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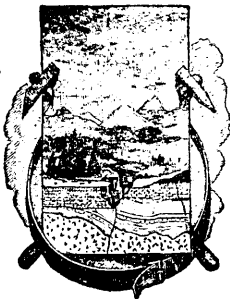
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# EARTHQUAKES IN CALIFORNIA

IN 1890 AND 1891

BY

EDWARD SINGLETON HOLDEN



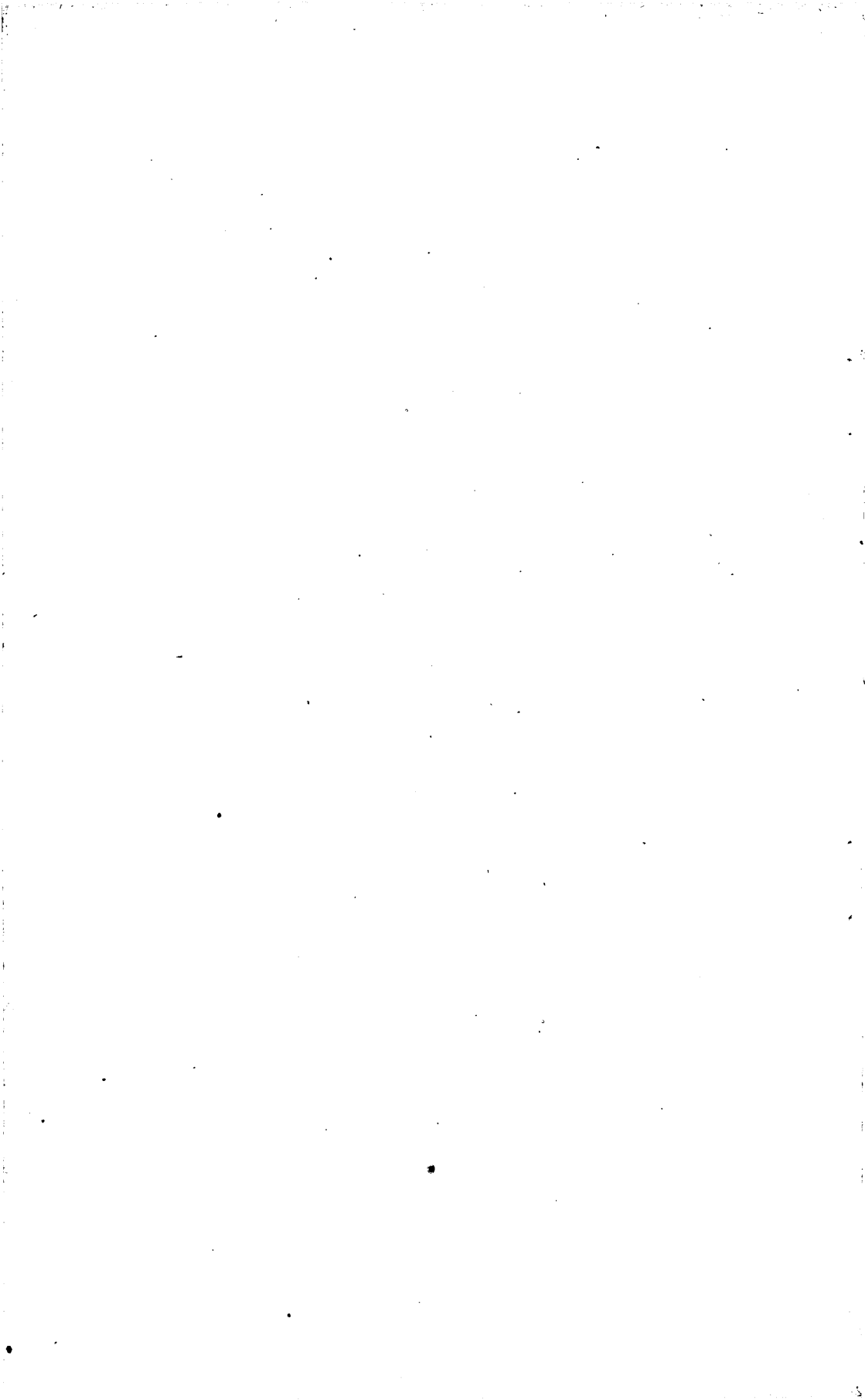
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## LETTER OF TRANSMITTAL.

