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SEISMOGRAPHIC STATIONS

No. 9, pp. 169-188 August 19, 1915

THE REGISTRATION OF EARTHQUAKES AT THE BERKELEY STATION

AND

AT THE LICK OBSERVATORY STATION

FROM

OCTOBER 1, 1914, TO MARCH 31, 1915

BY

E. F. DAVIS

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CONTENTS

Symbols and Notation

1. *Character of the Earthquake*—

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

d (terrae motus domesticus)	Local shock (origin nearby, perceptible at the station).
v (terrae motus vicinus)	Near shock (origin less than 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 (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 ($\mu = 1/1000$ mm.).

A_E E-W component of A.

A_N N-S component of A.

A_V vertical component of A.

THE BERKELEY STATION

CONSTANTS

Latitude and longitude of the center of the seismographic room:

$\phi = 37° 52' 15''.9$ N. Lat.

$\lambda = 122° 15' 36''.6$ 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
Weichert 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

GALITZIN PRISMS

Two sets of Galitzin prisms for the determination of the intensity of strong earthquakes were installed at the Berkeley Station on December 15, 1914. These prisms were constructed according to specifications given by Prince Galitzin.[1]

Briefly stated, the Galitzin earthquake prisms are a set of parallelopipeds so designed that they can overturn only by a rotation about a fixed horizontal axis. The prisms are of varying dimensions and overturn with different accelerations of the earth. The set includes ten prisms designed to overturn with accelerations ranging from 200 to 2000 millimeters per second per second. They constitute a scale of earthquake intensity, each division of which differs from the next by 200 millimeters per second per second.

As installed at Berkeley, the prisms are in two sets. One set overturns about axes which lie in a North-South line, while the other set overturns about axes lying in an East-West line. They are set up in the same room with the seismographs and it is planned to compare the intensities indicated by the Galitzin prisms with the intensities indicated by the instrumental records.

[1] Fürst B. Galitzin, Über eine dynamische Skala zur Schätzung von Makroseismichen Bewegungen, Comptes-Rendus, 18 Association Internationale de Sismologie, Manchester, 1911, p. 178. A review of this paper by H. O. Wood appeared in the Bulletin of the Seismological Society of America, vol. III (1913), p. 90.

