THE REGISTRATION OF EARTHQUAKES AT THE BERKELEY STATION

AND

AT THE LICK OBSERVATORY STATION

FROM

October 1, 1921, to March 31, 1922

BY

JAMES B. MACELWANE
AND
PERRY BYERLY, JR.

BULLETIN OF THE SEISMOGRAPHIC STATIONS, VOL. 2, NO. 3

UNIVERSITY OF CALIFORNIA PRESS
BERKELEY, CALIFORNIA
1924

UNIVERSITY OF CALIFORNIA PUBLICATIONS
BULLETIN OF THE SEISMOGRAPHIC STATIONS
Vol. 2. No. 3, pp. 29-54. March 15, 1924

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CONTENTS

Symbols and Notations

1. *Character of the Earthquake*—

I. Perceptible. II. Moderately strong. III. Strong.

d (terrae motus domesticus)	Local shock (origin less than 100 kilometers distant).
v (terrae motus vicinus)	Near shock (origin from 100 to 1,000 kilometers distant).
r (terrae motus remotus)	Distant shock (origin from 1,000 to 5,000 kilometers distant).
u (terrae motus ultimus)	Very distant shock or teleseism (origin more than 5,000 kilometers distant.)

2. *Phases of the Seismogram*—

P (undae primae)	Normal first phase, or first preliminary tremors.
$\bar{P}$	Individual, or upper first preliminary tremors.
PR_n	Waves n-times reflected at the earth's surface.
S (undae secundae)	Second phase, or second preliminary tremors.
SR_n	Waves n-times reflected at the earth's surface.
PS	Waves changed from longitudinal to transverse oscillation, or vice versa, through reflection at the earth's surface.
L (undae longae)	Long waves at the beginning of the chief phase, or principal part.
M(undae maximae)	Waves of greatest amplitude in the chief phase.
C (coda)	Tail or end portion.
F (finis)	End of discernible movement.

3. *Nature of the Motion*—

i (impetus)	Sudden beginning of the motion.
e (emersio)	Gradual beginning of the motion.
T (period)	Time of one complete oscillation.
A	Amplitude of the motion, measured from the median line in microns (μ=1/1000 mm.), +toward the north, east, or zenith, −toward the south, west, or nadir.
A_E	E-W component of A.
A_N	N-S component of A.
A_Z	Vertical component of A.

4. *Time*—

O (origin)	Time of shock at point of origin.

5. *Epicenter*—

Δ	Epicentral distance.

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CONSTANTS

Latitude and longitude of the center of the seismographic room:

φ=37° 52′ 15″.9 N. Lat.
λ=122° 15′ 36″.6 W. from Greenwich.

Time. All determinations are reduced to Greenwich mean civil time.

Altitude, 85.4 meters (280 feet) above mean sea level.

Constants of the Seismographs

Date	Apparatus	Component	V	T	ϵ
Dec. 5	Bosch-Omori 100 Kg. Wiechert 80 Kg. V.	E		14	1.1
		N		14	1.1
		Z		5.6	5
Jan. 16	Bosch-Omori	E	52	14	1.2
		N	64	14.5	1.2
	Wiechert	Z	43	5.6	5
Jan. 23	Bosch-Omori	E	53	13.8	1.2
		changed			3.3
		N	63	14	1.2
		changed			3.3
	Wiechert	Z	43	5.6	5.8
Feb. 3	Bosch-Omori	E	52	14	6.6
		N	62	13.6	2.4
		changed	56	13.6	3.7
	Wiechert	Z	43	5.6	5.4
Feb. 24	Bosch-Omori	E	48	14.6	3.5
		N	73	13.5	5.7
		changed	35	12.4	4.5
	Wiechert	Z	43	5.6	6
Mar. 21	Bosch-Omori	E	76	14	3.4
		N	60	12.1	3.4
	Wiechert	Z	43	5.6	5.3

The junior author is responsible for the measurement of the seismograms of the earthquakes of January 17 and for the discussion of the results obtained from them. The senior author is responsible for the remainder of the *Bulletin*.

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No.	Date	Character	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_Z	Remarks
	1921			h m s	s	μ	μ	μ	
1	10 Oct.	I_u	e_Z	2 19 45					There is no trace of the earthquake on NS.
			L_Z	2 55 33					
			L_E	2 57 30					
			F	3 30±					
2	14 Oct.	I_u	e_Z	17 23 00					
			F	18 24±					
3	15 Oct.	I_u	ePE_Z	5 10 57	8				The main phase is made up of a long series of sinusoidal waves.
			eS_E	5 12 25					
			L_{EZ}	5 37 23					
			L_N	5 37 33					
			M_{EZ}	5 38 01	25				
			F	6 31±					
4	18 Oct.	I	eL_{EZ}?	1 09 33					There is nothing certain on NS.
			F	1 40±					
5	20 Oct.	I_u	iP_E	6 14 58	3.5				△8400.
			iS?	6 24 37	5				The amplitudes of all the
			i	6 25 33	10				waves are very small.
			eL_E	6 41 00					
			F	7 15±					
6	26 Oct.	I	e	0 07 00					It was recorded both on EW and on Z, but not on NS.
			F	0 24±					
7	26 Oct.	I	e	0 58±					Similar to the preceding (No. 6).
			F	1 53±					
8	2 Nov.	I	e_Z	3 43 42					The amplitudes are very small.
			eL_E	3 52 29					
			M_E	3 54 19	20				
			e_N	3 55 00					
			M_{EZ}	3 58 00	12				
			F	4 15±					
9	7 Nov.		eP_Z	16 17 43	2				The amplitudes are small on EW and on Z, and no trace appears on NS.
			eL_{EZ}	16 46 46					
			M_{EZ}	16 48 24	25				
			F	17 52±					
10	11 Nov.		eL_E	14 51 53					
			e_Z	14 53 23					
			M_E	14 54 26	19				
			F	15 21±					
11	11 Nov.	II_u	P_{EZ}	18 50 23					△=10300. The coda is composed of long groups of regular sinusoidal waves with a period of about 17 seconds.
			i_E	19 00 54					
			S_E	19 01 34					
			L_{EZ}	19 23 35					
			M_E	19 28 23	23				
			F	21 05±					

