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SEISMOGRAPHIC STATIONS

No. 20, pp. 40 -422 April 29, 1921

THE REGISTRATION OF EARTHQUAKES AT THE BERKELEY STATION

AND

AT THE LICK OBSERVATORY STATION

FROM

APRIL 1, 1920, TO SEPTEMBER 30, 1920

BY

LEWIS A. BOND

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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)	First phase, or 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, chief phase, or principal part.
M(undae maximae)	Greatest motion 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.).
A_E	E-W component of A.
A_N	N-S component of A.
A_V	Vertical component of A.

4. *Time*—

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

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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

	Period	Magnif.	Damping
Bosch-Omori Seismograph N-S component	15ˢ	80	8–1
Bosch-Omori Seismograph E-W component	15ˢ	80	8–1
Wiechert Seismograph Vert. component	6ˢ	80	8–1
Omori Tromometer N-S component	2ˢ	60	.....
Omori Tromometer E-W component	2.5ˢ	60	.....
Marvin Strong-motion Seismograph—			
E-W component	6.5ˢ	5.8	1.3–1
N-S component	6.5ˢ	5.1	1.4–1

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1920			h m s	s	μ	μ	μ	
1	6 April	I?	e	16 59 08					Irregular waves of small amplitude on all components.
			F	17 08±					
2	6 April	I?	e	19 25±					Long flat waves barely perceptible on horizontal components. Not registered on V.
			F	19 48±					
3	12 April	I?	e	0 22±					Weak trace of distant quake on horizontal components only.
			F	0 44±					
4	16 April	I?	e	22 49±					Irregular waves obscured by microseisms.
			F	23 04±					
5	19 April	I?	i P_E	21 12 29					Beginning of P well marked but subsequent phases indeterminable.
			e P_N	21 12 30					
			e P_V	21 12 29					
			e $?_V$	21 23 10					
			F	21 41±					
6	7-8 May	I_u	*O*	*21 31 00*					
			e P_V	21 44 03					Δ=10,020 km.
			eP_N	21 44 11					No definite maximum.
			e P_E	21 44 12					
			e S_N	21 55 02					
			e L_N	22 08 38					
			e L_E	22 10 32					
			F	0 10±					
7	8 May	I?	e $?_N$	20 35 41					Series of widely spaced groups of sinusoidal waves of small amplitude and 10″ period.
			e $?_E$	20 36 02					
			F	23 43±					
8	10 May	I_r?	e $?_E$	19 13 35					Trace of a distant quake. Phases not discernable.
			e $?_N$	19 13 50					
			F	20 20±					
9	13 May	I_u	e P_V	2 01 49					Δ=9720 km.
			e L_{EV}	2 31 39	20				No definite maximum. Main phase consists of smooth regular waves of small amplitude.
			F	4 23±					
10	19 May	I_u	e P_E	19 38 22					Trace of a distant quake. Amplitudes very small. N-S record obscured by microseisms. Barely perceptible on V.
			e $?_E$	19 49 36					
			e L_E	20 03 51					
			F	20 55±					
11	26 May	I_u?	e L	12 31 06					Trace of a distant quake. on all components. Time marker on V out of order.
			F	14 18±					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1920			h m s	s	μ	μ	μ	
12	30 May	I_u?	e L_E	20 56 19					Trace of main phase of distant quake. Barely perceptible on V.
			e L_N	20 56 22					
			F	21 11±					
13	2 June	I_r	e P_{ENV}	22 06 41					Δ=1900 km. ?
			e L_E	22 11 01					
			e L_N	22 11 10					
			M_{E1}	22 13 53					
			M_{E2}	22 16 45					
			M_N	22 17 42					
			F	23 12±					
14	4 June	I_d	e	13 47 04					Trace of a weak local shock. Minute vibrations on all components.
			F	13 47 56					
15	4 June	I_u?	e $?_N$	15 29 20					Trace of a distant quake. Barely perceiptible on V.
			e L_E	15 34 09					
			F	15 55±					
16	5 June	I_u	*O*	*4 22 08*					Δ=9540 km.
			e P_{NV}	4 34 48					
			e P_E	4 34 50					
			e S_{EN}	4 45 25					
			e L_N	4 59 32					
			e L_E	5 00 56					
