapes showed the data to be very noisy and often dominated by 60Hz. Figure 3 shows one sweep from VP 4 N/S, in which some evidence of the Vibroseis signal may be present in the close-in traces (channels 1-4). For purposes of compact display, the time scale in this and all subsequent seismograms has been compressed. Note the high-amplitude traffic noise stepping out from left to right along the traces. The signal in channel 6 appears to be totally obliterated by noise.

Because of the noisy character of the field records, it was decided at the outset to analogue filter the data using an 8-32 Hz passband prior to digitization. Although, in principle, unwanted noise outside the swept frequency range could be filtered out digitally in later processing, it was feared that high noise levels in the unfiltered input would swamp the A/D converter, causing a loss of precision and leaving very little useful signal amplitude after post-filtering. After a protracted delay in digitizing new data due to the sequential breakdown of several Krohn-Hite filters in Datalab, however, the possibility of eliminating the analogue filtering was re-examined. The VP 4 N/S data was re-digitized without pre-filtering, then processed in the same manner as before.

Comparing the unfiltered results to those obtained previously, the uncorrelated field traces appeared noisier, but the final correlograms were clearer and more peaked. In addition, the polarity of several large-amplitude arrivals was seen to reverse and shift slightly in time. It thus appears that the phase distortion introduced with analogue filtering is more detrimental to Vibroseis processing than is weak signal amplitude without it; the efficiency of the crosscorrelation process in detecting weak signals in noise should not be underestimated. All the examples shown below are from the unfiltered data set.

Fig. 4 shows the vertically-stacked, amplitude-normalized section for group positions 4-9. Each trace represents the algebraic summation of all 32 sweeps of VP 4 N/S, including that shown in Fig. 3. All traces show a varying degree of signal in the early portion of the record. The large glitches at the immediate start and end of the seismic channels result from cross-feed from the trigger pulse on the time track.

An attempt was made in the field to record the actual downtravelling pulse from the vibrators for later use in match filtering. One of the vibrators was set up along side a geophone group, for which all the geophones save one were turned on their sides, and the output signal was recorded at the lowest level of gain. Unfortunately, later processing showed the signal to be severely overloaded and distorted. A theoretical pilot signal, having parameters identical to the vibrator input signal, was therefore devised to simulate the source pulse. This is the signal shown in Fig. 2.

Figure 5 shows the same set of traces as Figure 4 after cross-correlation with the theoretical pilot signal. Some coherent energy is apparent in the first few seconds, but the remainder of the correlogram appears to be incoherent noise. The oscillatory signals occurring in the last few seconds of the record are spurious correlation noise. It is difficult to compare the quality of this limited single-fold data with the Vibroseis data obtained at Ahbau Lake, B.C., since there we have only a finished 12-fold CRP stacked section from the contractor (Mair and Lyons, 1976). It would not appear to be as good as the better single-fold explosion data from B.C., however, since there is no evidence of deep reflectors. A contributing cause of this, no doubt, is the debilitating effect of higher cultural noise (AC powerlines, traffic, etc.) experienced in southwestern Ontario.

The above comments are about as far as we can go with the Sarnia data. Further elucidation of the seismological significance of the exercise would require the digitization and processing of much more data. In particular, the detection of any deep reflectors would probably not be possible before 12-fold CRP stacking of the complete data set to further enhance the signal-to-noise ratio. However, in view of the large amount of time that would be required to complete the project, and also of the projected computer costs being more than triple the $2K originally budgeted, the decision was made to terminate the project at this point. So, reluctantly, the "interpretation" must end here.

low priority

most important

5. Conclusions

Our experience with the Sarnia Vibroseis project has shown the concept of in-house recording (using essentially obsolescent fixed-gain analogue equipment) and processing (using general-purpose computers and designing the software virtually from scratch) of data requiring such ultra-sophisticated handling to be uneconomical in terms of the manpower and computer resources required. Sitting idle in the Vibro-X instrument truck during the survey was a special-purpose SUM-IT VII minicomputer and recording system which could produce vertically stacked, field-correlated digital data records on 9-track computer tape essentially in real time.

opposite conclusion to Universities

The limited processed data available at the termination of the project does not permit a determination of the nature or extent of any deep crustal structure in the survey area. We note that the COCORP group reports successful recording of Moho reflections using the Vibroseis technique in a sedimentary basin in Wyoming (S. Kaufman, personal communication). For similar surveys in the future, it would be advantageous to have a real-time correlation and stacking capability in the field. Then, by experimenting with the source parameters such as signal strength (number of vibrators), sweep duration, and redundancy (number of sweeps at each VP), an adequate signal-to-noise ratio at the receivers for the particular seismic horizon being mapped could be ensured.