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1914			h m s	s	μ	μ	μ	
1	3 Oct.	I_u	e P_E	17 32 00					Time determinations somewhat uncertain. Clock had been removed for repairs and was just being replaced when earthquake began. Vertical record good but minute marks are illegible through overscoring. See discussion in text.
			e P_N	17 32 17					
			e S_N	17 39 57					
			e S_E	17 40 12					
			e L	indefinite					
			M_N	17 54 57	22		20	9	
			M_E	17 59 08	21	7			
			C	indefinite					
			F	18 48±					
2	3 Oct.	I?	e	22 26 00					Trace of a distant earthquake on all three components.
			F	23 39±					
3	8 Oct.	I?	e	12 35					Barely perceptible trace of a distant earthquake. North-South component only.
			F	13 06					
4	22 Oct.	I?	e	6 48					Dying energy of chief phase of a distant earthquake. Horizontal components only. Vertical undergoing repairs at this time.
			F	6 58					
5	23 Oct.	I?	e	7 01					Trace of a distant earthquake. Not recorded by Vertical.
			F	7 26					
6	8 Nov.	I_V	e	11 43 12					No phases discernible. Slight disturbance on North-South. Very slight on East-West. See discussion in text.
			F	11 44 43					
7	9 Nov.	III_d	i P_V	2 31 19.0					Origin near Laurel, California. See discussion in text.
			i P_{EN}	2 31 19.4	$<\frac{1}{2}$	7	21		
			i L_V	2 31 30.0					
			i L_E	2 31 30.2					
			i L_N	2 31 30.4					
			M_E	2 31 31	4/10	294			
			M_{NV}	2 31 34	4/10		170	55	
			C	2 32 55					
			F	2 39 44±					
8	18 Nov.	I?	e	9 55 03					Dying energy of a distant earthquake. Simple sinusoidal waves from $10^h 08^m 35^s$ to $10^h 15^m 38^s$; period 14 seconds; amplitude on North-South 2 microns and on East-West 1 micron.
			F	10 40±					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1914			h m s	s	μ	μ	μ	
9	21 Nov.	I_V	i P_N	16 24 18.0					See discussion in text.
			i P_V	16 24 18.4					
			i P_E	16 24 18.5					
			i L_N	16 24 30.1					
			i LM_E	16 24 31.2	½	4			
			i L_V	16 24 31.8					
			M_N	16 24 31.8	½		4		
			C	16 24 54					
			F	16 25 35					
10	24 Nov.	I_r	i P_E	12 05 24					S indefinite. First part of Vertical record illegible through overscoring, so that time marks could not be distinguished. See discussion in text.
			i P_N	12 05 25					
			i L_E	12 15 06					
			i L_N	12 15 08					
			M_N	12 15 10	9		79		
			M_{V_1}	12 15 13	7½			29	
			M_E	12 15 11	11	185			
			M_{V_2}	12 15 50	6½			32	
			C	indefinite					
			F	14 04±					
11	20 Dec.	I_u	e P_E	14 20 23					No definite maximum on East-West record. Simple sinusoidal waves from $14^h\ 44^m\ 09^s$ to $14^h\ 47^m\ 24^s$; amplitude 4 microns and period 33 seconds. Not recorded by Vertical.
			e P_N	14 20 26					
			e S_{EN}	14 29 43					
			e L_{EN}?	14 38 52					
			M_N	14 43 44	30		10		
			C	indefinite					
			F	15 28±					
12	28 Dec.	II_a	i P_E	10 42 42.7					Felt in Berkeley. III of Rossi-Forel scale. Registered on Vertical by a thickening of the pen trace. Discrepancy in times on horizontal components probably due to an error in parallax determination.
			i P_N	10 42 45.1					
			i L_E	10 42 53.5					
			e L_N	10 42 57.1					
			M_E	10 42 55	$<\frac{1}{2}$	22			
			M_N	10 42 57	$<\frac{1}{2}$		9		
			C	indefinite					
			F	10 44 58					
	1915								
13	5/6 Jan.	I_{V-r}	e	23 39 39					Barely perceptible on East-West. No disturbance apparent on Vertical.
			e L	23 49 53					
			M	23 52 04	14½		10		
			F	0 43±					
14	12 Jan.	I_V	e P_E	4 31 56					Not recorded by Vertical. Origin near Los Alamos, California. See discussion in text.
			e P_N	4 32 00					
			e L_N	4 32 49					
			e L_E	4 32 54					
			M_N	4 33 26	8		63		
			M_E	4 33 30	7	52			
			C	4 35 39					
			F	4 48±					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1915			h m s	s	μ	μ	μ	
15	13 Jan.	I_u	e_N	7 18 09					Not recorded by Vertical. Barely perceptible long flat waves on East-West. Record of earthquake originating near Avezanno in Italy. See discussion in text.
			e L_N?	7 37 48					
			e L_E?	7 37 56					
			M_N	7 44 54	22		4		
			F	8 14 16±					
16	25 Feb.	I_r?	e_N	9 04 35					Both eP and F are confused by strong microseisms. Not recorded by the Vertical.
			e_E	9 04 38					
			e L_E?	9 06 49					
			e L_N?	9 07 24					
			M_E	9 08 47	8	9			
			M_N	9 09 12	8		18		
			C	9 12 36					
			F	9 34±					
17	25 Feb.	I_r	e P_N	20 47 13					No definite maximum on Vertical.
			e P_V	20 47 14					
			e P_E	20 47 20					
			e S	indefinite					
			i L_{EN}	20 56 31					
			e L_V	20 56 34					
			M_E	20 56 34	3	14			
			M_N	20 57 00	7		20		
			C	indefinite					
			F	21 49±					
18	28 Feb.	I_V	e	10 44 25					Not recorded by Vertical or by Omori. No definite maximum on North-South.
			M_E	10 45 05	2	5			
			F	10 46 36					
19	5 Mar.	I_{V-r}	e	4 26 24					Barely perceptible long flat waves on two horizontal components. Time as given somewhat uncertain on account of failure of clock to mark time during the earthquake.
			F	4 58±					
20	28 Mar.	I_r?	e_N	19 10 32					A fairly good record was obtained on the vertical component instrument, but it was rendered illegible by overscoring. F lost in microseisms after $12^h\ 08^m$
			e_E	19 10 56					
			M_N	19 12 01	11½		6		
			M_E	19 14 39	8	6			
			C	19 23 56					
			F	12 08±					
21	30 Mar.	I_V	e_N	0 09 17					Slight disturbance apparent on Vertical record.
			e_E	0 09 20					
			M_E	0 10 02	3	4			
			M_N	0 10 04	3		4		
			F	0 14 28					
22	31 Mar.	I_{a-r}	e	12 40 58					Thickening of pen traces on horizontal components. Not recorded by Vertical.
			F	12 41 51					