			e L_V	5 05 25					
			F	6 42±					
17	9 June	I_u?	e	11 55 53					Trace of distant quake on all components.
			F	13 05±					
18	16 June	I_d	e N	12 09 21					Trace of local shock. Beginning and end obscured by micros. No phases discernable. A series of irregular vibrations of small amplitude and about 1″ period.
			e V	12 09 34					
			e E	12 09 36					
			F	12 10 40					
19	17 June	I_d	i P_{EN}	17 50 21.3					Δ=30 km.
			i P_V	17 50 22.1					Registered by the Omori tromometer.
			i S_{EVN}	17 50 24.5					
			e L_{ENV}	17 50 26.7					
			M_E	17 50 26.8	1	5.0			
			M_N	17 50 27.3	½		7.5		
			M_V	17 50 27.4	1			10.6	
			F	17 50 55					
20	18 June	I_V	e P_V	10 09 20					Δ=555 km.
			e S_V	10 10 20					Reported felt at Los Angeles. Phasechanges very poorly marked. No definite maximum on any component.
			e S_N	10 10 23					
			e L_V	10 10 42					
			F	10 25±					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1920			h m s	s	μ	μ	μ	
21	22 June	II_V	*O*	*2 48 03*					Inglewood shock. See discussion in text.
			e P_V	2 49 19					
			e P_N	2 49 21					
			e ?$_E$	2 49 42					
			e S_E	2 50 21					
			e S_{NV}	2 50 23					
			e L_{EN}	2 50 41					
			M_{N1}	2 51 47	6½		18.1		
			M_V	2 52 24	7			10.4	
			M_E	2 52 25	6½	14.0			
			M_{N2}	2 52 32	6½		23.4		
			F	3 11±					
22	25 June	I_d	i P_{ENV}	22 51 39					Weak focal shock.
			M_{N1}	22 51 39	<½		4.4		
			M_V	22 51 44	1			5.6	
			M_{N2}	22 51 45	1		5.6		
			M_E	22 51 47	1	0.7			
			F	22 52 10					
23	2 July	I_u	*O*	*18 40 09*					Δ=9750 km. Amplitudes very small throughout.
			e P_{EV}	18 52 59					
			e P_N	18 53 00					
			e S_N	19 03 46					
			e L_E	19 21 40					
			e L?$_N$	19 22 23					
			F	19 46±					
24	7 July	I_r	*O*	*6 41 22*					Δ=2870 km. Faint record of a distant quake.
			e P_{NV}	6 47 06					
			e P_E	6 47 15					
			e S_N	6 51 50					
			e L_E	6 55 03					
			F	7 36±					
5	3 Aug.	I_r	e P_V	20 09 41					Δ=4020 km. ? Poorly registered distant quake.
			e L?$_E$	20 20 00					
			e L_N	20 20 05					
			F	20 28±					
26	15 Aug.	I?	e P_N	8 28 47					S and L indeterminable. No V record.
			e P_E	8 28 59					
			F	9 34±					
27	20 Aug.	I_u	e P_V	16 28 30					Δ=9600 km. ?
			e L_V	16 57 43					
			e L_E	16 57 53					
			e L_N	16 57 56					
			F	18 32±					
28	26-27 Aug.	I_r	e P_{EV}	23 06 52					Δ=3700 km. Barely perceptible on N-S.
			e ?$_N$	23 16 46					
			e L_{EV}	23 16 08					
			F	0 48±					
29	8 Sept.	I_r	e P_E	1 57 53					Δ=3900 ? Poorly registered on N-S.
			e P_V	1 57 57					
			e L?$_V$	2 07 47					
			e L?$_{EN}$	2 07 51					
			F	3 44±					
30	9 Sept.	II_d	e P_V	16 47 37.0					Δ=65 km. Felt at San Jose and in surrounding towns.
			e P_E	16 47 37.1					
			e P_N	16 47 37.0					
			e L_V	16 47 44.9					
			e L_E	16 47 45.2					
			e L_N	16 47 45.7					
			M_V	16 47 46.8	2			5.5	
			M_E	16 47 56.8	2	11.9			
			M_N	16 47 43.4	2		18.1		
			C	16 48 09.5					
			F	16 52±					
31	9 Sept.	I?	e P_V	19 09 01					Trace of a distant quake. Amplitudes very small.
			e ?$_E$	19 20 17					
			e L_E	19 34 00					
			e L_V	19 34 40					
			F	20 49±					
32	12 Sept.	I_d	e P	9 45 35					Weak local shock registered on horizontal components only.
			F	9 46 04					
33	20 Sept.	II_u	*O*	*14 39 21*					Δ=9280 km. See discussion in text.
			e P_V	14 51 47					
			e P_E	14 51 45					
			e P_N	14 51 49					
			e S_N	15 02 11					
			e S_E	15 02 12					
			e L_E	15 18 41					
			e L_N	15 18 46					
			M_E	15 23 43	20	287			
			M_{V1}	15 24 55	18			245	
			M_N	15 25 32	20		24		
			M_{V2}	15 26 09	18			245	
			F	17 45±					
34	27 Sept.	I?	e L_E	5 31 55					Trace of main phase of distant quake appearing on E-W only.
			F	5 54±					