With the increasing involvement of the Division in projects requiring high-resolution and/or repetitive source techniques, we should consider either acquiring the necessary state-of-the-art digital recording/playback equipment ourselves (through purchase or rental), or else contracting out the recording and pre-processing segments of the work to others who are so equipped.

6. Acknowledgements

Field operations were carried out by D.A. Forsyth, D. Hearty (summer student), J.A. Mair and J.A. Lyons. W. Shannon helped out on numerous occasions with the digitization process and programming in Datalab.

7. References

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Mair, J.A. and Lyons, J.A. (1976). Seismic reflection techniques for crustal structure studies. Geophysics 41, 1272-90.

Mateker, E.J. and Ibrahim, A.K. (1973). Deep crustal reflections from a vibratory source. Paper presented at the 43rd Annual International SEG Meeting, October 24, in Mexico City.

Robinson, J.C. (1975). A fast-correlation algorithm for swept-frequency seismic data. IEEE Trans. ASSP 23, #4, 346-52.

Seriff, A.J. and Kim, W.H. (1970). The effect of harmonic distortion in the use of vibratory surface sources. Geophysics 35, 234-46.

8. Figure Captions

Figure 1. Plan view of the survey area near the town of Rutherford, southwestern Ontario.

Figure 2. The swept-frequency Vibroseis pilot signal, with an 0.5 s cosine taper at each end.

Figure 3. Analogue playback of a sweep from VP 4 N/S.

Figure 4. The 32-sweep vertically stacked section from VP 4 N/S.

Figure 5. The correlated section from VP 4 N/S.

9. List of Tables

Table 1. Data processing sequence and approximate costs for 6 traces from VP 4 N/S.

