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# Observations from self-potential monitoring studies on Kilauea Volcano, Hawaii (1973-1975)

by

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## Introduction

Self-potential (SP) surveys made on Kilauea Volcano, Hawaii beginning in mid-1972 have shown that large magnitude, positive-potential anomalies are related to subsurface localization of heat (Zablocki, 1976). Soon after this relationship was established, a concurrent study was made to determine the stability of these natural potentials over long periods of time. This study was considered important because in eventually mapping the self-potential distribution over Kilauea's summit and upper rift zones, an area encompassing approximately 100 km$^2$, it was necessary to tie-in newly surveyed sections with sections previously surveyed. If the potentials measured earlier had changed appreciably, then errors would result when compiling the overall regional potential distribution.

Several factors were considered that could possibly result in temporal changes in these potentials: (1) variations in rainfall, particularly in view of the extreme range of precipitation that occurs on Kilauea; and (2) changes in the dynamic state of the volcano during the survey period in which six eruptive episodes took place. Also, some of these eruptions broke out exactly over, or immediately adjacent to, some previously mapped positive potential anomalies. This observation provided a further impetus to monitor potential differences in a few areas over long time periods to determine if perceptible changes could be correlated with an imminent eruption or magma migrations.

These monitoring studies were not comprehensive. They were limited in scope because of equipment and manpower limitations at the time. The results from these studies, nevertheless, did provide some information about the stability of the self potentials. In view of the continuing SP program at the Hawaiian Volcano Observatory (HVO), the measurement techniques, results, conclusions, and recommendations related to these studies are presented here as they should be helpful in designing more systematic studies in the future.

## Measurement Techniques and Results

In some of these studies, potential differences were measured periodically on a semi-daily or weekly basis at a few locations. Non-polarizing Cu/$CuSO_4$ electrodes were buried about 25 cm below the surface and connected to a high-input impedance voltmeter by an insulated wire laid out on the ground.

One such monitoring site was established about 300 m southeast of Halemaumau (D-D, fig. 1). A 120-m length electrode array was laid out across the northern edge of a steep gradient SP anomaly that was mapped earlier and which coincides with a local feature called Sand Spit horst (Zablocki, 1976). The magnitude and steep gradient of the anomaly (fig. 2) suggested that the top-of-the-source for these potentials was very shallow (< 30 m). It was suspected that a shallow source might especially be affected by changes in rainfall and thus alter the magnitude of the surface potentials.

A plot of the potential differences measured across D-D′ from November 13, 1973 through July 8, 1974 is shown in figure 3. The most striking feature noted in this plot is the rapid decrease in potential that is clearly related to periods of intense rainfall (also shown in figure 3). This is particularly so for November 17, 1973 and December 4, 1973 during which times, over 20 cm of rain was recorded at HVO. The sharp decrease in SP (~75 millivolts) was usually followed by a longer period of recovery to some increased value in potential. Possible explanations for these observations are:

1. The fresh rainwater may have diluted the known shallow, electrolytically conductive zone that coincides with the SP anomaly (Zablocki, 1978a). This could have resulted in a local decrease in the conductivity of the medium. If the source mechanism for these potentials is equivalent to a voltage source resulting from streaming potentials caused by the descent of meteroric water (Zablocki, 1978b), then such a decrease in the surface potentials would be expected.
2. The longer recovery time could be related to an increase in time required for the pore fluids at shallow depths to regain their higher concentration of electrolyte, and perhaps, their higher temperature.
3. The shallow-buried electrodes used in this study were not covered by a plastic sheet as they were in the monitor study in the upper east rift zone (to be described later). In the upper east rift zone study, no changes in potential could be related to changes in rainfall. Therefore, it is possible that the large changes noted in the Sand Spit study were due to local electrode effects.

Because of the large variations in potential observed in this area, tie-in points made to extend our SP coverage in Kilauea were located in areas that did not contain shallow, high-amplitude anomalies.

An in-line array of six 300-m spaced electrodes was placed across a previously mapped large-amplitude SP anomaly located about 3.5 km south of Halemaumau (stations 0-5, figs. 1, 4, and 5). The potential gradient in this area is about 1 millivolt per meter and exceeds 2 millivolts per meter at the steepest part of the gradient. It was thought that this gradient defined the southeast edge of Kilauea's magma reservoir (Zablocki, 1976) and that any measured changes in the gradient might be related to temporal changes in the state of the reservoir itself.

A plot of the measured potential differences between successive pairs of electrodes and the accumulative difference across the total array are shown in figure 6. The time period of this study was between January 18, 1973 and November 14, 1973; however, no data were obtained for the period July 13, 1973 through October 29, 1973 because of commitments to other projects. Some of the large, short-term changes in potential differences seen in the plot are due primarily to spurious potentials developed from one or more faulty porous pots. The effect of the resulting instability in the potential can be seen by noting that the changes in some adjacent electrode pairs are of opposite polarity. For example, on days 180 and 183, the changes are in opposite directions for SP differences 3-2 and 2-1. This can be explained by an anomalously higher potential at the number 2 electrode. Notwithstanding these short-term changes, there is long-term net decrease in the total potential difference over the period of these measurements. A plot of the potential differences across the whole array for the initial (1/18/73) and final (11/14/73) set of measurements is shown in figure 7. Virtually the entire decrease can be attributed to the decrease across the electrode pair 3-2; the section where the gradient is the largest. As seen in figure 6, most of this change occurred between days 18 and 123. It is interesting to note that this general monotonic decrease essentially ceased at the approximate time of the May 5th eruption (123 days). The eruption took place in the upper east rift zone, about 3 km east of the electrode array, and was accompanied by substantial deflation of the surface in the summit area (Hawaiian Volcano Observatory, unpublished data, 1973). A possible causal relationship between these observations is not clear. The near-daily measurements made a few days before, during, and after this eruption did not reveal any dramatic changes in these potentials (fig. 6).

Continuous measurements were recorded over long time periods across and parallel to a prominent ridgelike SP anomaly that lies over the surface expression of the upper east rift zone (fig. 8). Conventional Cu/$CuSO_4$ nonpolarizing porous pots were placed in holes about 50 cm below the surface at locations A, B, and C shown in figure 1. A 1 X 1 m piece of plastic sheet was placed over a pot, then covered with soil. It was felt that the plastic cover would reduce any deleterious effects at the electrode due to large variations in rainfall and ambient temperature.

Insulated wires, connected to electrodes B and C (fig. 8), were laid out and returned to the vicinity of electrode A near the intersection of the Hilina Pali and Chain of Craters roads. The potential differences between electrodes A-B and B-C were recorded using a simple, high-input impedance amplifier connected to a single stylus, multiplexed DC chart recorder. The recording system was placed in a small weatherproofed metal box. The box and a 12 V, 50 ampere-hr battery, used to power the recorder, were placed under a waterproofed, opened-bottom wooden box.

A schematic of the amplifier and multiplexing circuit used to record potentials from both legs of the array is shown in figure 9. The input leads from the electrodes were connected to a RC low-pass filter (1 second time constant). As the nominal potential differences between A-B and C-B were +1200 and +800 millivolts, respectively, an SP bucking circuit was designed that resulted in canceling these large voltages at the input of the amplifier. A double-pole double throw microswitch, actuated by a cam into the recorder, alternately switched the net voltages every 8 seconds into the recorder. The non-inverted configuration of the amplifier resulted in an input impedance of $10^9$ ohms. A voltage gain of five was used and the output gain to the recorder was trimmed to effect a full-scale chart sensitivity (50 mm wide) of 100 millivolts. The chart drive motor was speed regulated to about ±0.5 percent and fed the chart paper at a rate of about 15 cm per day.

The recording system, in design, could be left unattended for a maximum period of about 5 weeks, being limited primarily by the chart-paper capacity. Two 1.35 volt mercury batteries powered the amplifier and their expected life was 3 years. The 12 volt battery used to run the chart drive motor, was typically changed every five weeks. Interruptions in recording data, however, were caused either by an occasional loss of fluid in one fairly permeable porous pot (electrode C) or by commitments of personnel to other projects.

The monitoring system was operated essentially continuously between June 23, 1974, and October 17, 1974, and between November 12, 1974 and January 13, 1975. Records for the time interval June 23 - October 17, 1974 are shown in figures 10 a through g. Several characteristics of these recorded potential differences are noted:

1. The diurnal periodicity, best seen on the A-B trace, is due to induction from corresponding diurnal changes in the earth's magnetic field. In detail, the predominant frequencies of the diuranl changes noted on the traces are 2 and 4 cycles/day. Electric field power spectra made by Larson (1975) on Oahu show strong peaks at these diurnal harmonics that are related to the thermally-induced ionospheric currents.
2. The high-frequency disturbances, particularly seen across the B-C electrode trace, are related to micropulsations, that is, short-time variations in the magnetic field due to solar activity. The correlation between these electric field disturbances and the horizontal component of the magnetic field taken from magnetograms obtained from the magnetic observatory in Honolulu, Hawaii (figs. 11a, b, and c) is quite evident. Specific examples showing this correlation are indicated on the electric and magnetic field records by the circled letters, A, B, C, and D.
3. The larger high-frequency disturbances observed across B-C as compared to A-C possibly result largely from preferential polarization of the inducing field caused by the large conductivity contrasts between the island and the ocean. For a single vertical contact, the tangential electric field is continuous across the boundary, whereas the perpendicular component is discontinuous. The larger changes across B-C could occur, therefore, because this array was oriented nearly perpendicular to the coastline (see fig.

1). Another possible explanation for the larger high-frequency electric fields along B-C is that induced currents, collimated along the assumed higher conductivity east rift zone (ionically conductive magma), encounter a narrowing or increased resistivity in the zone beneath the region of these measurements.

4. Notwithstanding a nominal potential difference across A-B of about 1200 millivolts, there were no substantial changes in the steady-state potential differences noted (< 15 millivolts) during the entire period that this study was made. This period included the time of three eruptive events and some periods of extremely variable rainfall. The closest eruption to the monitoring site occurred on July 19, 1974 in the vicinity of Keanakakoi and Lua Manu crater (fig. 1). A short-lived eruption took place in and immediately southwest of Halemaumau (fig. 1) on September 19, 1974. The third eruption broke out on December 31, 1974 between the southwest rift zone and the Koae fault system (fig. 1). The time of the first two eruptions are indicated on the potential difference records (figs. 10b and e). No changes in the potentials were noted before, during, or immediately after these events. Remeasurements of SP profiles in the immediate vicinity of these eruptions, however, did produce substantial changes (see for-example, Zablocki, 1976). It is concluded, therefore, that changes in SP related to eruptions are probably very localized.

As mentioned previously, the porous pot used at electrode C was more permeable than the others and this lead to excessive loss of fluid. The results of this leakage are evident on the B-C trace for the time intervals 7/16-8/13 and 9/3-9/11/74.

## Conclusions

From the results of this study, the following conclusions may be drawn:

1. Large changes in potentials may occur with time, particularly in areas of very shallow anomalies such as at Sand Spit. The changes here possibly are caused by the infiltration of rainwater that alter the conductivity of the medium in and above the anomaly-producing source. In contrast, anomalies related to deeper-seated sources, such as occur in the upper east rift zone, appear to be stable over long time periods regardless of the amount of rainfall.
2. Other than obvious changes in potentials noted directly over or in the immediate vicinity of recent eruptions, the potentials appear to be stable several hundreds of meters away from the active vents.
3. The apparent decrease in potentials observed particularly across electrode pair 3-2 of the monitoring site in the south part of Kilauea's summmit area may be related to changes in the summit magma reservoir complex. It is important to realize, however, that the steep gradient of this SP anomaly implies a fairly shallow depth (< 300 m) to the top of the source. Therefore, the changes in potential must result from corresponding changes in the electrical properties of the lavas at shallow depths (that is, near the local water table) and not directly from the deeper reservoir (2-3 km).