THE LICK OBSERVATORY STATION

CONSTANTS

Constants of the Station

Latitude and longitude of the center of the seismographic room:

$\phi = 37° 20' 24.''5$ 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.

Constants of the Seismographs

	Period	Magnif.	Damping
Wiechert Seismograph N-S component	8.0	80	4:1
Wiechert Seismograph E-W component	7.0	80	5:1
Wiechert Seismograph Vertical component	2.5	80	2:1

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1920			h m s	s	μ	μ	μ	
1	19 April	I?	e ?	21 12 24					Waves of very small amplitude. Phases not determinable.
			F	21 28±					
2	28 April	I_d	i	18 32 33					Thickening of pen trace. May not be seismic.
			F	18 32 40					
3	29 April	I_d	i P_E	0 02 35.8					Δ=25 km.
			i P_N	0 02 37.6					Weak local shock. V record lost while changing drums.
			i LM_{EN}	0 02 38.3					
			F	0 02 48					
4	30 April	I_d	e P_E	1 25 42					Weak local shock. Thickening of pen trace on all components.
			e P_V	1 25 43					
			e P_N	1 25 44					
			F	1 25 52					
5	1 May	I_d	i N	16 32 14					Thickening of pen trace on all components. V illegible due to overcrowding.
			i E	16 32 16					
			F	16 32 22					
6	6 May	I_d	e	20 55 01					Thickening of pen trace on horizontal components
			F	20 55 07					
7	6 May	I_d	e	21 01 18					Slight thickening of pen trace on horizontal components only.
			F	21 01 48					
8	7 May	I_d	e	1 59 41					Minute vibrations on horizontal components only.
			F	2 01 40					
9	7 May	I?	e L_{EN}	21 55 05					Trace of a distant quake on horizontal components. Barely perceptible on V.
			F	23 26±					
10	8 May	I_d	i P_{EN}	3 57 22.2					Δ=16 km.
			i L_E	3 57 23.1					Not recorded on V.
			i LM_N	3 57 23.5	<½		4.4		
			M_E	3 57 24.4	<½	5.0			
			F	3 57 27					
11	8 May	I?	e L_N	21 14 10					Trace of main phase of distant quake on horizontal components only.
			e L_E	21 14 40					
			F	21 27±					
12	9 May	I_d	i P_{ENV}	14 21 42.1					Δ=32 km.
			i L_{EN}	14 21 45.6					
			F	14 21 20					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1920			h m s		μ	μ	μ	
13	9 May	I_d	e EN	22 42 13					Slight thickening of pen trace on horizontal components.
			F	22 42 27					
14	10 May	I?	e L_E	19 46 04					Trace of a distant quake. Barely perceptible on N-S.
			F	20 00±					
15	13 May	I_u	e P_V	2 06 04					Faint record of a distant quake.
			e $S?_E$	2 14 07					
			e L_{ENV}	2 32 03					
			F	3 24±					
16	14 May	I_d	e P_N	2 45 31.6					Δ=87 km.
			e L_N	2 45 43.1					Barely perceptible on V.
			M_N	2 45 44.4					
			M_E	2 45 49.3					
			F	2 48 03					
17	14 May	I_d	i P_V	6 27 53.0					Δ=25 km.
			e P_N	6 27 53.3					
			i LM_N	6 27 55.1	<½		5.0		
			F	6 28 19					
18	16 May	I_d	i P_E	4 45 22.8					Δ=29 km.
			e P_N	4 45 24.6					Barely perceptible on V.
			i L_N	4 45 25.9					Shift of pen trace on
			M_N	4 45 26.5	<½		16.2		E-W.
			F	4 45 45					
19	17 May	I_d	i P_{ENV}	1 47 28.1					Δ=17 km.
			i LM_{EN}	1 47 29.4	<½	11.9	7.5		Shift of pen trace on V.
			F	1 47 39					
20	17 May	I_d	i	23 06 29					Thickening of pen trace on all components.
			F	23 06 34					