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
	1914			h m s	s	μ	μ	μ	
1	3 Oct.	I_d	i P_{EN}	17 32 06					M_E not measurable on account of limitation of record by safety stop. Not recorded by Vertical. See discussion in text.
			i S_E	17 40 05					
			i S_N	17 40 06					
			e L_N?	17 49 37					
			M_N	17 55 04	19		25		
			C	indefinite					
			F	18 55±					
2	3 Oct.	I?	e	22 39 20					Trace of a distant earthquake on both horizontal records. Somewhat confused by microseisms.
			F	23 27 20					
3	17 Oct.	I_d	i P_{EN}	22 49 26.1					A few barely noticeable waves on Vertical.
			i LM_{EN}	22 49 27.3	$<\frac{1}{2}$	10	11		
			C	22 49 31					
			F	22 49 47					
4	22 Oct.	I?	e	6 47 55					Trace of a distant earthquake on horizontal components only.
			F	7 00±					
5	23 Oct.	I?	e	7 01 35					Trace of a distant earthquake on horizontal components only.
			F	7 25±					
6	7 Nov.	I_d	e P	16 21 47					Thickening of pen trace on North-South. Not recorded by Vertical.
			e LM_E	16 21 52	$<\frac{1}{2}$	7			
			C	16 21 55					
			F	16 21 57					
7	8 Nov.	I_r	e	11 40 56					Not perceptible on vertical record. See discussion in text.
			M_N	11 41 51	3		4		
			M_E	11 42 24	4	4			
			F	11 45 55					
8	9 Nov.	III_d	i P_{EV}	2 31 10.3					Effect of great friction apparent in Vertical record. M_N and M_E are the maximum *recorded* amplitudes. Pens were thrown off paper during part of the earthquake. See discussion in text.
			i P_N	2 31 10.5					
			i L_V?	2 31 19.1					
			M_V	2 31 22.0	?			563	
			M_N	2 31 24	?		563		
			M_E	2 31 28	?	710			
			C	2 33 25					
			F	2 37 00					
9	18 Nov.	I?	e	9 47 30					Barely perceptible waves of a distant earthquake on horizontal components only.
			F	10 40±					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1914			h m s	s	μ	μ	μ	
10	21 Nov.	II_d	i P_E	16 24 03					Differences in apparent time of iP and iLM are due to irregularities in the rate of the driving clocks during the earthquake. Chattering of pens on North-Soutth record.
			i P_N	16 24 04					
			i P_V	16 24 05					
			i LM_N	16 24 06	½		127		
			i LM_E	16 24 07	½	145			
			i LM_V	16 24 08	½			22	
			C	16 24 18					
			F	16 25 26					
11	24 Nov.	I_r	e P_N	12 05 23					Not recorded by Vertical. East-West record imperfect. See discussion in text.
			e L_N	12 15 15					
			M_N	12 15 29	7		198		
			F	13 45±					
12	4 Dec.	I_d	i P	22 32 26					Recorded on Vertical by a thickening of pen trace and a shifting of the line.
			i LM	22 32 28	<½	10	7		
			C	22 32 31					
			F	22 32 39					
13	20 Dec.	I_r	e P_N	14 20 24					North-South component only. Not perceptible on records of other components.
			e S_N	14 29 46					
			e L?	14 39 06					
			M_N	14 44 56	9		6		
			F	15 32±					
14	21 Dec.	I_r	e	18 53 46					North-South component only.
			M	18 54 13	4		4		
			F	19 00 57					
15	24 Dec.	I_d	e	17 30 48					Strongly marked thickening of pen traces on East-West component record. Barely noticeable on North-South and Vertical.
			F	17 31 06					
16	28 Dec.	II_d	i P_V	10 42 32.0					
			i P_{EN}	10 42 32.8					
			i L_{EN}	10 42 35.8					
			i LM_V	10 42 37.0	<½			25	
			M_{EN}	10 42 37.2	<½	100	116		
			C	10 43 05					
			F	10 45 05					
17	31 Dec.	I_{d-v}	e	0 43 13					East-West only. A barely noticeable record on Vertical.
			e L?	0 43 28					
			M	0 43 30	<½	8			
			F	0 43 44					
18	31 Dec.	I?	i	0 49 21	<½	7			Thickening of pen traces on Vertical and North-South.
			M	0 49 24	<½	9			
			C	0 49 30					
			F	0 49 37					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1915								