## Recommendations

This study has pointed out some of the following factors that should be considered in future self-potential studies on Kilauea:

1. Tie-ins to previously surveyed areas should be made at locations where the potential distribution is fairly uniform and not in the vicinity of steep gradients. Preferably, the tie-in should consist of at least a two-station overlap rather than at a single station.
2. The shortcomings of using conventional porous pots (too permeable) as monitoring electrodes could be overcome by using low-permeable gel-type electrodes.
3. Monitoring studies should be made only with a continuous recording scheme rather than by making periodic measurements. Only in this manner can spurious effects from telluric currents and micropulsations be recognized.
4. A continuous monitoring system over the Sand Spit SP anomaly could include a low-powered resistivity sounding system. Any possible correlation between changes in SP with respect to the resistivity of the shallow ash deposits here could shed some additional insight into the principal source mechanism responsible for these large magnitude anomalies.

The continuous monitoring studies in the upper east rift zone demonstrated the profound contrast in the responses between the mutually perpendicular electric field arrays caused by micropulsations. Some computer modeling studies might be helpful in determining wnether or not the island effect is the reason for the larger electric fields occurring across the B-C array (perpendicular to the coastline). The possibility that the reason lies in collimated induced currents along the conductive rift zone that encounter a narrower or increased resistivity zone could be reasonably tested. Telluric measurements could be made across the upper and lower parts of the east rift zone. Considering the difference in the alignment of rift zone with respect to the coastline in these two areas, one might be able to sort out the cause. If the differences in electric field responses would be determined to be due primarily to collimation of currents in the rift zone, then telluric current studies could provide useful information on the dynamic volcanologic processes in Kilauea.

## References

Larson, J. C., 1975, Low frequency (0.1-6.0 cpd) electromagnetic study of deep mantle electrical conductivity beneath the Hawaiian Islands: Geophys. J. R. Astr. Soc., v. 43, p. 17-46.

Zablocki, C. J., 1976, Mapping thermal anomalies on an active volcano by the self-potential method, Kilauea, Hawaii, in Proceedings of the Second U.N. Symposium on the development and use of geothermal resources, San Francisco, Calif., May 1975, v. 2: pp. 1299-1309.

________1978a, Application of the VLF induction method for studying some volcanic processes of Kilauea Volcano, Hawaii: Journ. of Vol. and Geotherm. Res., v. 3, pp. 155-195.

________1978b, Streaming potentials resulting from the descent of meteoric water--a possible source mechanism for Kilauea self-potential anomalies: Geothermal Resources Council Annual Meeting 25-27 July, 1978, Hilo, Hawaii Trans., v. 2, pp. 747-748.

## Figure Captions

Figure 1: Index map of Kilauea's summit area and upper rift zones. Lettered and numbered straight-lines segments are locations of self-potential monitoring sites discussed in text.

Figure 2: Self potential contour map of Sand Spit horst. Data obtained 7/73-8/73. Contour interval = 50 millivolts; dashed where inferred.

Figure 3: Plot of potential differences measured across D-D′ (fig. 2) for the period 11/3/73-7/8/74. Rainfall data for same period was obtained from rain gauge located near Hawaiian Volcano Observatory.

Figure 4: Map showing location of self-potential monitoring site in Kilauea's lower summit area.

Figure 5: Self potential contour map of a part of Kilauea's summit area (modified from fig. 2 in Zablocki, 1976). Numbered straight-line segment is location of self potential monitoring site shown in figures 1 and 4. Contour interval = 0.1 V; hachures indicate areas of closed lows.

Figure 6: Plot of self potential differences measured across successive pairs of electrodes and the accumulative difference across the total electrode array shown in figures 4 and 5. NR indicates no readings obtained across electrode pair 1-0 on days 170 and 179.

Figure 7: Plot of potential differences across electrode array shown in figures 4 and 5 for initial (1/18/73) and final (11/14/73) set of measurements. Potentials are referenced to electrode 5. Note that change can be attributed primarily to a decrease in potential across electrode pair 3-2.

Figure 8: Self-potential contour map of a part of Kilauea's upper east rift zone (modified from fig. 2 of Zablocki, 1976). Contour interval is 0.1 volts. Lettered straight-lines segments are locations of self-potential monitoring sites shown in fig. 1.

Figure 9: Schematic of amplifier and multiplexing circuit used to record potential differences between A-B and B-C (figs. 1 and 8).

Figure 10a through 10g: Records of continuous self-potential measurements across electrode pairs A-B and B-C (locations shown in fig. 8). Circled letters A through D designate specific examples of of times that correlate with magnetic events shown in figures 11a, b, and c.

Figure 11a, b, and c: Records of the horizontal component of the Earth's magnetic field (average declination 11° east of north) taken from magnetograms obtained at the magnetic observatory in Honolulu, Hawaii. Circled letters are keyed to specific magnetic events that correlate in time with potential difference records shown in fig. 10. HST is Hawaii Standard Time.

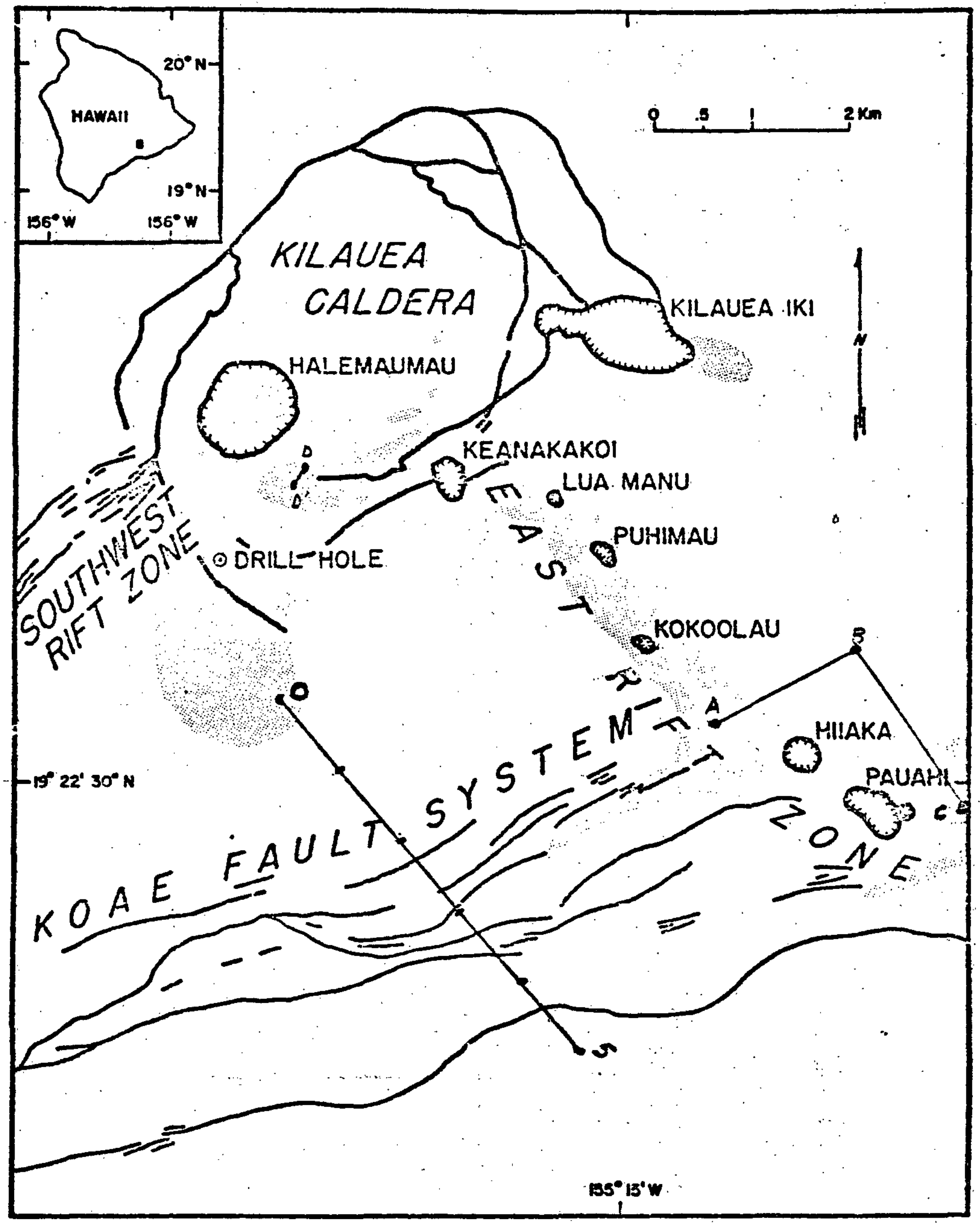

20° N
HAWAII
19° N
156° W
156° W
0 .5 1 2 Km
N
KILAUEA CALDERA
KILAUEA IKI
HALEMAUMAU
D
D'
KEANAKAKOI
LUA MANU
PUHIMAU
KOKOOLAU
DRILL HOLE
SOUTHWEST RIFT ZONE
EAST RIFT ZONE
B
A
HIIAKA
PAUAHI
C
O
5
19° 22' 30" N
KOAE FAULT SYSTEM
155° 15' W

Figure 1

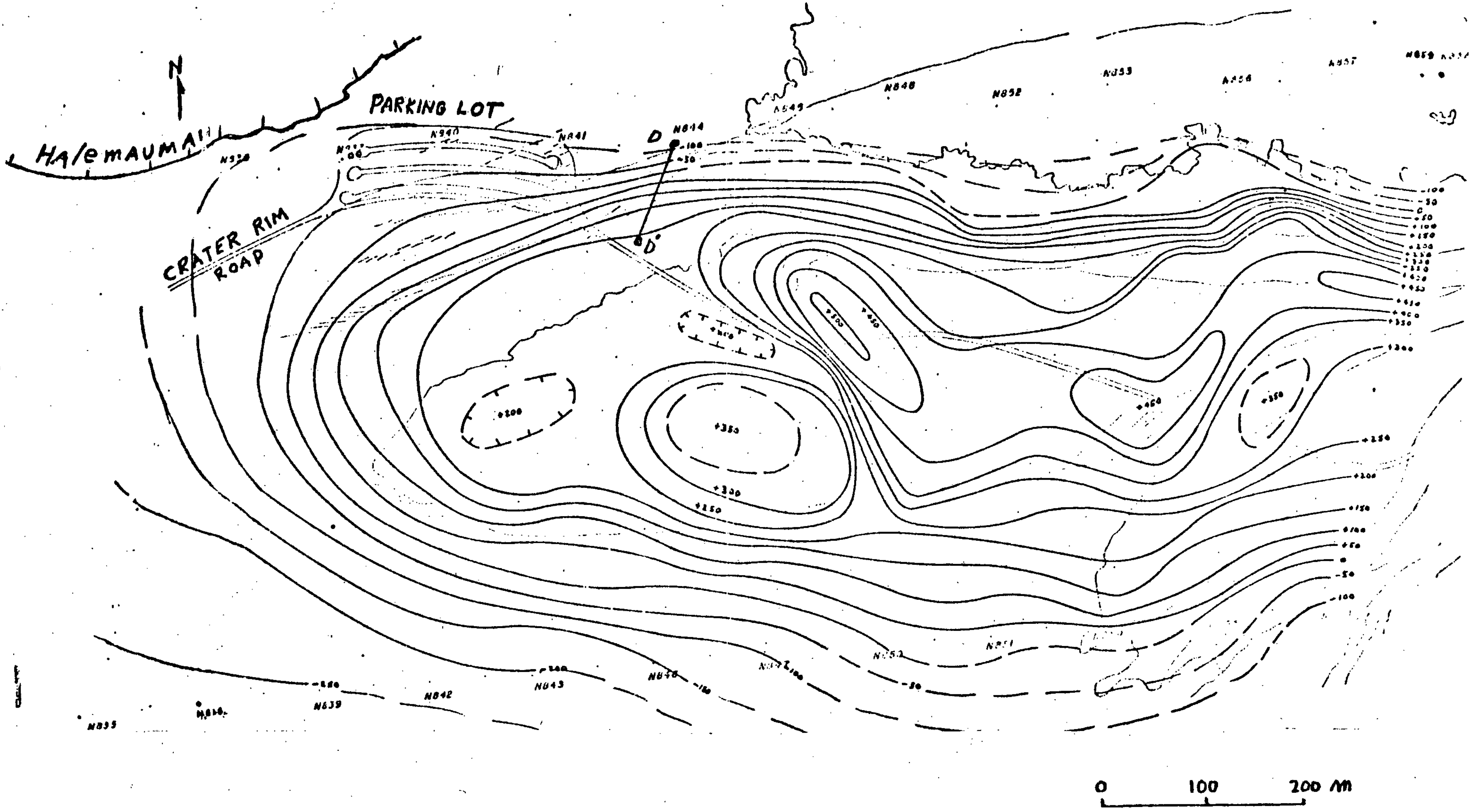

N
Halemaumau
PARKING LOT
CRATER RIM ROAD
D
D'
N844
N840
N841
N838
N848
N849
N852
N853
N856
N857
N859
N835
N839
N842
N843
N846
N852
-100
-50
0
+50
+100
+150
+200
+250
+300
+350
+400
+450
+500
0
100
200 m

