UNIVERSITY OF CALIFORNIA PUBLICATIONS

BULLETIN OF THE

SEISMOGRAPHIC STATIONS

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AND

AT THE LICK OBSERVATORY STATION FROM MAY 23 TO SEPTEMBER 30, 1911

BY

H. O. WOOD

BERKELEY

THE UNIVERSITY OF CALIFORNIA PRESS

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CONTENTS

THE BERKELEY STATION

CONSTANTS

Constants of the Station

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 Tromometer N-S component	15s	80	8–1
Bosch-Omori Tromometer E-W component	15s	80	8–1
Wiechert Seismograph Vert. component	6s	80	8–1

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).

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_N E-W component of A.

A_E N-S component of A.

A_V Vert. component of A.

No.	Date	Charac.	Phase	Time G. M. C. T. h	m	s	Period	Amplitude A_E	A_N	A_V	Remarks
	1911						s	μ	μ	μ	
38	1 Apr.	I	e	2	13	45	2-3				Barely discernible in N-S component.
			L		15	46	3-5				
			M_E		15	57		2			
			F		19±						
39	7 Apr.	I u	e	6	59	49	15				Registered distinctly in the vertical component. Barely discernible in the N-S component.
			M_E	7	08	59	25-20				
			M_E		12.5						
			F	8	20±						
40	10 Apr.	I u	e P	18	51	21	2-4				
			e S	18	59	14					
			e L	19	07	16	25-30	5			
			F		40±						
41	11 Apr.	I u	e	14	07	29					Barely discernible long flat waves.
			F	14	32±						
42	18 Apr.	I d	i P	20	20	19					Not felt in Berkeley.
			i M_N		20	20	Periods		10		
			i LM_E		20	25	unmeasurable	8			
			F		23.5	—					
43	19 Apr.	I d	i P	5	40	48					Not felt in Berkeley.
			i LM_E		40	54	Periods	3			
			M_N		40	58	unmeasurable		9		
			F		43.5	—					
44	19 Apr.	I d	i P	12	39	02	Periods				Not felt in Berkeley.
			M		39.5	—	unmeasurable	3	4		
			F		40.5	—					
45	21 Apr.	I	e	2	44	34					Well-marked sinusoidal waves at maximum.
			M_E		46	59	5-8	5			
			to		to						
			M_E		49	—					
			F	3	20	—					
46	25 Apr.	II d	e P	6	26	32	1-3				Not reported felt in Berkeley.
			i S		26	54					
			L		27	10	2-5				
			M_E		27	14		15	7		
			F		33±	—					
47	28 Apr.	I r	i P	10	02	10	1				Preliminary phases became almost imperceptible before the beginning of the chief phase.
			i L		10	19	5-7				
			M_N		10	18			9		
			M_E		10	27		7			
			F		26	—					
48	4 May	II r	i P	23	46	19	2-5				Irregular superposed movements in the principal portion.
			i M_V		46	29					
			i L		53	58	20				
48	4 May	II r	M_N		53	59			50		
			M		54	08	10-15	140			
			M_N		55	53			55		
	(5 May)		F	2	20+						
49	10 May	II v	e P	0	22	51	½-1½				Clearly registered in all three components.
			i L		23	42	4-10				
			M_V		23	46					
			M_N		24	22			30		
			M		25	12		55			
			M_E		26	36		44			
			M_N		27	37			40		
			F		20±						
50	11 May	I u	e	5	35	—	25				Barely perceptible — the dying out of the waves of the chief phase of a distant shock.
			F	6	—	—					
51	6 June	I d	i P	0	46	31	½				Not reported felt in Berkeley.
			i L		46	34	½-¾				
			M		46	36	—	15	30	6	
			C		46	40					
			F		48+						
52	7 June	III r		East-West-Component							*Focus near City of Mexico.*
			e P	11	08	22	8-10				
			? i S		13	08	8-10				Beginning of 2nd phase hard to distinguish.
			i		14	40	6-8				
			L		15	48					
			[M_1]		16	08		775			Pen swept off drum to E.
			[M_2]		23	22	15	750?			Pen returned to drum.
			M_3		24	06		570			
			M_4		25	54		500+			
			M_5		27	50	15	530			
			C		31+	—	10-15				"Tail" a complex of superposed waves.
			F	14	30±	—	—				
			? SR_1	11	13	48					No evidence of reflected waves in the 1st phase. These times probably do not represent changes of phase due to reflection.
			? SR_2		15	08					
			? SR_3		15	33					
			North-South-Component								
			e P	11	08	22	6-8				
			i S		13	29	—				Beginning of 2nd phase fairly well marked.
			i		14	37	—				
			L		15	48	25				
			[M_1]		16	33			875		Pen swung off drum to N.
			[M_2]		24	09	to		470?		Pen returned to drum.
			M_3		24	27			375		
			M_4		25	23	30		370		
			M_5		26	13	10		313		
			M_6		32	32	15 to		205		
			C		32	52	10				"Tail" a complex of superposed waves.
			F	14	—	—					

No.	Date	Charac.	Phase	Time	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1911			h m s	s	μ	μ	μ	
52	7 June	III r	?SR_1	11 15 09					No evidence of reflected waves in the 1st phase. These times probably do not represent changes of phase due to reflection.
			?SR_2	15 27					
			?SR_3	15 46					
				Vertical Component					
			e P	11 08 23.5	5-8				
			e S	13 40	10-15				Beginning of 2nd phase very well marked.
			i L	16 37	15				
			M_1	18 07	to			280	
			M_2	20 43	25			395	
			M_3	22 05				370	
			M_4	23 00				225	
			C	25 16	10-15				
			F	14 20± —					
			?SR_1	11 15 20					
53	11 June	I d	e P	23 22 19					Not reported felt at Berkeley.
			F	23 22 45					
54	15 June	II u		East-West-Component					
			i P	14 38 28	3 6				Record in this component is quite unusual in that chief maxima occur in 2nd phase.
			e S	48 39	8-10				
			M_1	48 58	15-20	140			
			M_2	50 01	to	265			
			i L	15 01 38	25				
			C	indefinite	15-20				
			*F	16 22+ —					*Record stopped accidentally before the complete cessation of earth motion.
				North-South-Component					
			i P	14 38 24	3-6				
			i S	48 35	8-10				Beginning of 2nd phase well-defined and distinct.
			e L	15 01 23	15-25				
			M	02 18	20			65	
			C	indeterminate	10-15				
			F	16 16 —					
				Vertical Component					
			i P	14 38 22	3-5				
			i M	38 29				125	
			? S	48 53	8-10				Only found upon careful search guided by horizontal components.
			? L	15 01 53					
			F	16 00 —					
55	1 July	III d	$i P_E$	Time magnet not working					V-VI R-F. in Berkeley.
			*$i P_N$	22 00 38					*Regarded as doubtful—probably there was temporary disturbance to parallax of writing point.
			†$i P_V$	22 00 19					
					2-3				
				See Discussion of this shock in text					†Regarded as *very reliable*.
			$e C_V$	22 04 54	5				
			F_V	22 45+ —					