19	12 Jan.	I_r	e P_N	4 31 30					Not recorded by Vertical. eP somewhat confused by microseisms. See discussion in text.
			e_E	4 31 47					
			e L_E	4 32 32					
			e L_N	indefinite					
			M_E	4 32 43	4½	102			
			M_N	4 32 57	9		189		
			C	4 33 56					
			F	4 42±					
20	13 Jan.	I_u	e	7 29 33					North-South only. Italian earthquake. See discussion in text.
			M	7 44 45	19		3		
			F	8 06 05					
21	15 Jan.	I_d		15 49					A barely perceptible disturbance appears on the horizontal records at about this time. The time is somewhat uncertain on account of clock failing to mark the time.
22	16 Jan.	I_d	e	0 30 11					Marked thickening of pen traces on horizontal components.
			F	0 30 17					
23	17 Jan.	I_d	i P	4 52 58					No definite maximum on Vertical.
			i LM	4 52 59	<½	18	12	—	
			C	4 53 02					
			F	4 53 25					
24	26 Jan.	I_d	e	16 28 14					Thickening of pen traces on horizontal components.
			F	16 28 23					
25	27 Jan.	I_d	e	1 06 04					Marked thickening of pen traces on both horizontal components.
			F	1 06 19					
26	2 Feb.	I_d	i P	4 37 28.3					All components.
			i LM	4 37 29.3	<½	24	36	7	
			C	4 37 35					
			F	4 37 51					
27	7 Feb.	I_{d-v}	e	8 06 03					Barely perceptible on Vertical and East-West.
			M	8 06 07	<½	3			
			F	8 06 30					
28	8 Feb.	I_d	i	9 12 40					Sudden strong shift of pens on horizontal components.
29	9 Feb.	I_{d-v}	e	23 11 42					Barely perceptible on East-West; not on Vertical.
			M	23 11 52	1		4		
			F	23 12 36					
30	22 Feb.	II_d	i P_{EV}	14 47 49.0					
			i P_N	14 47 49.3					
			i LM_{EV}	14 47 50.2	<½	40		11	
			i LM_N	14 47 50.4	<½		61		
			C	14 48 06					
			F	14 48 20					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1915.								
31	26 Feb.	I_{v-r}	e	20 49 18					Barely perceptible disturbance. North-South only.
			F	21 02 38					
32	28 Feb.	I_d	i P_{EN}	10 44 14					Registered on Vertical by a thickening of the pen trace and a shifting of the line.
			i L_E	10 44 25					
			i L_N	10 44 26					
			M_E	10 44 29	4	35			
			M_N	10 44 29	1		12		
			C	10 44 44					
			F	10 45 59					
33	3 Mar.	I_d	e	0 57 39					Strong thickening of pen traces on horizontal components.
			F	0 57 50					
34	4 Mar.	I_{d-v}	e	6 45 23					Strong thickening of pen traces on horizontal components.
			F	6 45 35					
35	6 Mar.	I_{d-v}	e	22 21 29					
			M_N	22 21 35	$<\frac{1}{2}$		7		
			M_E	22 21 48	2	12			
			F	22 22 35					
36	8 Mar.	I_d	i P_{EN}	0 35 01.6					Not recorded by Vertical.
			i LM_{EN}	0 35 03.9	$<\frac{1}{2}$	17	14		
			C	0 35 06					
			F	0 35 22					
37	17 Mar.	I_d	e_N	3 25 48					Strong thickening of pen trace on East-West component. No perceptible disturbance on Vertical.
			e L_N	3 26 05					
			M_N	3 26 12	2		4		
			C	3 26 25					
			F	3 26 51					
38	19 Mar.	I_d	e P_N	20 21 26					No disturbance perceptible on the Vertical.
			e P_E	20 21 27					
			e LM_{EN}	20 21 29	$<\frac{1}{2}$	5	4		
			C	20 21 31					
			F	20 21 35					
39	20 Mar.	I_d	e P_{EN}	8 07 58.7					Slight disturbance on Vertical.
			i LM_{EN}	8 08 00.7	$<\frac{1}{2}$	8	10		
			C	indefinite					
			F	8 08 03					
40	28 Mar.	I_r?	e	19 10 40					Trace of a distant earthquake on North-South component only.
			M	19 13 42	$8\frac{1}{2}$		13		
			F	20 09 42					
41	30 Mar.	I_r	e	0 09 37					North-South only.
			M	0 10 29	4		3		
			F	0 13 12					
42	31 Mar.	I_d	i P_V	12 40 51.4					
			i P_N	12 40 51.7					
			i P_E	12 40 51.9					
			i LM_V	12 40 54.1	$<\frac{1}{2}$			5	
			i LM_N	12 40 54.6	$<\frac{1}{2}$		14		
			i LM_E	12 40 54.8	$<\frac{1}{2}$	19			
			C	12 41 06					
			F	12 41 26					