Figure 2

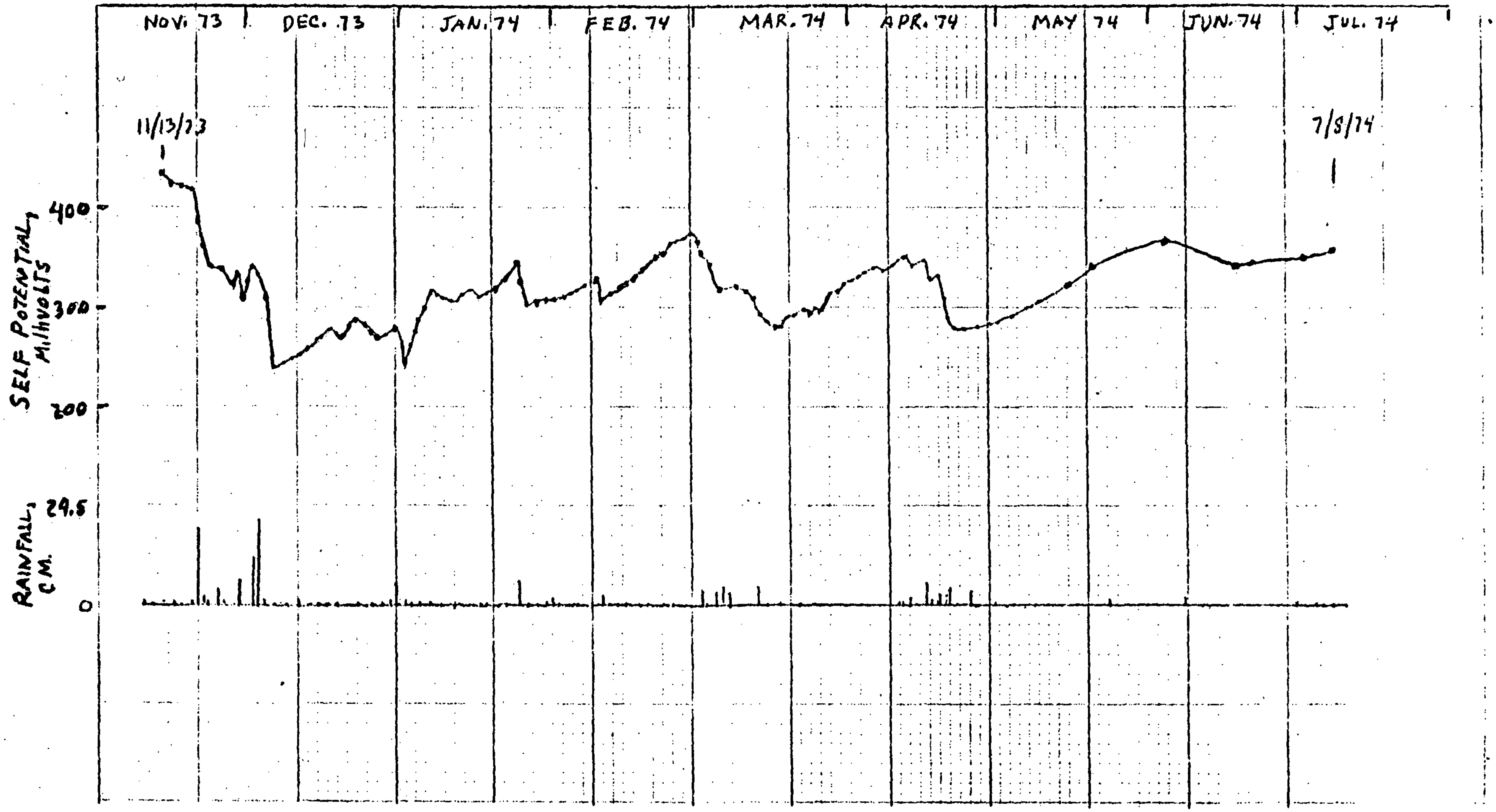

NOV. 73
DEC. 73
JAN. 74
FEB. 74
MAR. 74
APR. 74
MAY 74
JUN. 74
JUL. 74
11/13/73
7/8/74
SELF POTENTIAL, Millivolts
400
300
200
RAINFALL, CM.
24.5
0

Figure 3

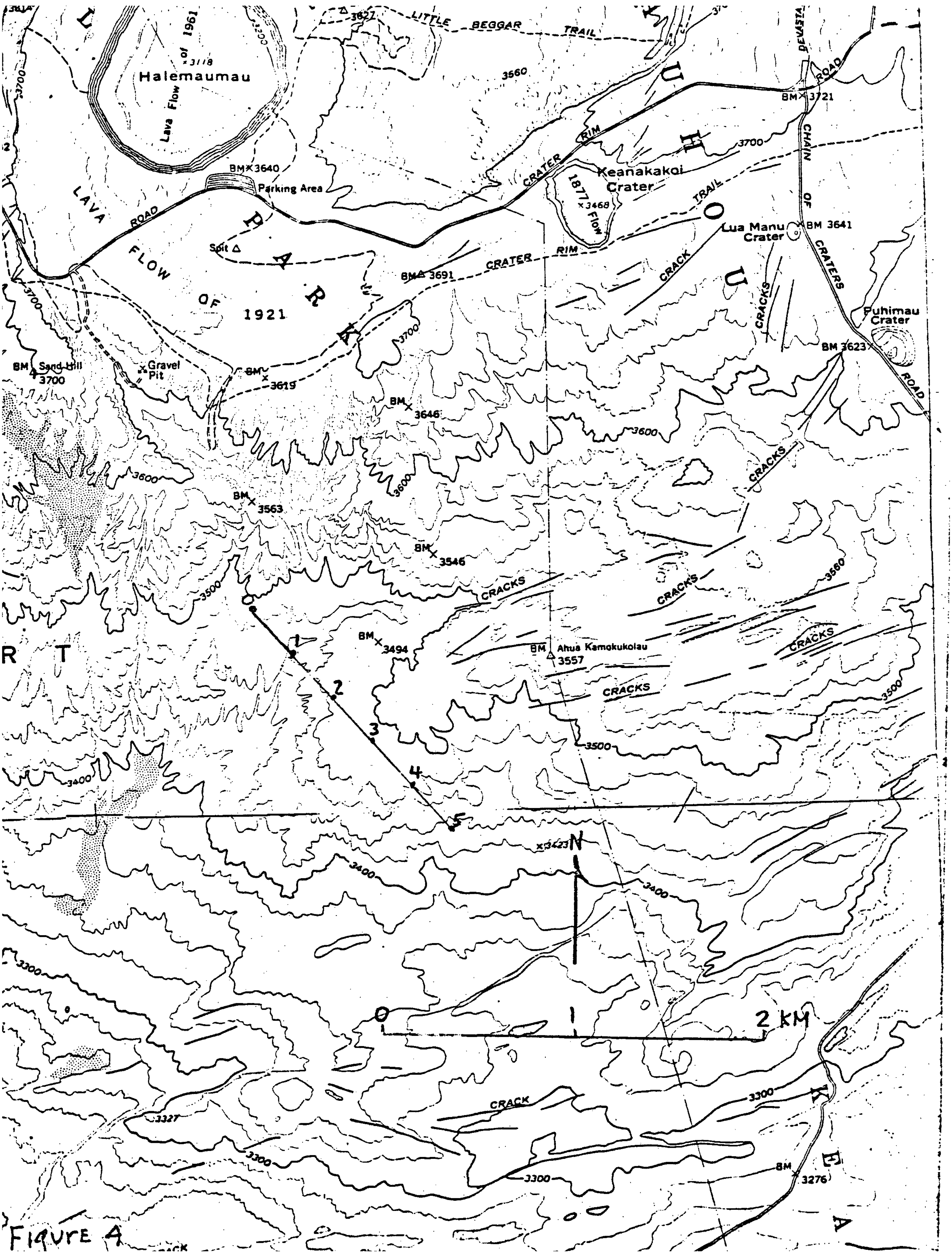

LITTLE BEGGAR TRAIL
Halemaumau
Lava Flow of 1961
3118
3627
3560
3700
BM 3640
Parking Area
LAVA FLOW OF 1921
ROAD
Spit
PARK
CRATER RIM
Keanakakoi Crater
1877 Flow
3468
BM 3691
TRAIL
Lua Manu Crater
BM 3641
BM 3721
DEVASTA
ROAD
CHAIN OF CRATERS ROAD
Puhimau Crater
BM 3623
CRACK
CRACKS
BM Sand Hill 3700
Gravel Pit
BM 3619
BM 3646
3600
BM 3563
BM 3546
3500
3560
BM 3494
BM Ahua Kamokukolau 3557
0
1
2
3
4
5
3423
N
3400
3300
3327
0
1
2 KM
BM 3276
R T
U H O U
K E A