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No.	Date	Character	Phase	Time G. M. T. C.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_Z	Remarks
	1921			h m s	s	μ	μ	μ	
12	13 Nov.	I	eL	9 12 17					
			M	9 15 38	17				
			F	9 25±					
13	14 Nov.	I	eL	7 30 35					
			F	7 58±					
14	15 Nov.	I_u	P_Z	20 50 27					△=11320. The approximate epicenter according to Jena is φ=40° N., λ=70° E. in the Ferghana Basin, Turkestan.
			eP_E	20 50 55					
			R_1P_E	20 54 43					
			R_1P_Z	20 54 56	6				
			S_Z	21 02 21					
			S_E	21 02 28					
			eL_E?	21 22 23					
			F	22 03±					
15	17 Nov.	I_v	eP_E	22 13 29					S−P=44ˢ
			eP_N	22 13 30					△=400 Km.
			iP_N	22 13 39					
			eS_N	22 14 13					
			eS_E	22 14 14					
			eL_E	22 14 20					
			eL_N	22 14 22					
			M_{E1}	22 14 22	6.5				
			M_{E2}	22 14 29	6.5				
			M_{N1}	22 14 31	3				
			M_{N2}	22 14 43	4				
			F	22 23±					
16	29 Nov.	I	e_{ENZ}	23 17 48					
			M_{ENZ}	23 20 32	7				
			F	23 50±					
17	18 Dec.	I	e_{ENZ}	13 18±					Because of the strong microseisms present and of the small amplitude of these longer sinusoidal waves, no more exact determinations can be made.
			F	13 38±					
18	18 Dec.	I_u	eP_N	15 38 42?					S−P=7ᵐ48ˢ △=6220.
			eP_E	15 38 46?					The exact time correction
			eS_N	15 46 30?					is unknown. The prob-
			eS_E	15 46 31?					able △t is +23ˢ, mak-
			iS_N	15 46 45?					ing eP_N 15ʰ39ᵐ5ˢ. The
			iS_E	15 46 51?					end of the record was
			F	After 16–44					lost owing to the chang-
	1922								ing of drums at 16ʰ 44ᵐ
19	1 Jan.	I	iP_Z	19 58 20	3				
			eP_N	19 58 20					
			eP_E	19 58 27					
			i_Z	19 58 59					
			eL_E	20 20 58					
			eL_N	20 20 59					
			eL_Z	20 21 15					
			M_E	20 22 27	30	24			
			F	21 53±					

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No.	Date	Character	Phase	Time G. M. C. T.	Period	Amplitude AE	Amplitude AN	Amplitude AZ	Remarks
	1922			h m s	s	μ	μ	μ	
20	3 Jan.	I_d	iP_{NEZ}	20 36 09	<0.5	15		4	
			iM_E	20 36 10	0.5	4			
			F	20 36 30					
21	5 Jan.	I	e_N	9 17 23					
			e_E	9 18 20					
			F	9 35±					
22	6 Jan.	II_u	eP_E?	14 22 28					△=8550 km., apparently.
			eS_E?	14 32 16					
			eL_E	14 45 44					
			eL_N	14 46 22					
			M_E	14 51 07	21	15			Such strong microseisms were running that the beginnings of the phases cannot be fixed with certainty.
			F	15 50±					
23	9 Jan.	I_u	P_{EZ}	5 20 20					△=7100 km.
			P_N	5 20 32					
			S_E	5 29 25					
			L_N?	5 39 51					
			M_Z	5 44 52					
			M_E	5 45 16					
			F	6 22±					
									This is a case of the superposition of three distinct South American earthquakes. See discussion at end of Bulletin.
24	17 Jan.	III_u	eP_Z	3 59 57	2.5			+ 2	Ecuador.
			eP_E	4 0 0	3.0	− 3			Ecuador.
			i_Z	4 0 0	3.0			− 7	
			eP_N	4 0 1	3.5		− 4		Ecuador.
			i_Z	4 0 2	3.0			+12	
			i_E	4 0 6	4.5	+ 7			
			i_Z	4 0 7	4.0			+17	
			i_Z	4 0 8	4.0			−35	
			i_Z	4 0 12	4.0			−22	
			i_N	4 0 12	3.0		+5		
			i_E	4 0 13	11.0	+ 3			
			i_N	4 0 14	3.0		− 7		
25		III_u	iP_E	4 0 16	8.0	−29			Venezuela.
			iP_Z	4 0 17	5.5			−52	Venezuela.
			iP_N	4 0 18	3.0		+14		Venezuela.
			i_N	4 0 21	1.5		+ 6		
			i_Z	4 0 23	4.0			+36	
			i_N	4 0 24	3.5		−17		
			i_Z	4 0 33	4.0			+27	
			i_E	4 1 9	9.5	+ 6			
26	17 Jan.	III_u	iP_Z	4 1 26					Brazil.
			iR_1P_Z	4 2 16	5.0			−14	Ecuador.
			iR_1P_{EN}	4 2 19	7.5	+19	− 5		
			i_N	4 2 20	7.0		+18		

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No.	Date	Character	Phase	Time G. M. C. T.	Period	Amplitude AE	Amplitude AN	Amplitude AZ	Remarks
	1922			h m s	s	μ	μ	μ	
26	17 Jan.	III_u	i_Z	4 2 21	7.5			−96	
			i_E	4 2 27	14.5				
			i_Z	4 2 34	5.5			−26	
			i_N	4 2 48	5.5		−12		
			iR_1P_N?	4 3 10					Venezuela.
			iR_1P_Z?	4 3 11					Venezuela.
			iR_1P_Z?	4 4 22	4.0			+6	Brazil, or R_1P_Z Venezuela.
			i_Z	4 4 26	5.0			+15	
			iS_Z	4 7 41	19.5			+140	Ecuador.
			iS_N	4 7 41	22.0		+149		Ecuador.
			iS_E	4 7 43	9.0	+14			Ecuador.
			i_E	4 7 47	9.0	−24			
			i_E	4 7 53	10.0	+12			
			i_Z	4 7 54	12.0			−90	
			i_N	4 7 56	16.0				
			i_E	4 7 57	11.0	−29			
			i_E	4 8 3	10.5	+40			
			i_N	4 8 4	20.5		+637		
			i_E	4 8 7	13.0				
			i_Z	4 8 10	7.5			+49	
			i_N	4 8 12	18.5		−194		
			i_E	4 8 13	12.5				
			i_Z	4 8 20	4.5			−20	
			i_E	4 8 20	9.5	−53			
			iPS_N?	4 8 22					Ecuador.
			i_N	4 8 24	18.5		+146		
			i_N	4 8 30	11.0		−18		
			i_E	4 8 55	15.0				
			iS_Z	4 9 2	9.5			+52	Venezuela.
			iS_E	4 9 2	15.0				Venezuela.
			iS_N	4 9 2	10.0		+29		Venezuela.
			i_N	4 9 5	23.0		−104		
			i_Z	4 9 11	3.0			+10	
			i_N	4 9 12	18.0		+45		
			i_E	4 9 13	12.0				
			i_E	4 9 22	11.0	−7			
			iPS_N	4 9 42	7.0		−16		Venezuela.
			i_N	4 9 46	7.0		+16		
			i_N	4 9 49	9.5		−16		
			iPS_N	4 11 21	14.5				Brazil.
			i_N	4 11 36	25.0		+84		
			i_E	4 11 38	49.0	+612			
			i_E	4 12 7	44.0	−417			
			iR_1S_Z	4 12 27	11.0			+64	Ecuador.
			iR_1S_N	4 12 28	24.5		+104		Ecuador.
			i_N	4 12 36	29.5		−86		
			iR_2S_E	4 13 57					Ecuador.
			iR_2S_N	4 13 59					Ecuador.
			IR_2N_N	4 15 44					Venezuela.
			F	9 40±					