No.	Date	Charac.	Phase	Time	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1911			h m s	s	μ	μ	μ	
55a	2 July	I d	e_V	00 54.5					Only the vertical seismograph working at this time. Only found after receipt of information from Lick Observatory Station.
			F_V	55.3					
56	2 July	I d		East-West-Component					Not reported felt at Berkeley.
			i P	3 00 06	½				No record on vertical seismograph.
			i L	00 16	½-¾				
			M_1	00 20	"	9.4			
			M_2	00 23	"	9.4			
			M_3	00 57	"	9.4			
			C	01 23	3-5				
			F	20+ —					
				North-South-Component					
			i P	3 00 07					
			(?) L	00 20					
			M_1	00 33			9.4		
			M_2	01 03			9.4		
			C	01 14					
			F	20+ —					
57	2 July	I d	e	6 20 25					Not felt at Berkeley.
			F	21 30					No records in N-S or vertical components. Vertical record lost.
58	2 July	I d	e_E	8 00 44					Not felt in Berkeley.
			e_N	00 45.6					Barely discernible short waves. Vertical record lost.
			F	02.5 —					
59	2 July	I d	e	13 30 52					Not felt at Berkeley.
			F	31.5 —					No record in N-S component. Vertical record lost.
60	3 July	I d	e_E	1 34+ —					
				Record further illegible					
				East-West-Component					
61	4 July	I u	e P	13 51 56	5				Beginning is very vague.
			e	57 44					Motion in vertical component is barely visible and quite illegible owing to overscoring due to temperature change.
			e	14 02 14					
			M	35+ —		25	6		
			F	15 — —					
				North-South-Component					
			e P	13 50 59					
			e	13 57 20					
			F	14 ± —					
62	4 July	I d	e_E	20 34 16			-		Not felt at Berkeley.