Figure 4

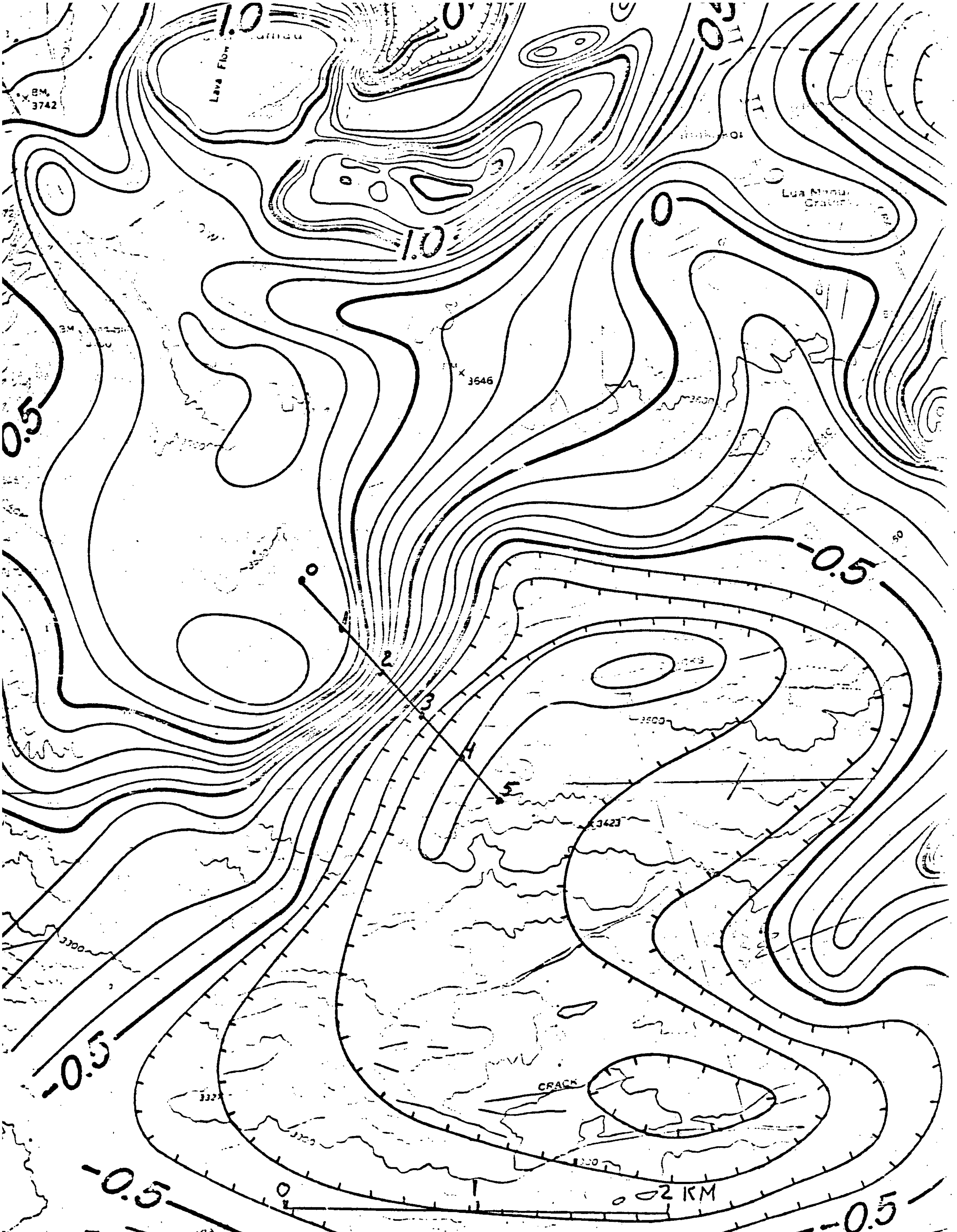
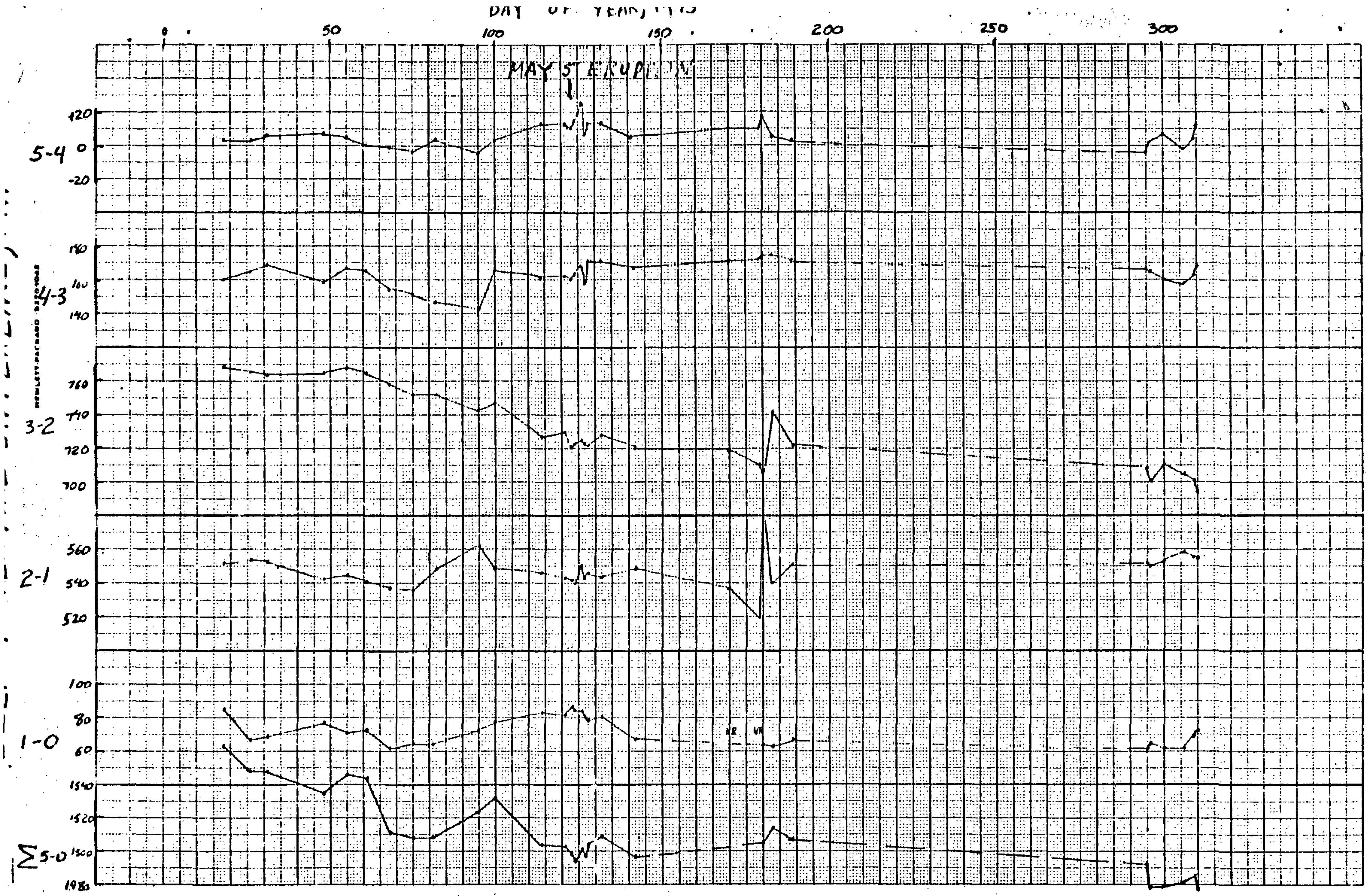

1.0
0
Lava Flow
BM 3742
Lua Manu Crater
0
1.0
0.5
3646
3500
-0.5
0
2
3
4
5
3423
3500
3300
CRACK
-0.5
-0.5
-0.5
0
1
2 KM

Figure 5


DAY OF YEAR,
0
50
100
150
200
250
300
MAY 5T ERUPTION
5-4
+20
0
-20
4-3
180
160
140
3-2
760
740
720
700
2-1
560
540
520
1-0
100
80
60
Σ5-0
1540
1520
1500
1480
HEWLETT-PACKARD

igure 6

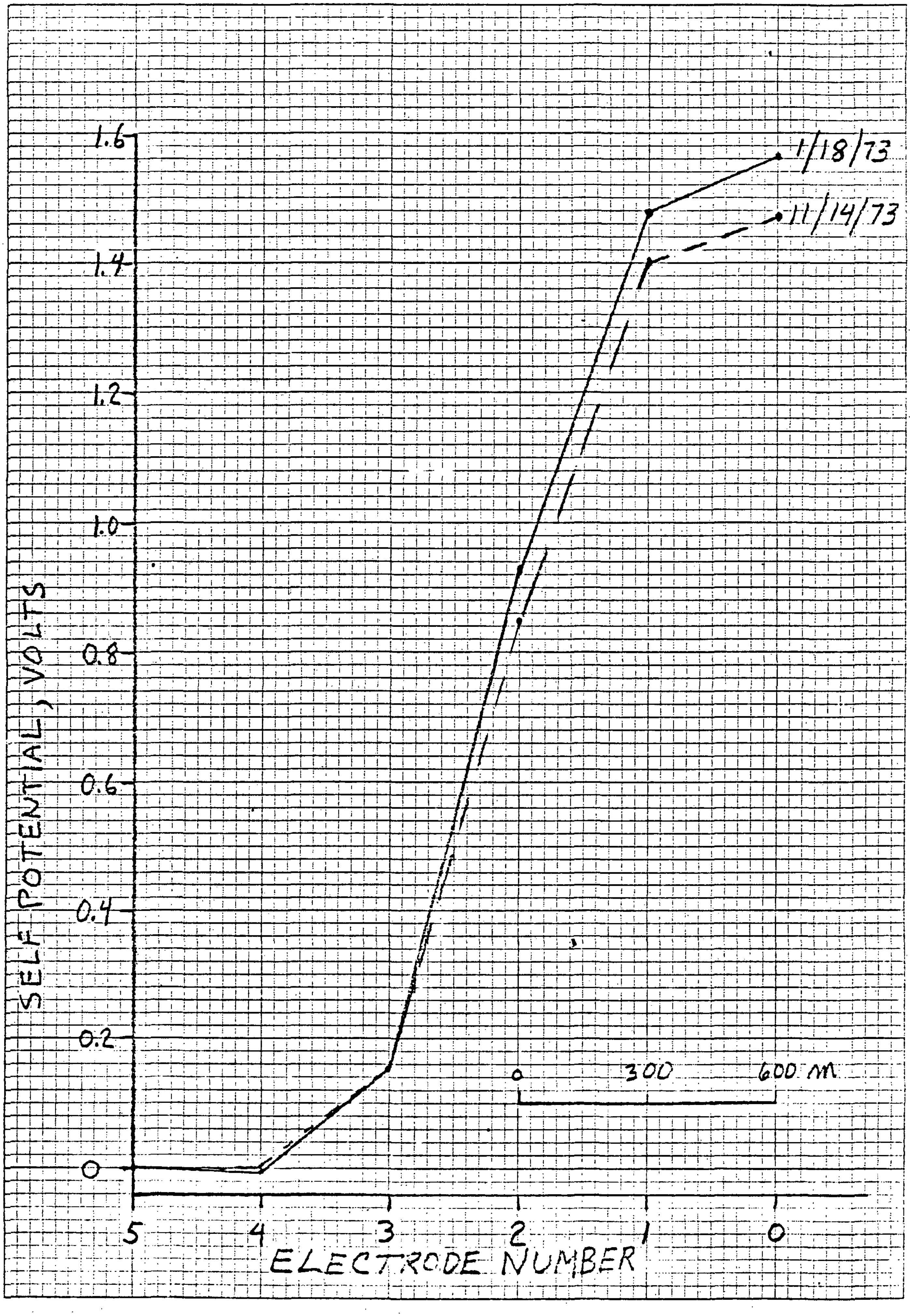

SELF POTENTIAL, VOLTS
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
5
4
3
2
1
0
ELECTRODE NUMBER
1/18/73
11/14/73
0
300
600 m