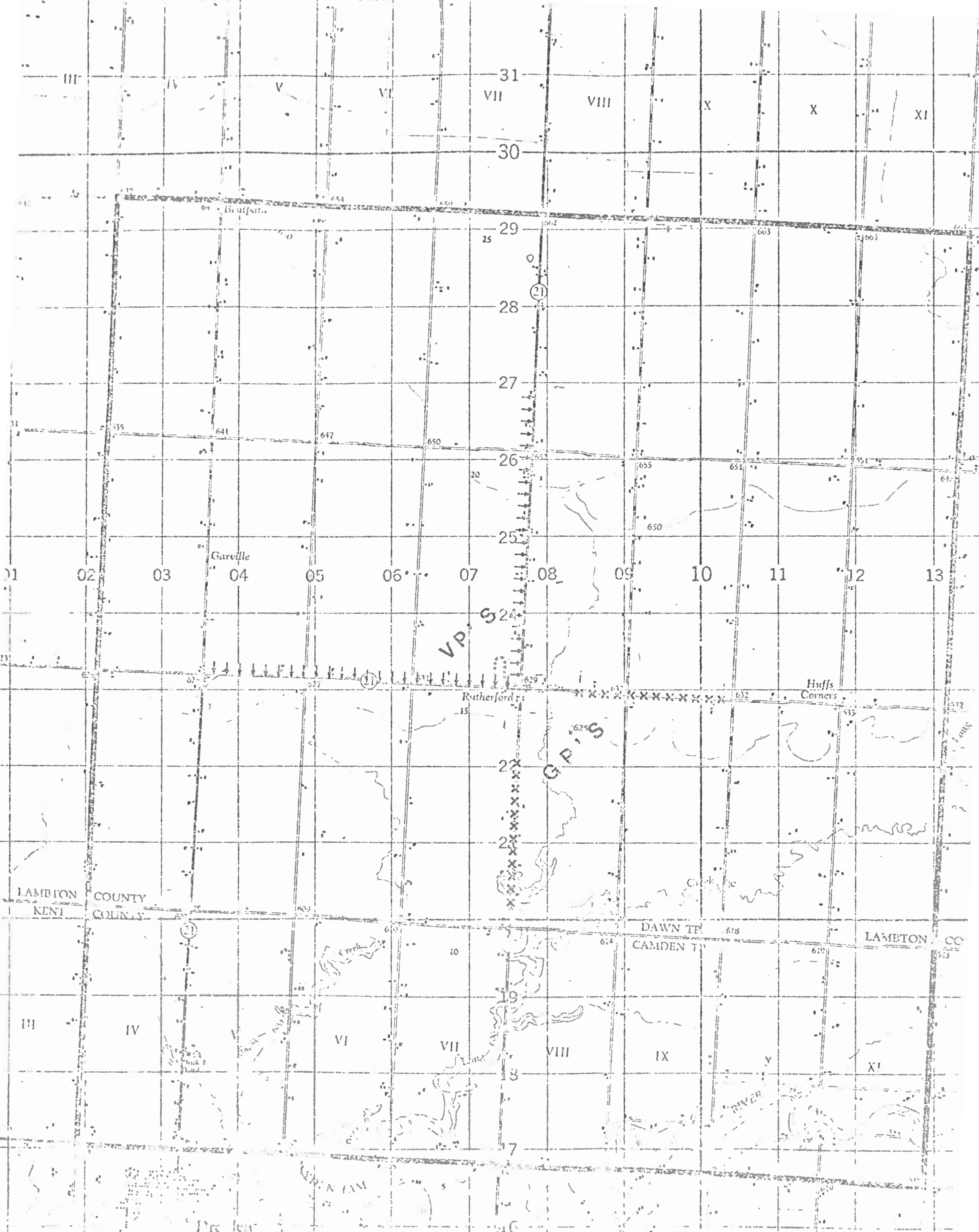
TABLE 1

Data Processing Sequence and Approximate Costs
for 6 traces from VP 4 N/S

Program Name	Operation	Cost ($)
	(a) Datalab PDP 11/40	
INPUT	Inputs digitization parameters	NA*
DGTIZ5	Digitizes analogue field tapes	NA
SEARCH	Detects trigger pulses separating sweeps on the time track	NA
VPEDB5	Edits the sweeps, partially demultiplexes the data, and re-formats it onto a binary output tape for use on Cyber	NA
LVPLT5	Plots the edited sweeps on the LV11 electrostatic plotter for quality control	NA
	(b) Departmental CDC Cyber 74	
VDMPXB	Reads the Datalab tape, converts to Cyber word structure, completes demultiplexing the data into trace order, and transcribes it to a standard Cyber-format output tape	$13.00**
VSTACK	Vertically stacks (sums) all 32 sweeps and transcribes to disk	5.50
MATCHF	Match filters (correlates) the field traces with the pilot sweep signal and transcribes to disk	51.00
VPLOTN	Produces calcomp plot of correlated traces with normalized amplitudes	5.00
	TOTAL	$74.50

*NA - costs not assessed

** - costs assessed by the Computer Science Centre


III
IV
V
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VII
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Bentpath
Garville
Rutherford
Huffs Corners
VP'S
GP'S
21
LAMBTON COUNTY
KENT COUNTY
DAWN TP
CAMDEN TP
LAMBTON CO
Creek
RIVER
CHATHAM

FIGURE 2.