21	19 May	I_d	e	0 20 42					Thickening of pen trace on all components.
			F	0 20 50					
22	21 May	I_d	i	21 47 29					Thickening of pen trace on horizontal components.
			F	21 47 40					
23	25 May	I_d	e	2 40 01					Minute vibrations on H only.
			F	2 40 24					
24	30 May	I?	e L_E	20 55 57					Trace of main phase of a distant quake. Barely perceptible on N-S. Not recorded on V.
			F	21 02±					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1920			h m s	s	μ	μ	μ	
25	1 June	I_d	i	15 52 04					Recorded on V while horizontal component sheet was being changed.
			F	15 52 14					
26	1 June	I_d	i	23 56 27					Thickening of pen trace on all components.
			F	23 56 35					
27	2 June	I?	e L_N	22 09 55					Trace of a distant quake. Not recorded on V.
			e L_E	22 10 02					
			F	22 28±					
28	3 June	I_d	i	1 08 05					Thickening of pen trace on all components.
			F	1 08 12					
29	5 June	I_u	e P_V	4 34 54					Δ=9500 km.
			e P_E	4 34 55					Barely perceptible on V.
			e P_N	4 34 57					
			e S_E	4 45 30					
			e S_N	4 45 45					
			F	6 18±					
30	15 June	I_d	i	0 08 00					Weak focal shock on all components.
			F	0 08 08					
31	16 June	I_d	e P_N	12 09 07					Δ=83 km.
			e P_E	12 09 08					
			e L_{EN}	12 09 18					
			M_N	12 09 21					
			M_E	12 09 31					
			F	12 10 17					
32	18 June	I_V	e N	10 09 05					Felt at Los Angeles. Not recorded on E-W, and barely perceptible on V. Fair record on N-S but phases not sufficiently well defined to be determinable.
			F	10 22±					
33	21 June	I_d	i	21 22 16					Thickening of pen trace on horizontal components.
			F	21 23±					
34	22 June	II_V	e P_V	2 49 16					Inglewood shock. See discussion in text.
			e P_N	2 49 21					
			e $?_E$	2 49 34					
			e L_N	2 50 15					
			e L_E	2 50 17					
			M_{N1}	2 50 41					
			M_E	2 50 44					
			M_{N2}	2 51 19					
			F	3 05±					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1920			h m s	s	μ	μ	μ	
35	23 June	I_d	i	22 00 24					Thickening of pen trace on horizontal components.
			F	22 00 33					
36	25 June	I_d	i	2 22 03					Thickening of pen trace on all components.
			F	2 22 29					
37	28 June	I_d	e_N	9 02 23					Small, irregular vibrations on all components.
			e_E	9 02 29					
			e_V	9 02 35					
			F	9 03 38					
38	30 June	I_d	i_{EV}	16 05 56					Weak focal shock.
			i_N	16 06 01					
			F	16 06 07					
39	1 July	I_d	i	21 14 10					Slight thickening of pen trace on horizontal components only.
			F	21 14 24					
40	1 July	I_d	i	23 52 00					Thickening of pen trace on all components.
			F	23 52 08					
41	3 July	I_d	e	0 49 08					Thickening of pen trace on all components.
			F	0 49 18					
42	3 July	I_d	i	18 25 48					Minute rapid vibrations on all components.
			F	18 25 57					
43	10 July	I_d	i	20 13 18					Pronounced thickening of pen trace on all components.
			F	20 13 24					
44	10 July	I_d	i	20 50 12					Weak focal shock on all components.
			F	20 50 28					
45	14 July	I_d	i	21 47 49					Thickening of pen trace on all components.
			F	21 48 00					
46	15 July	I_d	i	23 36 56					Thickening of pen trace on all components.
			F	23 37 03					
47	17 July	II_d	i P_{NV}	6 20 04.8					Δ=23 km.