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No.	Date	Character	Phase	Time G. M. C. T.	Period	Amplitude			Remarks
						AE	AN	AZ	
	1922			h m s	s	μ	μ	μ	
27	19 Jan	I	e_E	22 31 07					
			e_E	22 45					
			F	23 27±					
28	20 Jan.	I	eL_E	4 36 07					
			F	4 51±					
29	22 Jan.	I	iP_{EZ}	3 35 36					
			e_E	3 45 42					
			eL_N?	3 55 04					
			eL_{EZ}	3 57 52					
			F	4 30±					
30	22 Jan.	I	iP_Z	20 56 14					
			e_Z	20 56 14					
			eL_{EZ}	21 18 36					
			eL_N	21 19					
			F	22 29±					
31	26 Jan.	II	e_{NE}	9 21 36	1 6				The record is quite unusual in form, the waves falling mainly into two large groups. In view of the uncertainty of character of the groups, it was thought best to present a detailed measurement without attempting to name them. The beginnings of the two groups are $9^h\ 21^m\ 36^s$ and $9^h\ 33^m\ 42^s$ respectively.
			e_N	9 21 47	6				
			i_{NE}	9 22 07	14				
			i_{NE}	9 22 20	14			−9	
			i_N	9 22 25	13			+9	
			i_{NE}	9 22 31	13			−6	
			i_E	9 23 22	14				
			i_{NE}	9 23 28	9			−8	
			i_N	9 23 37	9			+18	
			i_E	9 23 45	13				
			i_N	9 23 54	8			+11	
			i_{NE}	9 23 58	9	+7		−14	
			i_E	9 24 04	9	−15			
			i_E	9 24 09	9	+12			
			i_E	9 24 40	7	−15			
			i_E	9 24 44	7	+15			
			i_N	9 24 51	7			+11	
			i_{NE}	9 25 09	6	+18		+21	
			i_N	9 25 14	6			−25	
			i_N	9 25 30	7			+18	
			i_E	9 25 44	7	−8			
			i_E	9 26 29	6	+20			
			i_N	9 33 42	18			+20	
			i_N	9 33 55	16			−40	
			i_{NE}	9 34 04	13			+78	
			i_{NE}	9 34 12	13			−108	
			i_{NE}	9 34 19	13			+115	
			i_{NE}	9 34 26	13			−122	
			i_{NE}	9 34 32	13			+96	
			i_{NE}	9 34 40	13			−65	
			i_E	9 34 45	11	+25			
			i_N	9 34 50	13			+36	
			i_N	9 34 58	13			−78	
			i_{NE}	9 35 23	12	−144		+32	
			i_{NE}	9 35 26	11	+145		−94	
			i_N	9 35 31	10			+120	

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No.	Date	Character	Phase	Time G. M. C. T.	Period	Amplitude			Remarks
						AE	AN	AZ	
	1922			h m s	s	μ	μ	μ	
31	26 Jan.	II	i_N	9 35 37	10		−140		
			i_E	9 35 43	12	+100			
			i_N	9 35 46	10		−62		
			i_N	9 35 54	10		+120		
			i_N	9 36 02	10		−100		
			i_{NE}	9 36 09	10	+138	+60		
			i_{NE}	9 36 15	9	−165	−210		
			i_E	9 36 19	11	+100			
			i_N	9 36 24	8		+155		
			i_N	9 36 29	8		−120		
			i_{NE}	9 37 08	8	+66	+52		
			i_{NE}	9 37 12	8	−70	−117		
			i_{NE}	9 37 28	9	+60	+96		
			i_N	9 37 32	8		−120		
			i_N	9 37 37	8		+110		
			i_N	9 37 41	8		−70		
			i_E	9 38 17	9	+56			
			i_E	9 38 26	9	+63			
			i_E	9 38 29	9	−73			
			i_E	9 40 28	8	+51			
			F	9 56±					
32	31 Jan.	III$_v$	iP_{NEZ}	13 18 21	20 and 3	−370	+115	−40	At $13^h\ 18^m\ 41^s$ the N-S pen was thrown to the floor, so that the rest of that component was lost; the E-W pen was deflected off the recording drum and did not begin to record again until $13^h\ 32^m\ 10^s$.
			i_{NEZ}	13 18 31	20	+1190	−495	+100	
			$e\overline{P}_{NEZ}$	13 18 38					
			$i\overline{P}_{NE}$	13 18 41	20 and 8	> −1700	> +1100		
			$i\overline{P}_Z$	13 18 41	16&2,3			−210	
			i_Z	13 19 03					
			i_Z	13 19 33					
			M_{Z1}	13 19 41	14 & 2			273	△ = 460 km.
			M_{Z2}	13 19 53	13			5000	O = $13^h\ 17^m\ 21^s \pm 1^s$
			M_{Z3}	13 20 19	9			3200	The epicenter was off the northern coast of California at $\lambda = 125°\ 30' \pm 3'$. $\varphi = 41°\ 8' \pm 3'$. For particulars see the discussion at the end of this Bulletin, and, especially, the Bulletin of the Seismological Society of America, June, 1923.
			M_{Z4}	13 21 10					
			M_{Z5}	13 21 54	7.5			1260	
			M_{Z6}	13 22 30	8			>2800	
			M_{Z7}	13 23 50	7			1980	
			M_{Z8}	13 26 50	7			990	
			M_{Z9}	13 31	8.3			1020	
			M_{E1}	13 32 10	10		530		
			M_{E2}	13 32 50	10		530		
			M_{E3}	13 33 50	10		390		
			M_{E4}	13 35 58	8.4		270		
			M_{E5}	13 36 50	9		270		
			M_{E6}	13 44 05	9.3		160		
			M_{E7}	13 49 01	10.8		220		
			M_{E8}	13 54 50	10		190		
			M_{E9}	13 57 04	10.5		150		
			M_{E10}	14 02 02	9.5		150		
			M_{E11}	14 06 50	10.8		120		
			M_{E12}	14 16 30	11		60		
			M_{E13}	14 20 06	10		68		
			F	Post $16^h 48^m$					