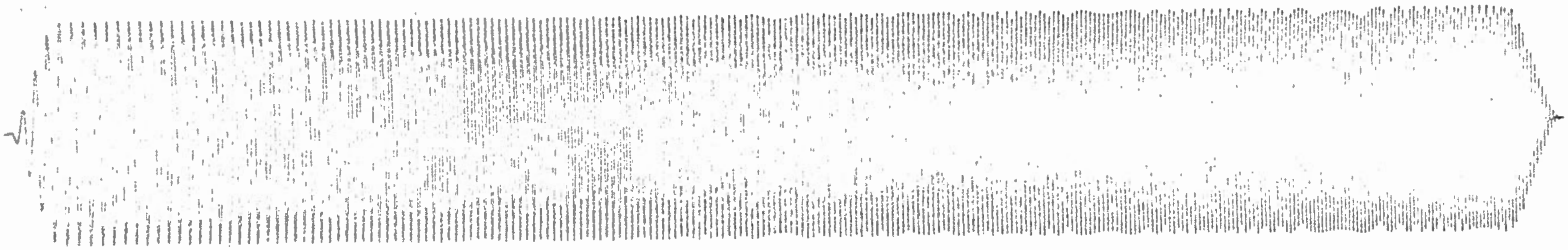
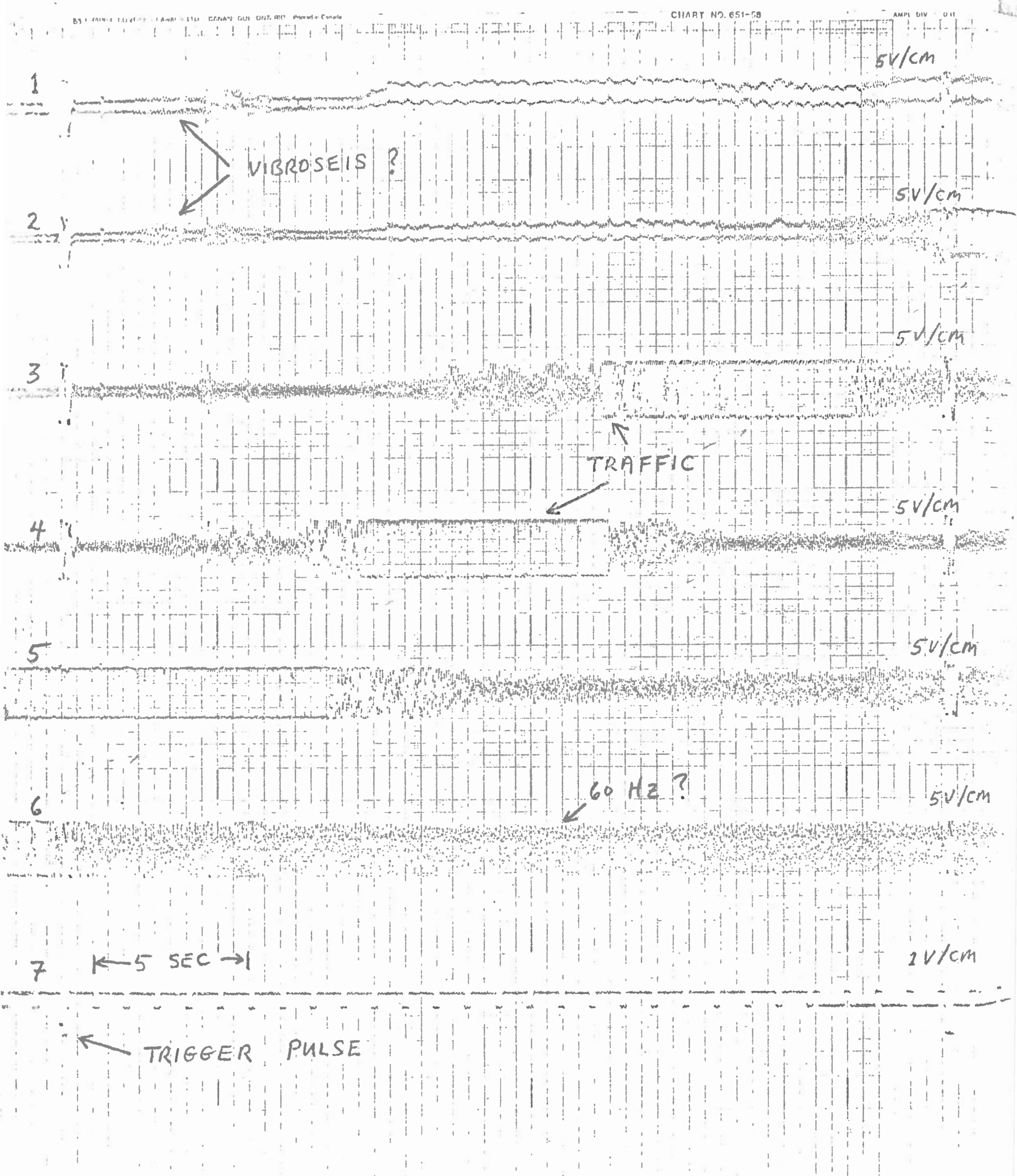


FIGURE 2.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VIBROSEIS ?
2
5V/cm
3
5V/cm
TRAFFIC
4
5V/cm
5
5V/cm
6
60 Hz ?
5V/cm
7
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1V/cm
TRIGGER PULSE

FIGURE 3.

