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LONG RANGE SEISMIC MEASUREMENTS

BOURBON

20 JANUARY 1967

Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER

Washington, D. C.

9 JUNE 1967

By

TELEDYNE INC.

Under

Project VELA UNIFORM

Sponsored By

ADVANCED RESEARCH PROJECTS AGENCY

Nuclear Test Detection Office

ARPA Order No. 624

LONG RANGE SEISMIC MEASUREMENTS

BOURBON

20 January 1967

SEISMIC DATA LABORATORY REPORT 186

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AVAILABILITY

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BOURBON

EVENT DESCRIPTION

DATE: 20 January 1967

TIME OF ORIGIN: 17:40:04.4

YIELD:

MAGNITUDE: 5.09 ± 0.61

LOCATION:

SITE: Nevada Test Site, Area U7n

GEOGRAPHIC COORDINATES:

Lat: $37^{\circ}05'59.0''$ N

Long: $116^{\circ}00'14.0''$ W

ENVIRONMENT:

GEOLOGIC MEDIUM: TUFF

SURFACE ELEVATION: 4375 ft.

SHOT ELEVATION: 2526 ft.

SHOT DEPTH: 1849 ft.

COMPUTED EPICENTER:

ALL STATIONS

GEOGRAPHIC COORDINATES:

Lat: $36^{\circ}58'48.0''$ N

Long: $116^{\circ}04'58.8''$ W

TIME OR ORIGIN: 17:40:03.6Z

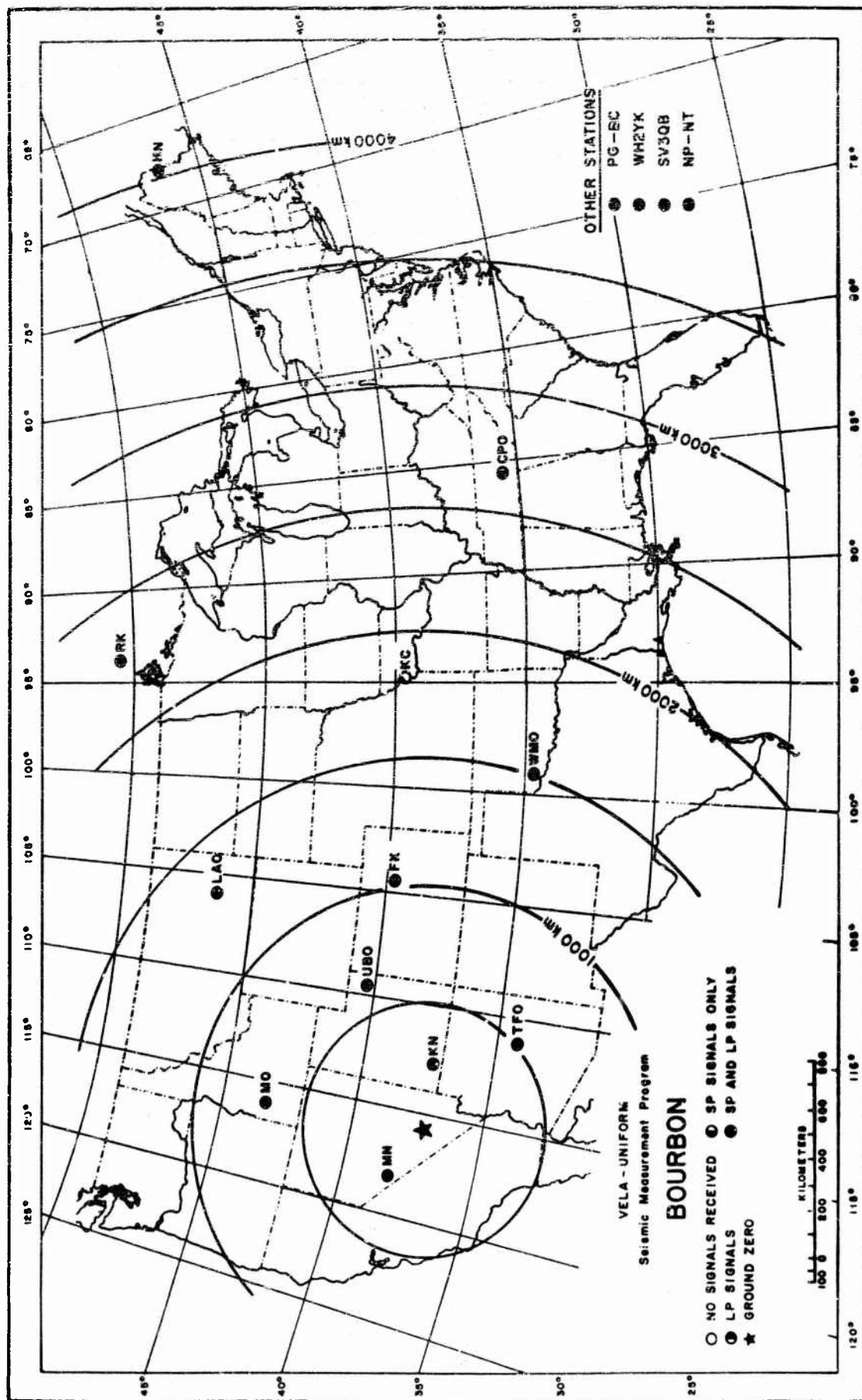
DEPTH CONSTRAINED TO: 0 km

EPICENTER SHIFT: 15.0 km, S 28° W

Code	Station	Final							Timing
		SPZ	SPR	SPT	LPZ	LPR	LPT	Tape	
MM-NV	Mina, Nevada	+	+	+	+	+	+	+	P
KM-UT	Kanab, Utah	+	+	+	+	+	+	+	P
TPSO	Tonto Forest Seismological Observatory, Arizona	+	+	+	+	+	+	+	P
MO-ID	Mountain Home, Idaho	+	+	+	+	+	+	+	P
UBSO	Uinta Basin Seismological Observatory, Utah	+	+	+	+	+	+	+	P
FK-CO	Franktown, Colorado	+	+	+	+	+	+	+	P
LAO	Subarray MO-10 Montana	+	M	M	+	-	-	-	P
WISO	Wichita Mountain Seismological Observatory, Oklahoma	+	+	+	+	-	+	+	P
STATION MOVING									
KC-MO	Kansas City, Missouri	+	+	+	+	+	-	+	P
PG-BC	Prince George, British Columbia, Canada	+	+	+	+	+	-	+	P
KK-ON	Red Lake, Ontario, Canada	+	+	+	+	+	+	+	P
CPSO	Cumberland Plateau Seismologi- cal Observatory, Tennessee	+	+	+	+	+	+	+	P
WHZYK	Whitehorse, Yukon Territory, Canada	+	+	-	+	+	+	+	P
HN-ME	Houlton, Maine	+	+	+	+	+	-	+	P
SV30B	Schefferville, Quebec, Canada	+	+	-	+	-	-	+	P
NP-NT	Mould Bay, Northwest Territories, Canada	+	+	+	+	-	-	+	P

N No Instrument + Signal
P Primary Timing - No Signal

STATION STATUS REPORT - BOURBON
TABLE 1



Recording Stations and Signals Received

Figure 1

INTRODUCTION

A long range seismic measurements (LRSM) program and several larger seismographic observatories were established under VELA-UNIFORM to record seismological data resulting from natural seismic activity and a planned series of U. S. underground nuclear tests. The LRSM teams are mobile and occupy locations selected to provide optimum data from events of special interest; the observatories are permanent installations as follows:

Wichita Mountains Seismological Observatory (WMSO)
Lawton, Oklahoma

Cumberland Plateau Seismological Observatory (CPSO)
McMinnville, Tennessee

Uinta Basin Seismological Observatory (UBSO)
Vernal, Utah

Tonto Forest Seismological Observatory (TFSO)
Payson, Arizona

Large Aperture Seismic Array (LASA)
Billings, Montana

The purpose of this report is to provide an analysis of data resulting from the BOURBON event recorded by the LRSM teams and the VELA observatories and a preliminary summary of data reported by other permanent and temporary seismographic stations.

INSTRUMENTATION AND PROCEDURE

The instrumentation at each of the LRSM locations consists of three-component short-period and three-component long-period seismographs. In general, data are recorded on 35 millimeter film and

on one-inch 14 channel magnetic tape, although recently more portable instrumentation has been incorporated which records only on magnetic tape. The stations are all equipped to record WWV continuously to provide accurate time control. Calibration is accomplished once each day and just prior to each shot at the operational settings. Pertinent information useful for analysis of LRSM data is available to qualified users of this data and is contained in Technical Report 65-43, "Interpretation and Usage of Seismic Data, LRSM Program." General information on LRSM van and portable system equipment and operation is given in Technical Report 66-27, "The LRSM Mobile Seismological Laboratory," and 65-74, "A Portable Seismograph." Copies of these reports may be obtained from DDC. The AD control number of Technical Report 66-27 is 480343. All the observatories have both long-period and short-period, three-component instrumentation, in addition to their other specialized facilities.

Station information is presented in Appendix I(A). This includes the station name and code; the geographic coordinates; the distances and azimuths involved; the station elevations; and the type of instruments in use at each location. Representative instrumental response curves are shown in Appendix II(B), II(C), and II(D).

The procedures used in measuring amplitudes reported herein are illustrated in Appendix II(A) and the unified magnitude is calculated as shown in Appendix I(B). The distance factors (B) beyond 16° are

from Gutenberg and Richter*. For distance less than 16° values were read from a curve in the Gutenberg and Richter paper back to 10° and then extrapolated to 2° , using an inverse cube relationship. An additional magnitude for less than 16° was computed using a method described by Evernden**. (Figure 3).

A standard hypocenter location program for a digital computer is used to determine the location using data from all stations analyzed. Best-fit values of latitude, longitude, and time of origin are determined statistically by a least squares technique. This utilizes a Jeffreys-Bullen travel-time curve as modified by Herrin in 1961 on the basis of Pacific surface-focus recordings. Precision of the computation is limited primarily by the accuracy of arrival times, the validity of the standard travel-time curve, and by local velocity deviations. This method is based on P-wave arrivals with depth constrained to zero.

DATA AND RESULTS (LRSM AND VELA OBSERVATORIES)

The parameters of the BOURBON event and a summary of the seismic evaluation is shown on the Event Description page. The operational status of the 16 LRSM stations and observatories is given in Table I and illustrated in Figure 1.

- 4 -

* Gutenberg, B. and Richter, C.F., Magnitude and Energy of Earthquakes, Ann. Geofis., 9 (1956), pp. 1-15.

** Evernden, J.F., Magnitude Determination at Regional and Near Regional Distances in the United States, AFTAC/VELA Seismological Center Technical Report VU-65-4A, (1965), pp. 6, 13.

Table 2 summarizes the measurements made of the principal phases from the BOURBON event at the LRSM and VELA stations. Included are the Pn and P arrival times, the maximum amplitudes (A/T) of Pn or P motion and other phases as seen on the short-period vertical instruments. Long-period Love and Rayleigh wave motion are also tabulated in (A/T) form. In addition, individual station Rayleigh wave areas (mm^2) is indicated as measured on the LPZ only. Although reduced to 1K magnification, they have not been normalized to any magnitude. Fifteen stations recorded short-period and long-period signals from this event.

The unified magnitudes determined from the LRSM and VELA observatories are shown in Figure 2. The average magnitude is 5.09 ± 0.61 . The adjusted unified magnitude is 4.78 ± 0.56 and is shown in Figure 3.

The travel-time residuals from the Pn and P phases are shown in Figure 4. Figures 5 through 9 illustrate plots of the amplitude of P, Pg, Lg, LQ, and LR.

Attached to the report are illustrative seismograms showing the signals recorded at four stations. The most distant station analyzed that recorded BOURBON was NP-NT at a distance 4368 kilometers.

PRINCIPAL PHASES
BOURBON
20 January 1967
17:40:04.48

Code	Station	Distance (km)	Lat.	Mag- nitude (k) File # 10	Phase	Observed Travel Time		Period T (sec)	Maximum Amplitude A/T	Mag- nitude		Area (mm ²) LPS
						(min)	(sec)			mb	mb	
NM-SV	Nina, Nevada	240	SPZ	2.4	Pn		35.9	0.4	745	5.15	4.68	490.00
			SPZ	2.4	a		36.9	0.25	1258			
			SPZ	2.4	Pg		38.8	0.55	4403			
			SPT	4.52	Lq			(0.8)	(5691)			
			LPT	19.42*	LQ			9.0	61.2			
NM-UT	Kanab, Utah	293	LIZ	3.0	LR			12.0	2751			127.22
			SPZ	4.04	Pn		41.6	0.4	2238	5.82	5.52	
			SPS	1.59*	Pg		(45.8)	0.6	9236			
			SPT	0.71*	Lq			1.3	16732			
			LPT	23.71*	LQ			11.0	526			
TFSO	Tonto Forest Seismological Observatory, Arizona	536	LPS	3.38	LR			13.0	623			195.38
			SPZ-60	13.8	Pn	1	13.3	0.35	146	5.49	5.07	
			SPZ-60	12.8	(PP)	1	22.8	0.45	76.0			
			SPZ-60	13.8	Pg	1	26.9	0.65	680			
			SPZ	13.1	Lq			(1.2)	(355)			
MO-ID	Mountain Home, Idaho	664	SPZ	13.1	Lq			1.2	559			63.89
			LFW	33	LQ			9.0	117			
			LPS	38	LQ			9.0	116			
			LPS	4.0	LR			15.0	347			
			SPZ	40.75	Pn	1	30.1	0.45	37.8	5.17	4.73	
UNSO	Uinta Basin Seismological Observatory, Utah	664	SPZ	40.75	a	1	32.2	0.5	(66.6)			63.85
			SPZ	40.75	a	1	38.5	0.5	182			
			SPS	40.75	Pg	1	47.4	(0.9)	(1094)			
			SPT	32.0	Lq			(1.1)	(2884)			
			LPT	65.6	LQ			---	---			
FK-CO	Franktown, Colorado	1045	LPS	4.5	LR			12	336			61.31
			SPZ-10	5.3	Pn	1	32.3	0.5	369	6.16	5.93	
			SPZ-10	5.3	Pg	1	47.6	.5	901			
			SPZ	5.3	Lq			1.3	1249			
			SPZ	5.3	Lq			(1.3)	(744)			
LAO	Subarray AQ-10, Montana	1337	LFW	11.5	LQ			20.0	22.2			25.46
			LPS	12.0	LQ			20.0	9.6			
			LPS	13.0	LR			15.0	75.4			
			SPZ	191.7	Pn	2	(18.4)	0.7	38.5	5.83	4.36	
			SPZ	191.7	(PP)	2	25.4	0.7	21.5			
MSO	Wichita Mountain Seismo- logical Observatory, Oklahoma	1591	SPZ	191.7	a	2	34.5	0.6	44.5			40.65
			SPZ	191.7	Pg	2	53.6	(0.9)	(161)			
			SPT	129.8	Lq			(1.6)	(485)			
			LPT	18.7	LQ			14.0	131			
			LPS	2.84	LR			11.0	727			
LAO	Subarray AQ-10, Montana	1337	SPZ	225	Pn	2	51.8	0.85	9.7	5.09	3.98	32.61
			SPS	325	a	2	53.8	0.75	25.3			
			SPZ	37.5	a	3	66.1	0.8	44.4			
			LPS	2.16	LR			11.0	321			
			SPZ-6	125	P		OBSERVED BY LOCAL EVENT					
MSO	Wichita Mountain Seismo- logical Observatory, Oklahoma	1591	SPZ-6	125	Pg	4	26.2	1.0	62.0			40.65
			SPZ	125	Lq			1.5	187			
			SPZ	125	Lq			1.4	35.7			
			LPS	48.0	LQ			20.9	19.4			
			LPS	10.7	LR			16.0	64.5			
PG-BC	Prince George, British Columbia, Canada	1945	SPS	162	P	4	66.8	(1.0)	(10.8)	(3.39)		32.61
			SPS	162	a	4	69.0	1.0	22.4			
			SPZ	152	Lq			1.8	(42.6)			
			SPT	170	Lq			1.8	38.1			
			LPS	23.0	LR			11.0	190			

Principal Phases - BOURBON

Table 2 Page 1

PRINCIPAL PHASE
BOURBON
20 January 1967
17:40:04.42

Code	Station	Distance (km)	Inst.	Magni- fication (k) Film x 10	Phase	Observed Travel Time		Period T (sec)	Maximum Amplitude A/T	Magni- tude		Area (mm) ² LPS
						(Min)	(Sec)			mb	ms	
RK-OM	Red Lake, Ontario, Canada	2339	SPZ	257	P	4	44.2	0.8	126	5.20		6.58
			FPZ	257	a	4	57.7	0.8	30.7			
			SPZ	257	(PP)	5	05.8	1.1	36.4			
			SPT	249	Lq			2.2	93.0			
			LPT	54.9	(LQ)			9.0	(130)			
			LPS	6.61	LR			(10.0)	(109)			
CPRO	Cumberland Plateau Seismological Observatory Tennessee	2726	SPZ-B	390	P	5	(20.3)	0.75	24.0	4.78		69.09
			SPZ-B	390	a	5	27.3	0.9	16.4			
			SPZ-B	390	(PP)	5	44.0	1.1	16.7			
			SPB	430	Lq			1.8	50.4			
			SPZ	420	Lq			(1.8)	(30.4)			
			LPH	7.5	LQ			15.8	28.0			
WIZYK	Whitehorse, Yukon Territory, Canada	2947	SPZ	5.5	LR			16.0	85.0			81.48
			SPZ	195	P	5	(19.2)	0.8	5.7	4.21		
			LPT	12.0	(LQ)			10.0	373			
HM-ME	Houlton, Maine	4062	LPS	5.4	LR			13.0	153			23.35
			SPZ	84.7	P	7	06.5	0.8	13.0	4.66		
			SPZ	84.7	a	7	06.0	0.8	21.7			
SVQB	Schafferville, Quebec, Canada	4185	LPS	31.9	LR			12.0	90.8			50.00
			SPZ	125	P	7	(15.0)	(0.8)	(26.5)	(4.92)		
			SPZ	125	a	7	19.4	0.8	14.7			
			SPZ	125	a	7	22.0	0.65	9.5			
			SPZ	125	PP	8	44.0	0.7	8.2			
			SFR	116	Lq			1.0	10.8			
NP-WT	Mould Bay, Northwest Territories, Canada	4368	LPS	23.4	LR			(14.0)	(29.0)			32.30
			SPZ	240	P	7	29.9	0.8	31.0	4.89		
			SPZ	240	a	7	36.8	0.75	16.5			
			SPZ	240	(PP)	9	(00.1)	1.2	(9.4)			
			SPZ	240	(PCP)	9	37.6	0.8	7.0			
			SPT	628	Lq			2.5	28.8			
			LPS	11.3	LR			17.0	49.1			

A/T m/sec
() Doubtful values or phases
* Measurements made from playouts
--- Maximum Amplitude clipped on film & tape