FIGURE 7

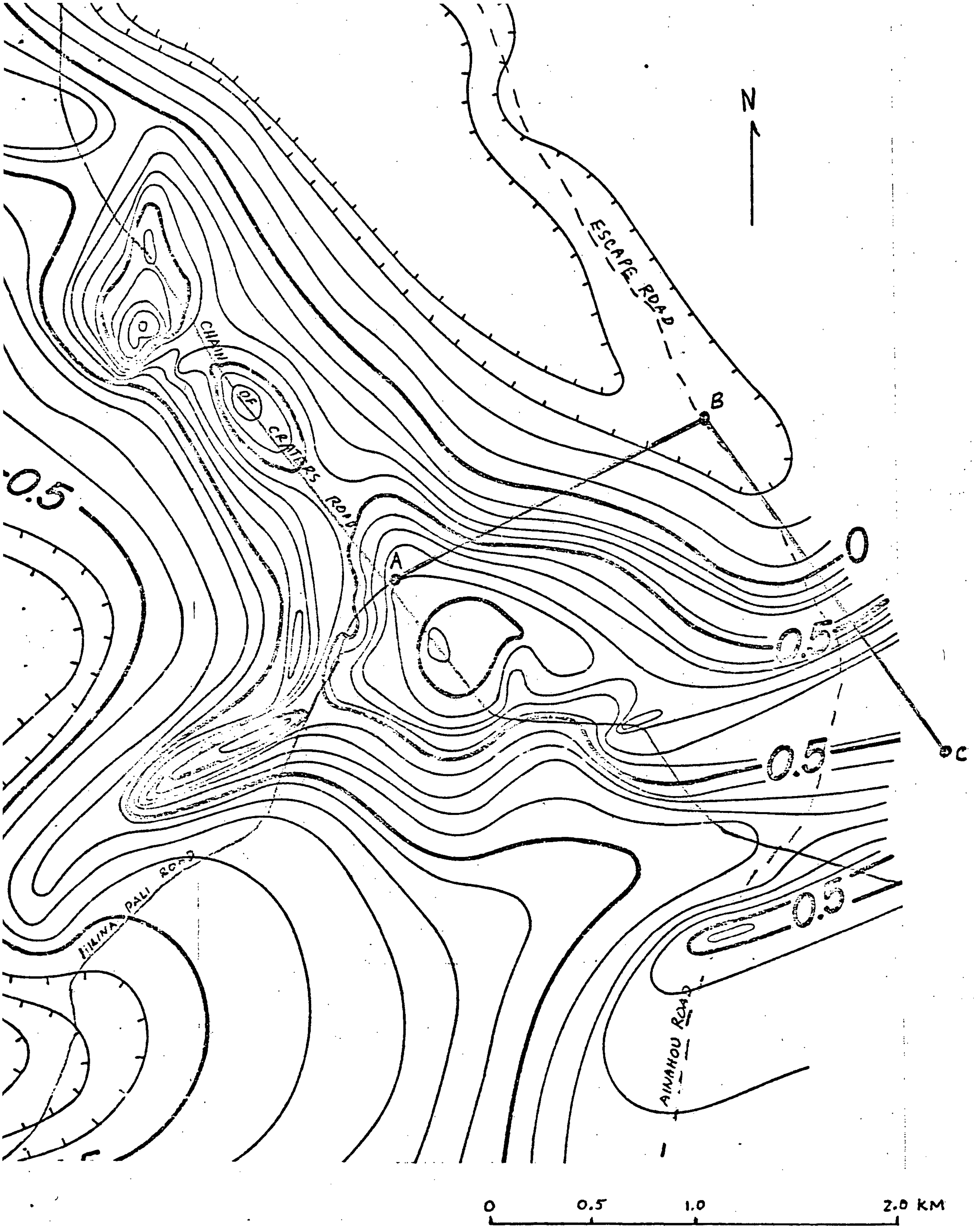
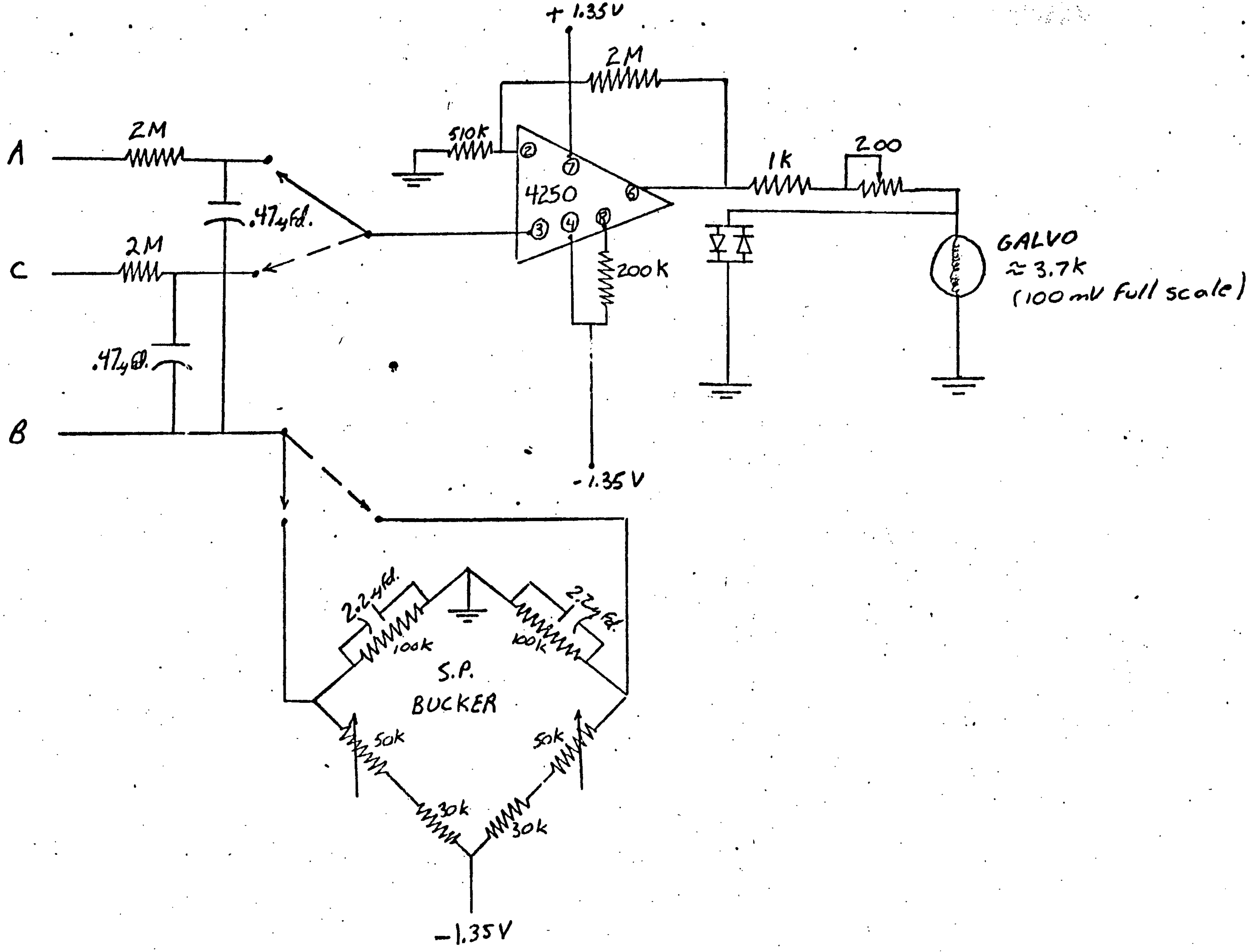

N
ESCAPE ROAD
CHAIN OF CRATERS ROAD
HILINA PALI ROAD
AINAHOU ROAD
A
B
C
0
0.5
0.5
0.5
0.5
0.5
0
0.5
1.0
2.0 KM

Figure 8.


+1.35V
2M
510K
A
2M
2
7
4250
6
3
4
8
.47μfd.
2M
C
.47μfd.
200K
1k
200
GALVO
≈3.7k
(100mV full scale)
-1.35V
B
2.2μfd.
100k
2.2μfd.
100k
S.P.
BUCKER
50k
50k
30k
30k
-1.35V

igure 9

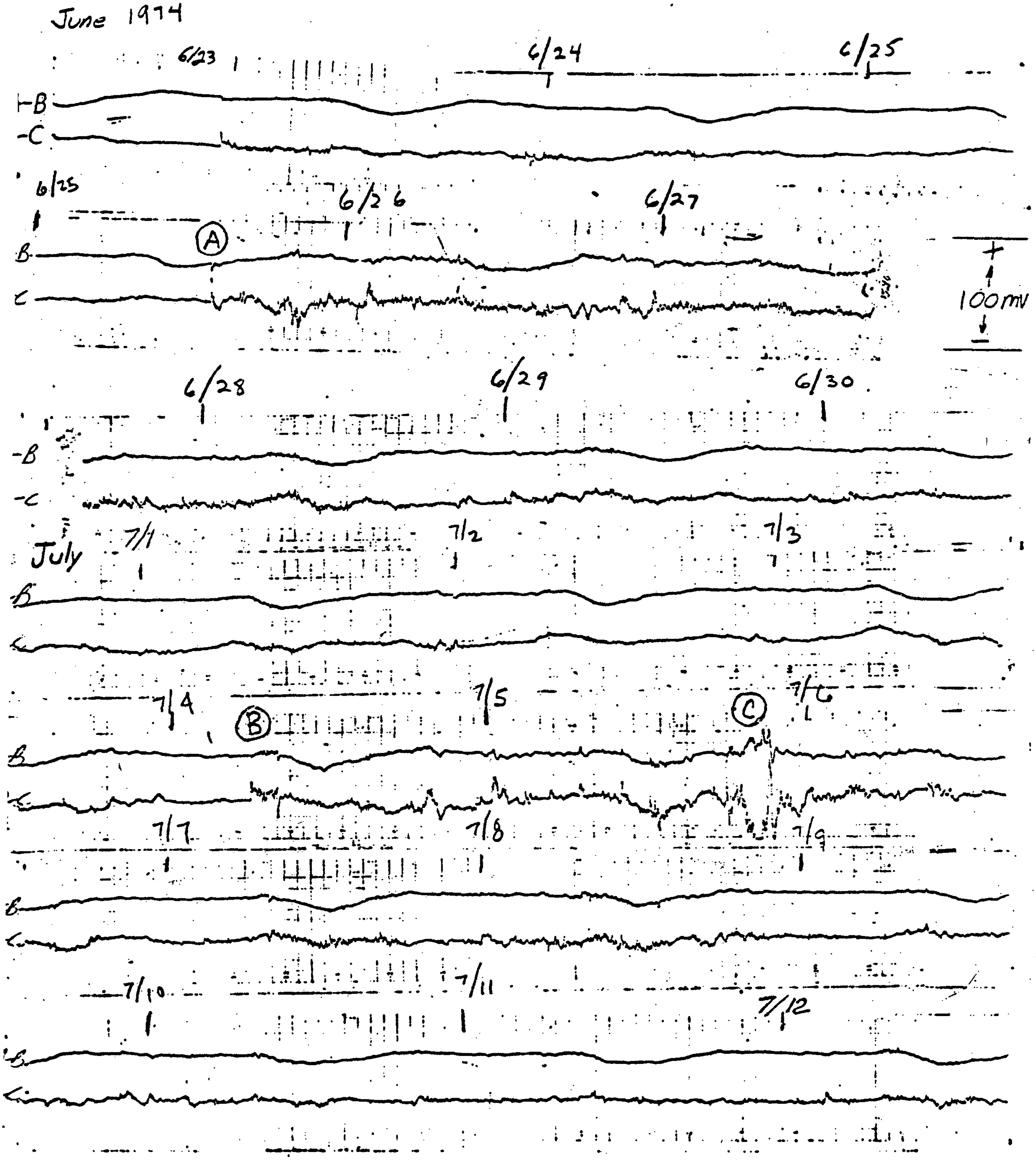

June 1974
6/23
6/24
6/25
-B
-C
6/25
6/26
6/27
A
B
C
+
100mV
6/28
6/29
6/30
-B
-C
July
7/1
7/2
7/3
B
C
7/4
7/5
7/6
B
C
B
C
7/7
7/8
7/9
B
C
7/10
7/11
7/12
B
C