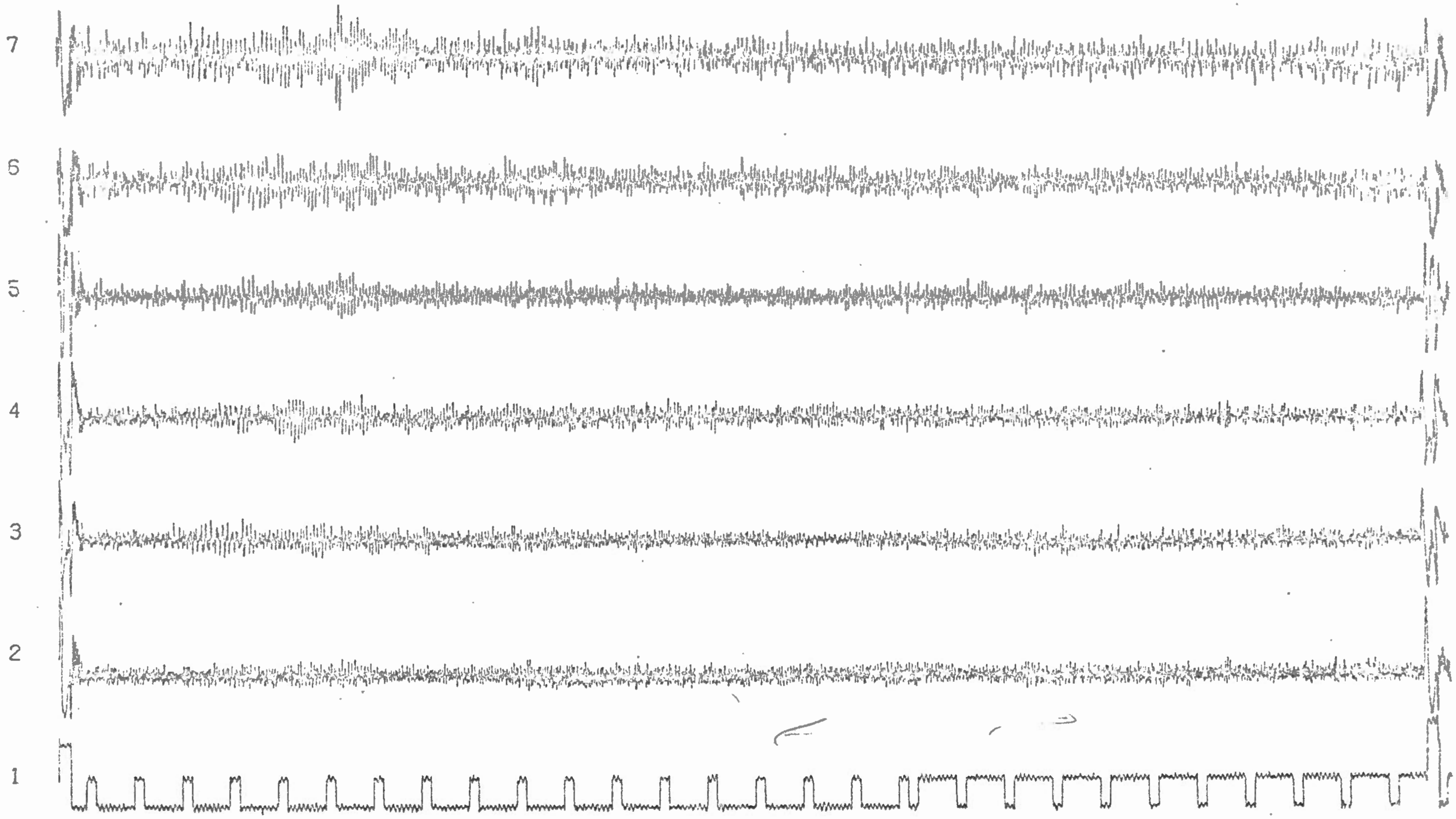

FIGURE 4.