Principal Phases - BOURBON

Table 2 Page 2

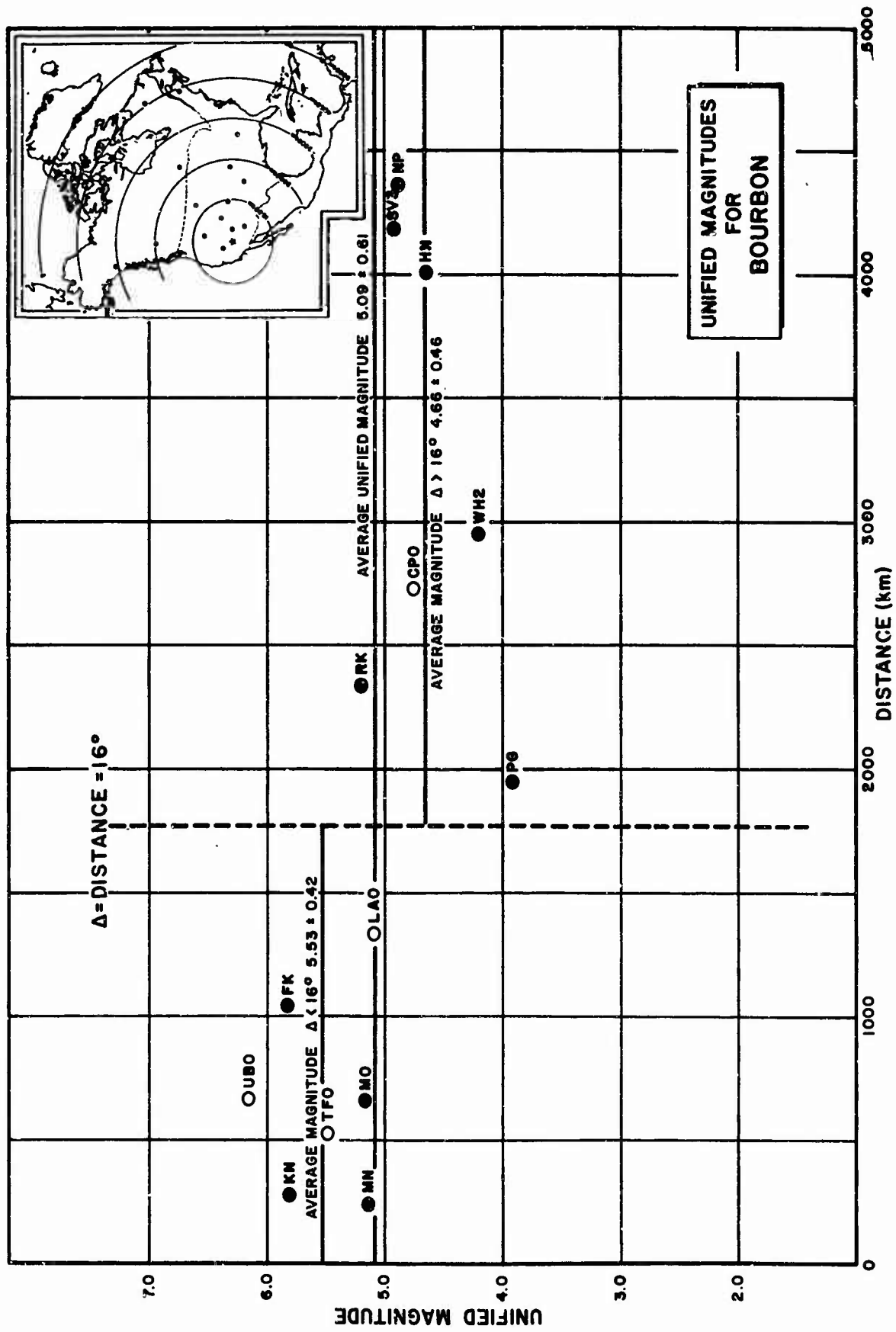


Figure 2

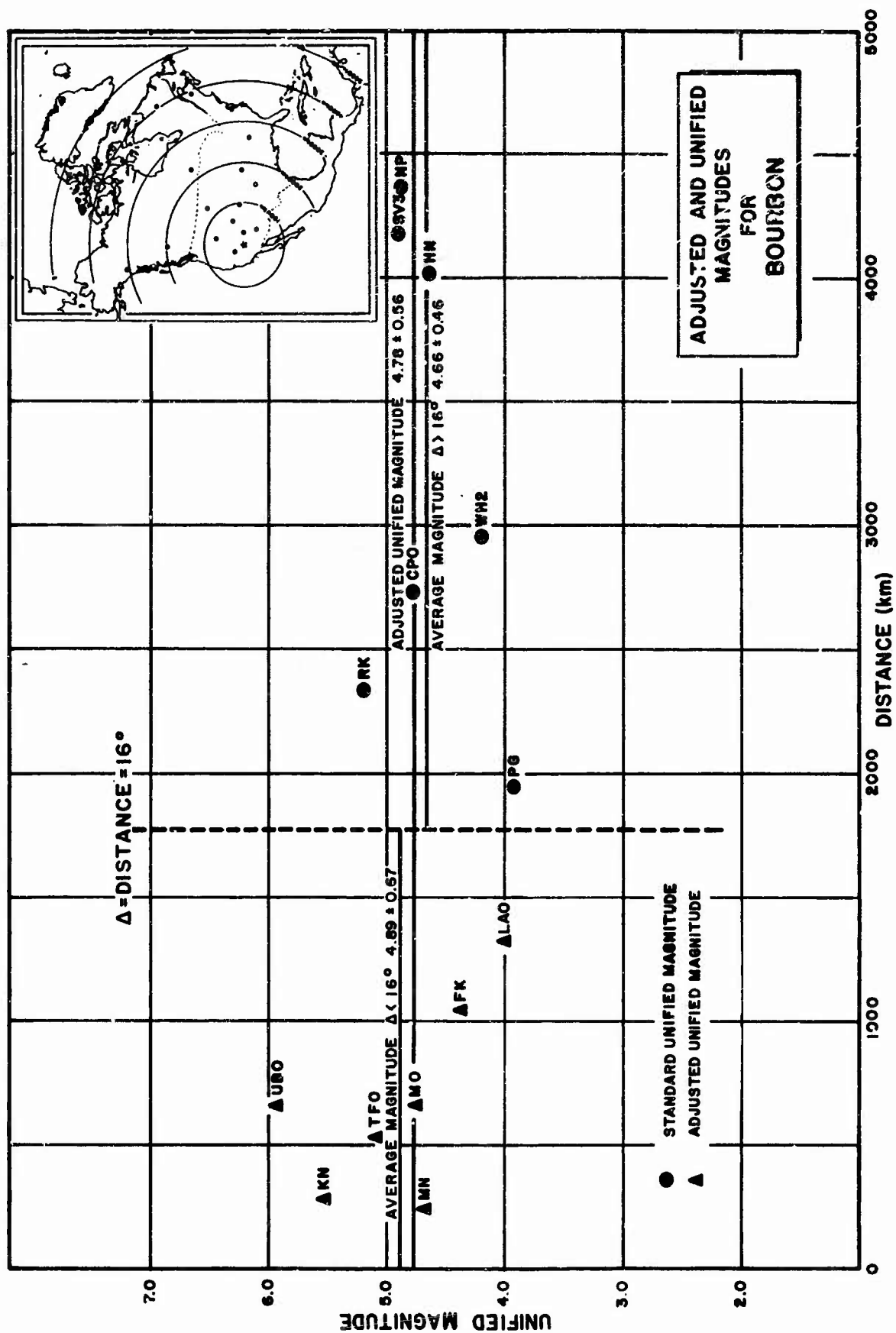


Figure 3

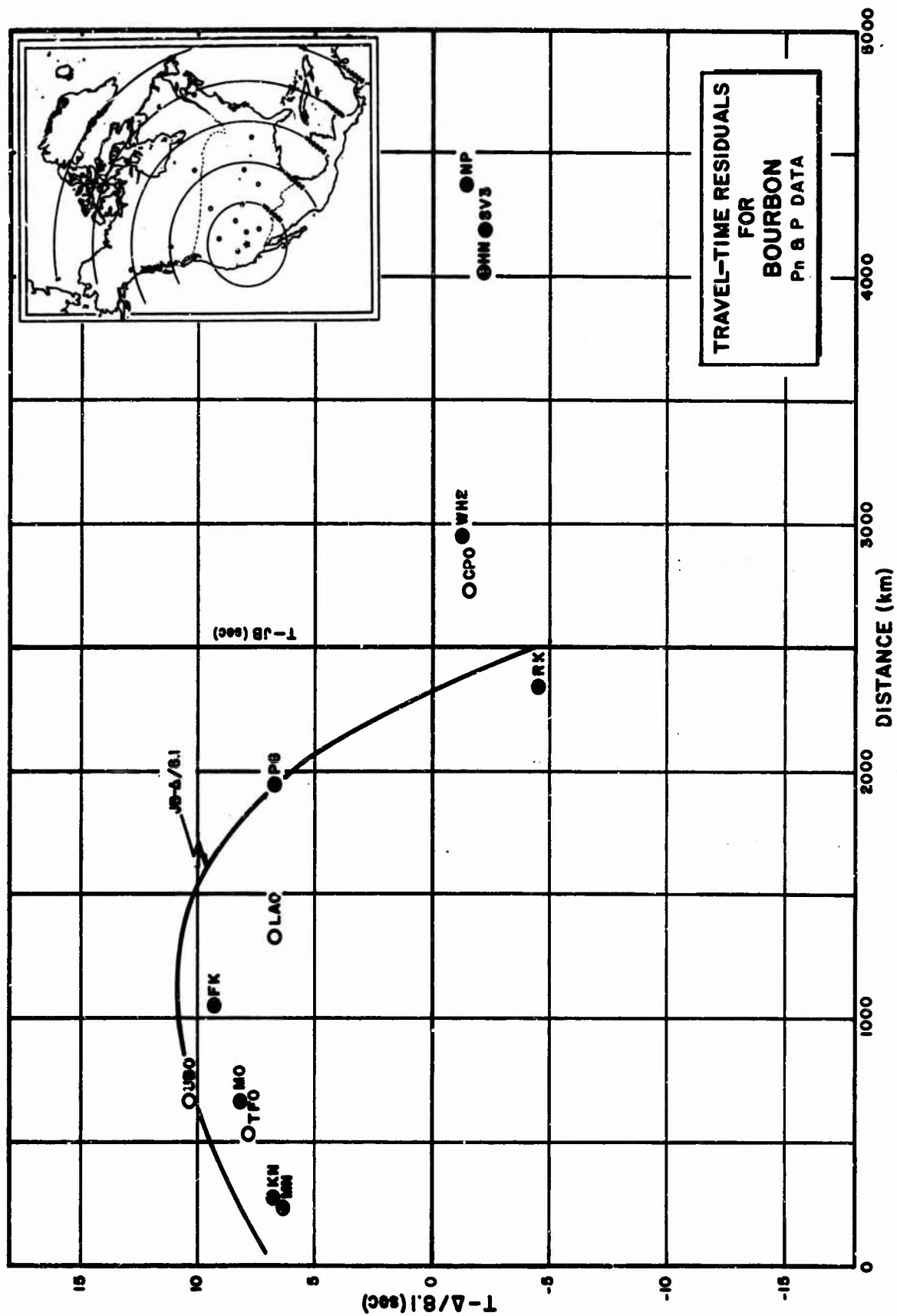


Figure 4

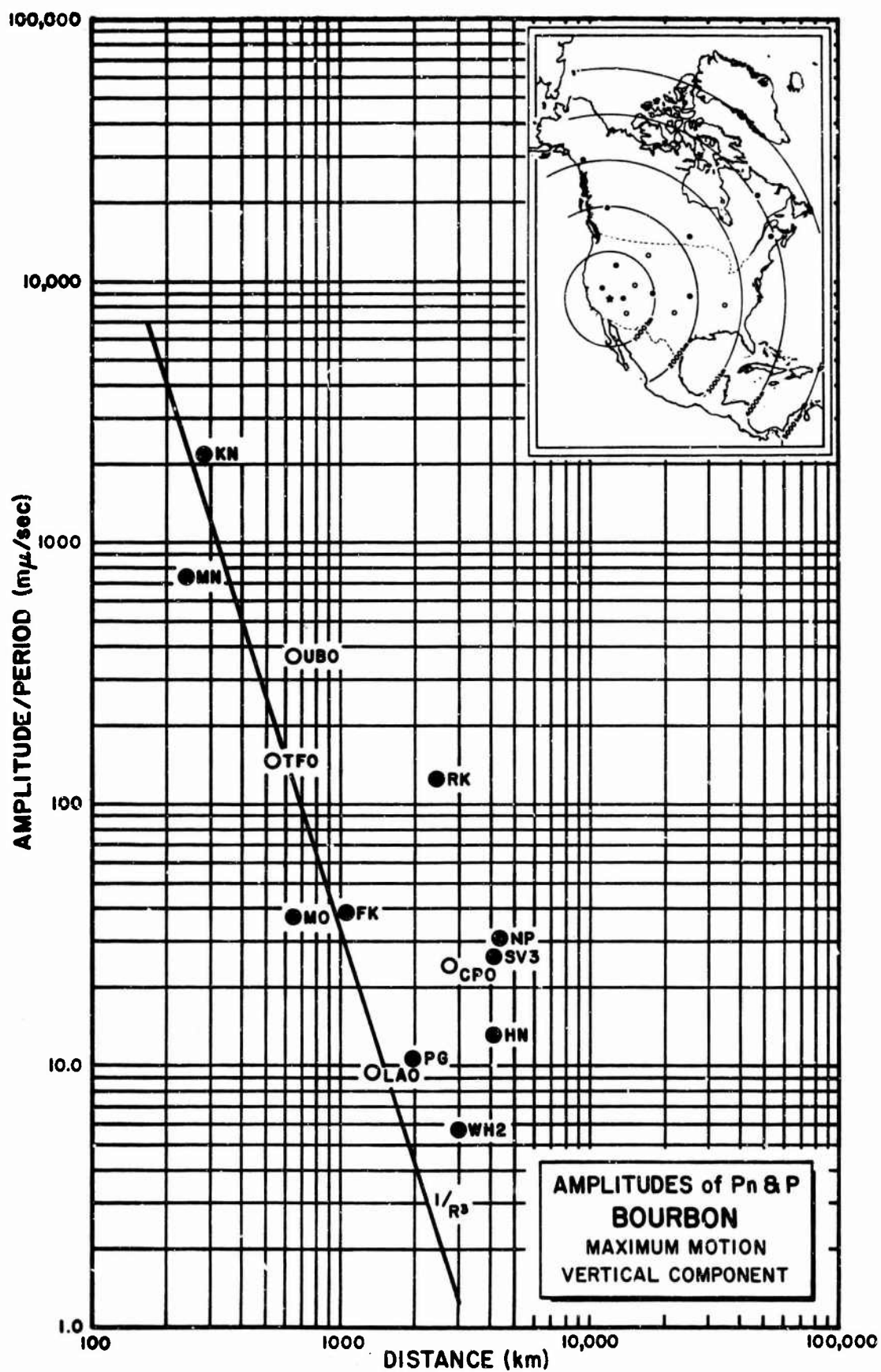


Figure 5

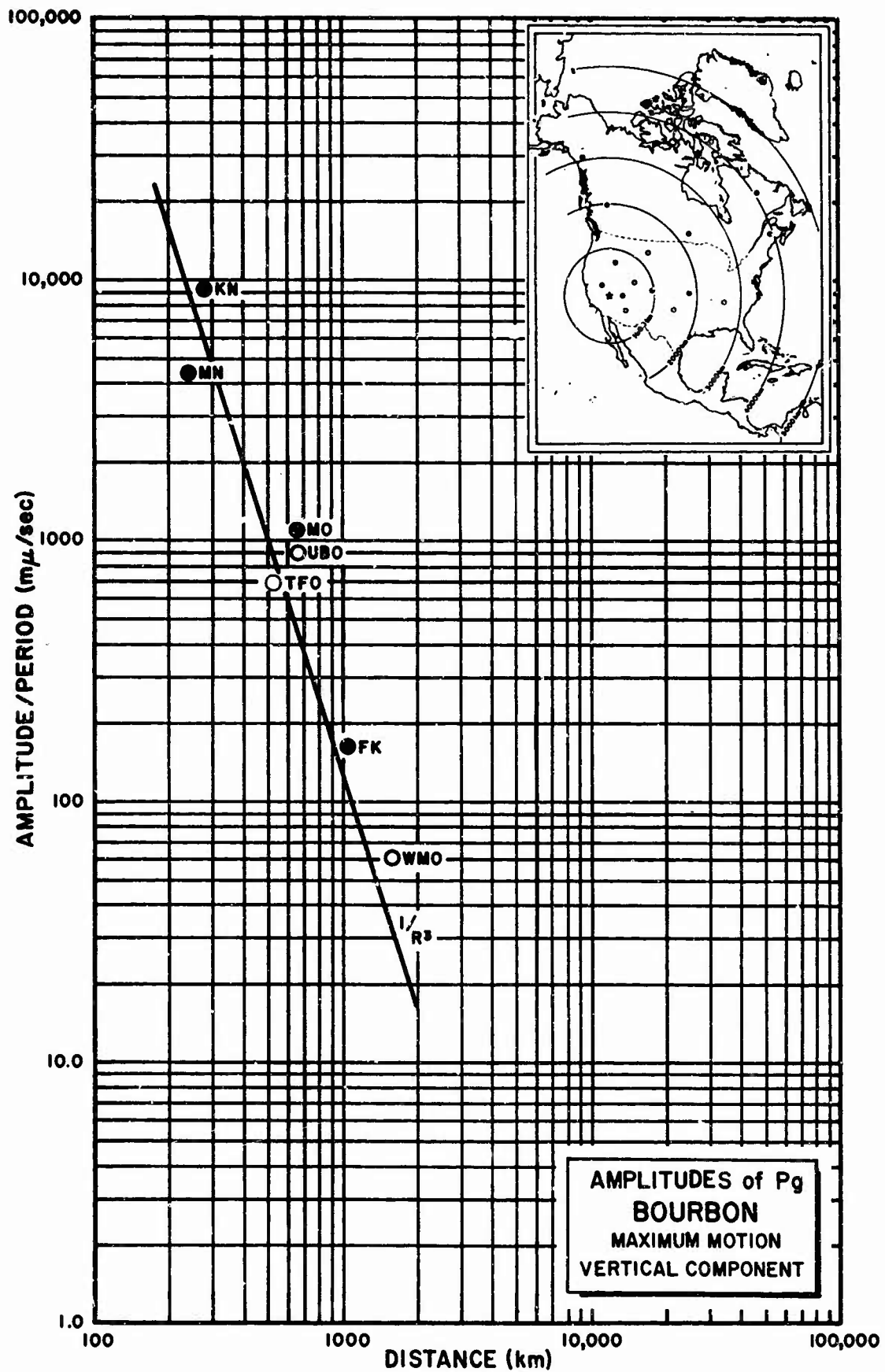


Figure 6

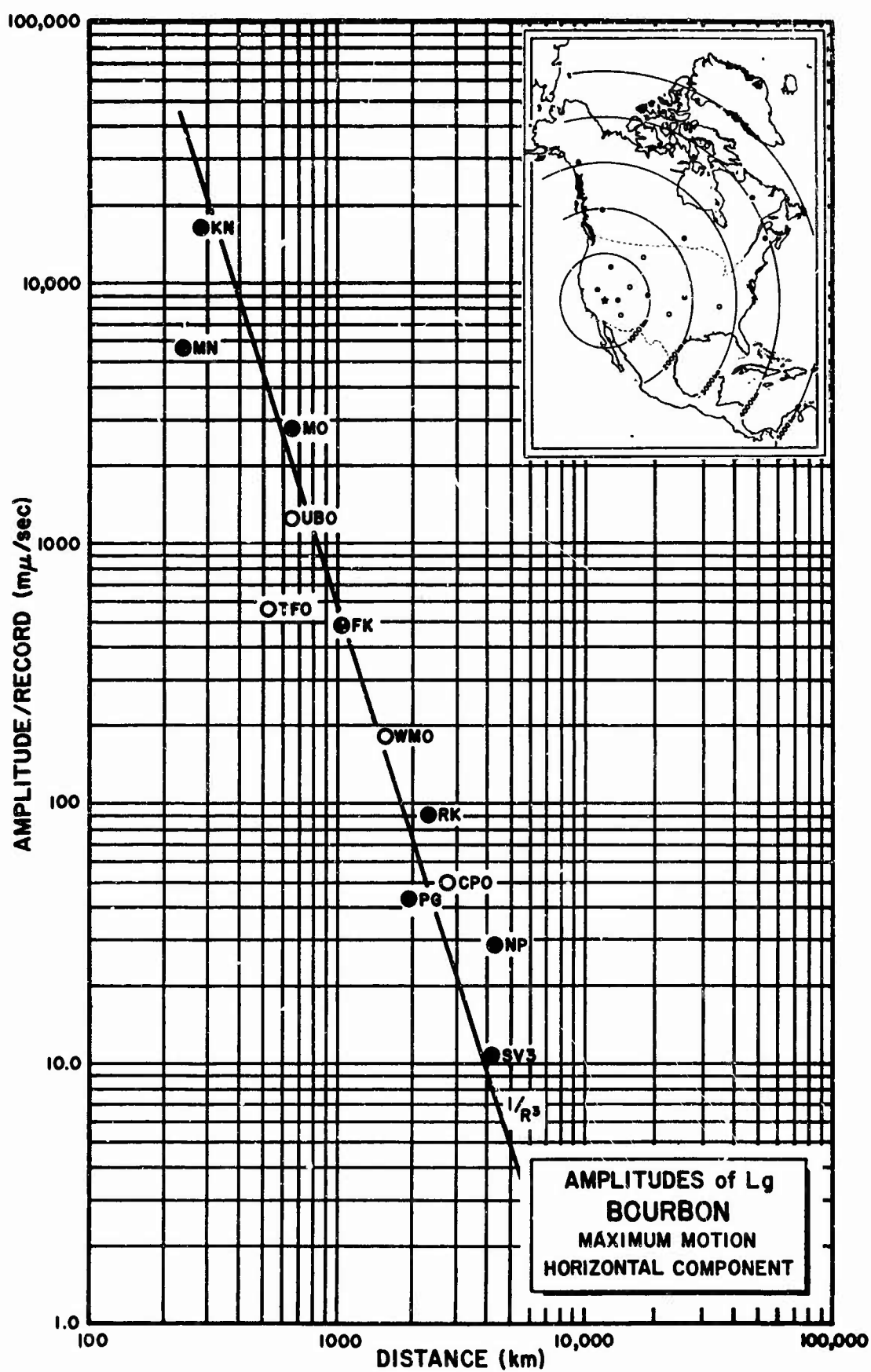


Figure 7

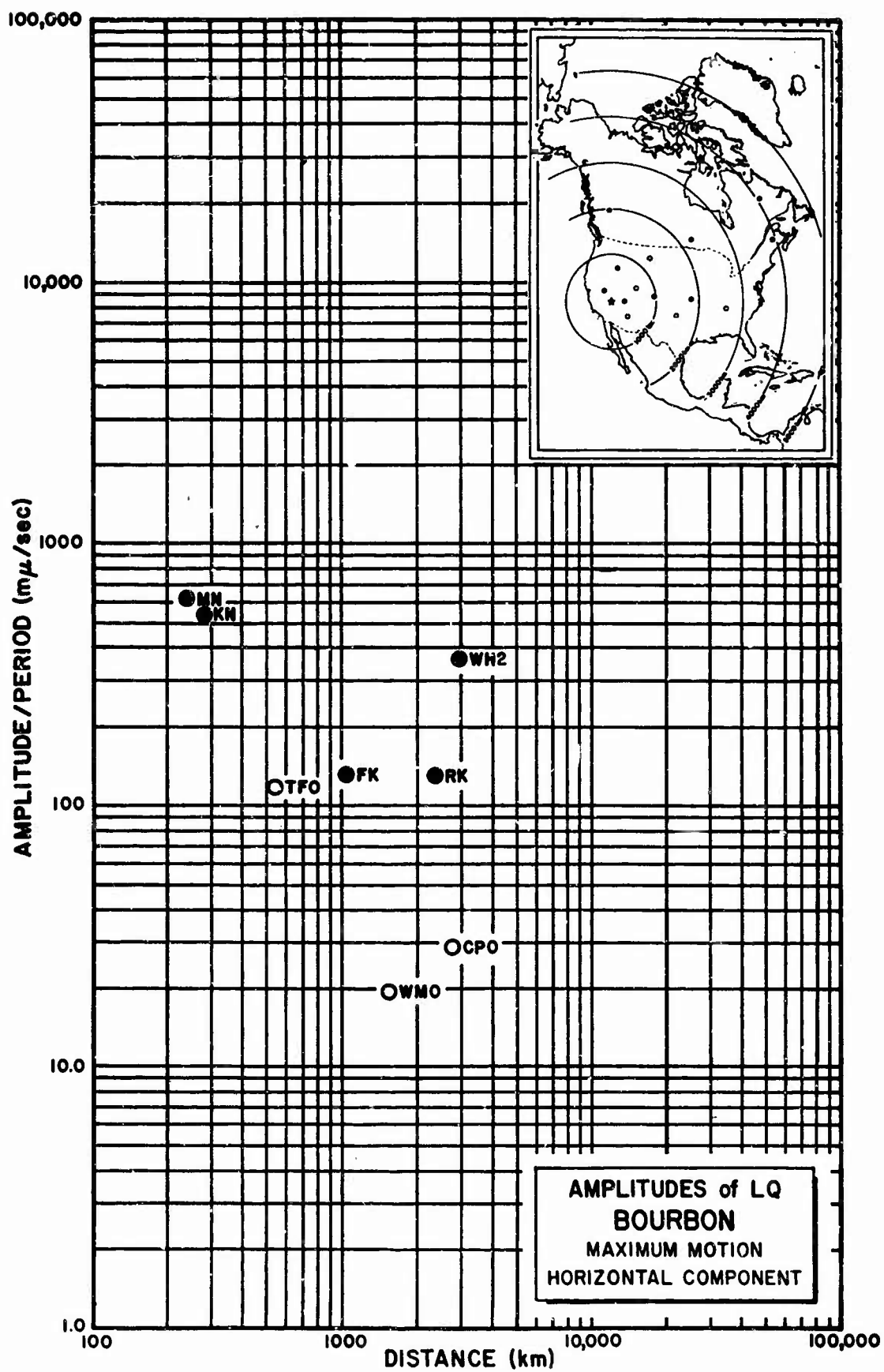


Figure 8

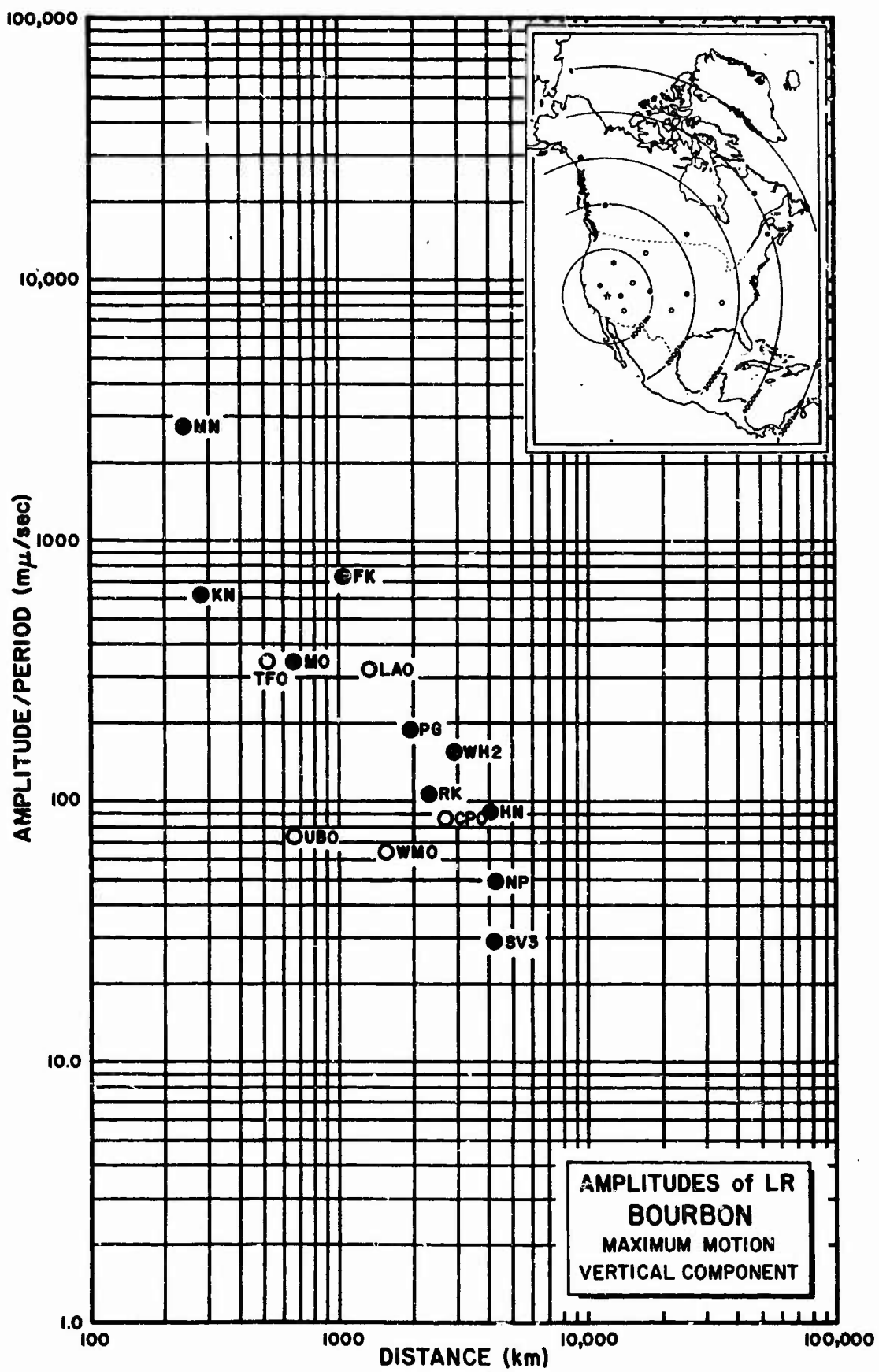


Figure 9

Code	Station	Distance (km)	Geographic Latitude	Geographic Longitude	Elav. (km)	Computed Azimuth		Installed Azimuth		Large or Small SP	LP Inat.
						Epi. Sta.	Epi. Sta.	Tang.	Radial		
HN-NV*	Mina, Nevada	240	38°26'10" N	118°08'53" W	1.52	309°	127°	308°	038°	L	X
KN-UT*	Kanab, Utah	283	37°01'22" N	112°49'39" W	1.74	91°	273°	95°	185°	L	
TF80-260	Tonto Forest Seismological Observatory, Arizona	530	34°17'12" N	111°16'03" W	1.49	125°	307°	90°	0°	JM	X
MO-ID*	Mountain Home, Idaho	664	43°04'19" N	116°15'56" W	.79	358°	178°	359°	89°	L	X
UB80-210	U.ita Basin Seismological Observatory, Utah	664	40°19'18" N	109°34'07" W	1.60	55°	239°	90°	0°	JM	X
FK-CO*	Frankton, Colorado	1045	39°35'12" N	104°27'42" W	1.80	71°	258°	79°	169°	L	X
LAO	Subarray AO-10, Montana	1337	46°41'19" N	106°13'20" W	.90	34°	221°	90°	0°	HSZ	X
WISO-26	Wichita Mountain Seismo- logical Observatory, Oklahoma	1592	34°43'05" N	98°35'21" W	.51	94°	235°	90°	0°	JM	X
KC-MO	Kansas City, Missouri	1881	39°21'21" N	94°40'17" W	.27	76°	269°	133°	223°	S	X
PG-BC	Prince George, British Columbia, Canada	1945	53°59'50" N	122°31'23" W	.91	347°	162°	110°	200°	L	X
RK-ON*	Red Lake, Ontario, Canada	2339	50°50'20" N	93°40'20" W	.37	42°	238°	58°	148°	S	X
CP80-28	Cumberland Plateau Seismological Observatory, Tennessee	2726	35°35'41" N	85°34'13" W	.57	84°	283°	90°	0°	JM	X
WH2YK*	Whitehorse, Yukon Territory, Canada	2947	60°41'41" N	134°58'02" W	.85	339°	144°	325°	055°	L	X