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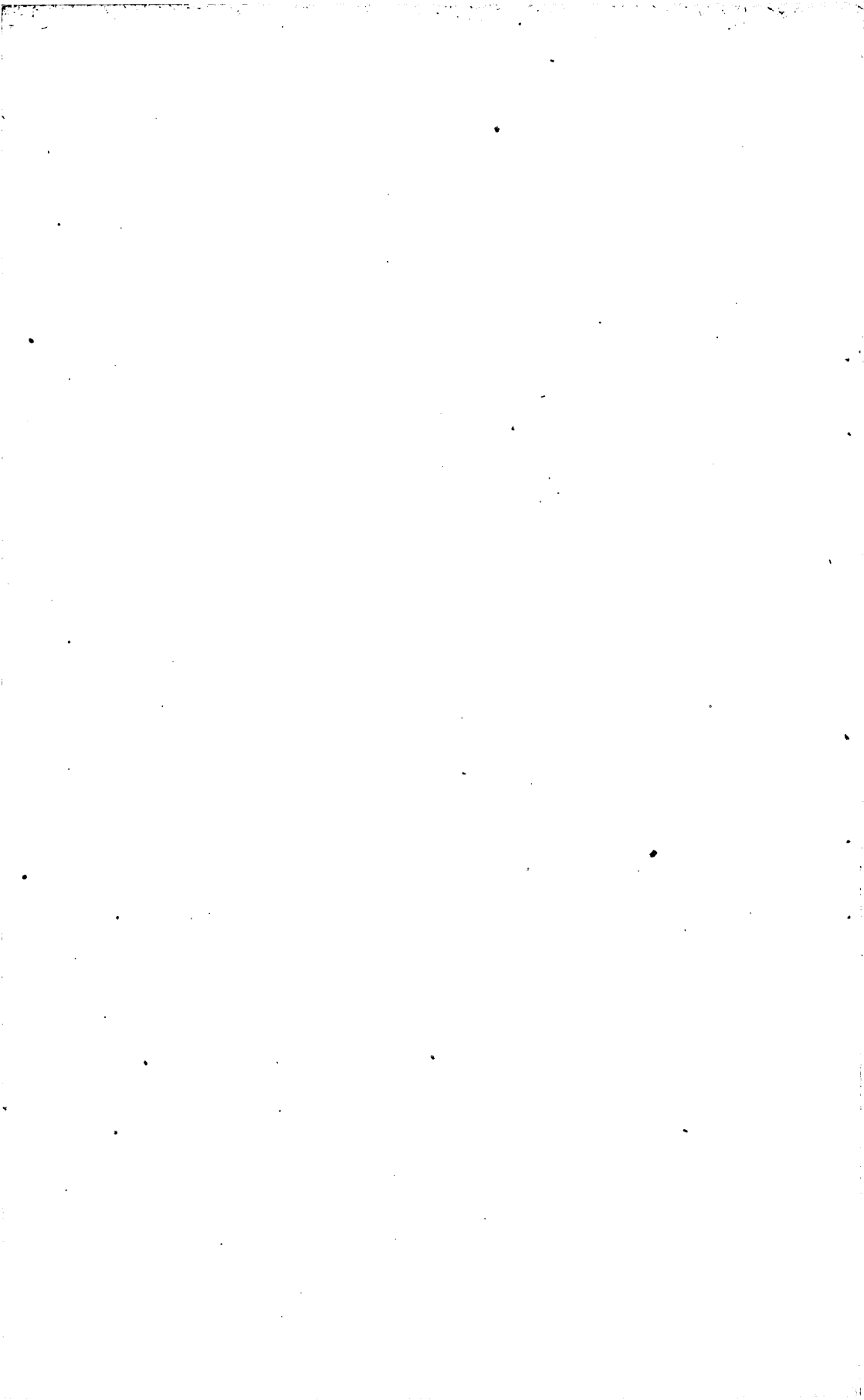
DEPARTMENT OF THE INTERIOR,  
UNITED STATES GEOLOGICAL SURVEY,  
*Washington, D. C., February 2, 1892.*

SIR: I have the honor to transmit herewith a manuscript entitled "Earthquakes in California in 1890 and 1891," by Edward S. Holden, and recommend its publication as a bulletin. It is the second of a series furnished the Survey by the Lick Observatory, the first having been prepared by Prof. J. E. Keeler and published by the Survey as bulletin No. 68.