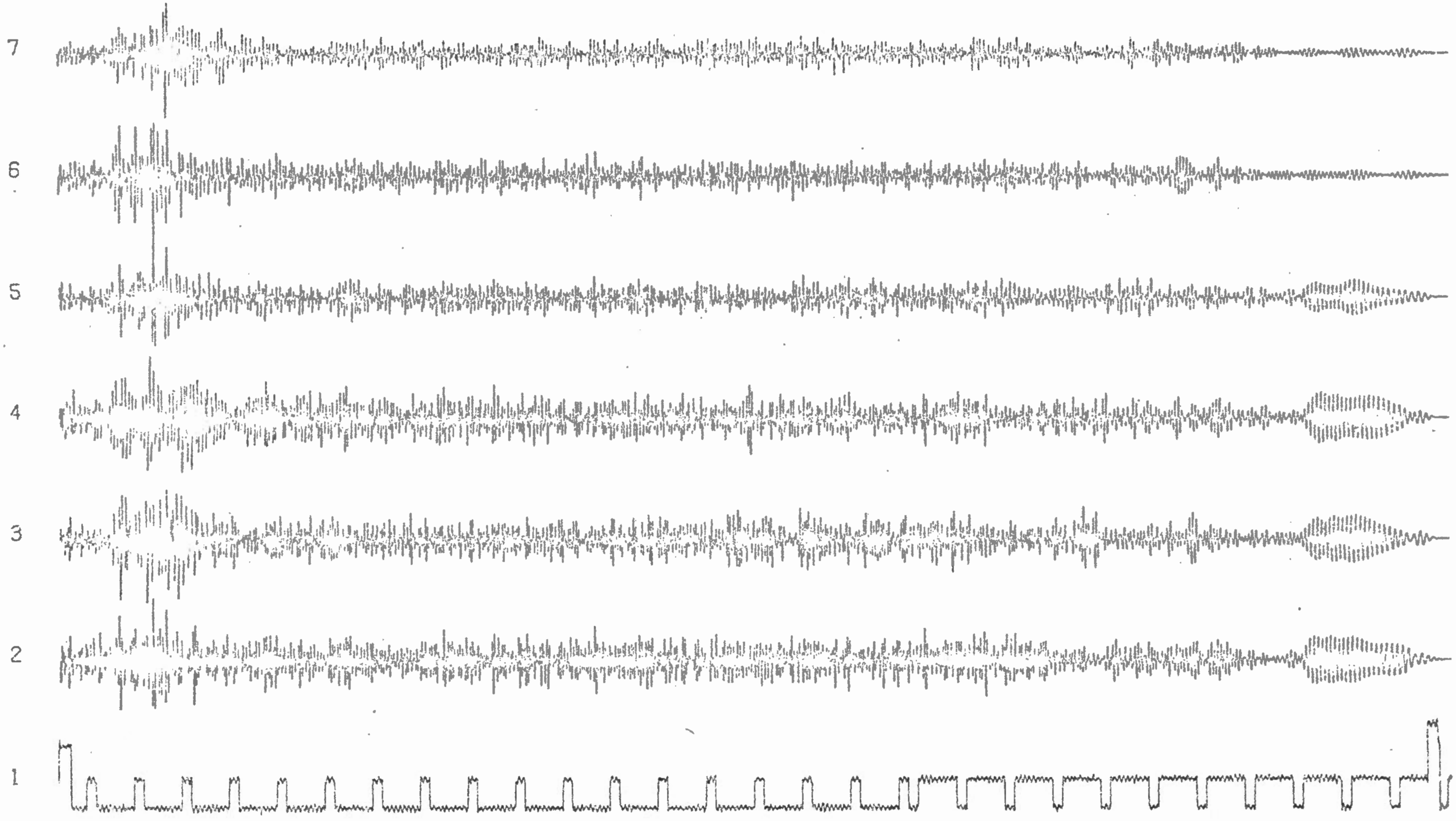

FIGURE 5.