HN-ME*	Houlton, Maine	4062	46°09'43" N	67°59'09" W	.21	60°	273°	93°	183°	S	X
SV3QB	Schefferville, Quebec, Canada	4185	54°48'39" N	66°45'00" W	.58	45°	263°	139°	229°	S	X
NP-WT*	Mould Bay, Northwest Territories, Canada	436A	76°15'08" N	119°22'18" W	.06	359°	176°	356°	86°	JM ²	X

*Seismometers Oriented Toward Nevada Test Site

Recording Site Information - BOURBON Appendix I(A)

Unified Magnitude: $m = \log_{10} (A/T) + B$

where

A = zero to peak ground motion in millimicrons
 $= \frac{(\text{mm}) (1000)}{K}$

K

T = signal period in seconds

B = distance factor (see Table below)

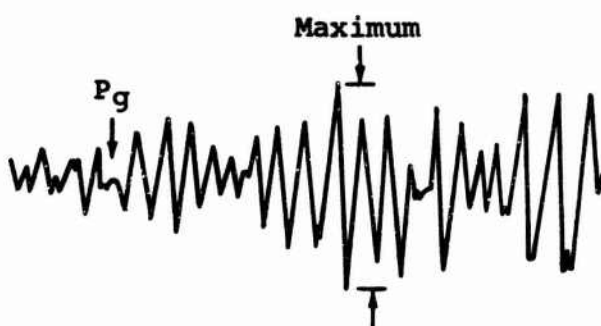
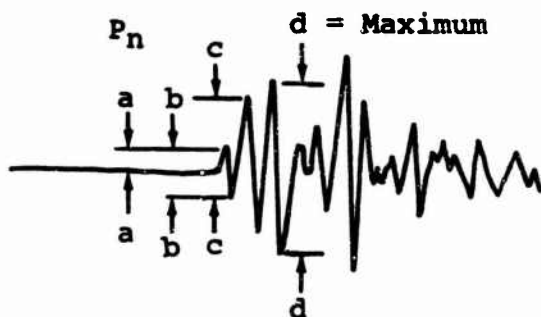
mm = record amplitude in millimeters zero to peak

K = magnification in thousands at signal frequency

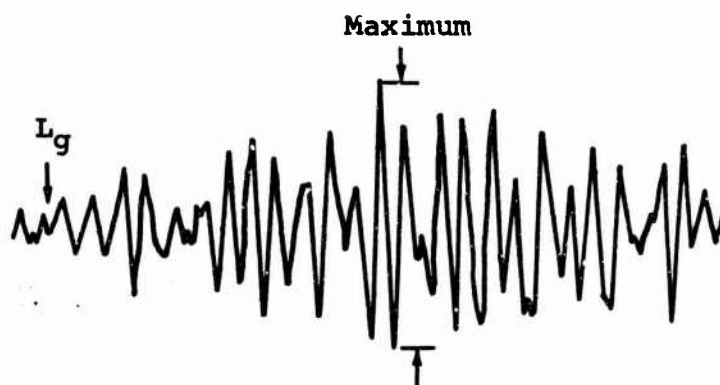
Table of Distance Factors (B) for Zero Depth

Dis (deg)	B	Dist (deg)	B	Dist (deg)	B	Dist (deg)	B
0°	-	27°	3.5	54°	3.8	80°	3.7
1	-	28	3.6	55	3.8	81	3.8
2	2.2	29	3.6	56	3.8	82	3.9
3	2.7	30	3.6	57	3.8	83	4.0
4	3.1	31	3.7	58	3.8	84	4.0
5	3.4	32	3.7	59	3.8	85	4.0
6	3.6	33	3.7	60	3.8	86	3.9
7	3.8	34	3.7	61	3.9	87	4.0
8	4.0	35	3.7	62	4.0	88	4.1
9	4.2	36	3.6	63	3.9	89	4.0
10	4.3	37	3.5	64	4.0	90	4.0
11	4.2	38	3.5	65	4.0	91	4.1
12	4.1	39	3.4	66	4.0	92	4.1
13	4.0	40	3.4	67	4.0	93	4.2
14	3.6	41	3.5	68	4.0	94	4.1
15	3.3	42	3.5	69	4.0	95	4.2
16	2.9	43	3.5	70	3.9	96	4.3
17	2.9	44	3.5	71	3.9	97	4.4
18	2.9	45	3.7	72	3.9	98	4.5
19	3.0	46	3.8	73	3.9	99	4.5
20	3.0	47	3.9	74	3.8	100	4.4
21	3.1	48	3.9	75	3.8	101	4.3
22	3.2	49	3.8	76	3.9	102	4.4
23	3.3	50	3.7	77	3.9	103	4.5
24	3.3	51	3.7	78	3.9	104	4.6
25	3.5	52	3.7	79	3.8	105	4.7
26	3.4	53	3.7				

Unified Magnitudes From P_n or P Waves
 Appendix I(B)



Detail Showing Allowance
For Line Width



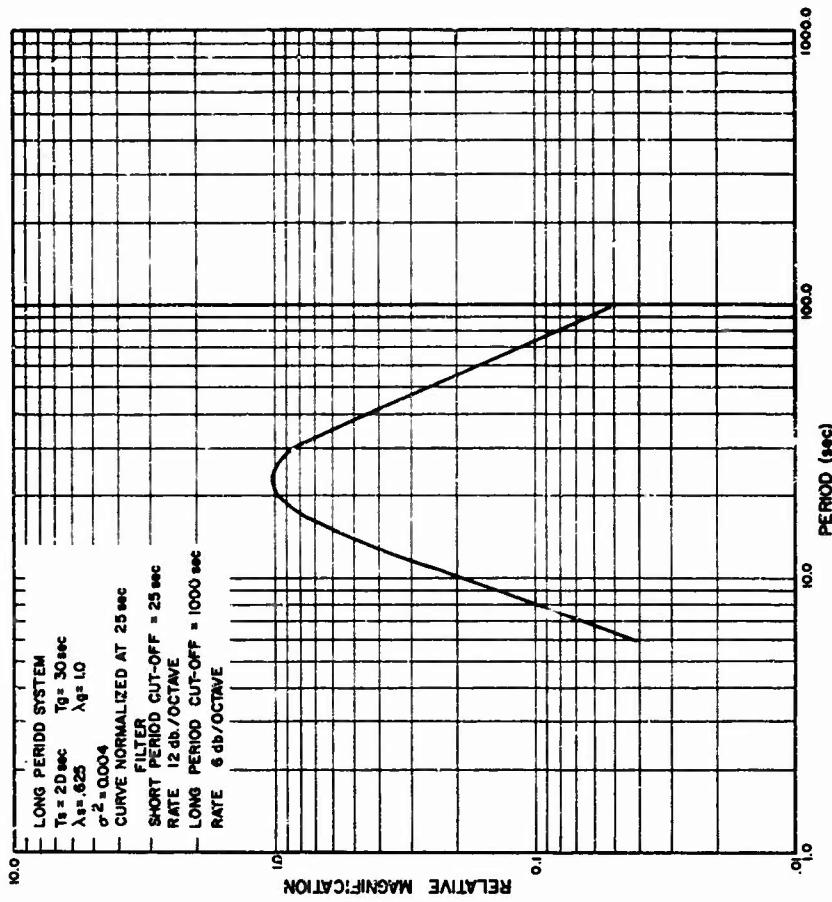
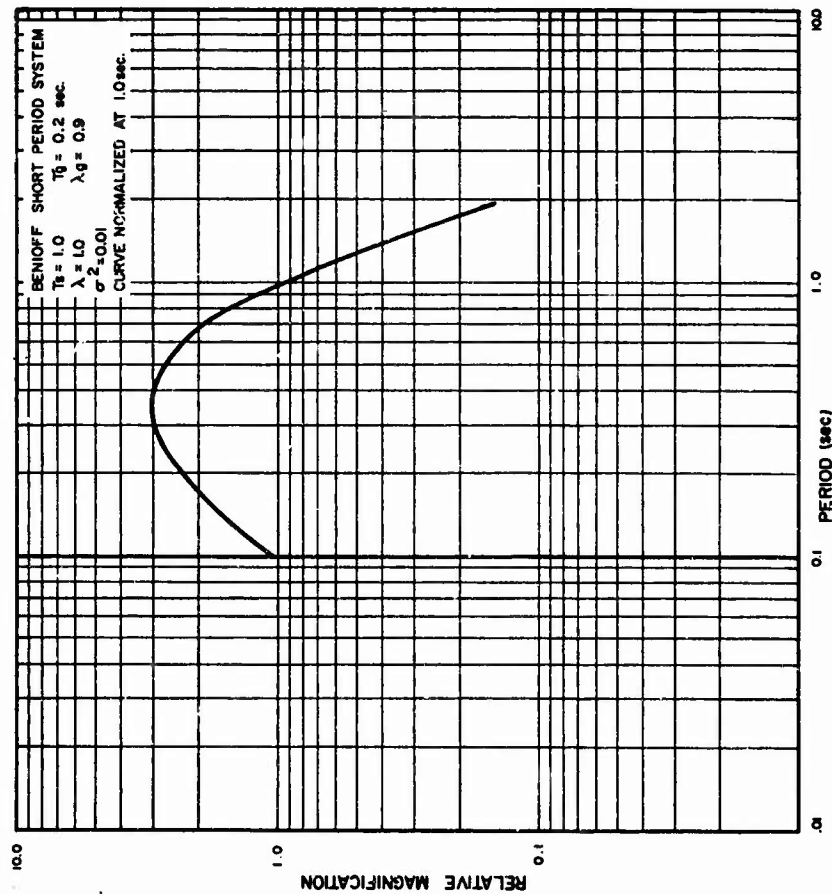
Pick time of Pn at beginning of "a" half cycle.