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1911			h m s	s	μ	μ	μ	
62	4 July	I d	e_N	34 18					Vertical record illegible.
			F	34 48					
63	5 July	I d	e_N	1 44 27					Not felt at Berkeley.
			e_N	44 29					Vertical record illegible.
			F	44 48					
64	8 July	I d		East-West-Component					
			P		½				Beginning of 1st phase is indefinite.
			L	9 39 22	¾	1.6			
			F	41					
				North-South-Component					Not felt at Berkeley.
			e P	9 39 14	½				
			i L	39 24	¾		3		Not registered by the vertical seismograph.
			F	40.6					
65	8 July	I d		East-West-Component					
			P		½				Beginning of 1st phase indeterminate.
			i L	11 48 21	¾-1	2			
			F	49+					
				North-South-Component					
			e P?	11 48 03					Beginning of 1st phase very doubtful.
			i L	48 23	½		1.6		Not registered by the vertical seismograph.
				49.6 —					
66	12 July	II u		East-West-Component					
			e P	4 21 39	3-5				
			i PR	25 52	8				
			i S	32 15	—				
			e L	54 08	30				
			M_1	57 10	25-20	75			
			M_2	5 03 29		24			
			C	04 08	10-15				
			F	6 23+ —					
				North-South-Component					
			e P	4 21 46	3-6				
			e PR	25 49	8-10				
			i S	32 19	—				
			e L	54 35	30				
			M	57 00	25-20		10		
			C	5 04.3 —	15				
			F	6 30± —					
				Vertical Component					
			e P	4 21 38					
			i PR	25 50					
			S	indeterminate					
			e L	54 07	25				
			M	57 07	20			10	
			C	5 04+ —	18				
			F	indeterminate					
67	14 July	I d	e	14 21 42					Not reported felt in Berkeley. Not discernible in N-S component. Vertical record illegible.
			F	21 47					
68	18 July	I d	e_E	21 55 49	½				Not reported felt at Berkeley. Vertical record illegible because of overscoring.
			e_N	55 52	½				
			F	57 —					
69	20 July	I d	*e_E	23 03 33					*Simply faint thickening of line for few seconds at this time. Not discovered until after study of of Mt. Hamilton seismogram. Not recorded in N-S nor in vertical component.
70	21 July	I d	e_V	00 09 37					Not felt at Berkeley.
			i_E	09 49	½-3				Barely discernible on the seismogram.
			i_N	09 56	"				
			F	11+ —					
71	21 July	I d	e_E	1 28 01					Not felt at Berkeley.
			e_N	27 58					Barely discernible.
			M_N	28 05			1		Not on vertical record.
			F	28 23					
72	31 July	I d	eP_E	13 12 45	½				Not felt in Berkeley.
			eP_N	12 56					Barely discernible.
			eL_E	12 55	2				Vertical record illegible.
			iL_N	13 06	2				
			F	13.8 —					
73	1 Aug.	I d	e_E	10 23 17					Not felt in Berkeley.
			e_N	23 44					Barely discernible.
			F	24.3 —					Vertical record illegible.
74	6 Aug.	II d		East-West-Component					Not reported felt in Berkeley, but felt at Mt. Hamilton and Santa Clara.
			i P	19 51 47					
			i L	51 57	¾-1				
			M	51 59			15		
			C	52 31	3-5				
			F	55+ —					
				North-South-Component					
			i P	19 51 46					
			i L	51 57	½-1				
			M	51 59			15		
			C	52 29	3-5				
			F	55 —					
				Vertical Component					
			i P	19 51 46	½				
			i L	51 58	1-1½				
			M	51 59				12	
			C	52 50					
			F	55 —					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1911			h m s	s	μ	μ	μ	
75	6 Aug.	I d	e	20 29 28					Not felt in Berkeley.
			F	29 50					Not registered by vertical seismograph.
76	14 Aug.	I d	eP_V	13 51 56					Not felt at Berkeley.
			e P	51 57					Barely discernible.
			e L	52 09	¾-1				
			C	52 15					
			F	53.3					
77	16 Aug.	I d	eP_N	1 32 40					Not felt in Berkeley.
			eP_E	32 47					Vertical record illegible through overscoring; this shock not found on it.
			eL_E	32 58					
			L_N	33 01					
			M_E	33 00		2			
			M_N	33 03			—		
			C_E	33 04					
			C_N	33 07					
			F	34 05					
78	16-17 Aug.	II u		East-West-Component					
			e P	22 54 33	3-5				In this component the chief phase is made up of six parts, in each of which the amplitude increases gradually to a maximum and then dies gradually away to comparatively small values —thus waxing and waning until the "tail" begins. The motion is simple and the trace a smooth harmonic curve.
			i S	23 05 24	8-10				
			e L	25 16	25				
			M_1	31 59	20 | to | 15	130			
			M_2	38 53		72			
			M_3	45 15		97			
			M_4	47 30		115			
			M_5	55 37		156			
	(17 Aug.)		M_6	00 01 01		112			
			C	05 10	10-15				
			F	57					
				North-South-Component					
	16 Aug.		e P	22 54 33	4-6				In this component amplitudes are much smaller than in the E-W component, but the same gradual waxing and waning in the chief phase is seen at approximately the same times.
			e S	23 05 27	6-8				
			L	indeterminate	25				
			M_1	23 31– —	25 | 15	6+			
			M_2	40– —		6			
			M_3	45–		6+			
			M_4	50-55 —	20	8			
			C	indeterminate	10-15				
	(17 Aug.)		F	1 00 —					
78	1911 16-17 Aug.			Vertical Component					The shock was well recorded by this seismograph, the earth motion continuing for more than two hours. Several maxima occur in the chief phase, and the waxing and waning in amplitude, seen in the horizontal components, is also present in this seismogram. However, because of temperature change, producing closely spaced overscoring, the record is quite illegible.
			M_1					28	
			M_2					15	
			M_3					12.5	
			M_4					11+	
79	21 Aug.	II v		East-West-Component					*[The instant of starting the record cylinder after the removal of the previous record.]
			*e	16 49 31					
	*		i L	49 55	5-8				
			M	49 58		37.5			
			C	50 53					
			F	17 30±					
				North-South-Component					This record was started earlier than the E-W record.
			e P	16 49 56					
			i L	50 27	5-8				
			M	50 29				24	
			C	50 47					
			F	17 15 —					
				Vertical Component					This started latest and most of the motion was, consequently, not recorded.
			F	17 30± —					
									*See discussion of this shock in text.
80	28 Aug.	I d	eP_V	3 04 16	¾				Not felt at Berkeley.
			e P	04 21	½-¾				
			i S	04 35	¾-1				
			L_E	04 53	¾-1½				
			L_N	04 56					
			M	04 57	1	9+	3		
			M_V	05 00				3	
			C	06 02	3-5				
			F	10 —					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1911			h m s	s	μ	μ	μ	
81	31 Aug.	I d	P_V	1 04 56					Not reported felt at Berkeley.
			e P	05 15	½				
			$i_{E,N}$	05 22					
			L_V	05 21	¾				
			$L_{E,N}$	05 24	1				
			M	05 25		6	3		
			C	05 32					
			F	07 —					
82	12 Sept.	I d		East-West-Component					Not reported felt in Berkeley.
			e P	2 54 04	½				
			i L	54 14	1½				
			M	54 16	to	4			
			C	54 29	1				
			F	55+ —					
				North-South Component					
			e P	2 54 04	½				
			i L	54 14	1				
			M	54 15			3		
			C	54 25					
			F	56+ —					
				Vertical Component					
			e P	2 54 03	½				
			i L	54 14	1				
			M	54 17				2	
			F	56.5 —					
83	15 Sept.	I u	eP_N	13 21 36	3-5				Chief phase a series of long-period simple sinusoidal waves of very small amplitude.
			eP_E	21 50					
			iS_E	31 24	—				
			eS_N	31 26	5-8				
			eL_E	47.5 —	25				
			eL_N	46.4 —					
			F_E	14 30 —					
			F_N	45 —					
84	17 Sept.	II u		East-West-Component					*Confused with microseismic waves.
			*e P	3 35 42	3-5				
			e S	42 31	7-9				
			e L	49 27	15-20				
			M_1	53 57	15-10	37.5			
			M_2	4 00 55		37.5			
			C	08 57	10				
			F	6 10± —					
				North-South-Component					†Very vaguely defined.
			e P	3 35 21	3-5				
			†S	42 23	—				
			?L	46 59	20				
			M_1	47 57	15-10		15		
			M_2	57 49			19		
			C	4 07 15	10				
			F	6 30± —					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1911			h m s	s	μ	μ	μ	
84	17 Sept.	II u		Vertical Component					
			e P	3 35 44	3±				
			i	38 10					
			? L	48 21	20				
			M	52 19	15			6.3	
			C	4 04 21	10				
			F	6 — —					
85	18 Sept.	I d	eP_E	21 45 13	½				*See text for discussion.
	*		iL_E	45 18	¾				
			§iL_N	45 29					§No preliminary waves in N-S component. No record in the vertical component.
			F_E	45 51					
86	21 Sept.	I d	e_E	7 23 44					
			e_N	23 48					
			F	24 38					No record in the vertical component.
87	22 Sept.	I r		East-West-Component					
			e P	5 07 16	3				
			e S	12 43	5				
			L	15 03	15				
			M	15 26			9		
			F	30 —					
				North-South-Component					
			e P	5 07 13	3				
			e S	11 53	4-5				
			*L	15 41	20-15				*L is very vaguely indicated.
			F	40± —					
				Vertical Component					
			i P	5 07 17					
			e L	14 52					
			M	15 26				3	
			C	17 12					
			F	30± —					
88	29 Sept.	I d	i P	17 12 42	½				No record written by the vertical pendulum which, through temperature change, had slackened against its safety stop.
			iL_E	12 53					
			L_N	12 55	½-1				
			M	12 56			6		
			C_N	13 04	3				
			C_E	13 09					
			F	16± —					

THE LICK OBSERVATORY STATION

EQUIPMENT AND INSTALLATION

Since its active work began in 1888 the Lick Observatory has included in its equipment a Ewing three-component seismograph and a Ewing duplex pendulum seismograph. These early instruments are fully described in the *Publications of the Lick Observatory*, vol. 1. While they are still of use occasionally in registering the motion of moderately strong earthquakes of nearby origin, these seismographs do not serve for the registration of strong earthquakes of distant origin. When this limitation of the seismographic equipment of the Observatory came to the attention of the Honorable William R. Hearst he generously provided for the purchase of seismographs of modern design. On the basis of his gift the Lick Observatory purchased, from Spindler & Hoyer, in Göttingen, a 200-kg. Wiechert horizontal seismograph and an 80-kg. Weichert vertical seismograph. These instruments, besides being adapted to the registration of distant shocks, write more useful records of weak local shocks than those written by the older Ewing seismographs; and they record many local shocks too feeble to be registered by the earlier equipment.

The Weichert seismographs were installed in the early part of 1911. They are seated directly upon concrete piers which extend down to bed-rock and are wholly isolated from the floor of the room in which the equipment is installed. This room is located in the basement of the meridian circle house, situated practically midway between the piers of the larger meridian instrument and the small transit instrument of the astronomical service.

The station began the routine operation of these modern seismographs on May 23, 1911. During the period ending with September 30, 1911, the Wiechert horizontal seismograph was adjusted to have a magnification factor of forty times, a period of between four and five seconds, and practically total, or dead-

beat, damping; while the Wiechert vertical seismograph was adjusted to have a magnification factor of eighty times, a period of between four and five seconds, and practically total damping.