Very respectfully,

G. K. GILBERT,  
*Chief Geologist.*

Hon. J. W. POWELL,  
*Director.*





# EARTHQUAKES IN CALIFORNIA IN 1890 AND 1891.

By EDWARD S. HOLDEN.

## INTRODUCTION.

The following paper is a continuation of records of the same kind by Prof. Keeler and myself<sup>1</sup> and it brings the list up to the end of the year 1891. It records all the shocks observed or felt on Mount Hamilton, and all those reported to the Lick Observatory by letter, as well as newspaper reports of such earthquakes as occurred in the state during that year. No systematic examination of the newspapers has been made, however, and reports may have escaped notice.

## INSTRUMENTS.

The instruments used for recording earthquakes on Mount Hamilton are described in Publications of the Lick Observatory, vol. 1, p. 82. The largest and most complete instrument records the north and south, east and west, and vertical components of the earth's motion, separately, on a smoked glass plate, which is started by the preliminary tremors of the earthquake and rotates uniformly in about three minutes, the edge of the plate being graduated into seconds at the same time by the clock, which also serves to record the time of occurrence of the shock. This instrument has been called the Ewing seismograph in the notes. Another simpler form consists of the heavy "duplex" pendulum adjusted to a long period of vibration, with a magnifying pointer or pen, which records on a smoked glass plate both horizontal components of the motion. The vertical component and the time are not recorded. The motion of the earth is magnified 4.0 times in the duplex seismometers.

The observatory possesses other seismographs of various patterns, but they are not constantly in use.

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<sup>1</sup>List of recorded earthquakes in California, Lower California, Oregon, and Washington Territory (from 1769 to 1888.) Sacramento: State Printing Office.

Earthquakes in California in 1888. American Journal of Science, vol. 37, May, 1889.

Earthquakes in California in 1889. Bulletin U. S. Geological Survey No. 68, 1890.

## SCALE OF MEASUREMENTS.

In the record made by the Ewing seismograph both horizontal components are magnified 3.3 times, and the vertical component is magnified 1.6 times. The measures of the vibrations as given in the notes are taken directly from the tracings, and therefore represent the magnified motion.

If both the period  $T$ , and the amplitude  $a$  of an earthquake wave are given, the maximum acceleration due to the impulse, which may be taken as a measure of the intensity or destructive effect of the shock, is given by the formula—

$$I = \frac{4\pi^2 a}{T^2}$$

in which the motion is assumed to be harmonic.

## DIFFERENCES OF INTENSITY.

Estimates of the intensity of shocks are also given (in Roman numerals inclosed in parentheses) according to the Rossi-Forel scale, which for convenience of reference is inserted below. Experience has suggested that for observations in California a few additions should be made to this scale, and these are printed here in *italics*. When these are in quotation marks also, they are expressions actually used in the newspapers, etc., in describing earthquake shocks, whose intensity is otherwise known. The scale, as amended, is as accurate as anything of the kind can be.

## I.

Microseismic shocks recorded by a single seismograph, or by seismographs of the same model, but not putting seismographs of different patterns in motion; reported by experienced observers only.

## II.

Shock recorded by several seismographs of different patterns; reported by a small number of persons who are at rest. "*A very light shock.*"

## III.

Shock reported by a number of persons at rest; duration or direction noted. "*A shock;*" "*a light shock.*"

## IV.

Shock reported by persons in motion; shaking of movable objects, doors, and windows; cracking of ceilings. "*Moderate;*" "*strong;*" "*sharp;*" (sometimes) "*light.*"

## V.

Shock felt generally by everyone; furniture shaken; some bells rung. *Some clocks stopped; some sleepers waked; "smart;" "strong;" "heavy;" "severe;" "sharp;" "quite violent."*

## VI.

General awakening of sleepers; general ringing of bells; swinging of chandeliers; stopping of clocks; visible swaying of trees; some persons run out of buildings. *Window glass broken; "severe;" "very severe;" "violent."*

## VII.

Overturning of loose objects; fall of plaster; striking of church bells; general fright, without damage to buildings. *Nausea felt; "violent;" "very violent."*

## VIII.

Fall of chimneys; cracks in the walls of buildings.

## IX.

Partial or total destruction of some buildings.

## X.

Great disasters; overturning of rocks; fissures in the surface of the earth; mountain slides.