Pick amplitude of Pn as maximum " $d/2$ " within 2 or 3 cycles of "c".

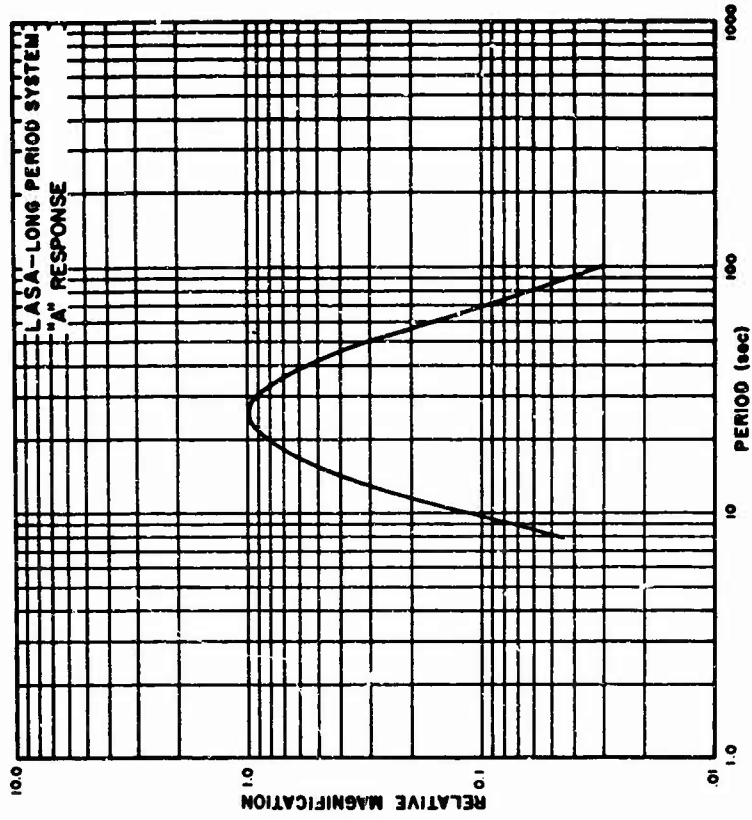
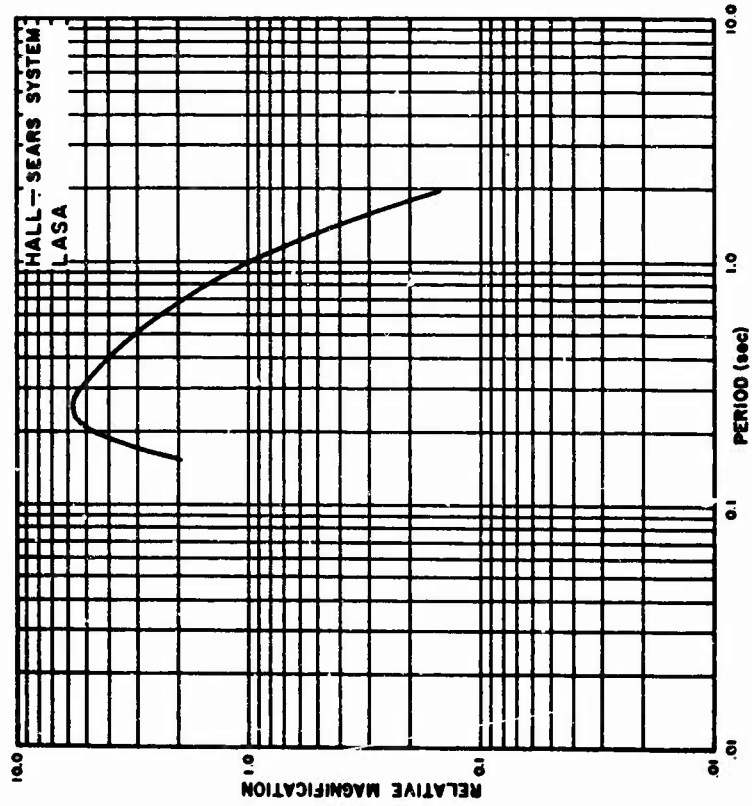
Pick amplitudes of Pg and Lg at maximum of corresponding motion.

Seismic Analysis Diagram

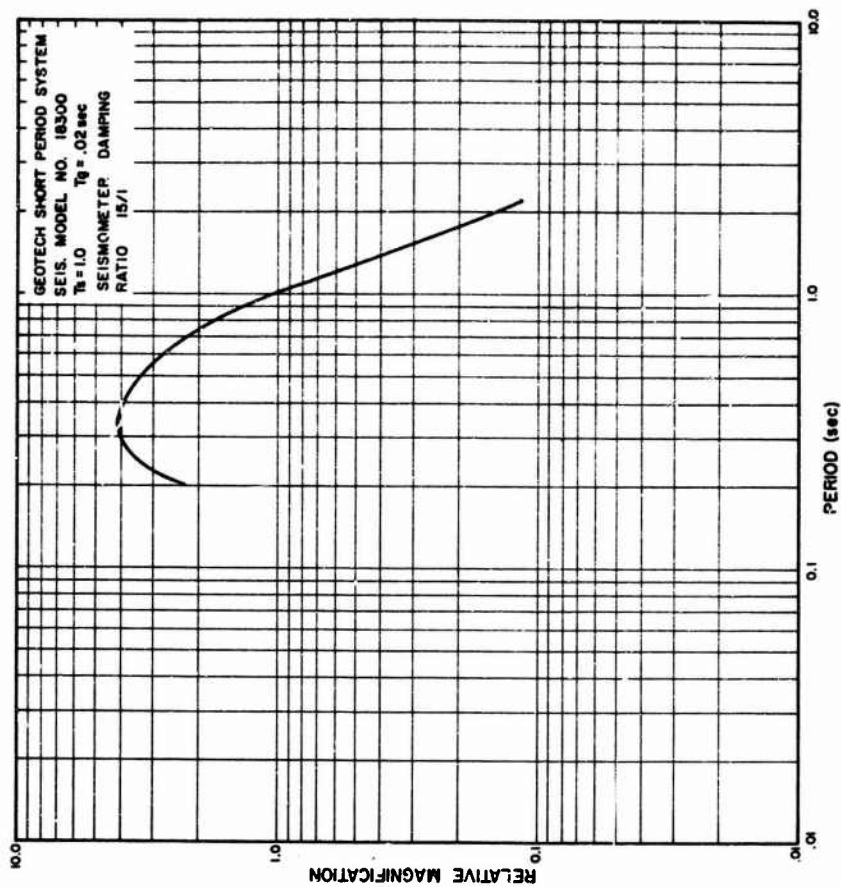
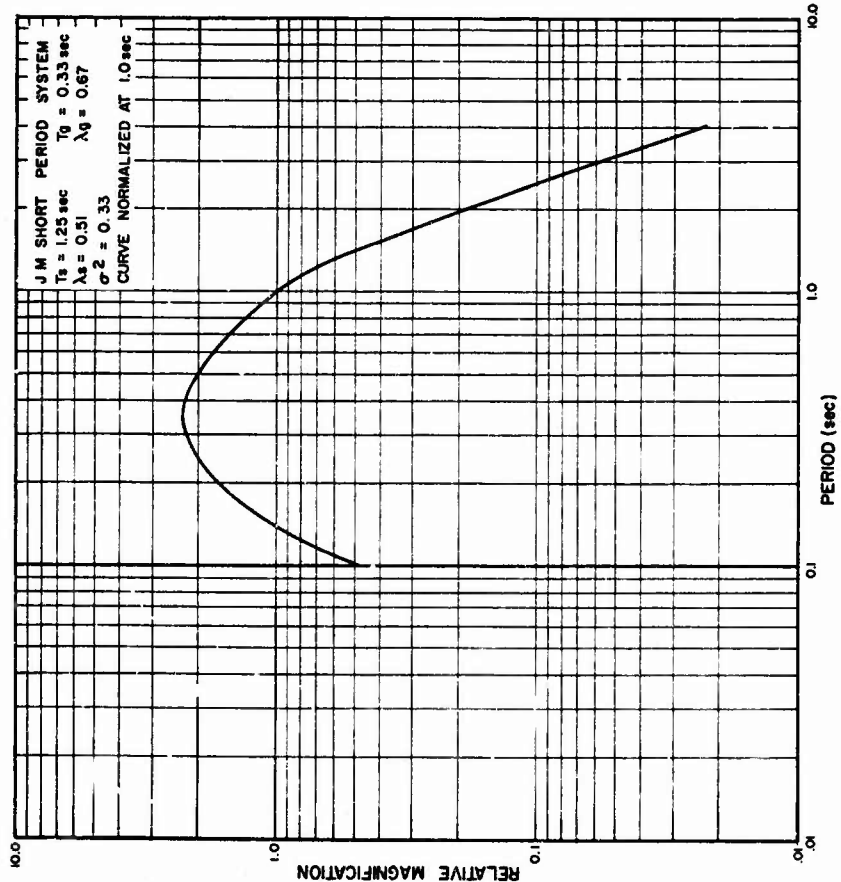
APPENDIX II(A)



INSTRUMENT RESPONSE CURVES - LRSM



INSTRUMENT RESPONSE CURVE - LASA



INSTRUMENT RESPONSE CURVES - OTHER SHORT PERIOD

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1 ORIGINATING ACTIVITY (Corporate author) TELEDYNE, INC. ALEXANDRIA, VIRGINIA		2a REPORT SECURITY CLASSIFICATION Unclassified
		2b GROUP -----
3 REPORT TITLE LONG RANGE SEISMIC MEASUREMENTS - BOURBON		
4 DESCRIPTIVE NOTES (Type of report and inclusive dates) Scientific		
5 AUTHOR(S) (Last name, first name, initial) Don M. Clark		
6 REPORT DATE 20 January 1967	7a. TOTAL NO. OF PAGES 23	7b. NO. OF REFS 2
8a. CONTRACT OR GRANT NO. F 33657-67-C-1313	9a. ORIGINATOR'S REPORT NUMBER(S) 185	
8b. PROJECT NO. VELA T/6702	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) -----	
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11. SUPPLEMENTARY NOTES -----	12. SPONSORING MILITARY ACTIVITY ADVANCED RESEARCH PROJECTS AGENCY NUCLEAR TEST DETECTION OFFICE WASHINGTON, D. C.	
13. ABSTRACT An analysis of seismological data from an underground nuclear explosion as a continuing study to provide information to aid in distinguishing between earthquakes and explosions. A table of travel-times and amplitudes of P, Pg, Lg, and surface waves are included along with other unidentified phases.		

DD FORM 1 JAN 64 1473

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Security Classification

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14 KEY WORDS	LINK A		LINK B		LINK C	
	NO.	WT.	NO.	WT.	NO.	WT.
Seismic Magnitude						
Seismic Travel-Time						
Seismic Amplitude						
VELA-UNIFORM						
Nuclear Tests						

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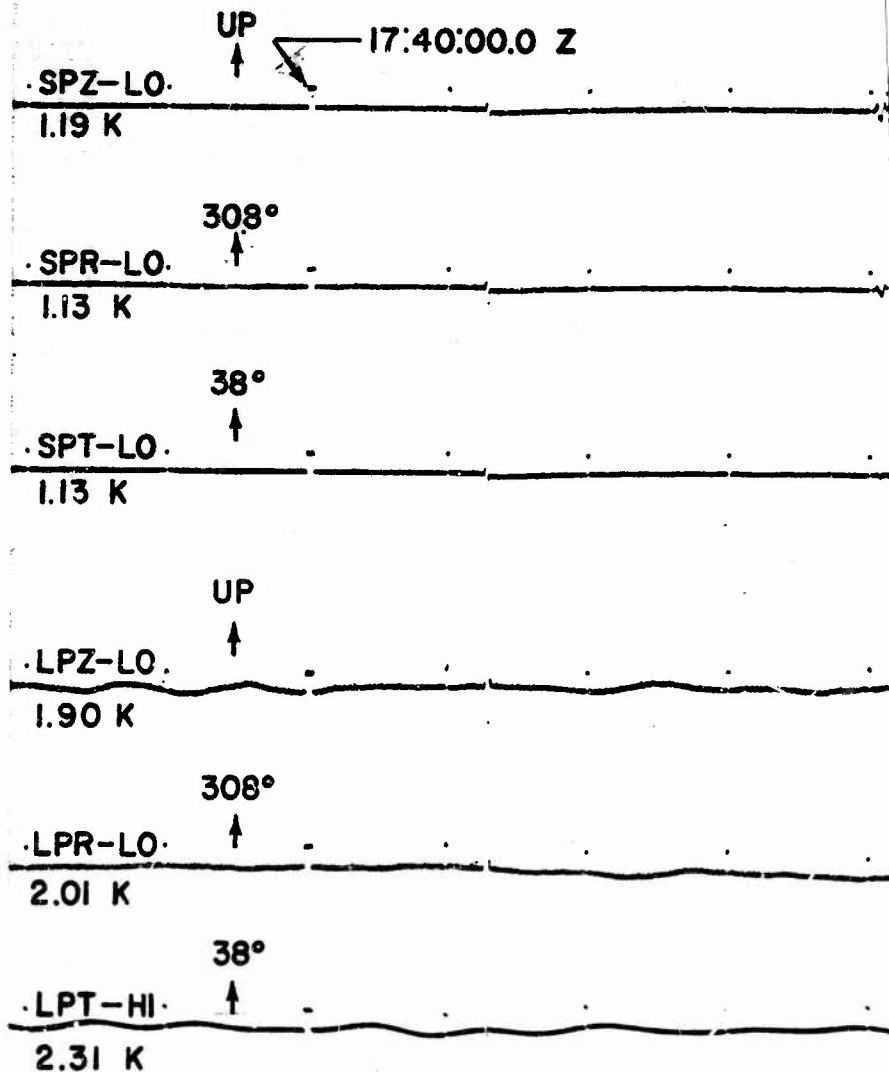
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MN-NV

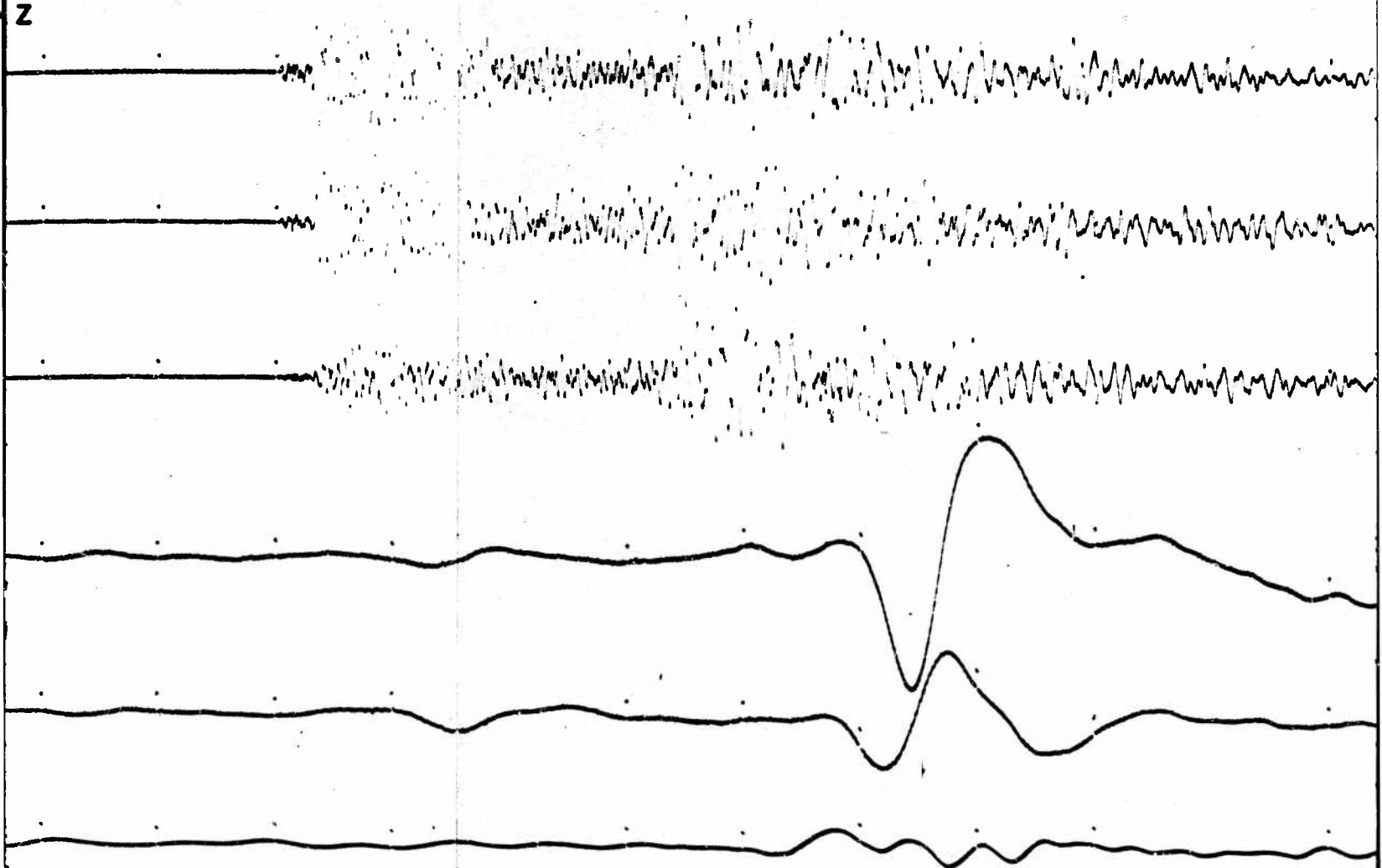
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20 JANUARY 1967