			i LM_{EN}	6 20 06.8		$<\frac{1}{2}$	29.4	25.0	
			F	6 20 45					
48	21 July	I_d	i	1 25 14					Weak focal shock.
			F	1 25 25					
49	22 July	I_d	i	0 09 35					Thickening of pen trace on all components.
			F	0 09 45					
50	22 July	I_d	i	1 21 17					Slight thickening of pen trace on all components.
			F	1 21 27					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1920			h m s	s	μ	μ	μ	
51	22 July	I_d	i	16 52 44					Thickening of pen trace on all components.
			F	16 52 51					
52	26 July	I_d	i	21 32 40					Slight thickening of pen trace on all components.
			F	21 32 51					
53	27 July	I_d	i P_{ENV}	17 56 22.0					Δ=37 km.
			e L_{EN}	17 56 26 2					
			M_N	17 56 27.3	$<\frac{1}{2}$		10.6		
			M_V	17 56 27 6	$<\frac{1}{2}$			3.8	
			M_E	17 56 28.5	$<\frac{1}{2}$	6.3			
			F	17 56 35					
54	17 Aug.	I_d	i	0 40 14					Slight thickening of pen trace on horizontal components only.
			F	0 40 21					
55	17 Aug.	I_d	i	1 02 02					Pronounced thickening of pen trace on horizontal components only
			F	1 02 13					
56	17 Aug.	I_d	e	7 19 32					Small, irregular, short period vibrations on horizontal components only.
			F	7 20 01					
57	20 Aug.	I?	e	16 57 45					Trace of distant quake on horizontal components.
			F	17 21±					
58	21 Aug.	I_d	i	6 58 58					Thickening of pen trace on all components.
			F	6 59 18					
59	31 Aug.	I_d	i	16 34 28					Slight thickening of pen trace on all components.
			F	16 34 36					
60	7 Sept.	I_d	i	21 37 24					Thickening of pen trace on all components.
			F	21 37 35					
61	7 Sept.	I_d	i	21 51 25					Thickening of pen trace on all components.
			F	21 51 30					
62	8 Sept.	I_r	e P_N	1 57 58					Δ=3900 km.
			e L_N	2 07 55					
			e $?_E$	2 08 14					
			M_N	2 08 02					
			F	2 38±					
63	8 Sept.	I_d	e	22 35 45					Sharp thickening of pen trace on all components.
			F	22 35 54					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude			Remarks
						A_E	A_N	A_V	
	1920			h m s	s	μ	μ	μ	
64	9 Sept.	III_d	i P_{ENV}	16 47 30.3					Δ=30 km.
			i LM_V	16 47 32.9	ca½			86	Felt at San Jose and neighboring towns.
			i LM_N	16 47 33.9	<1		315		
			i LM_E	16 47 33.6	<1	354			
			C	16 47 58					
			F	16 50±					
65	9 Sept.	I?	e V	19 34 37					Trace of distant quake.
			e E	19 37 09					
			e N	19 37 11					
			F	20 07±					
66	15 Sept.	I_d	i	11 48 44					Thickening of pen trace on all components.
			F	11 48 52					
67	16 Sept.	I_d	i	15 15 57					Thickening of pen trace on all components.
			F	15 16 05					
68	17 Sept.	I_d	i	0 43 33					Shift of pen trace on E-W. Thickening on N-S and V.
			F	0 43 41					
69	20 Sept.	II_u	*O*	*14 39 21*					Δ=9290 km.
			e P_N	14 51 48					See discussion in text.
			e P_E	14 51 50					V illegible because of overcrowding.
			e S_N	15 02 13					
			e S_E	15 02 14					
			e L_{EN}	15 19 16					
			M_E	15 23 24	20	274			
			M_N	15 27 50	17		121		
			F	17 30±					
70	27 Sept.	I_d	i	23 20 50					Weak local shock.
			M_N	23 20 51			30.6		
			M_E	23 20 52		12.5			
			F	23 21 35					
71	30 Sept.	I_d	i	1 29 09					Thickening of pen trace on all components.
			F	1 29 19					