Figure 10a

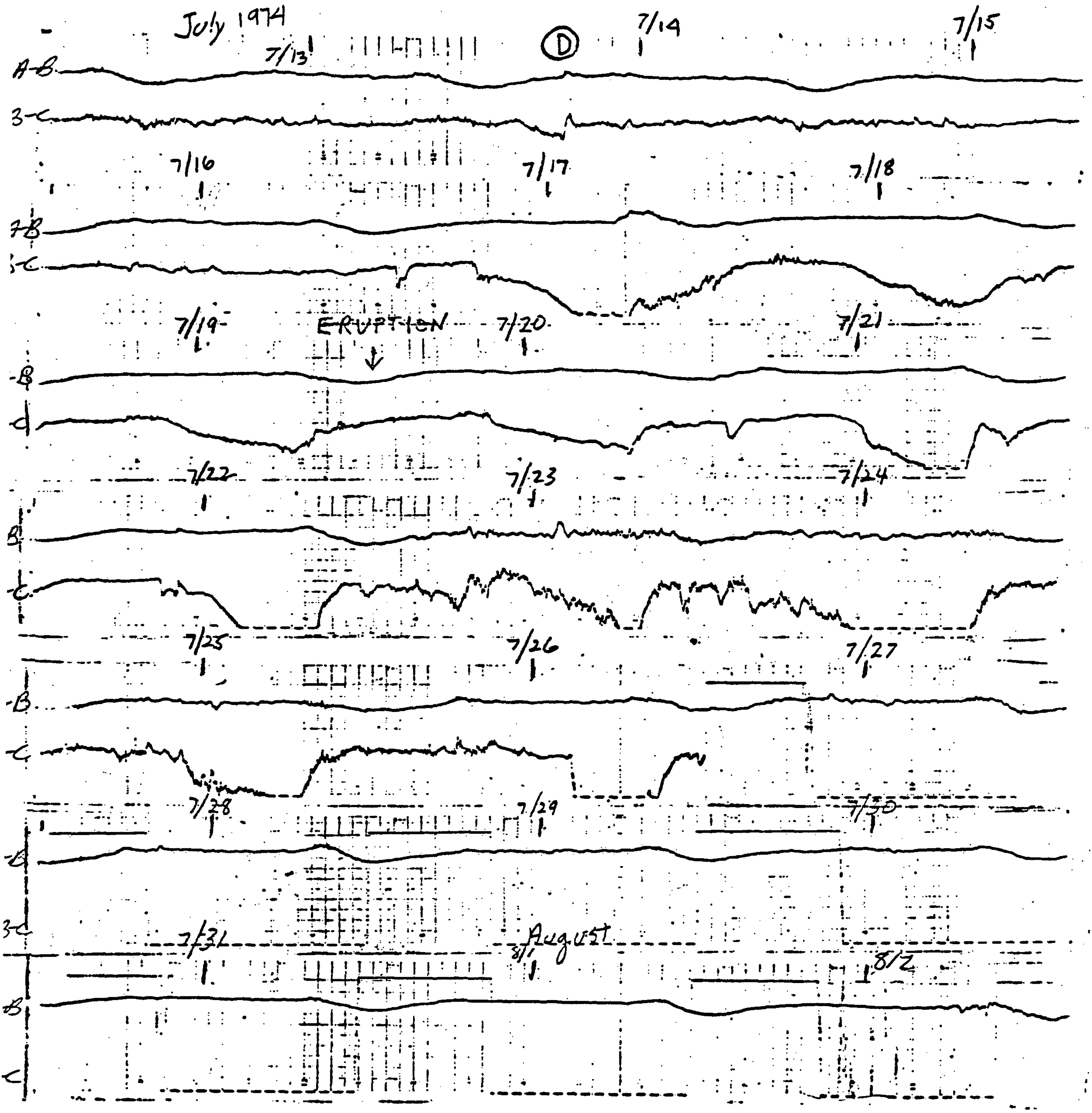
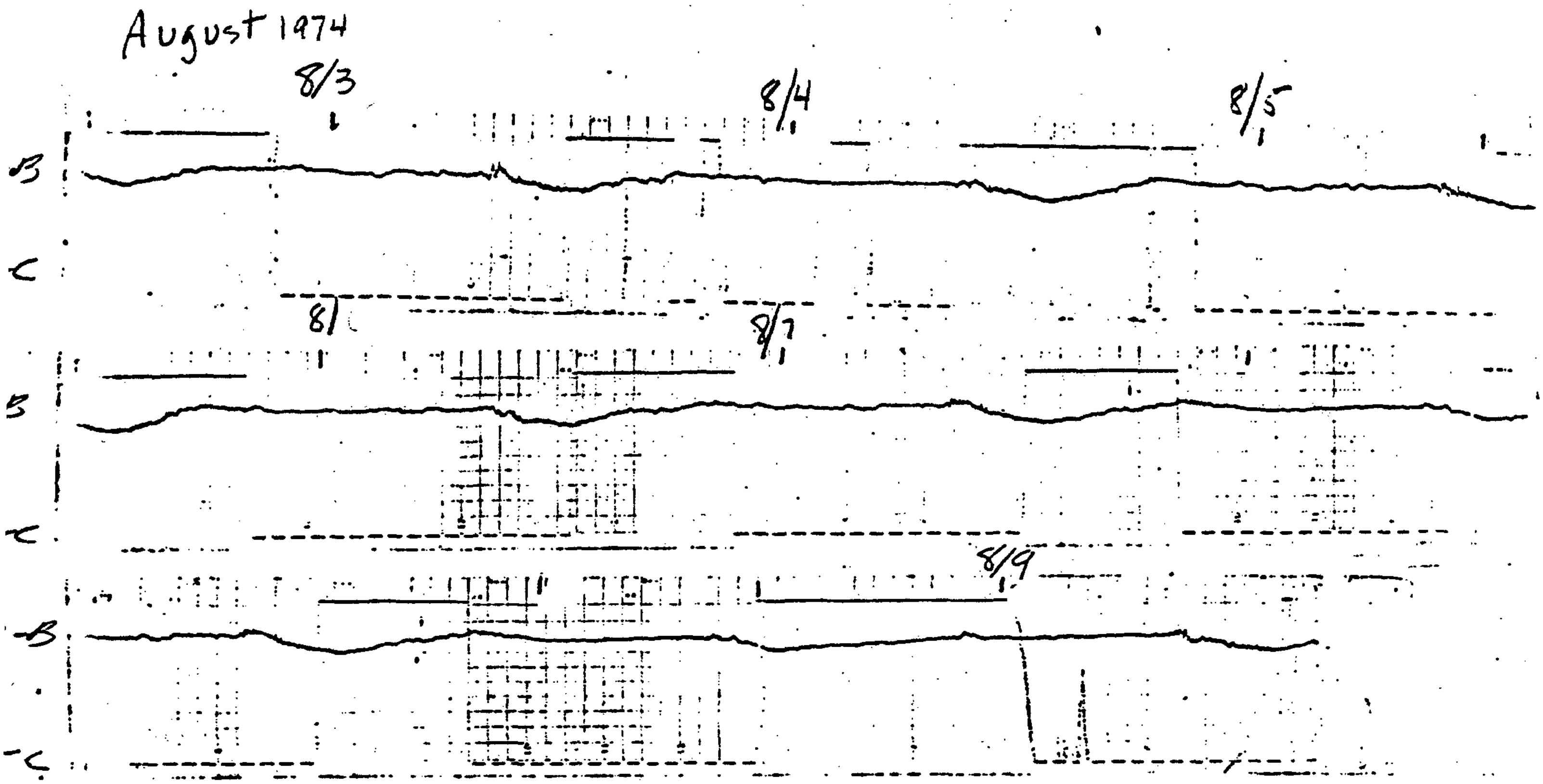

July 1974
7/13
D
7/14
7/15
A-B
3-C
7/16
7/17
7/18
-B
-C
7/19
ERUPTION
7/20
7/21
-B
-C
7/22
7/23
7/24
B
-C
7/25
7/26
7/27
-B
-C
7/28
7/29
7/30
-C
3-C
7/31
August
8/1
8/2
-B
-C

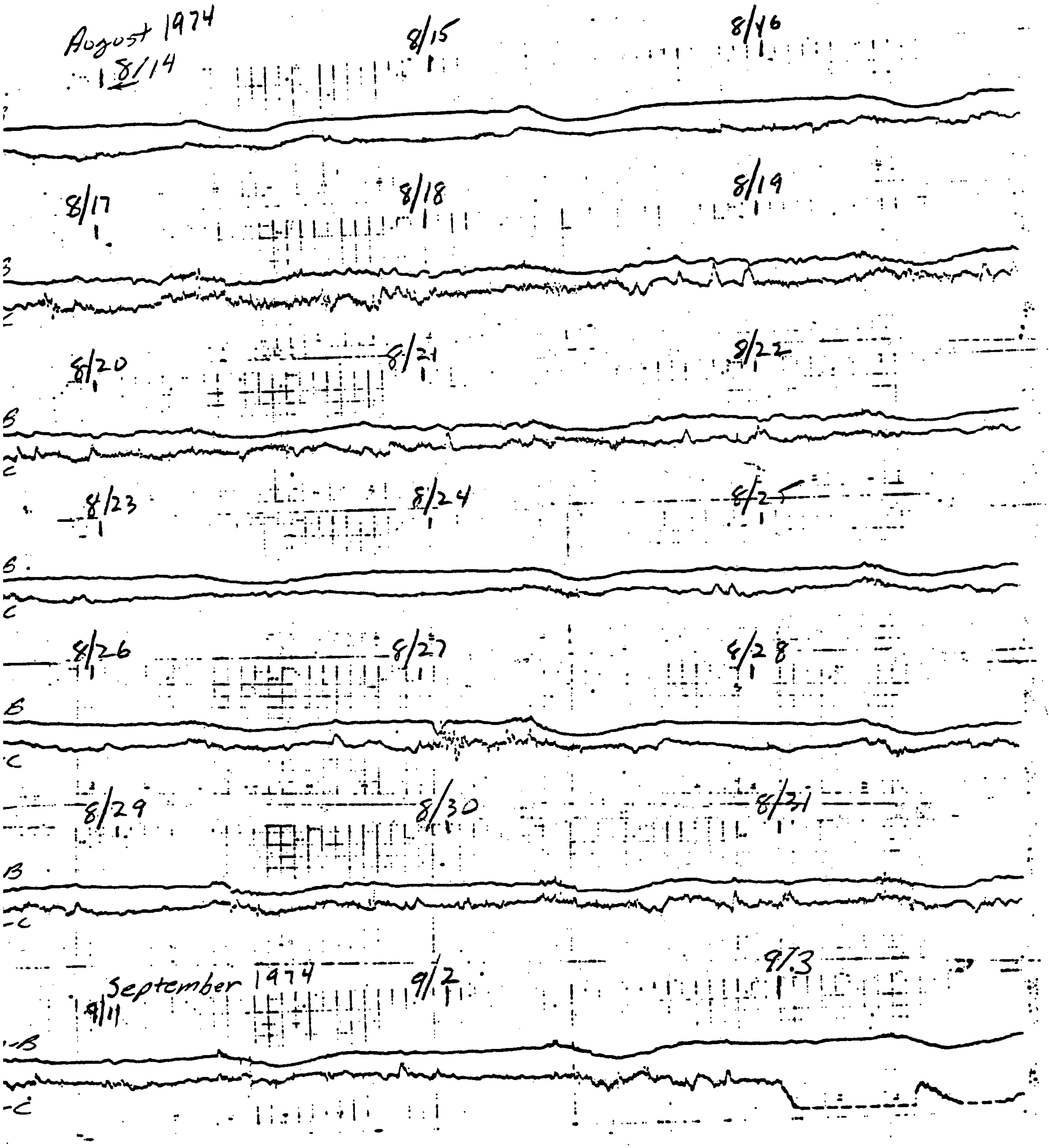
Figure 10 b



NO RECORDS 8/10 - 8/13/74

↓

FIGURE 10c


August 1974
8/14
8/15
8/16
B
C
8/17
8/18
8/19
B
C
8/20
8/21
8/22
B
C
8/23
8/24
8/25
B
C
8/26
8/27
8/28
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8/30
8/31
B
C
September 1974
9/1
9/2
9/3
B
C