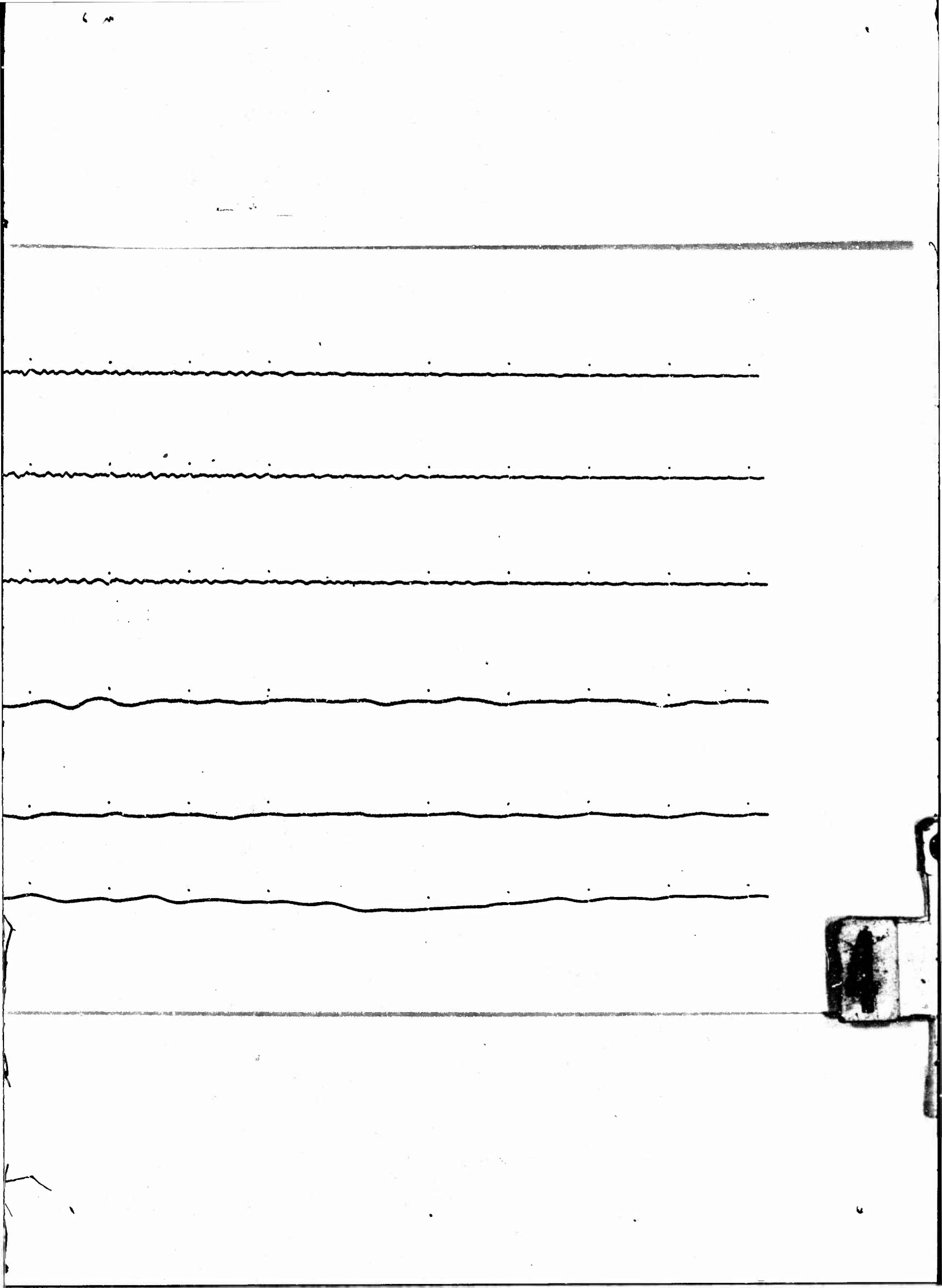
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2



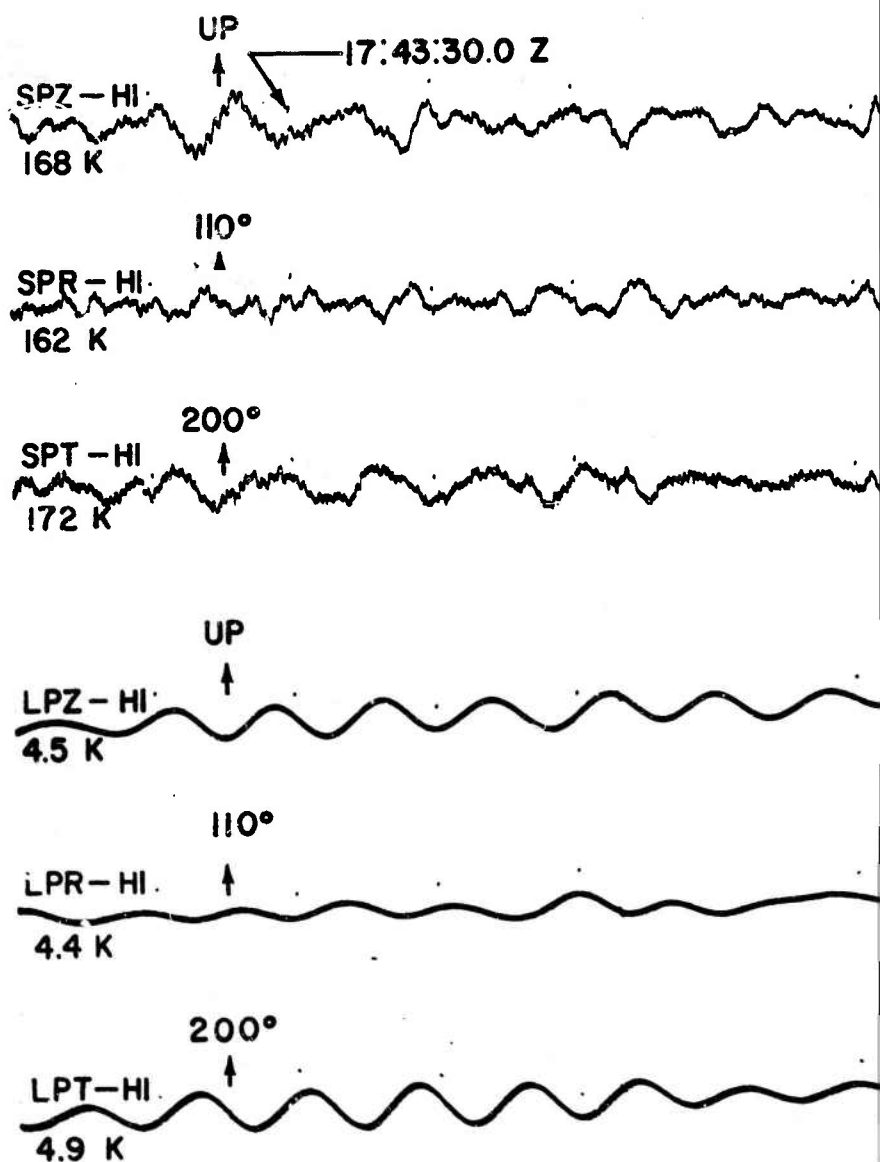
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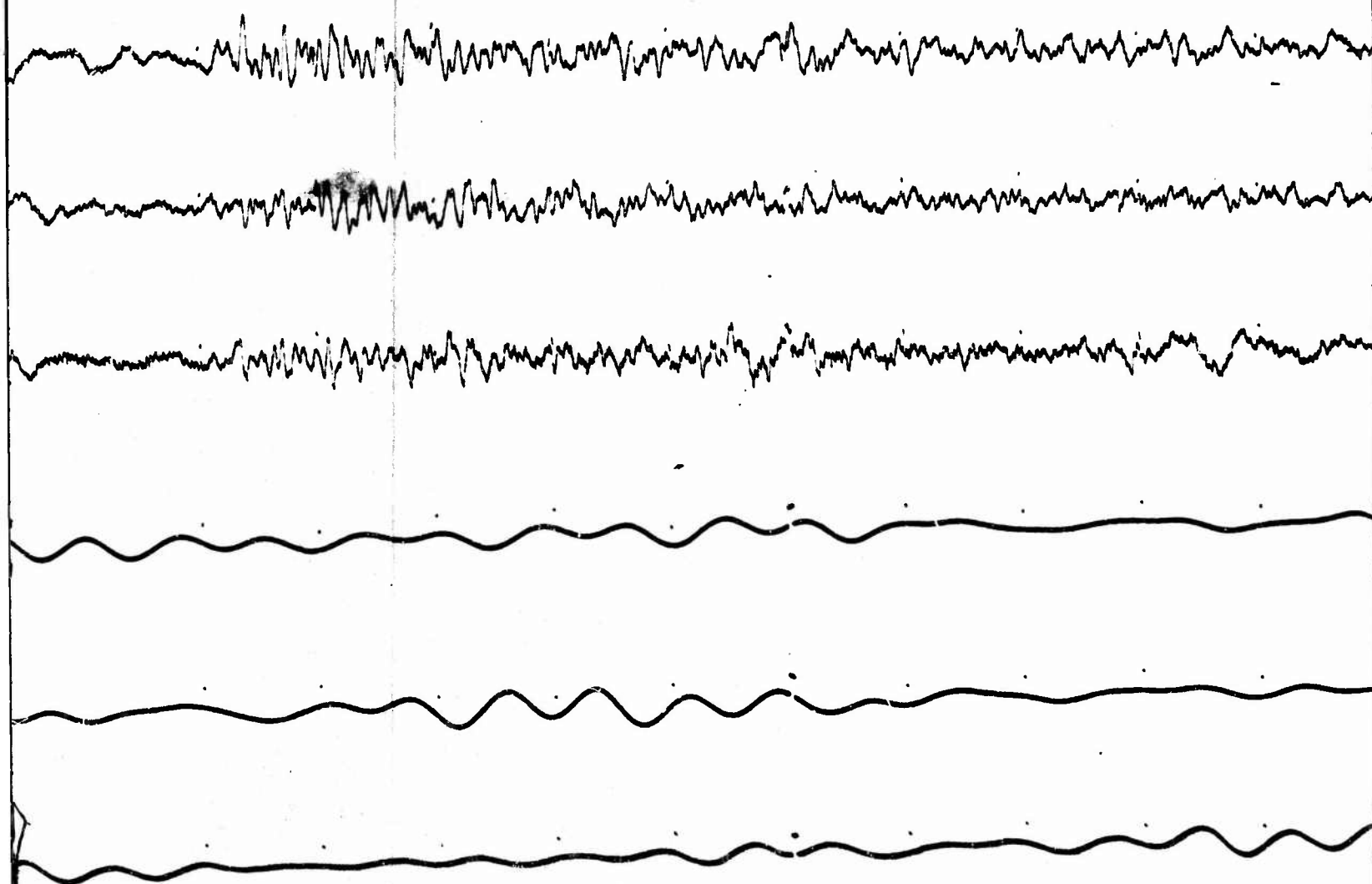
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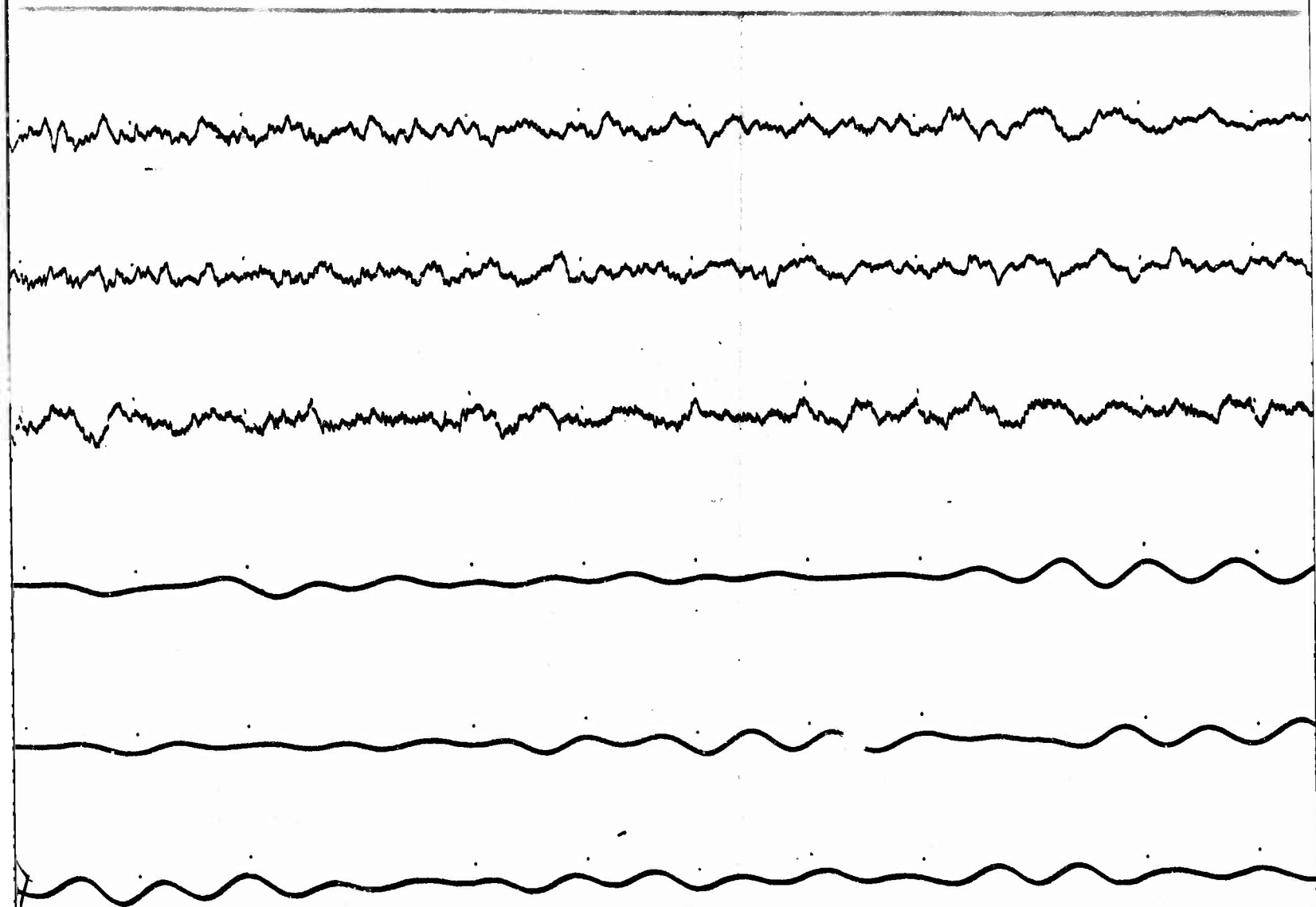
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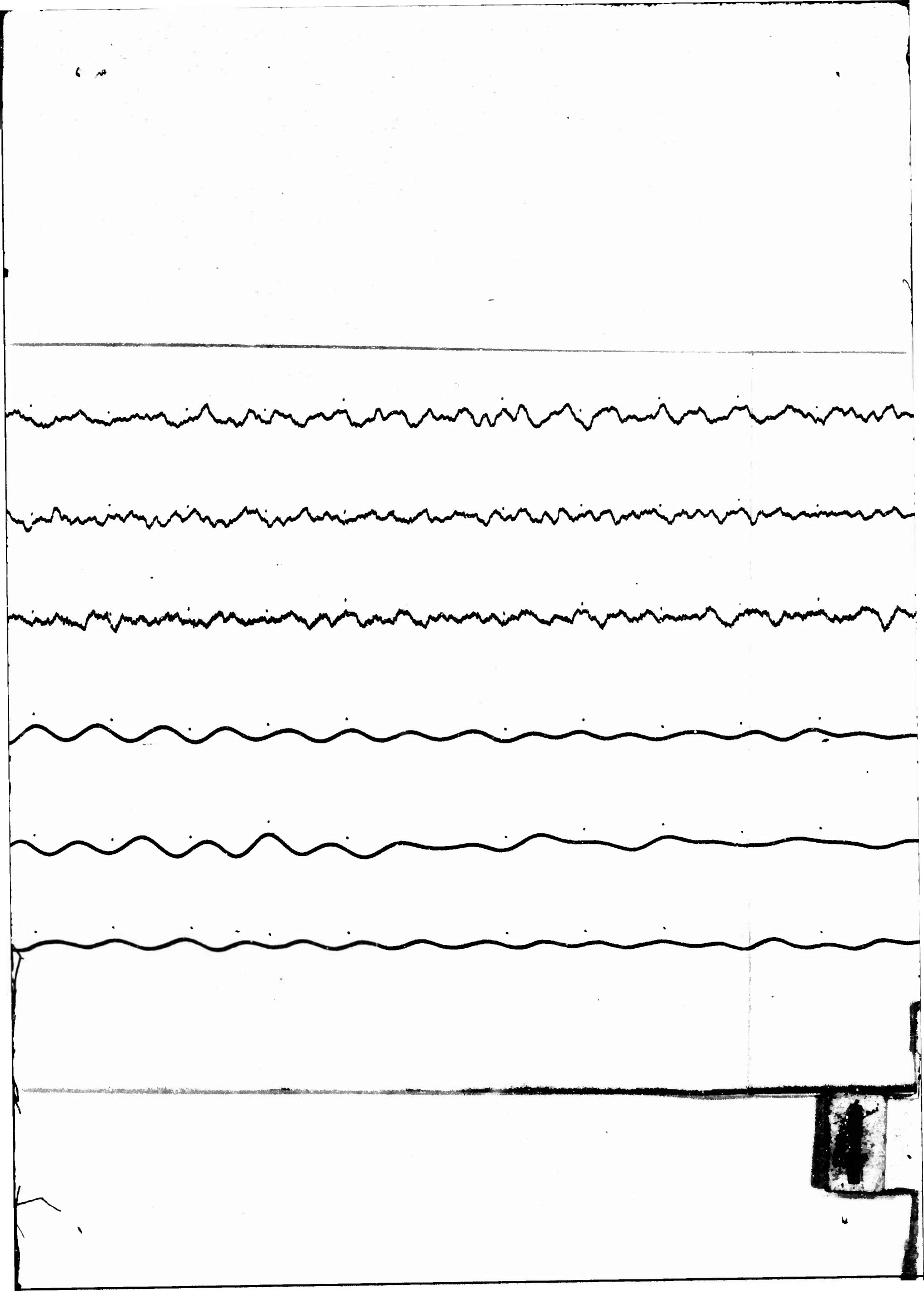
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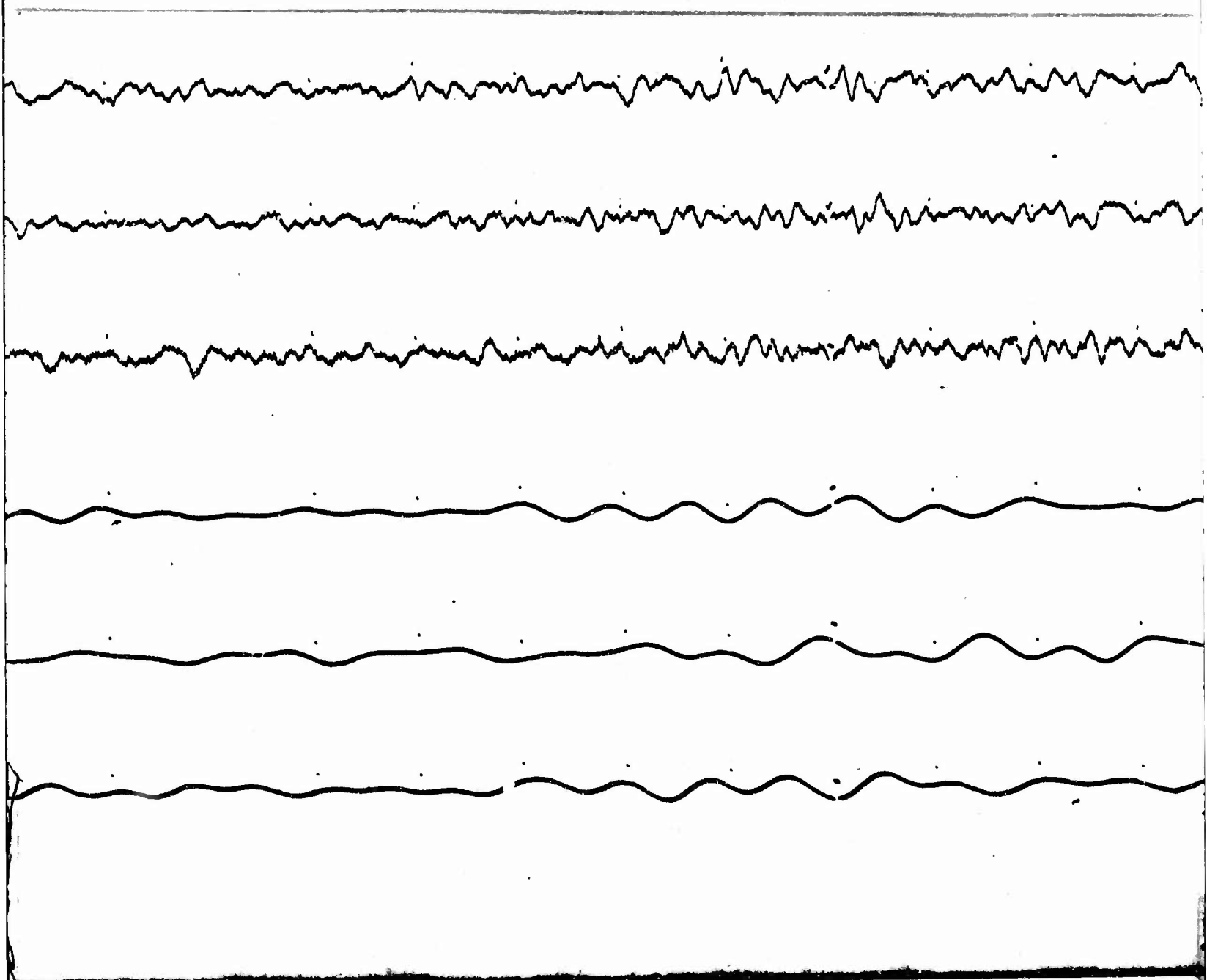
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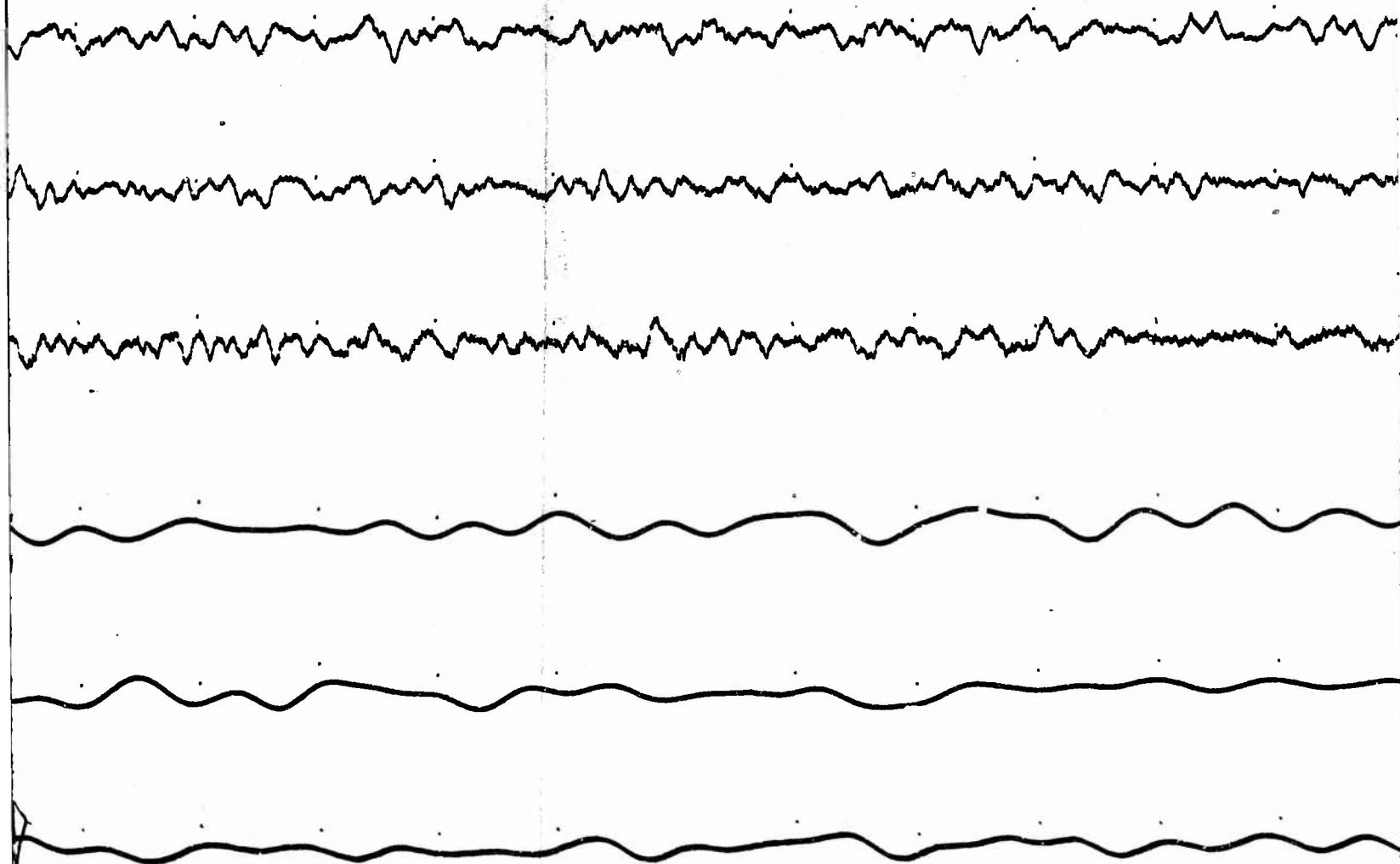