The time-marking magnetic devices of the recording apparatus are operated by a pendulum clock, supplied by the makers of the seismographs. Briefly, once each minute the second hand of the clock makes circuit, deflecting the writing pen slightly; and once each hour the minute hand also makes circuit, for a little longer time. The hour mark is inserted just before the first minute mark of the hour. The clock is compared daily with one of the standard clocks of the observatory, and is made to keep the standard mean time of the 120th meridian. In the measurement of the seismograms, however, all time determinations are reduced to Greenwich mean civil time.

This station, like that at Berkeley, is situated within the belt of seismic activity which is considered by de Montessus de Ballore practically to coincide with the circumpacific geosynclinal.

THE EARLY OPERATION OF THE INSTRUMENTS

As inevitably is the case with delicate physical instruments when newly installed, the seismographs have not worked with uniform efficiency from the time they were first set up. Sources of friction and similar troubles have come to light one by one and have been eradicated. In consequence, though the station began routine operation on May 23, 1911, no distant shock has been registered here legibly up to the end of September, 1911.

Moreover, besides the shocks measured and tabulated below, there appear on the seismographs for July, August and September hundreds of slight shifts of the writing pens, consisting of a single stroke, most commonly accompanied by a slight permanent shift as though, through friction, the pens were dragged to one side by the sidewise shift of the recording drum until sufficient moment accumulated wholly or partly to swing them back to position. Many of these displacements are seen in one component only, but usually they occur simultaneously upon

the N-S and E-W records, both of which are derived from a single steady mass. In every case in which such displacements appear at the same time in all three components they are considered to be due to seismic motion and are measured and tabulated below.

In the great majority of cases, not tabulated, there is doubt —at present unresolvable—whether these displacements are due to the action of friction as described above, to settling and mechanical readjustments in the swinging system or to feeble seismic pulses. To include so many wholly doubtful movements in the table of measured shocks would encumber them.

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	4–5	40	Total
Wiechert Seismograph E-W component	4–5	40	Total
Wiechert Seismograph Vert. component	4–5	80	Total

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.

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1911			h m s	s	μ	μ	μ	
1	1 July	III d	i_E	22 00 03.5		large			All pens at once flung off recording drum with the very first movement.
			i_N	00 05			large		
	*		i_V	00 05				large	
									*See discussion in text.
[1*a*	2 July	III d	—	00 55 10]					Not recorded by seismometer which were not yet in working order. *Felt* and time noted by Professor R. G. Aitken.
2	2 July	I d	i P	1 12 26	——			1	The vertical seismograph only in working order at this time.
			LM	12 29.5	——			2	
			F	12 35					
3	2 July	I d	i P	2 05 15				2	The vertical seismograph only in working order.
			i L	05 18	½-1			4	
			C	05 21	1			2	
			F	06 30					
4	2 July	I-II d	i P	3 00 11	½-¾			29	The vertical seismograph only in working order.
			i L	00 13	1-2			63	
			M	00 15				106	Time-correction doubtful.
			C	01 02	1-2				
			F	03.7 —					
5	2 July	I d	eP	3 41 53					The vertical seismograph only in working order.
			i L	41 56					
			M	41 56					
			F	42.3				5	
6	2 July	I d	i P	6 19 53	1-2			12.5	The vertical seismograph only in working order.
			L M	19 56.5	1-2			19	
			C	20 02	1-3				
			F	20.9 —					
7	2 July	I d	i P	8 00 25	¾-1½			7	The vertical seismograph only in working order.
			i L	00 27	1-3				
			M	00 29				29	
			C	01 01	1-2				
			F	01 24					
8	2 July	I d	i P	13 31 01				15.5	The vertical seismograph only in working order.
			i L	31 03					
			M	31 04				21	
			C	31 08	1-2				
			F	32 06					
9	2 July	I d	e	17 59 59					The vertical seismograph only in working order.
			M	18 00 01					
			F	00 05				3	
10	2 July	I d	i P	20 36 08				3	The vertical seismograph only in working order.
			L	36 10					
			M	36 10				21	
			C	36 16	1-2				
			F	36 43					
11	3 July	I d	i P	1 34 02				6	The vertical seismograph only in working order.
			i L	34 04	1-2			15.5	
			M	34 05				17	
			C	34 15	1-2				
			F	34 45					
12	3 July	I d	i P	14 47 55				3	III R. F at Mt. Hamilton. Time-correction uncertain. Vertical seismograph only in working order.
			LM	47 56				6.2	
			C	47 59					
			F	48 20					
13	4 July	I d	i P_V	20 33 59	¾-1			25	Horizontal seismograph restored to working order.
			i P	34 00	½-1	18			
			i L_V	34 01	1-2				
			i L	34 02					
			M	34 03		34		48	
			C_N	34 09					
			C_E	34 11	1-2				
			C_V	34 15					
			F_E	34.8 —					
			F_N	34.3 —					
			F_V	35 18					
14	5 July	I d	i P_V	1 44 05					No preliminary phase distinguishable. Origin must be very near to station.
			i P_E	44 08					
			M_E	44 08		4.3			
			C_E	44 10					
			F_V	44 26					
15	5 July	I d	i P	12 19 51					N-S component pen ran off drum, hence no record.
			LM	19 53					
			C	19 54					Vertical component driving clock stopped, no record.
			F	20 22					
16	7 July	I d	i_V	19 13 19				1	No record in horizontal components, yet *felt* by C. C. Kiess at work in the assembly room of Lick Observatory at Mt. Hamilton.
	*		F_V	13 24					
									*See text for discussion.