The relation between the intensity (I) of a shock as determined by the formula already given, and the numbers of the Rossi-Forel scale, has been reduced from all available data up to 1888, and is given below in tabular form. it is, of course, a rough approximation only.

Rossi-Forel scale.	Intensity.	Difference.
	<i>m. b. per sec.</i>	
I. ....	20	-----
II. ....	40	20
III. ....	60	20
IV. ....	80	20
V. ....	110	30
VI. ....	150	40
VII. ....	300	150
VIII. ....	500	200
IX. ....	1,200	700

One of the objects of the earthquake observations on Mount Hamilton is to obtain data for correcting this table, so that the intensity of a shock, as defined mathematically by the formula  $I = \frac{V^2}{a}$  (where  $V$  is the maximum velocity of the vibrating particle), can be inferred from the ordinary descriptions of its effects.

## STATIONS.

A number of duplex-pendulum seismographs, quite similar to the one used at the Lick Observatory, are placed at different points on the Pacific coast, but they are not all in operation. The stations are:

Student's Observatory, Berkeley, in charge of Prof. Soulé.

Chabot Observatory, Oakland, in charge of Mr. Burekhalter.

Private observatory of Mr. Blinn, in East Oakland.

Observatory of the University of the Pacific, San Jose.

Observatory of Mills College, near San Francisco, in charge of Prof. Keep.

Office of State Weather Bureau, Carson, Nev., in charge of Prof. Friend.

The reports of the United States Light-House Board and of the United States Signal Office (United States Weather Bureau) for 1890 and 1891 record a number of shocks not mentioned in the following list, and they should be consulted in this connection.

Prof. Keeler was in charge of the earthquake instruments of the Lick Observatory during 1890 and 1891. Most of the following statistics were, however, collected by myself. Dr. Henry Crew has kindly put them in chronological order, as follows:

## CHRONOLOGICAL RECORD, 1890.

**January 15.**—MOUNT HAMILTON, 5:05:±1m. a. m. (Prof. Holden).—Intensity = V—Rossi-Forel scale. Mr. Keeler was partly awake at the time, and counted one minute from the beginning of shock, and noted time by watch, P. S. T.<sup>1</sup> = 5:05:3±10s. a. m. Intensity = IV, Rossi-Forel scale. Time by earthquake clock = 5:02 a. m.

The record of the duplex seismograph shows the actual displacement of the pendulum bob to have been 2.6 mm., in a direction almost exactly northwest and southeast. The record consists of a single nearly straight line.

SAN JOSE.—Two shocks felt about 5 o'clock a. m., sufficiently heavy to awaken sleepers; from north to south.

**January 18.**—NAPA.—Two slight shocks. Vibrations from north to south.

SANTA BARBARA, 3:30 p. m.—Reported in the Chronicle as "quite a heavy shock."

**January 23.**—CHABOT OBSERVATORY, 4:18±1 m. a. m.—Time observed by George B. Fox. The seismographic record accompanying the report indicates the total actual displacement of the pendulum to have been 2.8 mm., in a direction from "north by east" to "south by west." The tracing is made up of five small waves (small with reference to the total length of the tracing), which look as if they might

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<sup>1</sup> P. S. T. = Pacific slope time.

have resulted from a simple harmonic motion having displacements in an east and west direction.

**January 24.**—**SANTA ANA.**—The San Jose Mercury reports this as follows:

"**SANTA ANA, January 24.**—A very distinct earthquake shock, lasting 4 seconds, was felt this afternoon at 1:15, and at 4:30 o'clock there was a larger and more pronounced shock, lasting ten seconds. The direction was northeast and southwest."

**February 5.**—**SAN DIEGO, 10:15 p. m.**—"Distinct shock; vibrations from east to west."

**SANTA ANA, 10:14 p. m.**—"Shock lasted eight seconds. Vibrations from northeast to southwest."

**SAN BERNARDINO.**—"Three distinct shocks, preceded by a low rumbling noise. The shock (?) lasted for four or five seconds."

The above three reports are all from newspapers.

**February 9.**—**SAN BERNARDINO.**—Following is the report published in the Times-Index of San Bernardino of February 10:

"Quite a heavy shock of earthquake visited this section yesterday morning at 6 minutes past 4 o'clock. The vibrations were north and south, and the shock caused a great many persons to arise much earlier yesterday morning than heretofore."