DISCUSSION OF PARTICULAR EARTHQUAKES

Teleseism of October 3, 1914

At Berkeley the first and second preliminary tremors on the seismogram of this earthquake were fairly distinct, though they began rather gradually and it was somewhat difficult to be certain of the exact instant of their beginning. It was not possible to determine with any certainty the time of beginning of the chief phase of this earthquake.

At the Lick Observatory the time of beginning of the chief phase was also indefinite. Very good horizontal records of the preliminary tremors were obtained. The first preliminaries began sharply on both components. On the East-West record the first preliminaries averaged about 13 microns for the first three minutes of their duration. The periods ranged from 2 to 4 seconds. On the North-South component the average amplitude for the first three minutes was 6 microns. The periods ranged from 2 to 4 seconds. After about three minutes there was a sudden decrease in amplitude, and for the rest of the time of duration of the first preliminary tremors, the amplitudes were very slight while the periods averaged about 2 seconds. On the East-West component, movement ceased entirely for a full minute before the beginning of the second preliminary tremors.

The second preliminary tremors began with quick shifts of comparatively large magnitude. For about a minute the periods ranged between 4 seconds and 5 seconds. The amplitudes on the East-West component were 25 microns, and on the North-South component they ranged about 12 microns. After the first minute there was a gradual decrease in amplitude. On the East-West record there was a complete cessation of movement at about the time of the beginning of the maximum waves. On the North-South component, however, a slight movement continued until the beginning of the main waves.

The main waves began gradually with movements of small amplitude. On the North-South component it was possible to make an approximate determination of the point of beginning of the chief phase, by noting the point where the period of vibration

changed from the short period of the preliminaries to the longer period of the main waves.

The epicentral distance and the time of arrival of this earthquake at this station indicate that this is the record of an earthquake originating on this day, near Martinique and St. Vincent in the West Indies.

Near Shock of November 8, 1914, Originating in Southern California

This earthquake occurred at about $3^h\ 40^m$ A.M. (Pacific Standard time) on the morning of November 8, 1914, and since it came at a time when most people were asleep very little information concerning it could be obtained.

At Los Angeles, Whittier, San Fernando and Montebello in Los Angeles County, the earthquake had an intensity between IV and V of the Rossi-Forel scale. At Avalon on Santa Catalina Island the intensity was between III and IV of the Rossi-Forel scale.

At Arroyo Grande, in San Luis Obispo County, an earthquake was reported as occurring at about $3^h\ 30^m$ A.M. on this same date. It had an intensity of III to V of the Rossi-Forel scale of intensity. The disturbance was strong enough here to wake sleepers and the intensity was at least IV and possibly V of the Rossi-Forel scale.

This earthquake was recorded both at the Lick Observatory and at Berkeley, but on account of the distance of origin from these stations the records were rather poor. None of the characteristic phases of the seismogram could be distinguished, and it was therefore not possible to determine the epicentral distances.

Central California Earthquake of November 8, 1914

At Berkeley, this earthquake was felt by almost everyone except those persons walking out-of-doors at the time of its occurrence. The preliminary tremors were distinctly felt by all those favorably situated for observing earthquake movement as a barely perceptible trembling motion. They were not, however, generally recognized at the time of their occurrence as a part

of an earthquake. The real nature of the movement was realized only when the waves of the chief phase arrived. Strong movement began with a lurching of buildings, accompanied by creaking of the walls and ceilings of frame houses. Small movable objects were not much disturbed by the shock in Berkeley. Though only a feeble earthquake, it produced a feeling of alarm among many people in this locality and a few of the more nervous left their houses. The intensity in Berkeley is estimated to have been between III and IV of the Rossi-Forel scale.