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1911			h m s	s	μ	μ	μ	
17	8 July	I d	i P	5 50 48					
			LM	50 49	½-1	3	3	3	
			F_V	50 54					
18	8 July	I-II d	i P	9 38 55	1-3	2.5	1.2		
			i P_V	38 56				3.8	
			L	38 58	3-5				
					¾-2				
			M_V	38 59				12.5	
			M_E	39 00	5	37.5			
			M_N	39 01			10		
			C_N	39 03					
			C_E	39 06					
			C_V	39 18					
			F_V	40 06					
19	8 July	I-II d	i P	11 47 56	½-1	2			
			LM	48 00	1-4		9	10	
			M_E	48 02		34			
			C_V	48 03					
			C_E	48 06					
			F_N	48 22					
20	11 July	I d	i P	15 39 27	½-¾	1			Driving clock of vertical seismometer stopped before occurrence of shock.
			L	39 29	1-2				
			M	39 30		15.5	10	19	
			C_N	39 32					
			C_E	39 35					
			F_E	39 44					
21	14 July	I d	i P	14 21 16		2.5	4		
			i PM_V	21 16—					
			LM	21 18		5	4+		
			L_V	21 18+					
			C	21 20	1-2				
			F_E	21 31					
			F_V	21 38					
22	14 July	I d	i	14 54 33					No record in vertical component. Doubtful shock —single stroke of pens.
23	14 July	I d	i	15 01 43					No record in vertical component. Doubtful shock —single stroke of pens.
24	16 July	I d	Shift	6 12 21					All components.
			"	12 37					Vertical only.
			"	12 53					Both horizontal components. *Friction* at pen points. Phases indistinguishable.
25	18 July	I d	eP_V	21 55 22					
			eP	55 23					
			e L	55 25+					
			M	55 27			3		
			M_V	55 30—	1-2				
			C	55 30	1-2				
			F	56+ —					
26	20 July	d	i P	23 02 07					
			LM	02 09—	½-1	6		4	
			M_N	02 09			5		
			C	02 10					
			C_N	02 12	1-2				
			F	02 40					
27	21 July	I d	eP_V	00 09 27	½				
			i P_N	09 27					
			eP_E	09 28					
			LM_E	09 32	¾-1½	8			
			L	09 31			6		
			C_N	09 33	1-2				
			CM_V	09 34				4	
			F_E	09 55					
			F_N	10 13					
			F_V	10 27					
28	21 July	I d	i P_V	1 27 38					
			eP_N	27 39					
			e_E	27 40					
			eL_V	27 42				3	
			i LM	27 43	½	3	3		
			C_V	27 46					
			C_E	27 47					
			C_N	27 48					
			F_V	28 27					
29	21 July	I d	i P	23 10 54		2	2		
			i LM	10 56		3	3	4	
			C_E	10 57					
			C_N	10 58					
			F_V	11 26					
30	24 July	I d	i P	5 54 48					Definitely a shock but the chief phase is indistinguishable.
			i P_V	54 49					
			M_V	54 50				1	
			F	54 51					
			F_V	54 59					
31	26 July	I d	i P	4 56 07					
			i LM	56 08		4	3		
			C	56 09					
			F_V	56 22					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1911			h m s	s	μ	μ	μ	
32	29 July	I d	i P_V	20 33 47				2.5	
			i P_E	33 47		3			
			i P_N	33 48			2		
			LM_E	33 50		3			
			LM_N	33 51—			2.5		
			C	33 51+					
			C_V	33 49				2.5	
			F	34+ —					
33	30 July	I d	i P_{NV}	18 09 47				2.5	
			i P_E	09 48		2			
			LM	09 49		6	4	2.5	
			C_E	09 50					
			C_N	09 52					
			C_V	09 55					
			F'_{EN}	10—					
			F_V	11+					
34	31 July	I d	i P	13 12 34	½		1		
			i P_V	12 35				6	
			LM	12 36+	½-¾	15.5	15	19	
			C_N	12 38					
			C_E	12 39					
			C_V	12 42					
			F_E	13 27					
			F_V	13 37					
35	31 July	I d	i P	13 17 03					Genuine shock but too feeble to write a characteristic record.
			F	17 06					
36	1 Aug.	I d	i P	10 08 07					Vertical component only. Genuine shock but too feeble to write a characteristic record.
			F	08 08					
37	1 Aug.	I d	i P_N	10 23 19			1		
			i P	23 20		3.0		12.5	
			LM	23 21	¾-1½	10	23		
			i LM_V	23 22				23	
			C_E	23 23					
			C_V	23 25					
			F_{EN}	23 44					
			F_V	25+					
38	4 Aug.	I d	i P_{VN}	5 16 57			3		
			i P_E	16 58		2.5			
			i LM_N	16 59			2		
			F	17+					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1911			h m s	s	μ	μ	μ	
39	5 Aug.	I d	e_V ?	15 56 25					
			i P	56 27			1		
			i_V	56 26					
			i LM	56 29		2	4		
			C	56 31					
			C_V	56 34					
			F_N	56 34+					
			F_V	57 17					
40	6 Aug.	I d	e P_V	7 51 10					
			e P	51 12					
			LM_V	51 13					
			i LM	51 15		1			
			F_E	51 15+					
			F_N	51 24					
			F_V	52+ —					
41	6 Aug.	I d	i	13 55 42		0.6	0.6		Horizontal components only. Doubtful shock—single stroke of pens.
42	6 Aug.	I d	i	13 58 18		0.6	0.6		Horizontal components only. Doubtful shock—single stroke of pens.
43	6 Aug.	I d	i_V	14 01 16					In all cases single strokes of pen. Friction? or else different cause for movement in vertical component.
			i_{EN}	01 30					
44	6 Aug.	I d	i P	19 39 25		1	1	2.5	
			i LM	39 26		6	4	6	
			C	39 28	¾-1½				
			C_V	39 29					
			F	39 33					
			F_V	39 36					
45	6 Aug.	I d	i P	19 41 56				1	All components alike.
			i LM	41 51		4	2	2.5	
			C	41 58					
			F	42+ —					
46	6 Aug.	I d	i P	19 42 09					
			i LM	42 10					
			i LM_V	42 11					
			F_V	42 15					
47	6 Aug.	I d	i P	19 51 28—		2	2		*Ending merges in following shock.
			i P_V	51 29				5	
			i LM	51 29		3	4		
			i LM_V	51 31				5	
			C	51 32—					
			*F	— —					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1911			h m s	s	μ	μ	μ	
48	6 Aug.	II-III d		East-West-Component					
			i P	19 51 36		19			Felt shock, moderately strong, at Mt. Hamilton.
			i L	51 37	¾-1½	102			
			M	51 43	¾-1½	180			
			C	51 56	¾-1½				*Ending merged in the following shock.
			F	52 33					
				North-South-Component					
			i P	19 51 36					
			i L	51 37	¾-1½		77		
			M_1	51 39	1-2		270		
			M_2	51 42	1-2		275		
			C	51 56	1-2				
			*F	— —					
				Vertical Component					
			i P	19 51 37					
			i L	51 39—					
			M	51 39				143	
			C	indeterminate					
			*F	— —					
49	6 Aug.	I d	†e_V	19 53 04					†Increase of amplitude in dying "tail" of preceding shock, no phases recognizable on vertical seismogram.
			e P	53 05					
			i LM	53 07		5	4		
			F	53 09					
50	6 Aug.	I d	i P	20 24 54		2.5	1		
			$i P_V$	24 55				5	
			$i LM_E$	24 56		5			