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No.	Date	Character	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_Z	Remarks
	1922			h m s	s	μ	μ	μ	
33	2 Feb.	I	e_Z	7 12 11					The record seems to be that of a slight, nearby earthquake.
			i_Z	7 12 17					
			e_E	7 12 51					
			i_E	7 13 45					
			i_N	7 15 09					
			i_Z	7 15 51	7			8	
			F	7 23±					
34	5 Feb.	I	e_{ENZ}	1 29 17					The phases cannot be identified either in this or in the following earthquake.
			i_E	1 30 43					
			i_{NZ}	1 31 17					
			i_E	1 32 07					
			i_Z	1 33 17					
			F	1 44±					
35	5 Feb.	I	e_Z	5 59.2					
			e_E	5 59.5					
			i_Z	6 00.4					
			i_E	6 01.8					
			i_E	6 02.4					
			i_Z	6 02.8					
			F	6 06±					
36	14 Feb.	I	eP_Z	12 33 20					
			e_{NE}	12 40 34					
			eL_E?	12 43 19					
			eL_{NZ}?	12 43 34					
			F	12 52±					
37	16 Feb.	II	eP_E	3 24 33					
			e_E	3 24 34					
			eL_{NE}	3 36 48					
			M_{NE}	3 38 28	20	15	8		
			M_{NE}	3 40 30	19	10	12		
			F	4 16±					
38	1 Mar.	I	e_{NEZ}	21 34 41					
			F	22 00±					
39	4 Mar.	I	iP_{NEZ}	13 16 54	5			8	
			i_{NEZ}	13 17 44	6			9	
			iS_{NEZ}	13 24 44	5	15	17		
			i_{NE}	13 26 24	4	11	8		
			eL_{NE}	13 31 18					
			F	14 14±					

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No.	Date	Character	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_Z	Remarks
	1922			h m s	s	μ	μ	μ	
40	10 Mar.	III_V	P_E	11 22 13	4	9		7	The epicenter was probably in the San Andreas Rift east of Shandon, California, The Union Oil Company's pipe line to San Luis Obispo was broken in four places in the region between Shandon and Antelope and between Cholame and Annette. Dr. H. O. Wood reported isoseismal evidence pointing to the vicinity of Parkfield and Cholame.
			P_Z	11 22 13	2.5				
			P_N	11 22 16					
			i_N	11 22 54					
			e_E	11 22 56					
			M_{Z1}	11 23 05	3.5			10	
			M_{EN}	11 23 14	17	285	370		
			M_{Z2}	11 23 14	3.5			82	
			M_{Z3}	11 24 38	5			86	
			M_{N2}	11 24 52	6		200		
			M_{N3}	11 25 50	7		113		
			M_{E2}	11 26 44	10	93			
			M_{E3}	11 29 40	9	91			
			M_{E4}	11 31 23	9	67			
			F	12 00±					
41	10 Mar.	I	i_Z	17 03 46					
			e_N	17 03 57					
			i_Z	17 05 43					
			eL_{NE}	17 12 58					
			eL_Z	17 13 05					
			F	17 25±					
42	16 Mar.	I_V	eP_Z	23 11 41					
			eL_{ENZ}	23 12 07					
			M_{E1}	23 12 29	15	15			
			M_{E2}	23 12 45	10	22			
			M_{E3}	23 12 55	10	29			
			M_{E4}	23 13 05	10	15			
			M_{E5}	23 13 13	9	18			
			F	23 22±					
43	28 Mar.	I	iP_Z	4 09 43	6			14	
			iP_E	4 09 45	6	7			
			i_{NZ}	4 09 46	6		2	12	
			iL_E	4 19 30	5	4			
			i_E	4 20 23	10	5			
			i_N	4 20 29	9		4		
			F	5 19±					

THE LICK OBSERVATORY STATION

CONSTANTS

Constants of the Station

Latitude and longitude of the center of the seismographic room:

$\varphi = 37° 20' 24''.5$ N. Lat.
$\lambda = 121° 38' 34''$ W. from Greenwich.

Time. All determinations are reduced to Greenwich mean civil time.

Altitude, 1281.7 meters (4202.25 feet) above mean sea level.

Since no adjustment of the seismographs was made which would materially change them, the following constants were assumed to hold for the winter earthquakes, although determined a very considerable time before.

Wiechert 180-Kg. Horizontal: E-W, $T_o = 3$ sec., $V = 106$, $\epsilon = 5$; N-S, $T_o = 3.2$ sec., $V = 98$, $\epsilon = 5$.

Wiechert 80-Kg. Vertical: $T_o = 3.3$ sec., $V = 50$, $\epsilon = 4$.