At the Lick Observatory the earthquake was somewhat more severe. Director Campbell estimated the intensity there as ranging from IV to V of the Rossi-Forel scale. Here also the first preliminary motion was distinctly perceptible to those who were favorably situated.

Good records were obtained on all the instruments at Berkeley with the exception of the Marvin strong-motion seismograph. The intensity of the earthquake at Berkeley was not sufficiently great to operate the starting device of this instrument.

At Berkeley, the first shift of the ground in the North-South component was to the South. Also there appeared to be a separation of the preliminary tremors into two divisions—*possibly* representing the first and second preliminary tremors.

On the East-West component the separation of the preliminary tremors into two parts was quite noticeable. On this record the first shift of the ground was toward the East. The East-West record on which the maximum movement occurred showed "tangled" lines. That is to say, the lines representing successive earth movements crossed each other, indicating that there was some differential movement in the mechanism of the seismograph other than that which was due to the registration of the earthquake.

On the vertical component record the first movement of the ground was downward. The separation of the preliminary tremors was not apparent on this record.

The origin of this earthquake lay off to the southeast of Berkeley. The fact that the first movement of the ground in this earthquake at Berkeley was *toward the origin* is rather peculiar. Usually tectonic earthquakes begin with a wave of

expansion and not a wave of contraction so that the first shift shown on the horizontal records is away from the origin, and the first movement on the vertical record is upward.

In some cases, as for example, in the Central California earthquake of July 1, 1911,[2] there has been observed an *apparent* initial shift of the ground toward the origin, at places near the epicenter. However, in these instances, the first shift of the horizontal pens is slightly toward the origin and is followed almost immediately by a sudden reversal movement with a strong counter movement away from the origin. In such cases it appears that the first impulse of the earth shock was so rapid that what has been called a "whip-effect" was produced. That is to say, the first movement was so sudden that the inertia of the pier came into action and the result was a sudden slight tilt of the upper part of the pier toward the origin, followed by its recovery and movement with the earth. This, however, does not seem to have occurred in this case. The records are definite and the first impulse was a sudden strong shift toward the origin, there being no minor preliminary shift due to the inertia of the pier.

At Lick Observatory the pens on the horizontal component instrument were thrown off the paper during the last part of the preliminary motion and remained off during the rest of the preliminary movement and the first part of the main phase. The vertical record was poor, the friction being so great that no phases could be distinguished.

The horizontal records obtained at the seismographic station at Santa Clara University were not complete, the intensity of the shock being great enough to throw the pens off the paper during the greater part of the motion. It was not possible to determine the distance of the epicenter by means of the vertical record at Santa Clara station. On the vertical record the preliminary tremors were about as strong as the first part of the main waves. On this account, and also due in part to the short period of the vibrations, which caused the records of various impulses to be run together, it was not possible to separate the phases and thus determine the time of duration of the preliminaries. (Interval L–P.)

[2] H. O. Wood, Univ. Calif. Publ., Bull. Seismographic Stations, no. 2 (Sept. 5, 1912), p. 41.

An approximate determination of the position or origin was made by using epicentral distances from Berkeley station combined with arrival times of the first impulse of the earthquake at Santa Clara and Lick Observatory. In this way it was determined that the probable origin was on the San Andreas Rift, near Laurel, California. This determination agrees with the result of field study of the distribution of intensity made by Mr. Carl H. Beal of Stanford University.

Articles dealing more in detail with this earthquake appeared in the Bulletin of the Seismological Society of America.[3]

Central California Earthquake of November 21, 1914

This earthquake was not felt in Berkeley, though fairly good records of it were obtained there by the Bosch-Omori and Wiechert instruments. The earthquake was also recorded by the East-West component of the Omori tromometer. Only a barely noticeable disturbance appeared on the North-South component, however.

At the Lick Observatory the earthquake was felt distinctly by persons walking indoors, but those outside did not feel it. It is described as a sudden jolting movement of the ground. The seismograms obtained at the Lick Observatory station were good, except for the fact that the intensity of the earthquake was sufficient to cause irregularities in the rates of the clocks driving the recording drums. Also there was considerable chattering of the pen on the North-South component.