			i LM	24 57			4	6	
			C_E	24 58					
			C	25 00					
			F	25 18					
51	6 Aug.	I d	i P	20 29 09		2	2.5		
			$i P_V$	29 10				6	
			i LM	29 11		5	0.6	6	
			C	29 13					
			C_V	29 13+					
			F_{EN}	29 17					
			F_V	30 —					
52	6 Aug.	I d	i M	20 50 50				5	Vertical component only; practically a single stroke of the pen.
			F	50 55					
53	7 Aug.	I d	i P	12 32 21		2	3	7.5	
			i LM	32 23		10	7	6	
			C	32 26					
			C_V	32 27					
			F	33 —					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1911			h m s	s	μ	μ	μ	
54	7 Aug.	I d	i	16 18 04		4	1		Horizontal components only. Doubtful shock—single stroke of pens.
55	7 Aug.	I d	i	16 22 38		2	1		Horizontal components only. Doubtful shock—single stroke of pens.
56	7 Aug.	I d	i	16 29 19					Horizontal components only. Doubtful shock—single stroke of pens.
57	7 Aug.	I d	i	16 38 09					Horizontal components only. Doubtful shock—single stroke of pens.
58	7 Aug.	I d	e P	23 56 09					
			i LM	56 12		3			
			e_V	56 12					
			C	56 12+					
			F_E	56 17					
			F_V	56 21					
59	9 Aug.	I d	i	13 58 56		4	3		Horizontal components only. Doubtful shock—single stroke of pens.
60	9 Aug.	I d	i	14 03 25		3			Horizontal components only. Doubtful shock—single stroke of pens.
61	9 Aug.	I d	i	16 33 30					Horizontal components only. Doubtful shock—single stroke of pens.
62	9 Aug.	I d	i	16 40 50					Horizontal components only. Doubtful shock—single stroke of pens.
63	9 Aug.	I d	i	19 00 31					Horizontal components only. Doubtful shock—single stroke of pens.
64	9 Aug.	I d	i	19 57 56					Horizontal components only. Doubtful shock—single stroke of pens.
65	10 Aug.	I d	i P	21 53 07		1	1	1	
			i LM	53 09	1-1½	6	4		
			M_V	53 11				5	
			C	53 10	1-2				
			C_V	53 12					
			F	53 25					
			F_V	53.6 —					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	A_N	A_V	Remarks
	1911			h m s	s	μ	μ	μ	
66	10 Aug.	I d	e P	22 42 43		0.6	0.6		In vertical seismogram only slight widening of trace of pen without distinguishable phases.
			e_V	42 44					
			i LM	42 45			2.5		
			C	42 50					
			F	43+ —					
67	11 Aug.	I d	i P	8 37 29		3.7	1	2.5	
			i LM	37 31	½-¾	6	11		
			i LM_V	37 32	½-1			9	
			C	37 33					
			F	37 42					
68	13 Aug.	I d	i	2 44 44					Horizontal components only. Single stroke of pens. Very doubtful shock, for the vertical seismograph was in an unusually sensitive state.
69	14 Aug.	I d	i	13 50 28					All three components: hence *real shock* though only a single stroke of the pens.
			i_V	50 25					
70	14 Aug.	I-II d	i P_V	13 51 43				10	
			i P	51 44	½-¾	1	3		
			i LM_V	51 46	¾-1½			20	
			i LM	51 47—	¾-1	20	17		
			C	51 54					
			C_V	51 55					
			F_N	52 18					
			F	52 27					
			F	52 34					
71	14 Aug.	I d	i	13 54 30					Single strokes of the pen in all three components. The feeblest *sure* earthquake yet detected at either the Lick Observatory Station or that at Berkeley.
72	16 Aug.	I d	i P	1 52 33		12	3	15	
			i LM_V	52 34				10	
			i LM	52 35	½-¾	18	14		
			C_V	52 38	¾				
			C	52 39					
			F	53+ —					
			F_V	53.6					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	A_N	A_V	Remarks
	1911			h m s	s	μ	μ	μ	
73	18 Aug.	I d	i P	1 35 46		1	3		
			i P_V	35 47				3	
			i LM_E	35 48		12.5			
			i LM	35 49			9	4	
			C	35 53	1-1½				
			F	36+ —					
			F_V	37— —					
74	27 Aug.	I d	i P	12 54 35		1	0.6		Vertical seismogram does not exhibit any sure movement.
			i LM	54 37		0.6	0.3		
			C	indeterminate					
			F	indeterminate					
75	27 Aug.	I d	i	12 59 14					Horizontal components only. Doubtful shock—single stroke of pens.
76	28 Aug.	I d		East-West-Component					
			e P	3 04 01					
			i S	04 05	¾-1½	1			
			L	04 10		2.5			
			M	04 11		9			
			C	04 27					
			F	05 06					
				North-South-Component					
			i P	3 04 01			1		
			S	indeterminate					
			L	3 04 10	1		3		
			M_1	04 12	¾-1		9		
			M_2	04 21	¾-1		7		
			M^3	04 27	¾-1		6		
			C	04 38					
			F	05 09					
				Vertical Component					
			i P	3 04 01				6	
			e S	04 04					
			L	04 11	¾-1				
			M	04 11+				7.5	
			C	04 30					
			F	04 54					
77	31 Aug.	I d	i *all*	5 44 10					In horizontal components only single stroke of pens. No phases distinguishable in vertical component.
			F_V	44 15					
78	5 Sept.	I d	i P	12 09 03			3	15	
			i LM	09 04.5	¾-1	6	12.5	7.5	
			C	09 10	¾				
			F	09 25					
			F_V	10 15					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1911			h m s	s	μ	μ	μ	
79	6 Sept.	I d	eP_N	15 44 11					
			i P	44 12					
			i LM	44 13				2.5	
			$i\ LM_E$	44 14		9	11	9	
			C_N	44 15					
			C	44 16					
			F_E	44 28					
			F_N	44 31					
			F_V	44 50					
80	10 Sept.	I d	e	10 48 07					
			M	48 08					Vertical component only. Driving clock of horizontal seismograph stopped prior to the occurrence of the shock.
			F	48 47					
81	12 Sept.	I-II d	i P	2 53 48					
			i LM	53 50	¾-1½	3	7.5	15	
			C_N	54 05	¾-1	48	70	38	
			C_E	54 07	¾-1				
			C_V	54 04					
			F_N	54 20					
			F_E	54 30					
			F_V	54 35					
82	17 Sept.	I d	$i\ P_V$	15 46 54					
			i P	46 55				5	
			i LM	46 56			1		
			C	46 59		6	6	5	
			F	47 05					
83	18 Sept.	I d	i	9 55 22					Horizontal components only. Doubtful shock—single stroke of pens.
84	19 Sept.	I d	eP_V	3 08 51(?)					
			eP_E	08 53					
			$i\ LM_V$	08 53+				5	
			$i\ LM_N$	08 55			4		
			$i\ LM_E$	08 56		4			
			C	08 58					
			F_N	09 05					
			F_V	09 10					
85	19 Sept.	I d	i	3 12 02					Horizontal components only. Doubtful shock—single stroke of pens.
86	21 Sept.	I d	eP	11 23 35					
			i LM	23 36		2.5	1	1	
			C_E	23 38					
			C_N	23 39					
			F	23 50					