LICK OBSERVATORY STATION

No.	Date	Character	Phase	Time G. M. C. T.	Period	Amplitude			Remarks
						A_E	A_N	A_Z	
	1921			h m s	s	μ	μ	μ	
1	17 Oct.	I_d	iz	23 49 19	<1				This sharp, local shock registered only on the Z component.
			F	23 49 22					
2	18 Oct.	I_d	iz	0 06 12	<1				This shock also was recorded only by the vertical seismograph
			F	0 06 18					
3	19 Oct.	II_d	eP_Z	22 18 54					
			eP_E	22 19 00					
			M_{ENZ}	22 19 07	<1				
			F	22 19 15					
4	19 Oct.	I_d	iP_{ENZ}	23 46 35					
			M_E	23 46 37	<1				
			M_{ENZ}	23 46 40	<1				
			F	23 47±					
5	20 Oct.	I_u	eP_N	6 14 57					△=8140?
			iS_N?	6 24 30					The main phase scarcely appears.
			F	6 41±					
6	21 Oct.	I_d	iP_{ENZ}	3 12 19					This is a beautifully registered shock a few kilometers away. iS may be iLM. The record is too compressed to be certain of the phases.
			iS_{EN}?	3 12 21	<1				
			F	3 13 30					
7	24 Oct.	I_d	iP_{ENZ}	23 35 07	<1				This sharp, local shock is well registered on all components.
			F	23 35 37					
8	26 Oct.	I	e_N	0 07 25					The earthquake can be recognized only on the NS record. The beginning is masked by microseisms.
			M_N	0 09 38					
			F	0 45±					
9	2 Nov.	I_d	iP_{ENZ}	0 48 25					S-P=2ˢ.5. L-P=2ˢ.9. △=25 km.
			iS_{EZ}	0 48 27.5					
			iL_{ENZ}	0 48 27.9					Beautifully registered.
			F	0 48 54					
10	2 Nov.	I	e_N	3 54±					There are only a few irregular waves on the NS component. Nothing appears on EW or Z.
			F	4 04±					
11	11 Nov.	I_u	e_N	18 57±	2				The amplitudes are very small.
			M_{N1}	19 27±	18				
			M_{N2}	19 40±	18				
			M_{N3}	19 46±	18				
			F	20 20±					
12	17 Nov.	II_v	iP_{EN}	22 13 16					S-P=37ˢ △=330 km. The periods of the waves are very short. The vertical record is illegible because of the crossing of lines.
			iS_{EN}	22 13 53					
			M_N	22 14 00	<1				
			F	22 16±					

LICK OBSERVATORY STATION

No.	Date	Character	Phase	Time G. M. C. T.	Period	Amplitude AE	Amplitude AN	Amplitude AZ	Remarks
	1921			h m s	s	μ	μ	μ	S-P = 1ᵐ6. △ = 16 km.
13	16 Dec.	I_d	P_{ENZ}	16 59 44.2					
			S_{ENZ}	16 59 45.8					
			M_E	16 59 46.3	<1				
			F	16 59 51					
14	17 Dec.	I_d	P_{EZ}	18 41 52					
			e_N	18 41 58					
			M_Z	18 42 08					
			F	18 42 18					
15	18 Dec.	II_u	P_N	15 36 57	1		6		Nothing was registered on the vertical component but a few PP waves. L or M scarcely appear on any component. Since PP arrived 12ˢ too soon to be consistent with S-P = 7ᵐ 39ˢ, and as this latter interval is too short when compared with the Berkeley records (No. 18), it would seem that eP was too weak to be registered.
			P_E	15 37 00					
			R_1P_{NZ}	15 39 03					
			S_N	15 44 36	4		8		
			S_E	15 44 46					
			PS_{EN}	15 44 54	4	5	4		
			F	16 08±					
	1922								
16	6 Jan.	I	e_N	14 22 37					
			eL_N	14 47					
			F	15 20±					
17	9 Jan.	I_u	eP_N	5 20 28					
			eL_N	5 39 33					
			F	5 50±					This is a case of the superposition of three distinct South American earthquakes. See Berkeley Station, Nos. 24, 25 and 26.
18	17 Jan.	III_u	eP_N	3 59 55					Ecuador.
			eP_E	4 0 0					Ecuador.
			iP_N	4 0 2	2.0		+3		
			eP_Z	4 0 4					Ecuador.
			iP_Z	4 0 7	1.5			−39	
			i_Z	4 0 15	3.5			−97	
19			iP_N	4 0 23	2.0		−21		Venezuela.
			i_N	4 0 25	2.0		+21		
			iP_Z	4 0 28	1.5			−18	Venezuela.
			i_E	4 0 36	4.0	−22			
			iR_1P_Z	4 2 16					Ecuador.
			iR_1P_{EN}	4 2 17					Ecuador.
			eS_N	4 7 36					Ecuador.

LICK OBSERVATORY STATION

No.	Date	Character	Phase	Time G. M. C. T.	Period	Amplitude AE	Amplitude AN	Amplitude AZ	Remarks
	1922			h m s	s	μ	μ	μ	
			iS_E	4 7 40	2.5	−4			Ecuador.
			iS_N	4 7 40	3.5		+7		
			i_{EN}	4 7 43	3.0	−6	+13		
			i_E	4 7 45	3.0	+9			
			i_E	4 7 46	3.5	−22			
			i_N	4 7 46	4.5		+31		
			i_E	4 7 48	8.0	+121			
			i_N	4 7 49	3.5		−73		
			i_N	4 7 51	2.5		+8		
			i_N	4 7 52	4.0		−42		
			i_N	4 7 54	2.5		+19		
			i_N	4 7 57	3.5		+13		
			i_E	4 7 58	7.5	−139			
			i_N	4 7 58	4.0		+34		
			i_E	4 8 0	5.5	+23			
			i_N	4 8 0	2.5		−14		
			i_N	4 8 2	3.5		+20		
			i_E	4 8 6	4.5	+26			
			i_E	4 8 8	3.0	−13			
			iS_{EN}	4 8 59	4.5		−25		Venezuela.
			i_N	4 9 1	4.0		+19		
			i_N	4 9 4	5.5		−13		
			i_N	4 9 7	4.5		+15		
			i_N	4 9 9	3.5		−20		
			i_N	4 9 11	4.0		+14		
			i_N	4 9 12	5.0		−10		
			i_N	4 9 15	6.0		+34		
20			iS_N?	4 10 26	5.0		+10		Brazil.
			iPS_N	4 11 24	10.0		−38		Brazil.
			iR_1S_N	4 12 12	11.0		−58		Ecuador.
			F	9 52±					
21	22 Jan.	I	eL_N	3 54					At 4ʰ 02.4ᵐ there were four regular waves, and at 4ʰ 8ᵐ waves of longer period and smaller amplitude began.
			F	4 25±					
22	22 Jan.	I	eP_Z?	20 57 08					
			e_N	21 19 09					
			F	21 45±					
23	26 Jan.	I	e_N	9 20 40					
			i_N	9 21 35					
			i_N	9 22 35	7				Sinusoidal waves.
			eL_N	9 33 03					
			i_N	9 34 42	11				
			i_E	9 35 59					
			i_E	9 36 47	10				This may be the maximum phase.
			F	9 58±					