Figure 10d

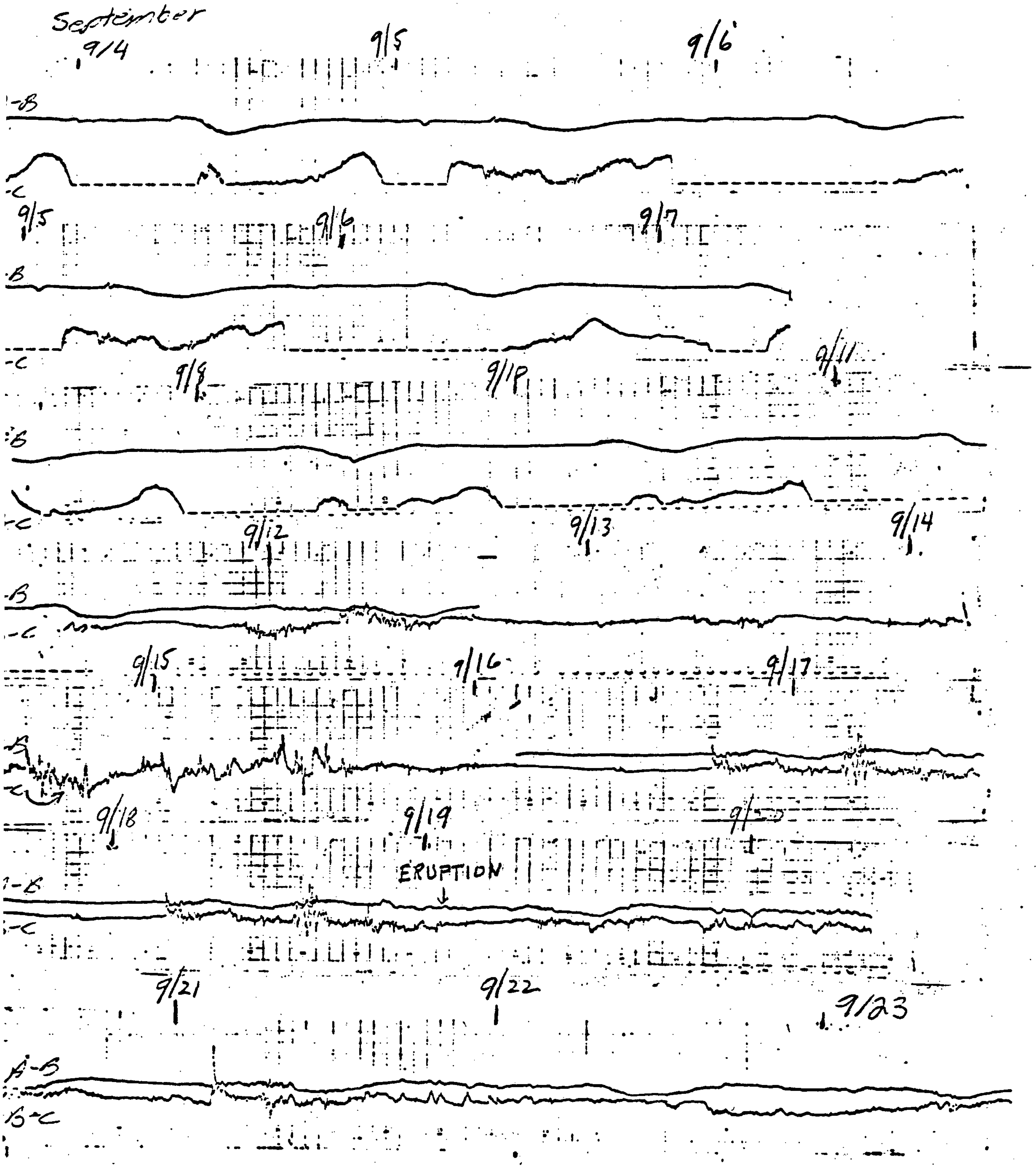
September
9/4
9/5
9/6
-B
-C
9/5
9/6
9/7
B
-C
9/8
9/10
9/11
B
-C
9/12
9/13
9/14
-B
-C
9/15
9/16
9/17
B
-C
9/18
9/19
9/20
ERUPTION
-B
-C
9/21
9/22
9/23
A-B
B-C

Figure 10e

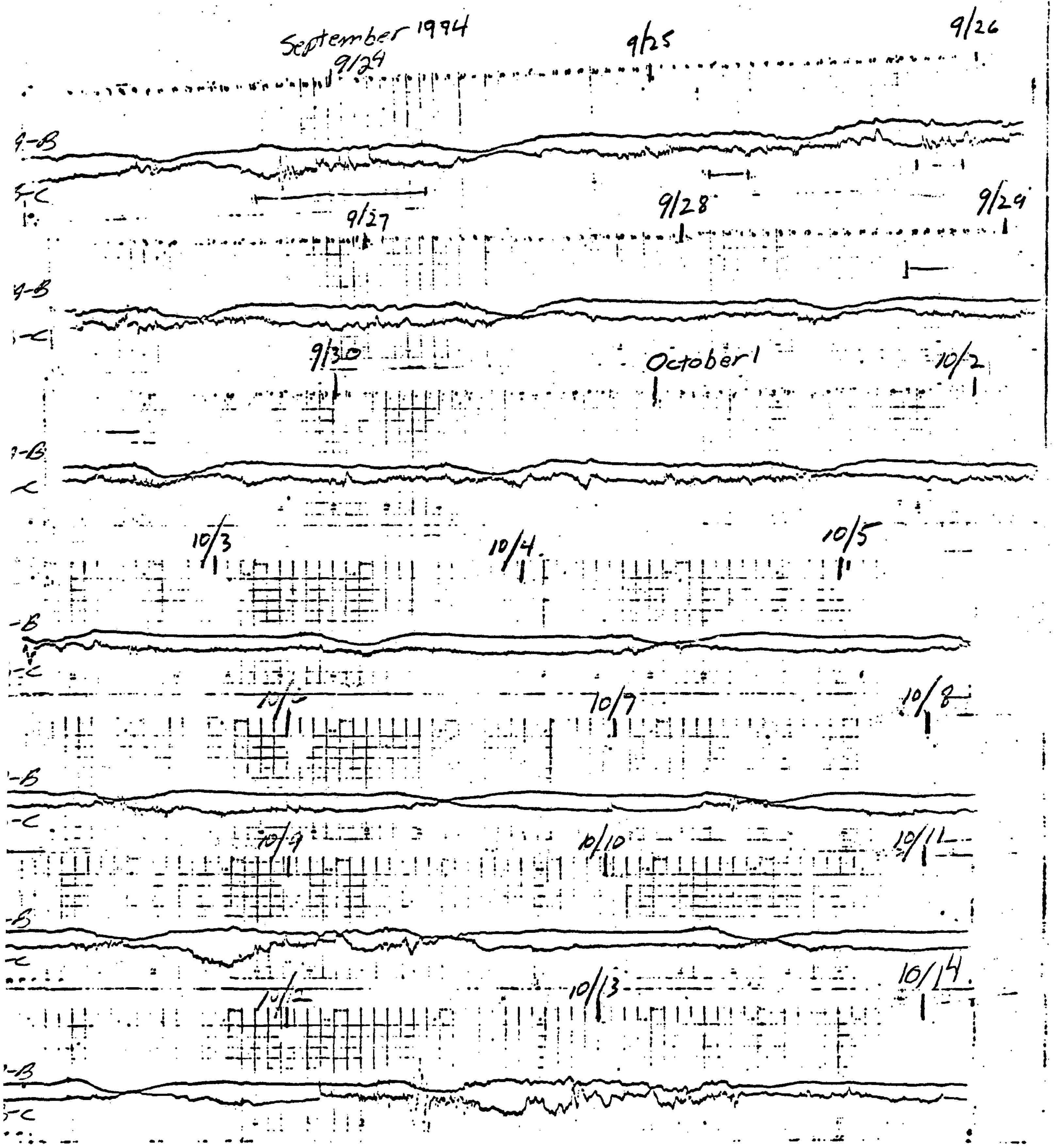
September 1994
9/24
9/25
9/26
9-B
5-C
9/27
9/28
9/29
9-B
9/30
October 1
10/2
9-B
10/3
10/4
10/5
-B
5-C
10/7
10/8
-B
-C
10/9
10/10
10/11
-B
10/13
10/14
-B
5-C