No.	Date	Charac.	Phase	Time G. M. C. T.	Period	Amplitude A_E	Amplitude A_N	Amplitude A_V	Remarks
	1911			h m s	s	μ	μ	μ	
87	27 Sept.	I d	eP	22 23 23					No record in vertical component.
			i LM	23 24		5	3		
			F	23 33					
88	27 Sept.	I d	eP_V	23 43 11					
			i LM	43 13	¼	6	4		
			$i\ LM_V$	43 14				1	
			M_V	43 15				5	
			C	43 16					
			F	43 45					
89	29 Sept.	I-II d	i P	17 12 25	½	3	4		
			$i\ P_V$	12 26	1			12.5	
			i LM	12 28	¼	42	34	25	
			C	12 37	¾-1				
			F_{EN}	13 16					
			F_V	13 31					

DISCUSSION OF PARTICULAR SHOCKS

The Strong Mexican Earthquake of June 7, 1911

The energy transmitted to the seismographs at the Berkeley Station by this earthquake was much in excess of that communicated by any other of the distant shocks thus far registered here. In both horizontal components the amplitude of the chief phase exceeded the range of the recording apparatus.

In all phases the motion of this shock was very complex, waves superposed upon waves with frequent abrupt reversals in direction along the pen-trace—all pointing to complex motion at the origin. It is the most tangled, as well as the most energetic, group of waves yet recorded here.

At the Lick Observatory Station this shock produced motion of the pens in all three components; but at this time these seismographs were newly installed and were not yet working uniformly. Owing to pronounced friction of the damper pistons on this day the seismograms are poorly traced and yield no serviceable measures of the characteristic phases or magnitude.

A Peculiar Teleseism Recorded on June 15, 1911, at the Berkeley Station

Moderate energy was transmitted to this station by a shock originating at great distance from Berkeley on this date. Unusual features appear in the seismograms of this earthquake. The record of the N-S component is normal in character and on it the usual changes of phase are well marked. On the E-W seismograph, however, the maximum amplitude occurs during the second phase, and on hasty examination this motion would be considered the chief phase. But careful comparison with the N-S record shows that the long waves appear at about the same time on both seismograms. Furthermore on the vertical seismogram a sharp maximum occurs early in the first phase and after this the motion dies away gradually. The points of beginning of the second phase and the chief phase are hard to decipher and can be found only by comparison with the N-S record.

The Moderately Strong California Shock of July 1, 1911

At the Berkeley Station—This shock was so energetic that with the arrival of the very first waves the writing points of both horizontal seismographs were flung far off the recording drums, even out of their bearings in the writing arms, so that no further motion was registered until they were replaced sometime after. In the E-W component the first shift of the pen was slightly to the *east*, followed at once by very sudden arrest and reversal with a violent sweep to the west far off the recording drum. Similarly in the N-S component, the first shift of the pen was slightly to the *south*, with instant arrest and reversal, the pen sweeping off the drum to the north. The focus of the shock unquestionably lay some fifty to seventy miles to the SSE and, theoretically, the first shift of the pens, like that of the earth particles, should have been in the west and north directions respectively. Their actual behavior suggests strongly that the very first pulsation was so violent that a *whip-effect* was produced in the writing boom causing a little *backward* fling of its free extremity just as its swing began.

The writing point of the vertical seismograph did not leave the smoked paper belt permanently, though for a little time it kept swinging off one edge of the belt. However, from the very first instant it described a series of *chattering* swings as wide in amplitude as the safety stops of the swinging system would permit and this violent, chatter-mark swinging continued for several minutes. Hence in all components the initial pulses of this earthquake were too energetic to be registered properly by these delicate seismographs. In the absence from Berkeley of the present writer, it was stated to the press, and later repeated in a note in the *Bulletin of the Seismological Society of America*, vol. 1, no. 3, pp. 111, that "There was . . . . no preliminary tremor . . . ." and "The unusual and interesting feature of the earthquake is that there was no preliminary tremor." With this opinion the writer does not concur, holding rather to the conclusion that the waves of the first phase, or preliminary tremor, as well as those of the chief phase, were too energetic to be

registered within the range of motion permitted to the writing apparatus of the instrument.

Unfortunately, at the time of this shock the writer, who was absent on vacation, was in the high mountains and could not conveniently return at once. At the time of his departure some two weeks before the shock, the seismographs and station equipment were left in good order under the daily care of a man acting as substitute to the regular routine attendant. The regular caretaker returned to duty on the morning of July 1, the day of the shock, and found that the potential of the storage batteries of the electric time-service had become weak. Further, examination of the records brought out the fact that some unnoticed disturbance to the parallax, the interval between the position of the writing point and that of its time-marker, had occurred in the registration of the N-S component. Hence for this shock the time-correction for the N-S seismogram is unknown. Also, when the shock came the time-marking magnet of the E-W registration apparatus was not in operation owing to the weakened condition of the electric batteries.

Hence the time of beginning of the earthquake can be determined only on the vertical seismogram, but here fortunately the determination is very accurate, for there is no parallax error and the clock error is known precisely.

The time of beginning thus determined is *nine seconds earlier* than the time noted by two astronomers working at the Students' Observatory, both practiced and reliable time observers, who counted seconds from the first sensation of motion. This interval, nine seconds, is close to the duration of the first phase in the seismograms of aftershocks of this earthquake registered here. The suggestion is obvious, though by no means sure, that the first pulses of the first phase arrived nine seconds before sensible motion but that, though unfelt, these were strong enough to fling the writing pens off the recording drums.

A matter important to notice is the apparent continuance of strong motion on the Berkeley vertical seismogram, written less than seventy miles from the focus, for more than fifteen minutes,

while the most sensitive observers did not perceive a longer duration than from one-half to three-quarters of a minute. The seismograph was damped in the ration of 8:1 so that any motion proper to its swinging system should die away at once upon the cessation of earth motion. Consequently the interpretation of this continued strong displacement is in doubt.

At the Lick Observatory Station—On the summit of Mount Hamilton this shock was far too energetic for successful registration by the delicate Wiechert seismographs. The local estimate of the intensity was given out as VII of the R-F scale. Yet Professor R. G. Aitken states: "The earthquake of July 1, 1911, was in some respects the most severe one experienced since the observatory was founded. The amplitude of vibration was less than in the shock of April 18, 1906, and the duration was much less, but the motion was more violent." This conclusion seems amply borne out by the permanent phenomena cited by Professor Aitken and Mr. C. C. Kiess in the *Bulletin of the Seismological Society of America*, vol. 1, no. 3, pp. 114–115. Moreover, a shock on August 2, 1903, the strongest experienced at Mount Hamilton up to that time, was then rated at VII-VIII of the R-F scale. This former shock was by no means so strong as that of July 1, 1911. In the view of the writer, who obtained considerable experience in the determination of intensity during a comprehensive study of the effects produced in San Francisco in 1906, the intensity at the mountain summit, where bed-rock is exposed, was fully VIII of the R-F scale—that, indeed, it very likely would not be an exaggeration to rate it in the lower range of scale-number IX. The "brick" dormitory was rendered unsafe for occupation. It was not of superior construction, and possibly it had been weakened by previous shakings; but its foundations rested upon bed-rock.

Mr. C. C. Kiess, who had direct supervision of the seismographs, states that "In all three components the pens made but one sweep across the sheets and were then thrown from the carriers. The weight of the pendulum of the horizontal machine was displaced northward, rendering the machine useless for some

time." "One of the cardan springs of the vertical was sheared." The vertical seismograph was very soon restored to use, but the horizontal instrument remained out of commission until the morning of July 3, 1911.