DISCUSSION OF PARTICULAR SHOCKS

The Inglewood Earthquake of June 22, 1920†

The earthquake at Inglewood, California, on June 22, 1920, has been investigated in the field by Dr. Stephen Taber.* It was hoped that a study of the seismograms, in connection with his field determination of epicenter and time of origin, would contribute to our knowledge of the hodograph for such epicentral distances. But the seismograms proved to be somewhat disappointing in several respects: On all components, at both the Lick and Berkeley stations, the beginning of the first preliminary tremor takes the form of a very gradual *emersio*, so that a determination of the exact time of arrival of the first waves is impossible. Changes of character which might be consistently interpreted as the inception of subsequent phases are ill-defined and sometimes entirely wanting. Taber does not give the degree of accuracy with which the time of occurrence of the shock was determined, and there is a discerpancy of slightly more than one minute between the time reported and that calculated from the seismograms.

Of the Berkeley records, the vertical component sheet shows the earliest perceptible movement. A very faint *emersio* sets in at $2^h\ 49^m\ 19^s$. The amplitudes are exceedingly small and the period a little less than 2″. At $2^h\ 49^m\ 37^s$ the amplitude and the period simultaneously increase. A similar but less striking variation takes place on the N-S component record at about the same time. This occurrence is interpreted as the arrival of one of the groups of reflected or refracted waves with which the seismograms seem to abound. At $2^h\ 50^m\ 23^s$ there occurs on V a further increase in period but no corresponding increase in amplitude. So poorly marked is this change that it was not detected until after a careful comparison with N-S. On the latter component there is at this time an increase in both period and amplitude, and this change

*Bull. Seis. Soc. Amer. Vol. 10, p. 129, September, 1920.

†G. M. C. T.