LICK OBSERVATORY STATION

No.	Date	Character	Phase	Time G. M. C. T.	Period	Amplitude AE	Amplitude AN	Amplitude AZ	Remarks
	1922			h m s	s	μ	μ	μ	
24	31 Jan.	III_v	eP_N	13 18 38	1.6				△ = 540 km. The epicenter was at Φ = 41° 8′ ± 3′ λ = 125° 30′ ± 3′. O = 13h 17m 21s ± 1s
			eP_{EZ}	13 18 39	1.6				
			iP_{ENZ}	13 18 42	19	480	340	320	
			i_Z	13 18 51	17			530	
			i_{EN}	13 18 53	18	560	480		
			iP_Z	13 19 01	16 & 2			92	
			iP_{EN}	13 19 03	16 & 2	880	960		
			i_{NE}	13 19 11	16	1440	1450		
			i_Z	13 19 11	14			530	
			i_{EN}	13 19 19	16	1220	1250		
			i_Z	13 19 19	14			1050	
			i_{NE}	13 19 30	5 & 2.6	14	115		
			i_{NZ}	13 19 33	5 & 2.7		340	40	
			i_N	13 19 39	2.6				
			i_N	13 19 43	6				
			iM_{ENZ}	13 19 55	18&2.5	7200	>8700	240	
			M_{ENZ}	13 21 16	12 & 3	4000	>9200	730	
			M_{ENZ}	13 22 16	10	2640	>3400	3200	
			M_{NE}	13 23 15	9	1770	2600		
			M_Z	13 23 27	9				
			M_{NE}	13 23 52	8	1400	2200		
			M_Z	13 23 52	9			>3600	
			M_{ENZ}	13 24 15	8	1570	>1480	1430	
			F	16 00±					
25	2 Feb.	I	e_N	7 13 56					
			e_Z	7 14 52					
			e_E	7 18 16					
			F	7 50±					
26	5 Feb.	I	e_N	1 28 48					
			e_E	1 41					
			F	4 00±					
27	5 Feb.	I	e_N	6 01 31					
			F	6 10±					
28	10 Mar.	II_v	eP_{NEZ}	11 22 01					The epicenter was probably on the San Andreas Rift. See Berkeley Station, No. 40.
			iP_N	11 22 07	3		−6		
			iP_N	11 22 13	3		+15		
			iP_E	11 22 14					
			i_E	11 22 32	3	−27			
			i_N	11 22 37	3		−50		
			i_Z	11 22 39	3			−66	
			i_E	11 22 40	4	+107			
			i_Z	11 22 41	3			+98	
			i_N	11 22 55	2		−100		
			i_N	11 22 56	2		+145		
			i_E	11 22 56	4	+140			
			i_N	11 23 01	3		+120		
			i_N	11 23 02	3		−102		
			F	11 43±					

LICK OBSERVATORY STATION

No.	Date	Character	Phase	Time G. M. C. T.	Period	Amplitude AE	Amplitude AN	Amplitude AZ	Remarks
	1922			h m s	s	μ	μ	μ	
29	10 Mar.	I	e_N	17 08					The beginning and the end are lost in microseisms.
			F	17 23±					
30	16 Mar.	I_v	iP_{NE}	23 11 31					
			iP_Z	23 11 41					
			i_N	23 11 50					
			i_N	23 11 57					
			i_E	23 11 59					
			i_N	23 12 08	4		+15		
			i_{NE}	23 12 10	4		−15		
			i_N	23 12 16	3		+12		
			i_N	23 12 18	3		−10		
			F	23 25±					
31	20 Mar.	I_d	e_Z	0 44 48					
			e_{NE}	0 44 49					
			i_{NEZ}	0 44 51					
			F	0 46±					
32	28 Mar.	I	iP_{NZ}	4 09 44					The amplitudes are very small and the waves are partially masked by microseisms.
			e_N	4 13 27					
			i_N	4 20 24					
			F	4 45±					

DISCUSSION OF PARTICULAR SHOCKS

The Earthquake of January 31, 1922

by
James B. Macelwane

The shock which occurred on January 31, 1922, was of such magnitude as to register on seismographs throughout the world. It was felt, however, over a comparatively small area and nowhere had an intensity greater than VI on the Rossi-Forel scale. On the one hand the energy was so great that the first preliminary waves threw the pens from the drums on the seismographs at Berkeley, jarring one of the pens to the floor. The waves of the maximum phase generally throughout North America were too large to register on the first or second-class seismographs. On the other hand, no region could be found where the earthquake was of the destructive violence that such energy would lead one to expect.

This apparent inconsistency, the undoubted importance of the earthquake, the possible relation of the epicenter to the San Andreas Rift, and the fact that the senior author was then at work on the much discussed problem of change of frequency of vibration with time of travel of earthquake waves, led him to ask Professor Andrew C. Lawson, the chairman of the Department of Geological Sciences of the University of California, to write letters to about eighty carefully selected seismographic stations of the world, requesting the loan of their original seismograms or the sending of exact copies of them.

The response to Professor Lawson's letter was most generous. Original seismograms were sent by the University of Santa Clara (Santa Clara, Calif.), the Dominion Observatory of Victoria, B. C., Gonzaga University (Spokane, Wash.), the University of Saskatchewan (Saskatoon, Canada), the St. Louis University (St. Louis, Mo.), the University of Michigan (Ann Arbor, Mich.), the Hawaiian Volcano Observatory, the U. S. Weather Bureau (for Chicago, Ill., Northfield, Vt., and Washington, D. C.), Fordham

University (Fordham, N. Y.), the Meteorological Observatory of the College Saint-Martial at Port-au-Prince (Haiti), the Seismologic Station at Balboa Heights (Panama Canal Zone), the Samoan Observatory (Apia, Samoa), the Seismologic Station at Le Mans (France), the Geodätisches Institut at Potsdam, the Zentralstelle für Erdbebenforschung at Jena, the Observatorio Meteorológico de Coimbra, the Observatorio Central Meteorológico de Lisboa, the Erdbebenwarte Muenchen (for München and Nördlingen), the Erdbebenwarte Zürich, the Zentralanstalt für Meteorologie und Geodynamik von Wien, the University of Buda-Pest, the Geofizicki zavod Zagreb (Jugoslavia), the Observatoire Alger-Bouzareah (Algeria), the R. Osservatorio Geodinamico di Rocca di Papa. To all of these our grateful appreciation and acknowledgment is hereby tendered.