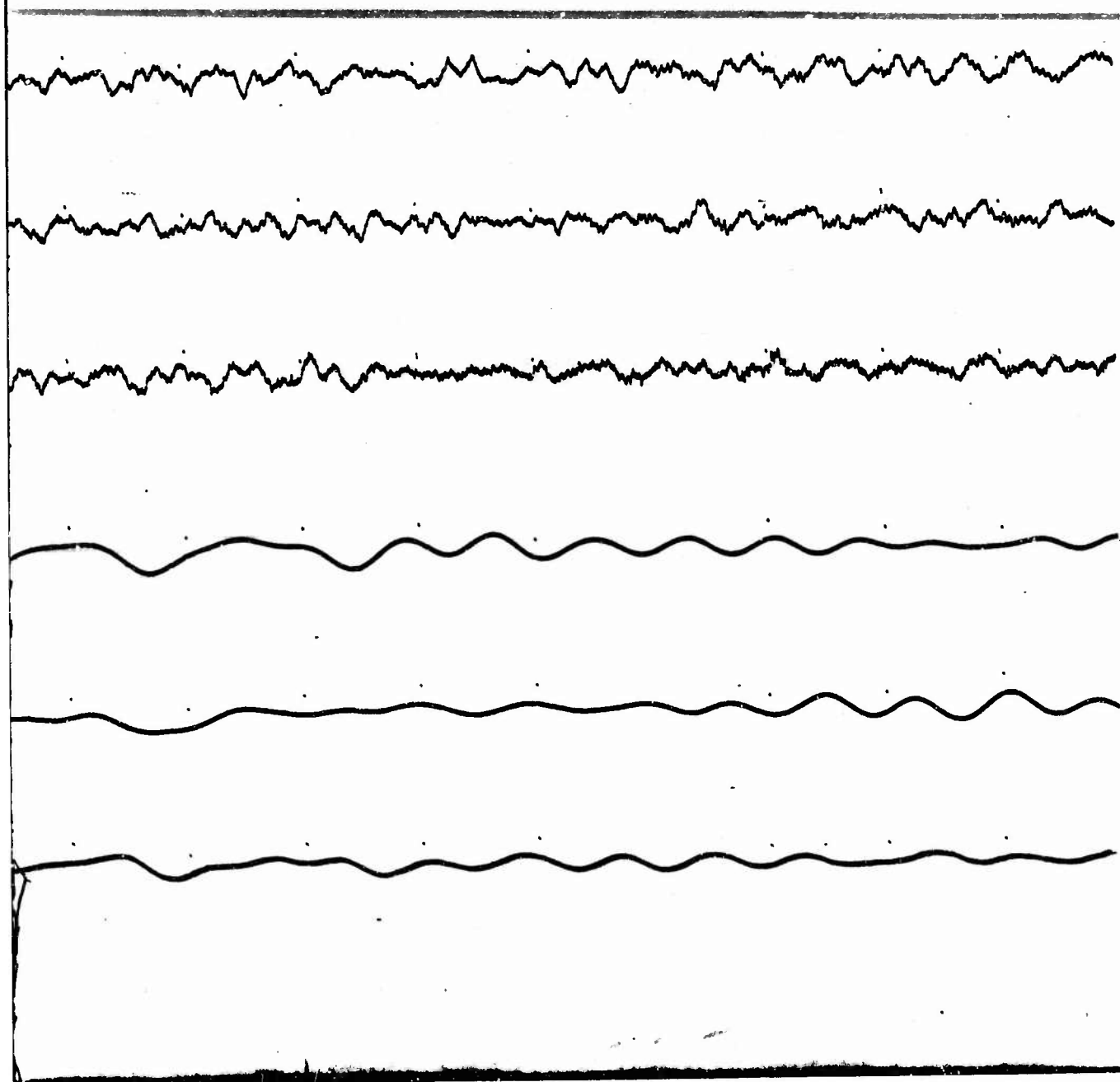












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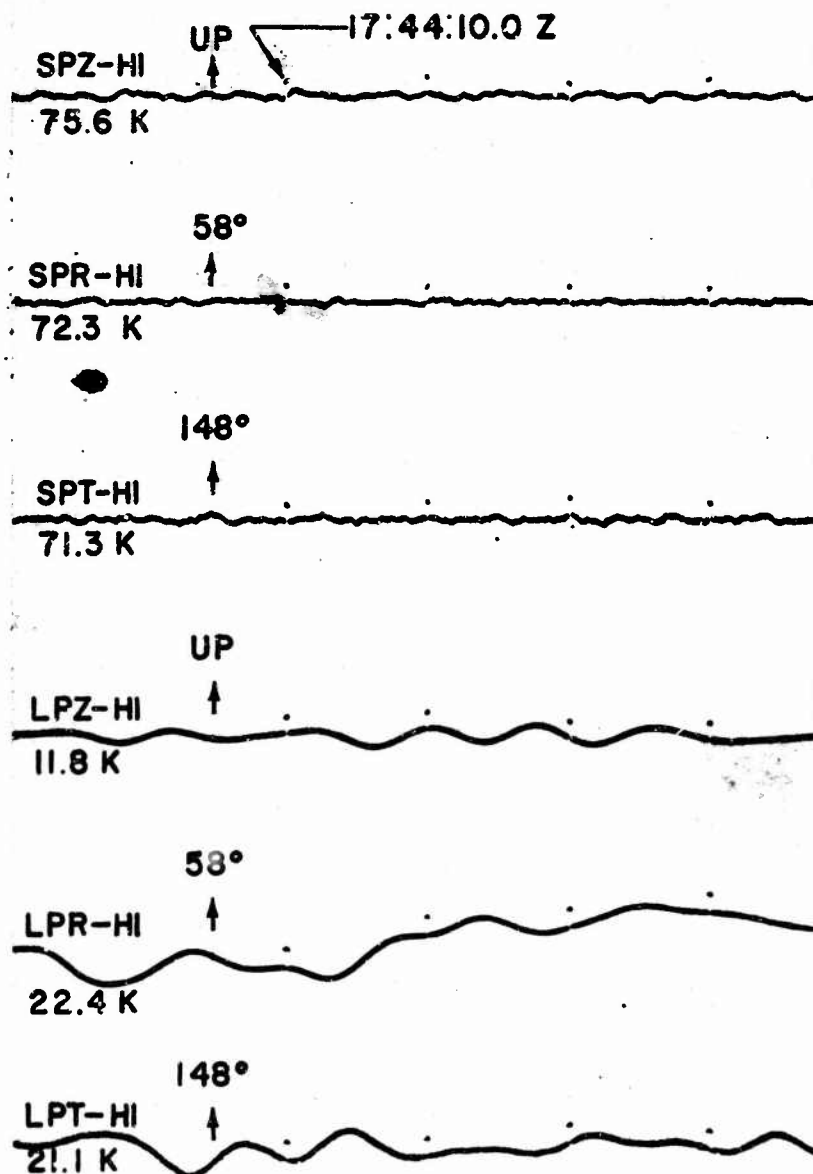
BOURBON