Figure 10f

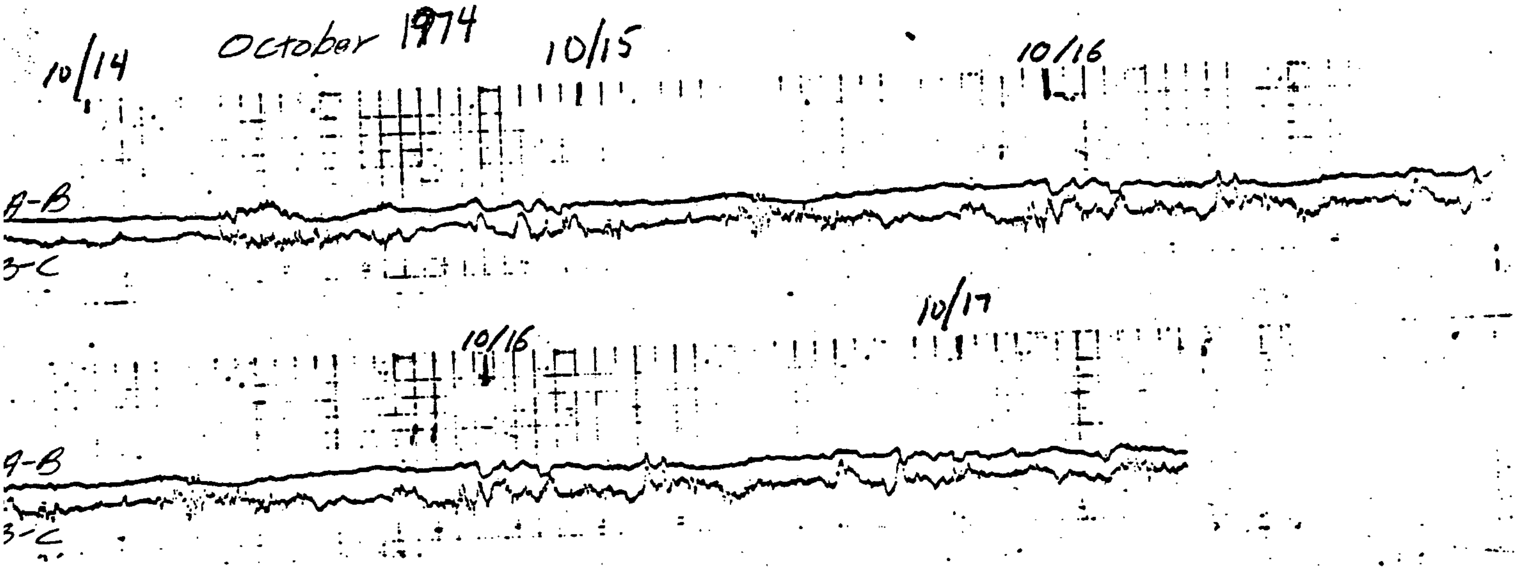

Figure 10g

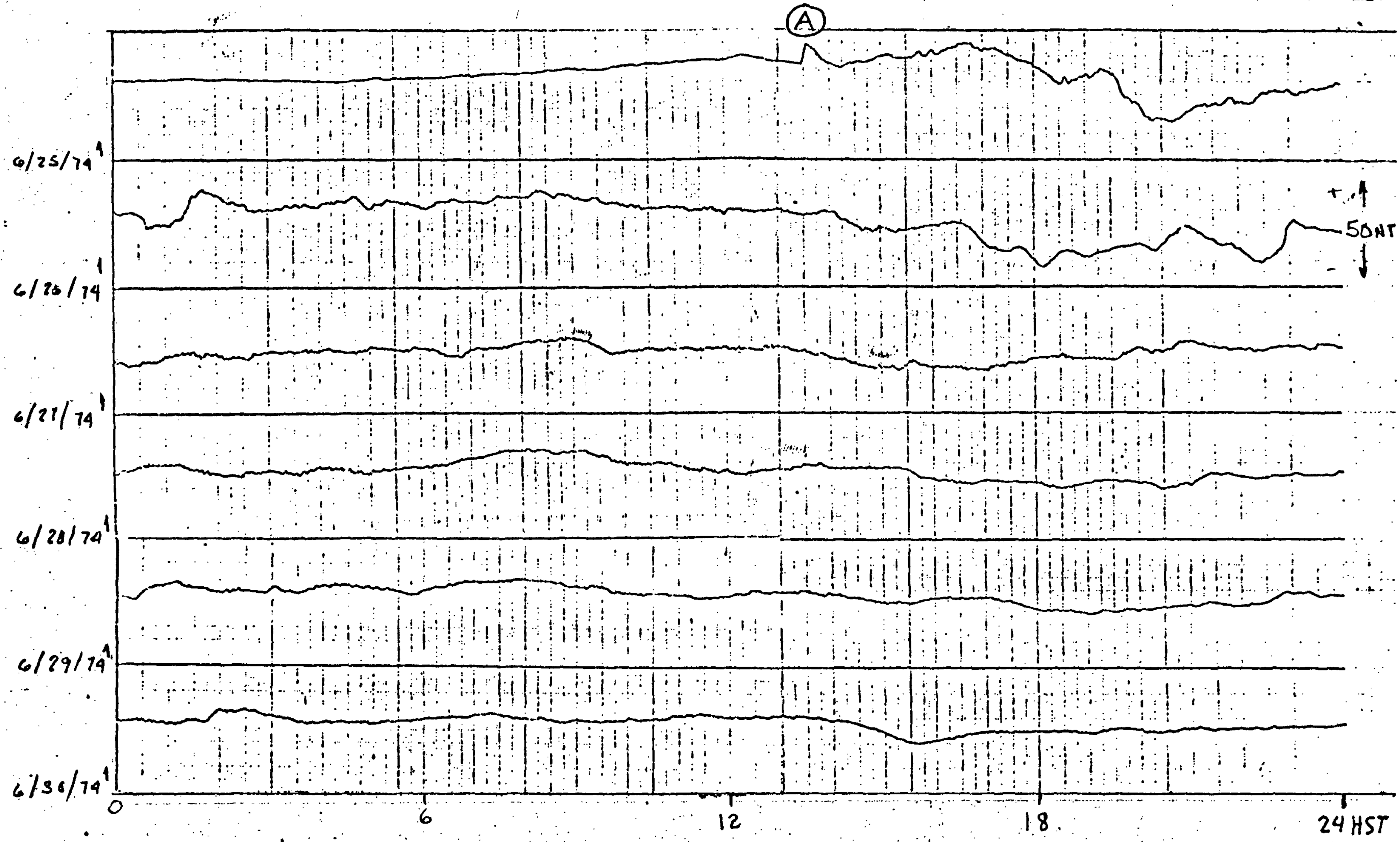

Figure 11a

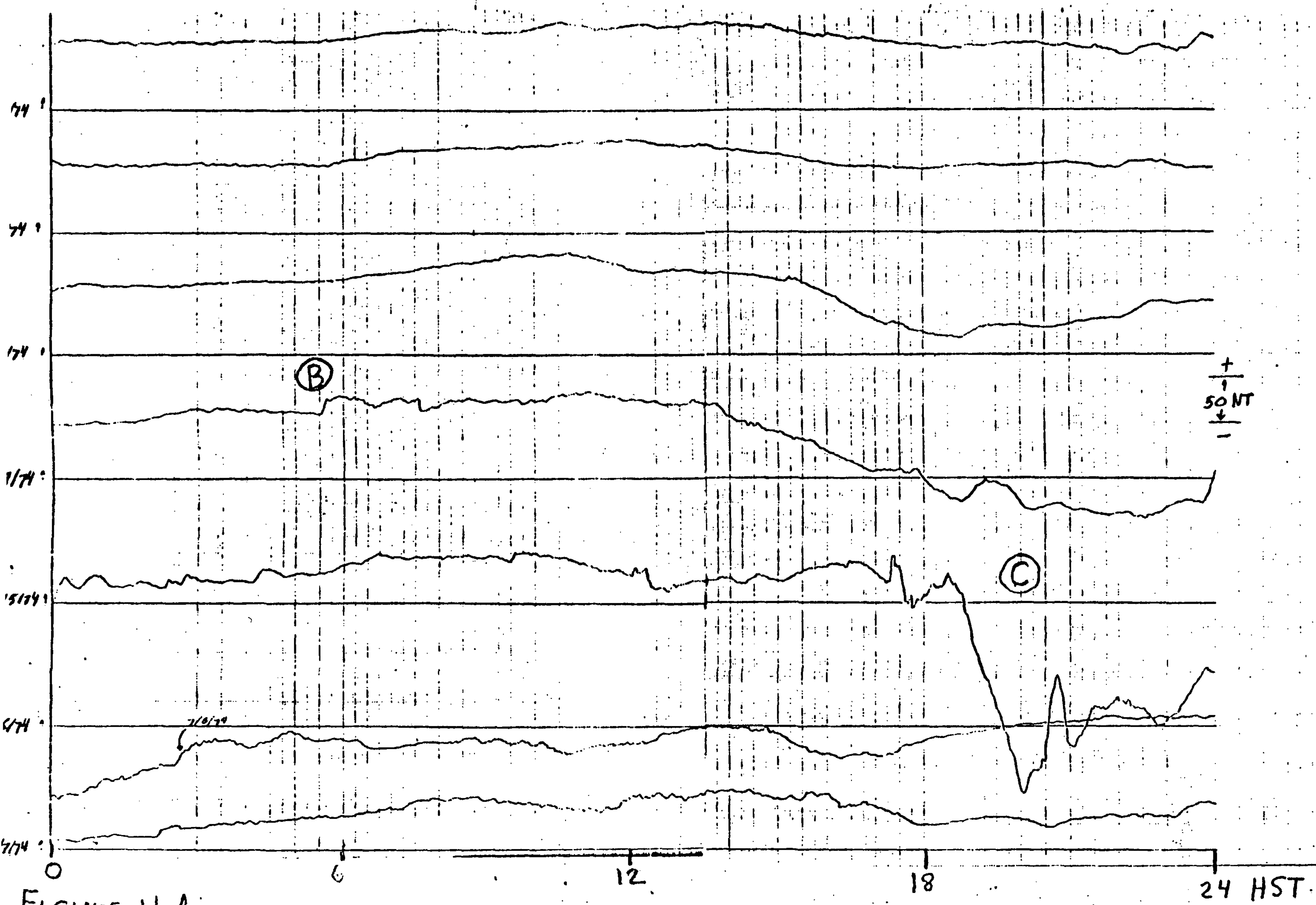

Figure 11 b

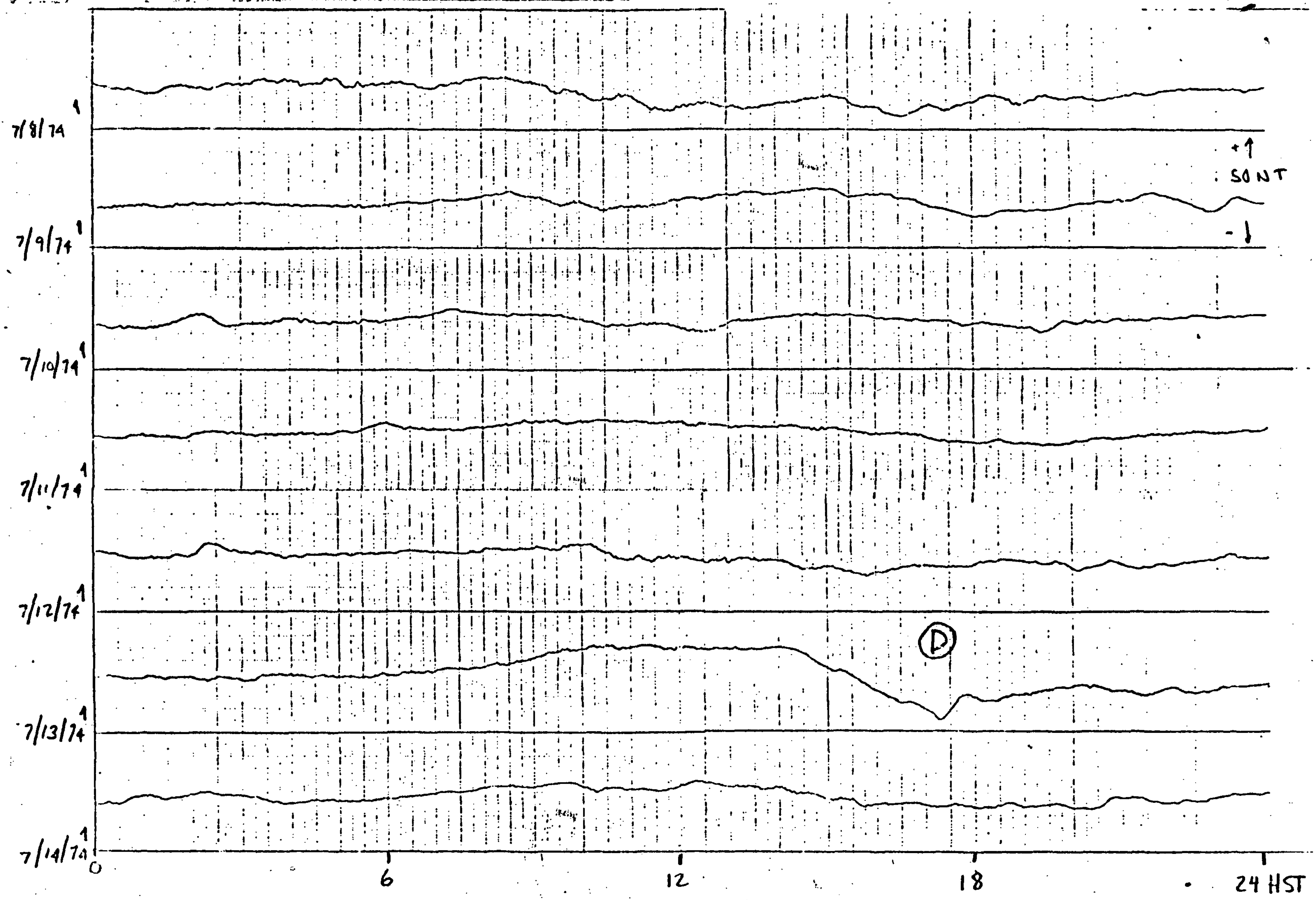

Figure 11c