Our thanks are also due to the following, who sent blue prints or photographic copies of their records: The U. S. Coast and Geodetic Survey (for Cheltenham, Honolulu, Sitka, Tucson, Viequez), the Estación Sismológica Central de Tacubaya (Mexico), the Meteorological Service of Canada (for Toronto), the Dominion Observatory (at Ottawa), the Observatory of Mukaiyama (Sendai, Japan), the Royal Netherlands Meteorological Institute (De Bilt, Holland), the Hauptstation für Erdbebenforschung in Hamburg, the Observatoire Royal de Uccle, the Estación Sismológica San Calixto (La Paz, Bolivia), the Observatoire de Parc Saint-Maur, the Geophysikalisches Institut der Universität Göttingen, the Station Sismologique de l'Institut du Physique de Globe de Strasbourg, the Observatorio del Ebro (Tortosa), the Observatoire de Zi-ka-wei, the Stazione Sismologica di Pola, the Osservatorio Ximeniano di Firenze, and the Kon. Magnetisch en Meteorologisch Observatorium van Batavia (Weltevreden, Java).

Both the time of occurrence and the position of the epicenter were unknown, so that preliminary values of each had to be obtained from the analyses of the seismograms. The stereographic projection method of Dr. Klotz's was tried, but the preliminary values of S–P were so inconsistent that no choice of intersection

[1] These seismograms, together with those from the same stations for the earthquake of January 17, will be returned to the respective directors in the very near future, as soon as the junior author has completed his investigation of that set.

could be made with confidence. After several other attempts, a modification of the Oxford method was adopted. One difficulty that arose was the predominance of observations in the first quadrant. As this could not be obviated, a selection was made of those stations whose data were most consistent, and their measurements combined with the measurements from all the stations in the other three quadrants. The final values were:

$0 = 13^h\ 17^m\ 21^s \pm 1^s$ G.M.C.T.
Lat. $= 41°\ 8' \pm 3'$ North
Long. $= 125°\ 30' \pm 3'$ West

How does this location agree with the macroseismic reports? The data gathered by the U. S. Weather Bureau and published in the Weather Review for January, 1922, were collated with reports assembled by the various press associations. The shock was felt as far north as Florence and Eugene, Oregon; as far east as Bend and Klamath Falls, Oregon, and Fall River Mills and Grass Valley, California; and as far south as San Francisco and Berkeley, California. The intensity was greatest at Eureka, Calif., where it was of degree VI Rossi-Forel. In general, the apparent intensity was relatively greater on the unconsolidated sediments of the interior valleys than in the mountains and on the older rock areas, as is usually the case. But when this factor is taken into account, the distribution of intensities unmistakably pointed to an offshore epicenter in the general neighborhood of Eureka, which is situated in Lat. 40° 48′ North and Long. 124° 10′ West.

The results of the investigation with regard to change of period were exceedingly interesting. No functional relation was found between the periods of the second preliminary waves and the distance traveled by them. But the case of the first preliminary and maximum waves was quite different.

In the P-waves at stations near the epicenter, there were two periods present, the one very long and with a large amplitude, the other very short, and with a small amplitude, superposed on the first. As the waves were followed from station to station, the period of the longer wave decreased rapidly with the distance while that of the shorter wave slowly increased. At stations farther away than fifty degrees the distinction between the two waves disappeared.

As is well known, the main phase of an earthquake is made up of two groups of waves of distinctly different character. The L group consists of transverse waves without a vertical component. These waves travel along the surface of the earth with the speed of S-waves. On the other hand, the M group is composed of pseudo-Rayleigh waves whose plane of vibration is vertical and parallel to the direction of propagation. The speed of these waves is only about nine-tenths that of the L waves. The maximum amplitude of the earth motion is usually found shortly after the beginning of the M group. Two maxima were chosen for study of change of period, respectively two and four minutes after the beginning of the M waves on each record. The periods of both maxima were found to increase as an approximately linear function of the distance. Furthermore, the rate of increase was surprisingly rapid. A wave, which had an average period of nine seconds in the first ten degrees of its path, lengthened its period to an average of twenty-one seconds between 80° and 90° epicentral distance.

A full account of the investigation and a detailed discussion of the results has been published by the senior author in the Bulletin of the Seismological Society of America, June, 1923.

The South American Earthquakes of January 17, 1922

by
Perry Byerly Jr.

A study of the unusual seismograms of January 17, 1922, was undertaken by the writer because of their intrinsic interest with a view, also, to an investigation of the behavior of waves in groups. The original seismograms of this date were loaned to the Berkeley station by the directors of a large number of seismographic stations throughout the world. Other stations sent copies of their seismograms. (See pp. 46 and 47.)

The most marked features of these records are the great prominence of the second preliminary group and the insignificance of the surface waves.

The epicentral distances, as calculated from the apparent S–P intervals of the various stations, are all too short to reach any common point. This was noted in particular by the La Paz station, and the possibility of two earthquakes was suggested. In the reports of a number of stations, the seismogram was mentioned as being abnormal, and in most of the records an excessive number of marked wave groups was evident.

These seismograms have been found to be the superposed records of three distinct South American earthquakes.

The first of these occurred at $0=3^h\ 50^m\ 20^s$, M.G.T., with an epicenter in Brazil at $\varphi=4°\ 35.2'\pm32''$ South; $\lambda=63°56.3'\pm22''$ West.

The second occurred at $0=3^h\ 50^m\ 22^s$, with an epicenter in Venezuela at $\varphi=5°11.5'\pm5'$ North; $\lambda=66°\ 45.2'\pm4'$ West.

The third occurred at $0=3^h\ 50^m\ 24^s$, with an epicenter just off the coast of Ecuador at $\varphi=3°\ 12.1'\pm3'$ South; $\lambda\pm82°\ 50.2'\pm3'$ West.

In these three earthquakes may be found the explanation for the many marked wave groups on the records, the P and S groups with their reflections being present for each epicenter. There are no other possible solutions that can account for them.

The most obvious solution would be a single earthquake. But this proves to be unsatisfactory. If a single earthquake be assumed, its epicenter must be taken in or near Ecuador since newspapers in Guayaquil reported a shock felt throughout that country at this time. The S–P arcs fall far short of an epicenter in northern Ecuador, located by the assumption of a time of occurrence and by the drawing on a large terrestrial globe of arcs with the stations for centers and their respective P–O and S–O distances as radii. The S–P arcs of Europe and eastern North America traverse Venezuela at distances of from 450 to 1200 kilometers from the northern Ecuador epicenter. And the S–P arcs of La Paz and of Rio de Janeiro fall short of it by 500 and 900 kilometers, respectively. Those of western North America and the Hawaiian Islands also lie at too great a distance.