RK-ON

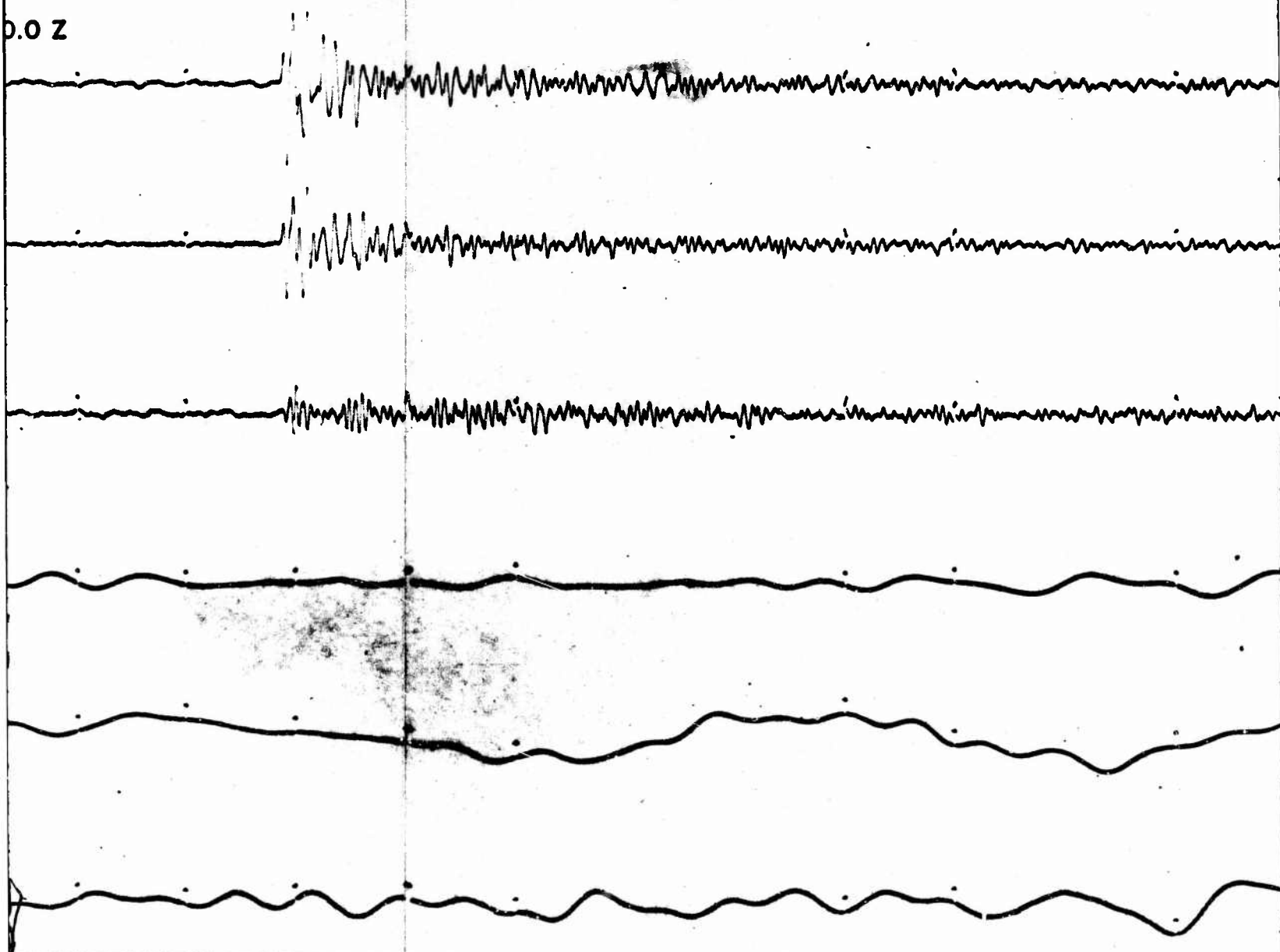
RED LAKE, ONTARIO

20 JANUARY 1967

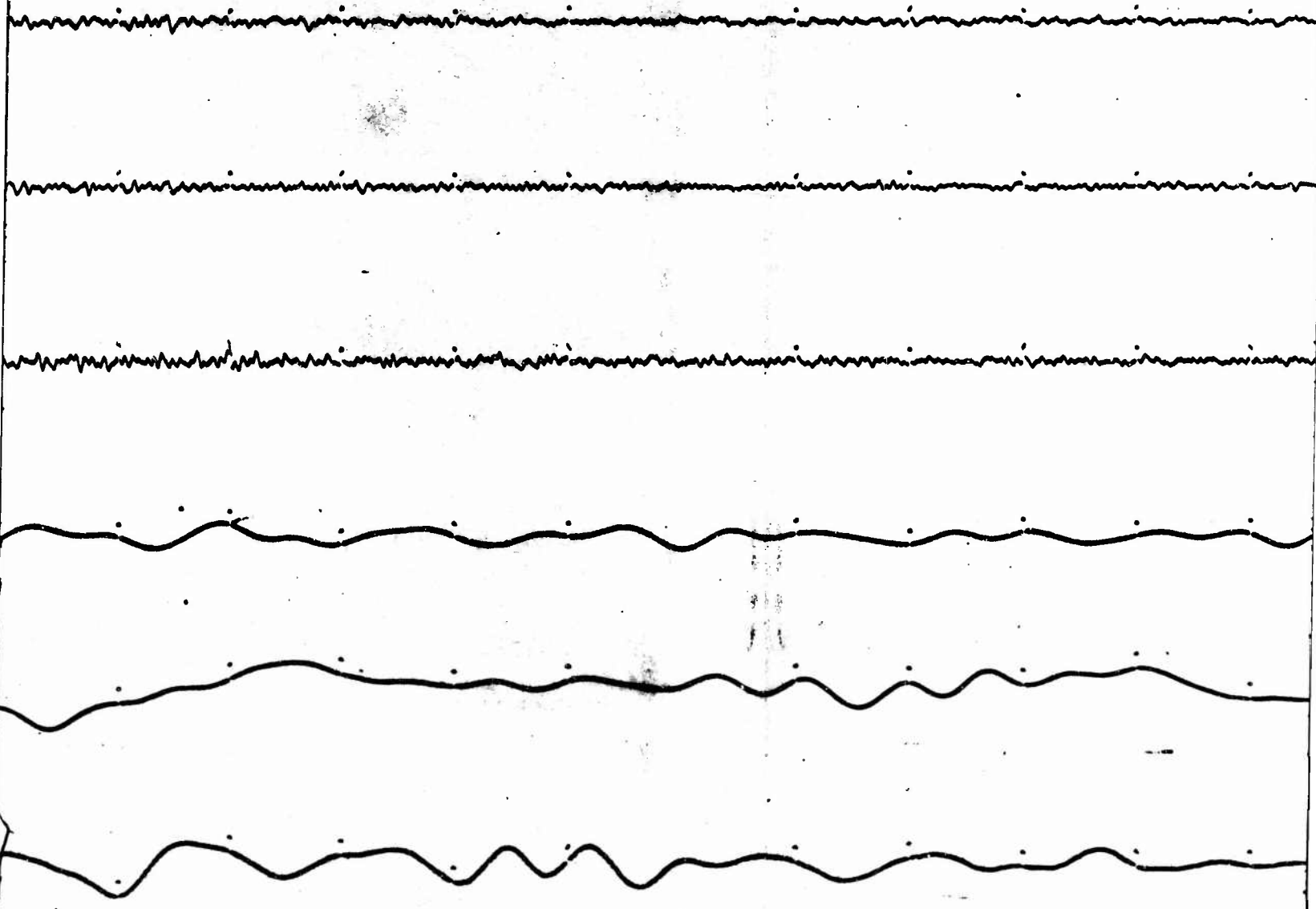
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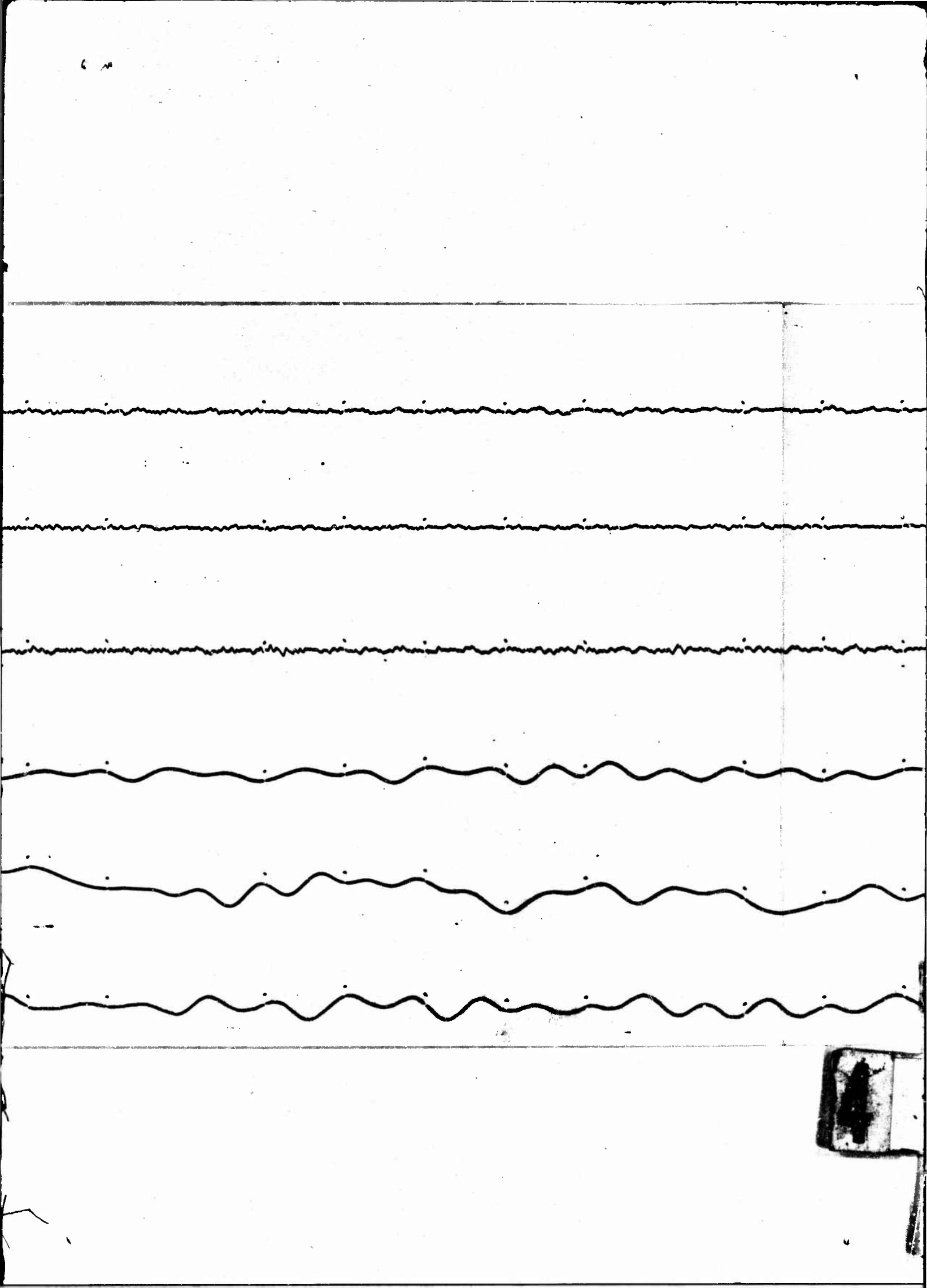


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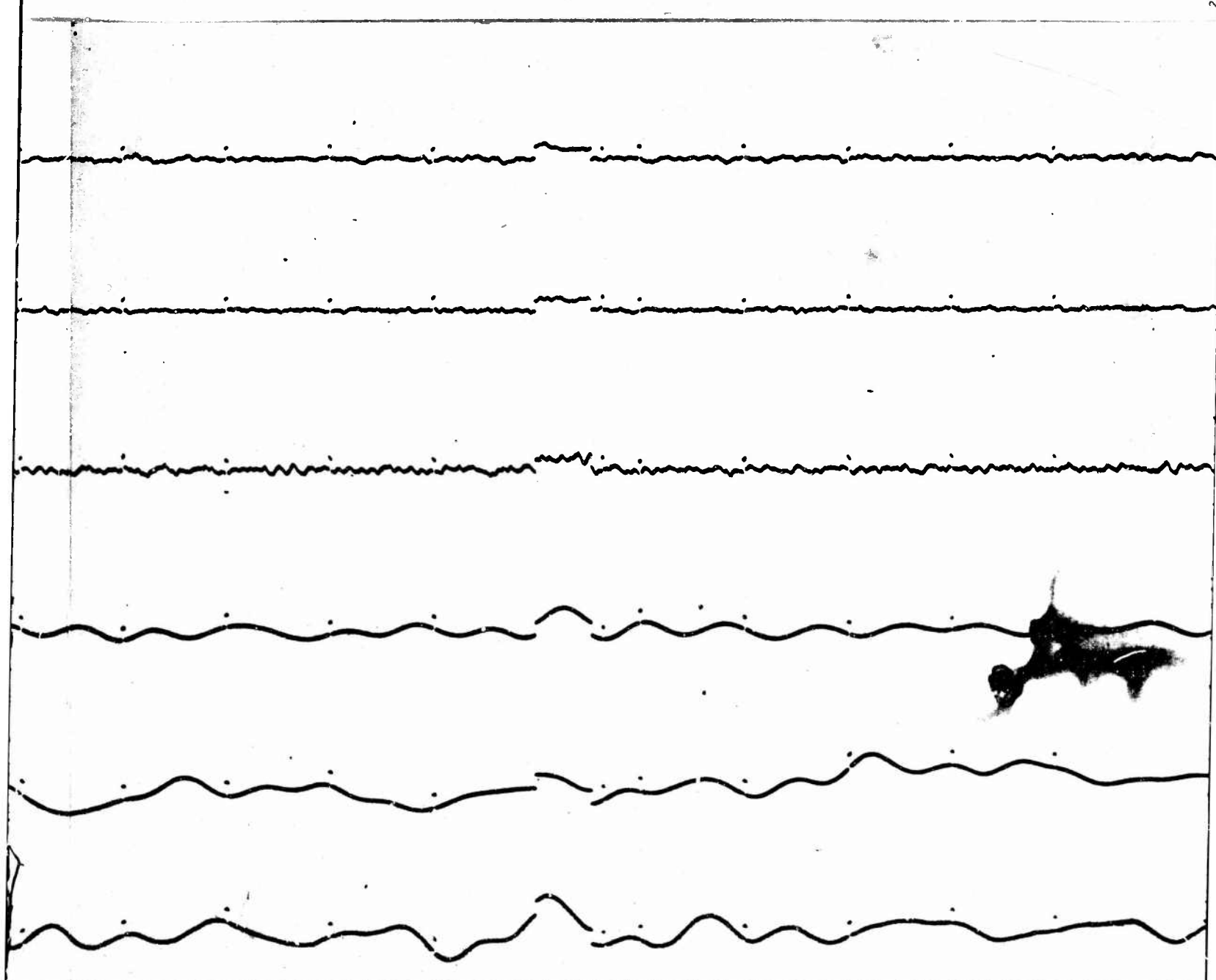


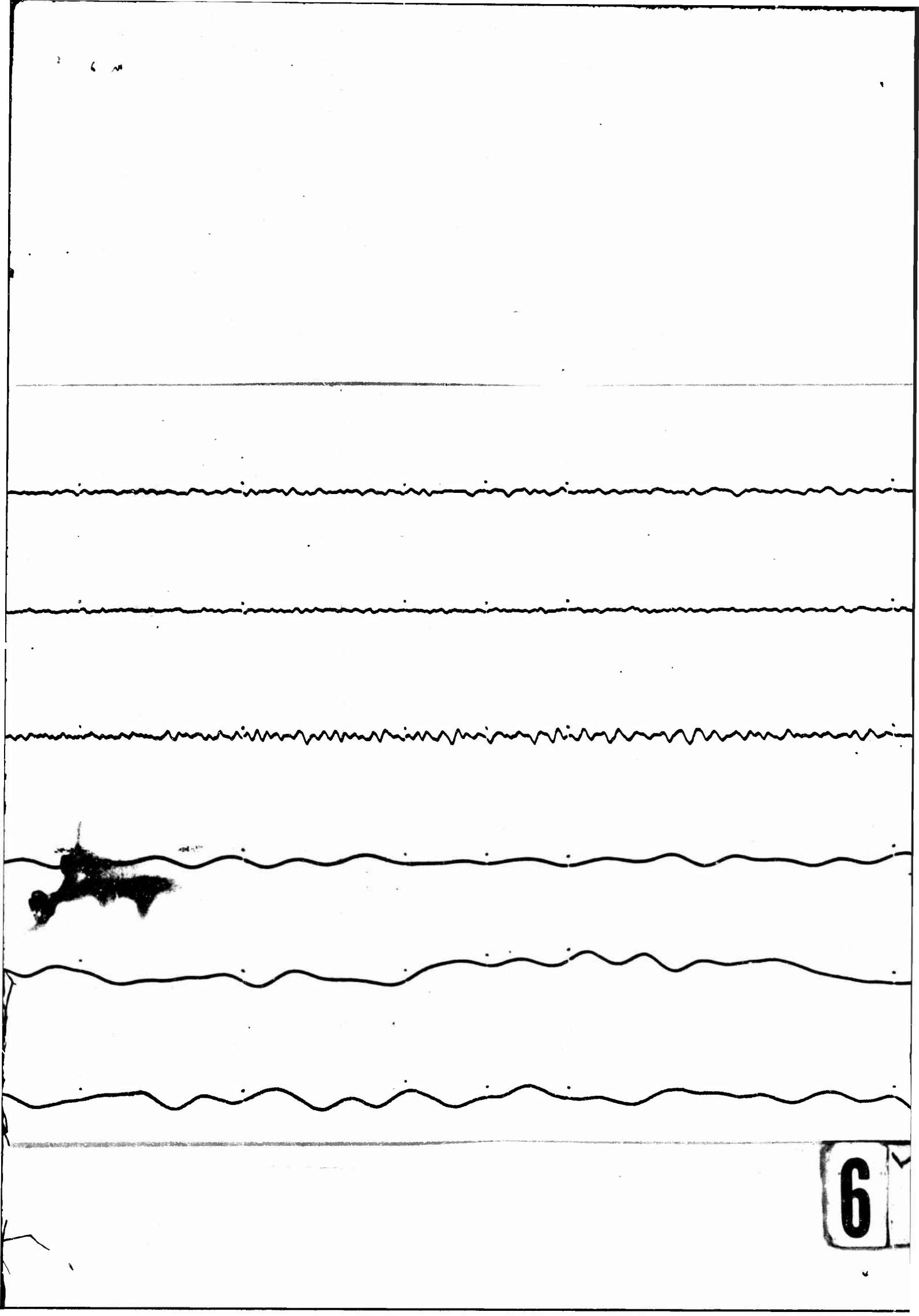
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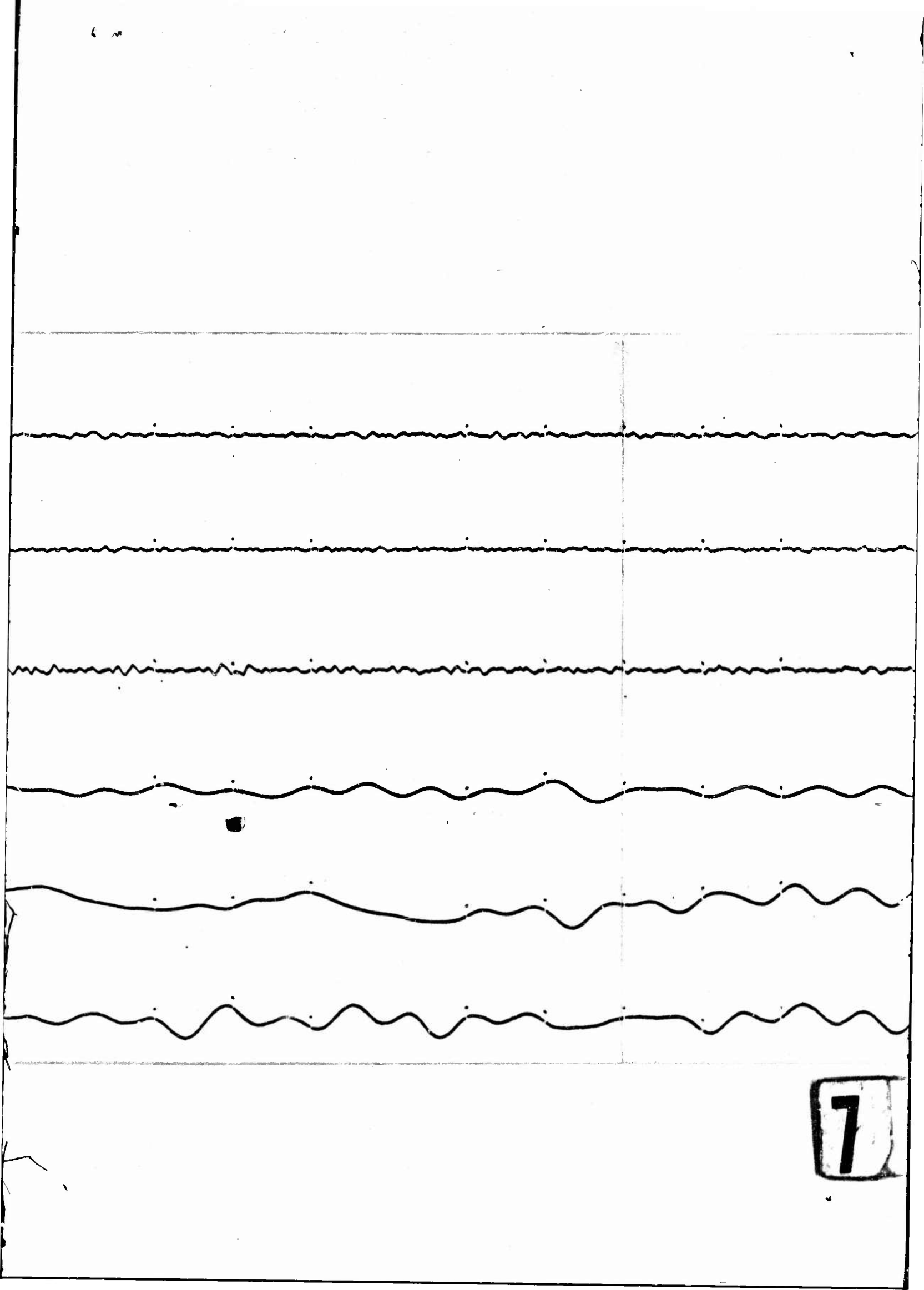