of character is sufficiently pronounced to suggest that it is due to the arrival of the second preliminary tremor. $2^h\ 50^m\ 23^s$ is therefore taken as the time of arrival of the S waves. The registration of the preliminary tremors on the E-W component is very unsatisfactory. The first perceptible movement is noted at $2^h\ 49^m\ 42^s$ but the amplitudes remain so small, and the movement so irregular that eS can not be determined. A very pronounced increase in period and amplitude at $2^h\ 50^m\ 41^s$ marks the beginning of the main phase on N-S. There is a corresponding change of character on E-W, though less striking, but on V the only variation observable is a gradual increase in period, accompanied by irregular fluctuations in amplitude, which begins before and continues after the time taken for the inception of L on the horizontal components. Two definite maxia occur on N-S, the first at $2^h\ 51^m\ 47^s$, the period being $6\frac{1}{2}''$ and the amplitude 18.1 microns; the second is at $2^h\ 52^m\ 32^s$, with a displacement of 23.4 microns, the period remaining the same. Maxima on V and E-W are recorded at $2^h\ 52^m\ 24^s$ and $2^h\ 52^m\ 25^s$ respectively. The amplitudes are notably less than on N-S, being 10.4 microns on V, and 14.0 on E-W. The corresponding periods are $7''$ and $6\frac{1}{2}''$. Following the maxima the periods decrease somewhat, and the amplitudes wax and wane irregularly for some three minutes, after which the smaller waves of the tail portion dominate the seismogram. In general character the records of the Lick station resemble closely those described above. They show the same gradual beginning of movement and lack of definition of phases. They differ in that the period of the waves at the time of maximum displacement ranges from $2''$ to $5''$, as compared with $6\frac{1}{2}''$ for Berkeley, and the amplitudes are notably smaller. This is particularly true of the vertical component record, which nowhere shows a displacement exceeding 3 microns, and which can not be said to possess a definite maximum.

Taber* estimated the maximum intensity of this shock at about eight and one-half in the Rossi-Forel scale, and noted that the intensity diminished rapidly on passing outward from the epicenter. The comparatively small displacements recorded at the Lick and Berkeley stations accord with his observation and support his conclusion that the origin was of shallow depth. If

Op. cit.

this be true it helps to explain another interesting peculiarity of the seismograms — the lack of definition of phases and the irregularity of movement throughout. The middle ordinate for an arc of 500 km. (Δ for Berkeley = 560 km.) is 5 km. If the depth of origin of the shock were shallow, it is probable that the paths of all the waves reching the stations lay entirely within the heterogeneous outer portion of the earth's crust, where surfaces of discontinuity of one kind and another exist which would give rise to repeated reflection and refraction of the waves. Such surfaces might be expected to be especially numerous along the course of the seismic rays in question, traversing, as they do for almost the entire epicentral distance, a portion of the structurally complex Coast Ranges. Frequent reflections and refractions at various points along the wave paths might result in the almost continuous arrival at the recording stations of more or less irregular and heterogeneous vibrations, which, when superimposed, would tend to obliterate the distinct changes in character of the record which are ordinarily associated with the sequence of phases.

Teleseism of September 20, 1920.

The teleseism of September 20, 1920 was well registered at both the Berkeley and the Lick Observatory stations, except for overcrowding on the record of the vertical component at Berkeley which rendered that particular sheet illegible. The first preliminary tremor begins with a wave of condensation, as evidenced by a pronounced upward movement of the ground that is well registered on V. This phase consists of irregular waves having periods of from $2\frac{1}{2}''$ to $3''$, upon which are superimposed minute vibrations of less than $\frac{1}{2}''$ period. The movement continues for approximately one minute, after which it dies out except for scattered, discontinuous vibrations of small amplitude. The second preliminary tremor is represented by an outstanding group of waves having periods of about $20''$ and comparatively large amplitudes, which contrast sharply with the diminutive movements of the preceding minutes. The interval S-P is $10'\ 24''$ for Berkeley and $10'\ 25''$ for Lick, corresponding to epicentral distances of 9280 and 9290 km. respectively. The pronounced

movement due to the arrival of S waves continues for two or three minutes, after which it dies away. The main phase begins with a few long waves (s=30″), slightly irregular and of small amplitude at the start. The amplitudes rapidly increase while the periods decrease to about 20″, the waves at the same time becoming very smooth and sinusoidal. The maximum displacement recorded is 287 microns. It occurs on the E-W component at Berkeley. At both stations the greatest N-S displacement is notably less than that on E-W. Two maxima are found on the record of the vertical component at Berkeley, and the displacement of the ground, 245 microns in each case, is unusually large compared with the horizontal displacements. After the maxima the waves continue sinusoidal in form, but gradually decrease in amplitude, with somewhat periodic recurrences of groups of larger waves. Perceptible movement extends over approximately three hours.