On all the seismograms the arrival of the second preliminary group is very marked. This large wave can be tested by the vector method on a number of records where the beginning is very sharp and can be shown to be certainly a transverse wave.

Two movements on the northern Ecuador epicenter cannot be made to explain the seismograms, even though they be assumed to be of such a nature that the P waves set up by the first disturbance were of so small a magnitude that they did not register at any of the stations, while the P waves of the second quake were those which were recorded. These latter P waves, together with the S waves of the first quake, would account for the too short S–P intervals; and for such an assumption, a time of occurrence for quake number one may be assumed which will reduce the discrepancies between P calculated and P observed to values from -43 to $+25$ seconds, and a time of occurrence for quake number two which will reduce the discrepancies between S calculated and S observed to values from -55 to $+65$ seconds. Still this assumption calls for the presence of an S group for the second earthquake, and this is not found on the seismograms. Also certain marked wave groups are left unexplained. An example of this is the very marked wave group in Europe which follows the first S after an interval of about four minutes. It arrived at Göttingen at $4^h\ 15^m\ 58^s$, and at Coimbra at $4^h\ 13^m\ 47^s$, and is noticeable on all the records.

Two epicenters will not suffice. If in addition to the one in northern Ecuador, another is taken in Brazil, determined from the La Paz record and the Rio de Janeiro report, it is found that the time of occurrence of the Brazilian earthquake differs by only a very few seconds from that of the Ecuador quake. Therefore it would not be possible for both the P and S groups from Brazil to fall within the S–P interval of the Ecuador quake on the European seismograms and thus explain the too short S–P interval. The almost simultaneous times of occurrence also prevent an explanation of the shortness of any of the S–P intervals by means of these epicenters.

If it be assumed that an earthquake took place in Venezuela on an epicenter satisfying the S–P intervals of Europe and eastern North America, its time of occurrence is found to be within a few seconds of the times found for the other two epicenters. Therefore if two earthquakes be assumed, one of which is on the Venezuela epicenter and the other of which is on the Ecuador epicenter, the S–P intervals at La Paz and Rio de Janeiro, together with the P arrival time at Johannesburg, are not explained. And again certain wave groups are not accounted for. If the Venezuelan epicenter is taken with the Brazilian epicenter, there is not only the unanswered problem of the S–P intervals of western North America and the Hawaiian Islands, but also the unexplained shock felt in Ecuador.

If only two of the foregoing epicenters are taken, later shocks on one or both of them will not afford a solution of the problem. Therefore only the assumption of three epicenters will satisfy the seismograms.

These three epicenters, as located above, and their times of occurrence, have been calculated as follows. A first approximate position of each was located on the globe by drawing the S–P arcs as above. These arcs arranged themselves in three very definite groups. The intersections of the arcs from eastern North America and Europe were grouped in Venezuela. Those from western North America and the Hawaiian Islands pointed to an epicenter off the coast of Ecuador. La Paz and Rio de Janeiro located the other in Brazil. This last location also satisfies the P arrival time at

Johannesburg, which is the only other station from which we have reports that would have registered this earthquake before it recorded either of the others. Johannesburg gave no S arrival time.

Approximate epicenters were thus located and the distances from each of these to the stations measured on the globe. Only those stations were used in the adjustment of an epicenter which received the waves from it before those from either of the others. A time of occurrence was assumed for each quake. The measured distance to each epicenter was compared with the P–O and S–P calculated distances, and the epicenter was adjusted to minimize discrepancies, the stations being weighted according to the quality of their seismographs and the accuracy of their time service. In each case the newly adjusted epicenter was taken, and the distance from it to each station was calculated, by the solution of a spherical triangle. Again the epicenter was adjusted and the time of occurrence also. The final epicenter was then located.

The wave group mentioned above, which arrived on the Göttingen record at $4^h\ 15^m\ 58^s$, proves to be the PS group from the Ecuador epicenter. That these three earthquakes explain the many wave groups is well illustrated by the seismograms of the United States Weather Bureau, Washington, D. C. The arrival times of the various wave groups at this station are as below:

Epicenters

Group	Venezuela	Ecuador	Brazil
P	3–57–39	[3–58–51]	[3–59–30]
PR_1	[3–58–51]	4–0–34	
PR_2	[3–59–30]		
PR_3			4–2–10
S	4–3–26	4–4–45	4–5–52
PS			[4–6–33]
SR_1		4–8–6	
SR_2	[4–6–33]	4–8–41	4–9–58
L	4–7–48	4–11–10	

Whenever two groups are due to arrive at nearly the same time, the corresponding arrival time is enclosed in brackets.

The PR_1 waves arriving at $4^h\ 0^m\ 34^s$ are of much greater amplitude than any of the preceding longitudinal waves. The distance from Washington to the Ecuador epicenter is 42.5°. For

this distance we should expect PR_1 to be of greater amplitude than P, since the latter has grazed a surface of discontinuity in the earth.[2]

The PR_3 group from Brazil is very large exceeding all the other longitudinal wave groups in amplitude. The distance from Washington to the Brazilian epicenter is 45°.2.

The great magnitude of the reflected waves in comparison with the directly transmitted waves at the critical distances is noticeable on many of the records. This is particularly marked in Europe for the PS and SR_1 groups from the Ecuador earthquake. For example, in Göttingen the S waves from this epicenter are very small, while the PS and SR_1 waves are those of the greatest amplitude on the record. The distance from Göttingen to the Ecuador epicenter is 94°.3 and hence within the interval $92° < \triangle < 102°$. In traveling such a distance, the S waves have grazed another surface of discontinuity which corresponds to that found by Gutenberg for longitudinal waves.[3] On the other hand, for both the Venezuela and the Brazil epicenters, the distances to Göttingen are less than 90°, and we find the amplitudes of the reflections in a more nearly one to one ratio to those of the directly transmitted waves.

The writer wishes to express his thanks to Professor Macelwane, whose advice has made this investigation possible.

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[2] Geiger and Gutenberg, Über Erdbebenwellen, VI, Nach. Kön. Gesell. Wiss. Göttingen, Math-phys. Kl., H.6, 1912. Also B. Gutenberg, Über den Erdkern in 2900 km Tiefe und die an ihm stattfindenen Reflexionen und Brechungen von Erdbebenwellen. Zeitschr. für angewandte Geophysik, Bd. 1, H.4 (May, 1923).

[3] B. Gutenberg, Ueber Erdbebenwellen VII A, Nach. Kön. Gesell. Wiss. Göttingen, H.2, 1914.