Under this date the Examiner, of San Francisco, reports the following:

"**SAN PEDRO, February 9.**—Three mild but distinct shocks of earthquake were felt at San Pedro at 4:07 o'clock this morning. The vibrations lasted for several seconds and were from east to west.

"**COLTON, February 9.**—A heavy shock of an earthquake was felt in Colton at 4 o'clock this morning.

"**POMONA, February 9.**—At 4 o'clock this morning three distinct shocks of an earthquake were felt here. Nearly every one was roused from his slumbers, but little damage was done. In the Progress office type was 'pied,' and some panes of glass were broken about the city.

"**SAN DIEGO, February 9.**—Another shock of an earthquake was felt in this city at 4 o'clock this morning. It lasted about a minute, and was accompanied by rumbling noises."

**February 13.**—**TEHACHAPI, 2:10 a. m.**—The following is from the San Bernardino Times-Index:

"**TEHACHAPI, February 13.**—Three light but distinct shocks of earthquake were felt here about 2:10 this morning. They occurred at intervals of about twenty minutes. The second shock lasted several seconds."

**February 15.**—**LOS ANGELES, about 4 a. m.**—Reported as follows in the Los Angeles Herald of February 16: "Residents in this city and dwellers in its suburbs generally were very rudely awakened from their slumbers yesterday morning at about 4 o'clock. A long, low rumbling noise as of distant thunder along the crests of the mountains was heard

by people who were awake at that hour, and this was soon followed by a very decided shock of earthquake. Houses shook, windows rattled, pictures vibrated on their hooks, and it was only very sound sleepers who were not roused to full consciousness that the giant tread of the shaker was abroad. The oscillations were of a long, steady character rather than of the short, jerky order often felt in earthquake movements. The vibrations were nearly from northeast to southwest, and were separated into three distinct divisions. The first was the heaviest, followed by another lighter one at a short interval, and then, after a pause, a third little kick, less pronounced than the others. This is the second shock in this section within a year. In old days it was noted for its frequent seismic manifestations, but for forty years they have not been pronounced. Their center is near the San Jacinto peak."

GILROY, midnight.—A light shock.

**April 11.**—UKIAH, 11:30 a. m. (?)—Vibrations from southeast to northwest.

**April 15.**—MOUNT HAMILTON, 2:00 a. m.—No record but the tracing of the duplex seismograph, which is an almost perfectly straight line running northwest and southeast. The total actual displacement of the pendulum bob is 1.9 mm.

**April 24.**—MOUNT HAMILTON, 3:36 a. m.—The duplex seismograph gives an exceedingly complicated tracing in the general direction northwest and southeast. The maximum possible displacement of the pendulum bob was 4.0 mm. in the direction indicated above.

At right angles to this the maximum displacement was 1.4 mm. The tracing is folded on itself from nine to eleven times.

MILLS COLLEGE, about 3:39 a. m.—The tracing from the duplex seismograph indicates motion in every possible azimuth. There is no marked tendency in any one direction. The maximum excursion of the pendulum bob is 11.1 mm. running from north-northeast to south-southwest. By maximum excursion is here meant the maximum diameter of the diagram.

The tracing is such as might have been produced by "resonance," the amplitude increasing as the earthquake proceeded.

BERKELEY, 3:38 a. m. (Prof. Soulé).—The tracing from duplex seismograph gives maximum displacement (6.4 mm.) in a direction northeast and southwest.

There is quite a well-marked displacement of 4.3 mm. in an azimuth which may be defined as "west-northwest" to "east-southeast." The tracing recrosses itself from fifteen to twenty times. The disturbance at Berkeley seems to have been considerably smaller than at Mills College.

CHABOT OBSERVATORY, 3:37:44 a. m.—Duration six seconds; preceded by a rumble lasting ten to fifteen seconds. General character and size of tracing from duplex seismograph about the same as that observed at Berkeley. Maximum double amplitude of pendulum bob nearly east and west, amounting to 5.7 mm. (Mr. Burckhalter).

EAST OAKLAND, 3:37:40 a. m.—Mr. F. G. Blinn reports the duration at ten seconds and the intensity as IV (R. F.).

The seismograph tracing is exceedingly complicated, recrossing itself probably fifty times. The maximum displacement is east and west.