Distant Earthquake of November 24, 1914

At the Berkeley Station the seismogram of this earthquake was characterized by a sharply marked initial movement on all components. On the record of the vertical component the first movement was a distinct maximum, after which the amplitude gradually decreased to a series of very minute vibrations which continued until the beginning of the chief phase. On the hor-

[3] Carl H. Beal, Earthquake in Santa Cruz Mountains, November 8, 1914, Bull. Seis. Soc. Am., 4 (1914), 215.
E. F. Davis, Central California Earthquake of November 8, 1914, Bull. Seis. Soc. Am., 5 (1915), 5.

izontal component records the first movement was not the maximum, though it was noticeably strong. It was not possible on any of the records to find any sign of the beginning point of the second preliminary tremors. On the horizontal records the maximum movement of the chief phase occurred very shortly after the time of arrival of the first of the main waves. On the vertical two definite maxima appeared, the first occurring about 6 seconds after the main waves began and the second 37 seconds later.

At the Lick Observatory the seismogram of the East-West component was imperfect, due apparently to the binding of the damper on the pen of that component. A very good record was obtained on the North-South component. As at Berkeley, the first impulse was distinct, but no trace of the beginning of the second preliminaries could be found on the record. The earthquake seemed to begin with the first impulse of the first preliminaries and then there was continued slight motion until the time of beginning of the main waves. Here as at Berkeley the main waves began rather suddenly and there was a great contrast between the main waves and the preliminary tremors in point of amplitude. The preliminaries were rather minute waves and for the most part were barely perceptible, while the main waves were of noticeably large amplitude.

The first part of the chief phase was made up of at least nine separated groups of waves. The amplitude of the first wave in each group was rather small but it continued to increase with successive strokes of the pen until it attained a maximum value, when it began to decrease again. Each group of waves consisted of five or six complete vibrations and required half to three-quarters of a minute for its development and disappearance, when it was followed by another group of waves. The tendency for waves to come in groups of this sort continued all through the chief phase and was very noticeable in the tail portions of the seismogram. This tendency to grouping of waves was clearly seen in the records obtained at Berkeley. It was not so well marked here as it was at the Lick Observatory, possibly due to the lower damping ratios at Lick Observatory.

Southern California Earthquake of January 12, 1915[4]

Records of this earthquake as obtained at Lick Observatory and Berkeley were unsatisfactory. The time of beginning of earth movement was somewhat uncertain on account of the very gradual beginning and also due to the fact that slight microseisms were running at the time of registration of the earthquake. Further the point of beginning of the main phase was more or less indefinite. No very accurate determination of distance could be made, but it was estimated that the distance of the origin from Berkeley was in the neighborhood of 450 kilometers.

Mr. Carl H. Beal[5] of Stanford University, who has studied this earthquake in the field, reports that its origin was near Los Alamos, California.

Italian Earthquake of January 13, 1915

At the Lick Observatory only a barely perceptible disturbance was apparent on the North-South component record.

The seismograms of this earthquake which were obtained at Berkeley were imperfect. Characteristic phases were not well marked and it was not possible to make any determination of the distance of origin from this station. The first preliminaries were obscured by strong microseisms, so that the first movement of the ground could not be made out. The beginning of the main phase of the seismograms obtained on the horizontal components seems fairly definite.

There is no doubt that these seismograms are those of the Italian earthquake. The distance of Avezanno (which lies near the origin of this earthquake) from Berkeley is about ninety degrees of arc. It would therefore require about forty-three minutes for the main waves of a shock originating at this place to travel to the Berkeley Station. C. Davidson[6] gives the time of occurrence of this earthquake as $7^h\ 53^m$ (Italian time), which

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[4] This earthquake occurred at about $8^h\ 32^m$ P.M. on January 11, 1915 (Pacific Standard time).

[5] Carl H. Beal, The Earthquake at Los Alamos, Santa Barbara County, California, January 11, 1915, Bull. Seis. Soc. Am., 5 (1915), 14.

[6] Nature, 94 (January 21, 1915), p. 565. Geographical Journal, 45 (1915), p. 145.

would be $6^h\,53^m$ when reduced to Greenwich Mean Civil Time. Adding forty-three minutes to this, we should expect to find the first impulse of the main waves reaching Berkeley at $7^h\,36^m$. At Berkeley the main waves apparently begin at $7^h\,37^m\,48^s$. While the agreement is not very close, doubtless due to the poor record obtained at Berkeley, still it is close enough to indicate certainly that the record obtained at Berkeley is that of the Italian earthquake.