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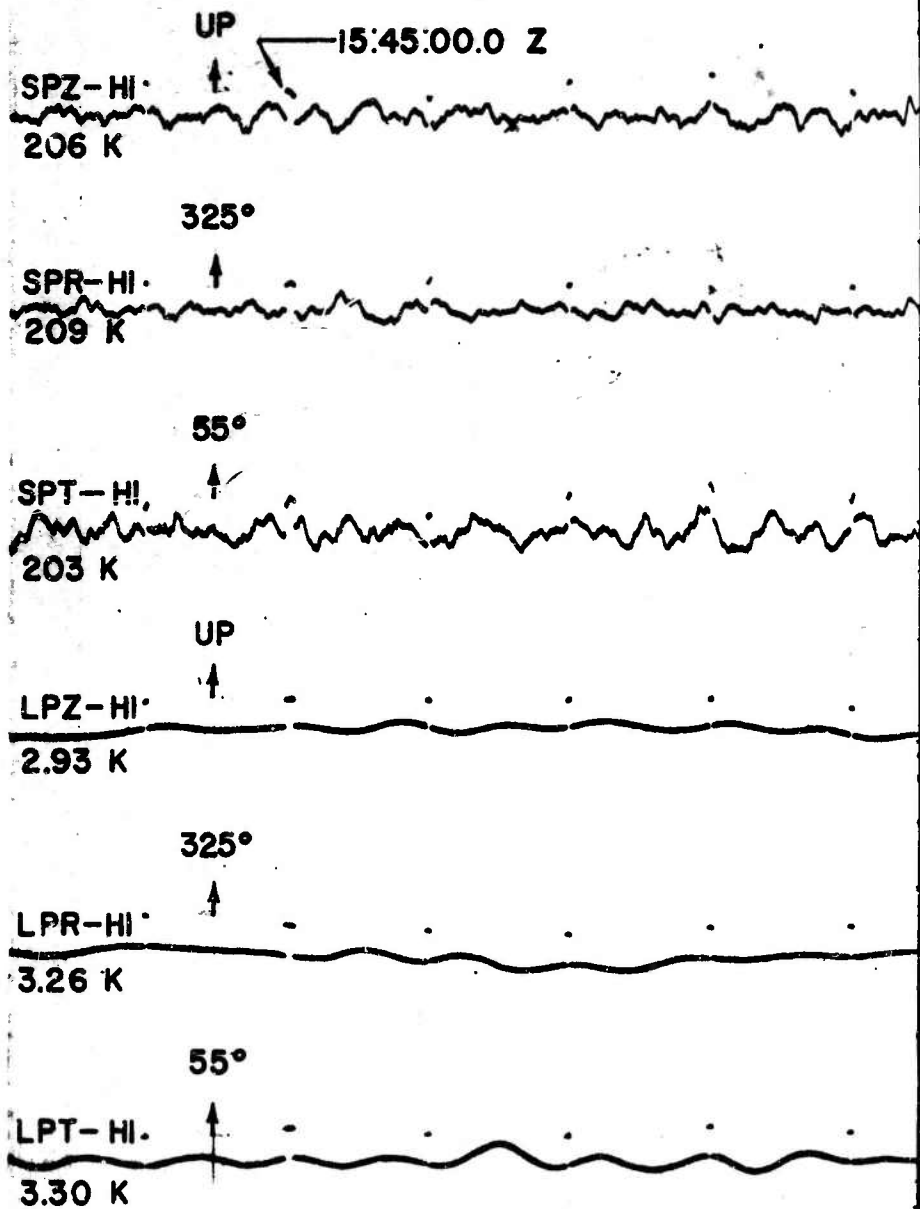
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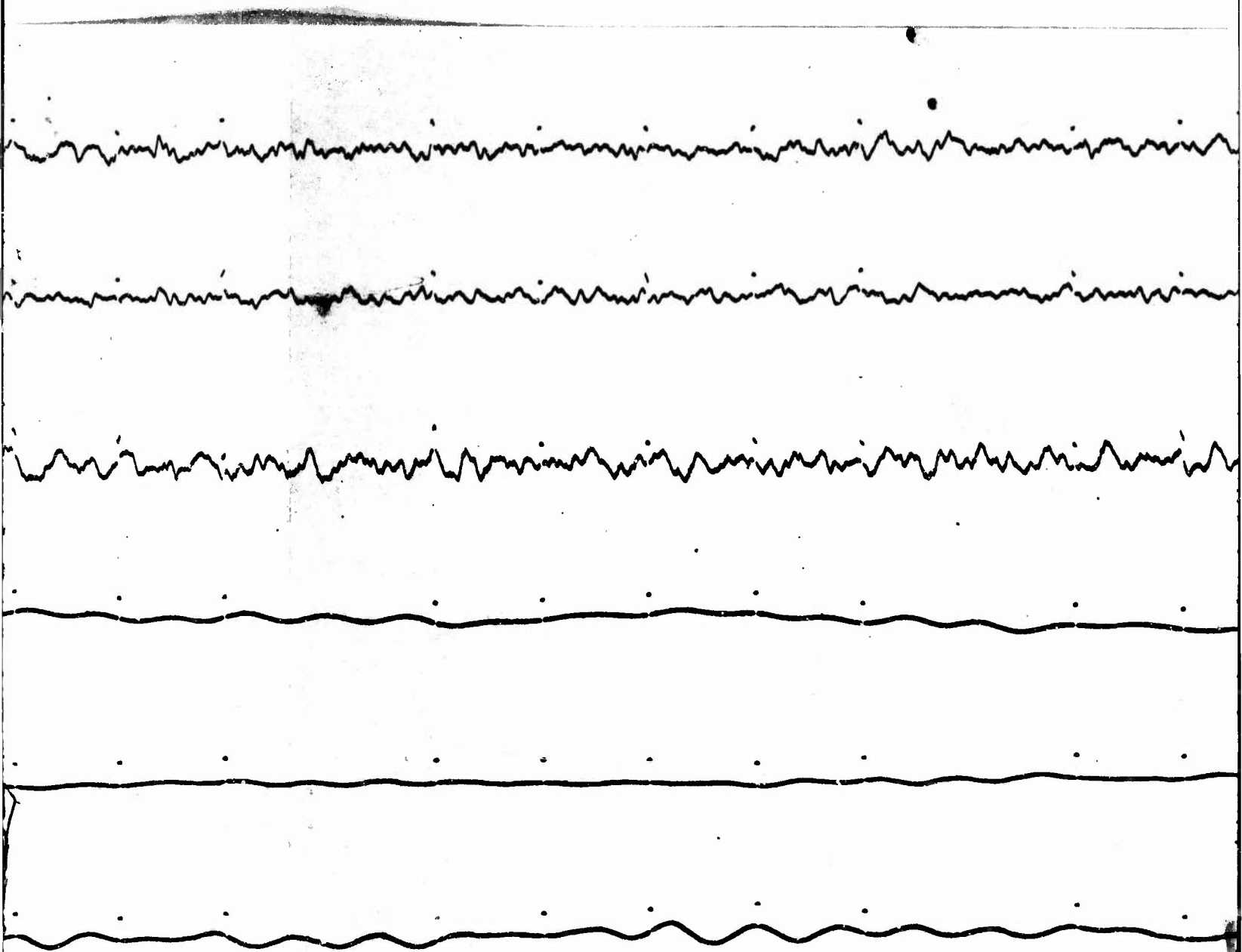
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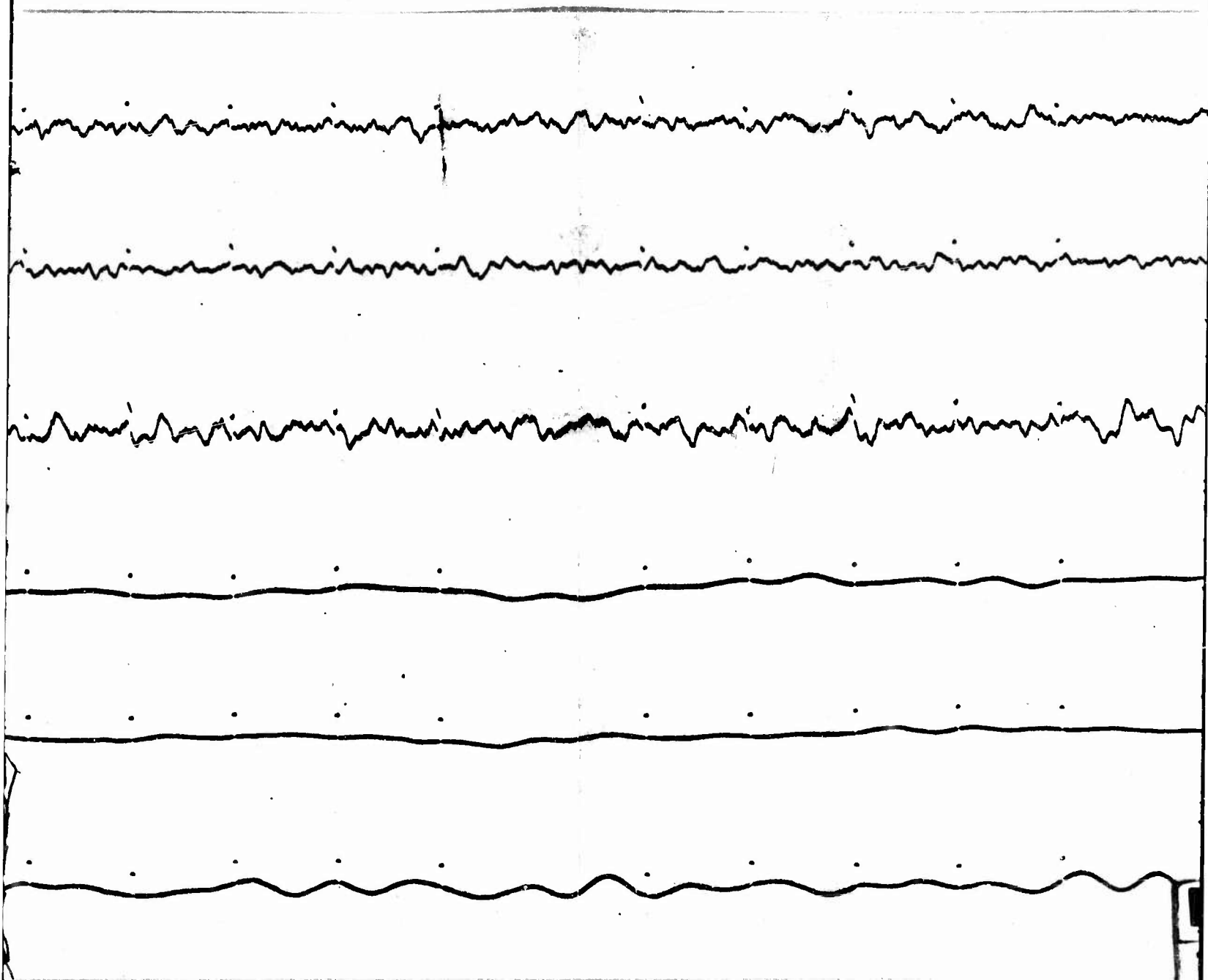
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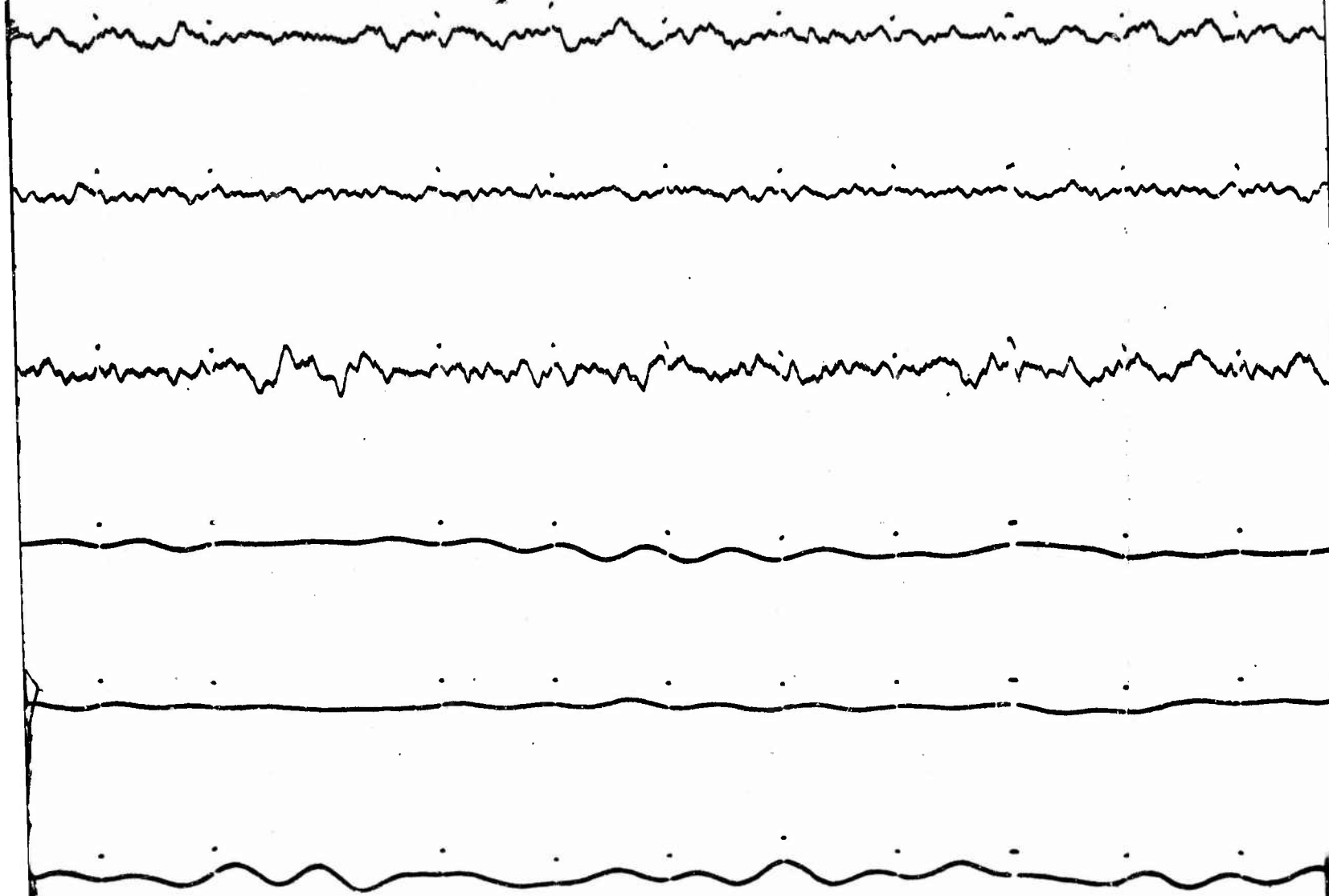
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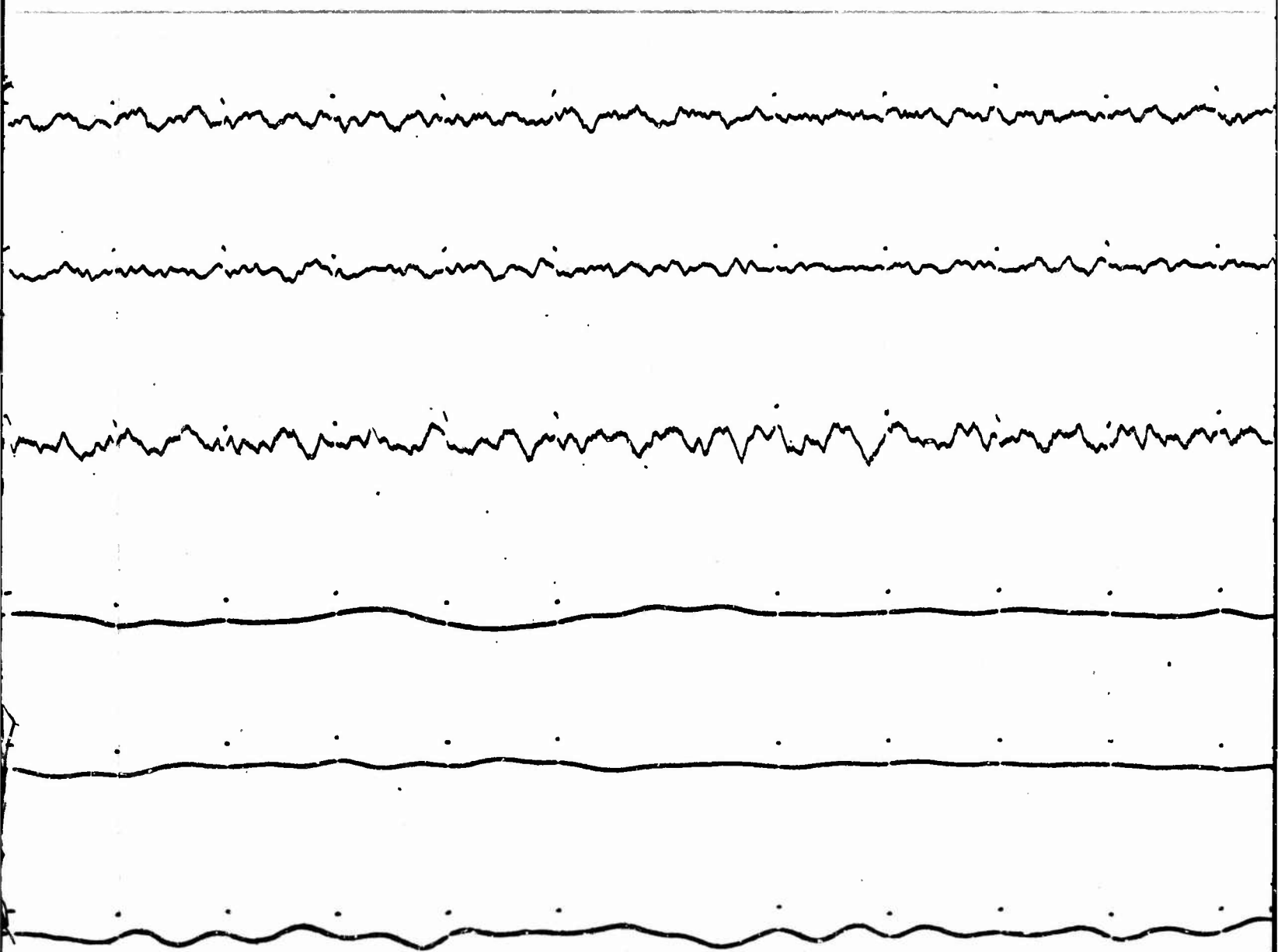
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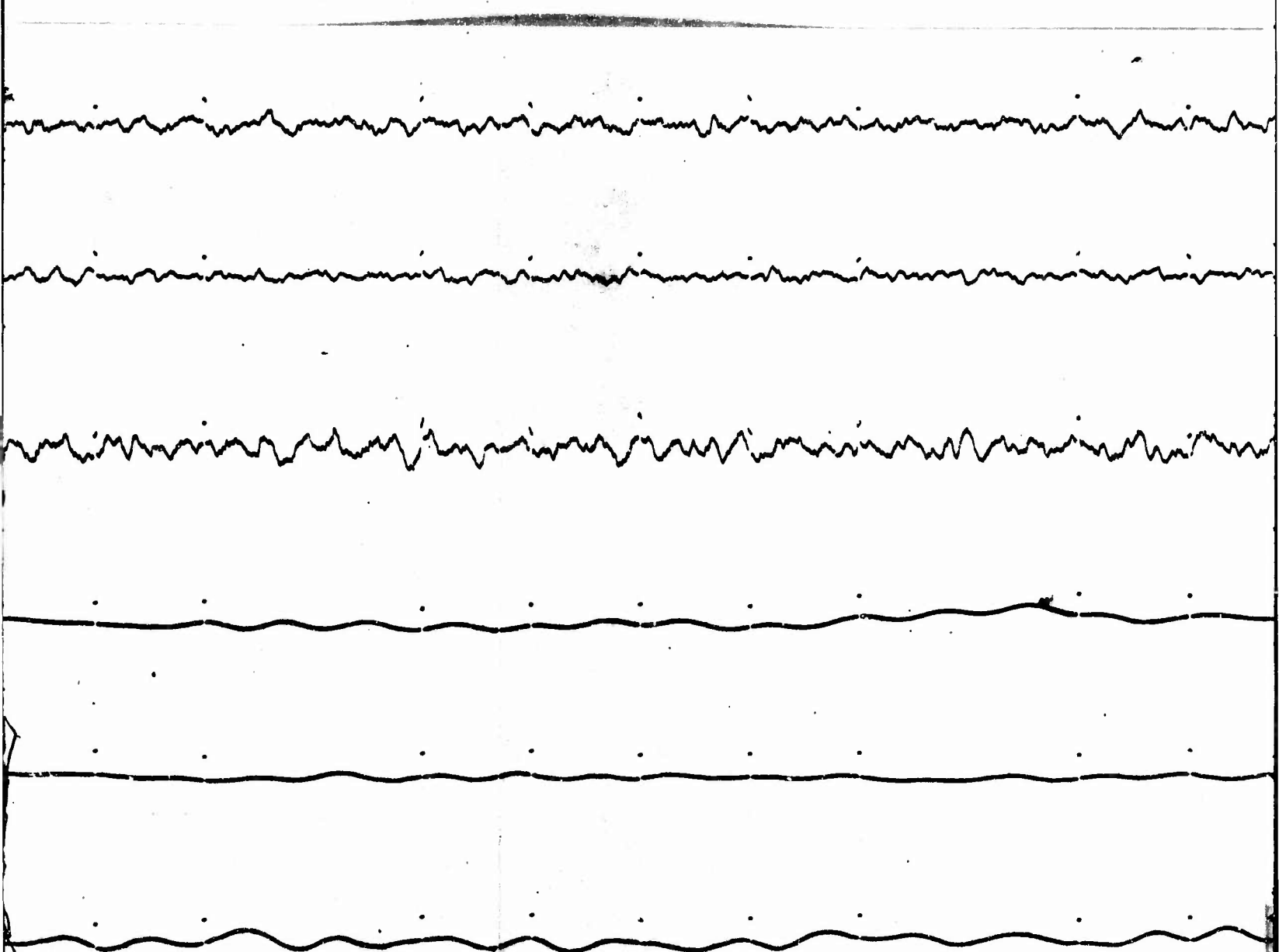












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