Just as at Berkeley, the first shifts of the pens of the horizontal components were slightly to the *east* and *south,* followed by sudden, abrupt reversal with violent fling to the west and north respectively. The explanation of "whip-effect" offered for this behavior at Berkeley is considered to apply in this instance also.

For there is no question that the origin of this earthquake lay to the southward of this station. This is demonstrated by the movement of heavy objects whose inertia prevented them from sharing fully the fling of the earth particles. For example, the base and mounting of the great 36-inch telescope, weighing about fifty tons, was shifted on its concrete pier nearly three-quarters of an inch almost due south. Moreover, the great majority of the aftershocks, whose seismograms do not show the "whip-effect," also emanate from foci to the southward of the mountain.

An Aftershock Registered at Berkeley but not at the Lick Observatory

Before the vertical seismograph at the Lick Observatory Station had been restored to working order, one aftershock was *felt* and the time of its occurrence was estimated by Professor Aitken at $5^h\,55^m\,10^s$ p.m. Pacific standard time, July 1, 1911—or $00^h\,55^m\,10^s$ Greenwich mean civil time of July 2, 1911. This shock was feebly and vaguely registered by the vertical seismograph at the Berkeley Station, no. 55a, e $00^h\,54^m5$, F $00^h\,55^m3$ G.M.C.T. of July 2, 1911.

Certain Doubtful Records of Shocks at the Lick Observatory Station

In addition to the shocks whose measurements are tabulated above, a dubious movement of the vertical pendulum occurred on July 2 at $3^h\,04^m7$ G.M.C.T. It is impossible to judge whether this was due to earth movement or to settling of the swinging system.

In the case of the shock which occurred at $6^h\,19^m\,33^s$ G.M.C.T. on July 2 there appears in the tail phase an increment of amplitude which may be due to a second shock following quickly upon the shock measured, but it is impossible to draw a definite conclusion in regard to it.

On July 7 at $19^h\,13^m\,19^s$ G.M.C.T. a vague, feeble movement was registered by the vertical seismograph but not by either horizontal component. Mr. C. C. Kiess, at work in the assembly room at the observatory, *felt* a disturbance at this time. No phases are discernible in the vertical seismogram and its trace does not resemble those produced by shocks strong enough to be felt. It is difficult to believe that a "felt" shock could occur without being registered by all components. Nevertheless the slight displacement on the vertical seismogram coincides in time with the sensation noted by Mr. Kiess. It is worthy of note here that a sensitive observer can perceive very slight vibratory motion in the earth, such as is quite unnoticed by a person of ordinary sensibility.

The Strong Aftershock of August 6, 1911, at the Lick Observatory Station

The strongest of the aftershocks consequent upon the earthquake of July 1 occurred on August 6, beginning at $19^h\,51^m\,36^s$ G.M.C.T. This shock was immediately preceded by four distinct but feeble shocks beginning at $19^h\,39^m\,25^s$ $19^h\,41^m\,16^s$, $19^h\,42^m\,09^s$, and $10^h\,51^m\,28^s$ respectively. The motion of the tail phase of the last of these merges in the initial phase of the strongest shock. This earthquake started the driving clock of

the Ewing seismograph and it is the only one of the numerous train of aftershocks strong enough to operate this older instrument. The shock was distinctly felt, according to Mr. Kiess, not only at the observatory on the summit but also by a party of people outdoors part way down the mountain. It was accompanied by a low, rumbling sound.

Before its motion died away completely there occurred another feeble shock, beginning at $19^h\ 53^m\ 04^s$ G.M.C.T.

A Near Earthquake Registered at the Berkeley Station on August 21, 1911

Earth motion was registered by all three seismographs on the morning of August 21, 1911. The motion began while the work of changing the record sheets was in progress. The newly replaced smoked paper band for the pendulum which records N-S motion had been registering for some minutes when the waves began to arrive. Consequently there is a complete record in this component. The earth motion had already begun when the E-W recording apparatus was newly started, and on this record the chief phase set in almost at once. By the time registration was started on the newly replaced vertical record the earth motion had begun to die away. Hence the only complete record of this shock is that of the N-S component.

On this record the first shift of the pen, like that of the earth particles, was to the south. Also the amplitude of the chief phase was somewhat greater in the E-W component than in the N-S component. Together these circumstances indicate that the origin of this shock was a little north of northwest of this station. Measurement of the seismogram yields the value, 31 seconds, for the interval L–P which indicates, according to Omori's formula $x^{km} = 7.27\ y^{sec} + 38^{km}$, that the origin was about 260 kilometers from Berkeley.

The energy transmitted to this station was moderate in amount, indicating a fairly strong shock at the origin,—yet the shock made no trace on the seismograms written at the Lick Observatory Station, some 80 kilometers further to the southeast than Berkeley. Moreover, in general appearance the seismograms written at Berkeley are not typical of a simple near shock, but more resemble in character the complicated motion of the chief phase of a more distant earthquake. Consequently there is doubt as to the proper interpretation of these records. No shock was reported as felt in any part of northern California on this date.

A Near Shock Registered at both Stations on August 28, 1911

This shock requires notice simply because it was clearly and sharply registered both at the Berkeley Station and at the Lick Observatory Station, but upon utilizing Omori's formula for distance of origin discrepancy appears. At Berkeley the interval L–P was 33 seconds, indicating an origin-distance of 235 kilometers, according to the formula $x^{km} = 6.86\ y^{sec} + 81^{km}$, or of 278 kilometers, acording to the formula $x^{km} = 7.27\ y^{sec} + 38^{km}$. At the Lick Observatory Station the interval L–P was 10 seconds, indicating an origin-distance of 77 kilometers according to the formula $x^{km} = 6.86\ y^{sec} + 8.1^{km}$.

Now the distance from Berkeley to Mount Hamilton is very nearly 80 kilometers. If the origin of the shock lay to the south-southeast of Mount Hamilton on the line projected from Berkeley through the mountain top, the Berkeley determination of distaice would place the origin further south than the Lick Observatory determination by 78 kilometers if the first formula be used for the Berkeley reduction and by 121 kilometers if the second formula be used. Still greater discrepancies come in if the origin lies in any other azimuth.

A Weak Local Shock Registered at the Berkeley Station on September 18, 1911

In the case of this earthquake there is discrepancy between the times of beginning of the phase L on the N-S and E-W seismograms. The shock was not registered by the vertical pendulum. No motion was recorded by any of the seismographs at

the Lick Observatory Station. On the E-W seismogram the interval L–P was 5 seconds, indicating an origin-distance from Berkeley of 42 kilometers. This probably is not one of the train of aftershocks, for if it were its origin should lie to the southeast of Berkeley, about equidistant from Berkeley and Mount Hamilton, in which case the motion should have been registered at the Lick Observatory Station as well.