SAN FRANCISCO.—Following is the report of Prof. Davidson, as given by the Examiner: "(1) First shock light, but awakened observer 3:36:18 P. S. T. Direction, east and west. (2) Continuous shock 3:37:03 to 3:37:23; first part slight; last 'shock like a terrier-dog worrying a rat.' Trace east and west and north and south, giving resultant northeast and southwest or northwest and southeast, according to circumstances. Shock rang doorbell in Davidson's room. Stopped clock in room 39, Appraisers' Building. Recorded by Frank Edmonds as northwest and southeast."

The following from the Evening Bulletin gives observations in other parts of the state:

"SALINAS, April 24.—The heaviest temblor ever known here occurred at 3:40 this morning. Two light shocks were followed by a third and heavier, which lasted about twelve seconds. These were followed by four or five more, one of which was sharp and abrupt. The vibration was from east to west. Clocks were stopped, but no damage was done.

"BENICIA, April 24.—The people were awakened from slumber this morning at 3:45 by a very distinct shock of earthquake. The vibrations lasted some seconds and seemed to be from east to west.

"LOS GATOS, April 24.—Two distinct and severe earthquake shocks were felt this morning about 3:40, the last shock being much heavier than the first and of longer duration. The vibrations were from east to west. No damage was done, but many persons were considerably frightened and a few clocks were stopped. A slight shock was also felt about 5:30, but it was scarcely noticeable.

"BRENTWOOD, April 24.—A slight shock of an earthquake at 3:30 this morning.

"GILROY, April 24.—The damage by the earthquake this morning was not great. The gas mains were disjointed and the lights extinguished.

"SAN JOSE, April 24.—The shock of earthquake this morning was very sharp, but no damage is reported. Many people were frightened out of their beds.

"HOLLISTER, April 24.—Temblors began here at 3:32 a. m., lasting until 5:30 a. m. Thirteen distinct shocks were felt, and during the entire two hours a continuous vacillating motion was observable. The shocks were not sharp, but long continued and heavy rolling, the worst that have ever been experienced here. Only nominal damage was done. A private dispatch states that the McMahan House was twisted so badly that cracks were opened in it sufficiently large to admit a man's hand and that other damage was done.

"REDWOOD CITY, April 24.—Three shocks of earthquake occurred this morning, ending with a severe jar, which threw crockery and other articles from the shelves of several residences. Clocks were stopped at 3:37, the hour of the occurrence. The vibrations were east and west and the duration twenty seconds. The residents assert these were the severest shocks since 1868.

"POINT REYES, April 24.—A sharp shock of earthquake occurred here very early this morning.

"CENTERVILLE, April 24.—A heavy earthquake shock was felt here at 3:40 this morning. It was preceded by two light shocks. Many were frightened, but no damage has been reported.

"WATSONVILLE, April 24.—There were twelve distinct shocks of earthquake felt here after 3:30 this morning, the first and second being the most severe. The vibrations were from west to east. In the country north of town nearly all the chimneys were thrown down. The railway bridge across the Pajaro was misplaced and the train delayed.

"NAPA, April 24.—At 3:40 o'clock this morning a heavy shock of earthquake was experienced here. The vibrations were north and south.

"SANTA CRUZ, April 24.—There was a heavy earthquake shock this morning at 3:48, but very little damage.

"MAYFIELD, Cal., April 24.—A slight shock of earthquake was felt here and in neighboring towns this morning. The vibrations were from northeast to southwest, and lasted eight seconds. There was a heavy atmosphere, with no wind. The tops of trees rocked, making a noise like a heavy wind blowing. Plastering was broken and the depot clock and others stopped at 3:37 o'clock. The temperature was 48°. Superintendent Bassett and Assistant Superintendent Haydock went south by a special train to look after the damage done to the track by the shake between Pajaro and Sargents. It is reported that the track was moved a foot out of line, and that the ground settled six inches in places. The bridge, fifty feet high, is impassable at both ends, the rails being pulled a foot apart. A large force of men is at work, and they expect to have the track so that trains can pass in a few hours. At Sargents and Gilroy there were more than a dozen shakes, and chimneys were knocked down."

CARSON CITY, NEVADA.—No time reported. The duplex seismograph indicates a disturbance about one-quarter as large as that at Berkeley. (C. W. Friend.)

SAN JOSE, 3:37:43 a. m.—Seismograph at the University of the Pacific furnishes a diagram having a maximum double amplitude of 16.2 mm; from the manner in which the index has run all over the glass one would think the equilibrium of the pendulum too nearly neutral.

**May 11.**—EAST OAKLAND, 1:00:15 p. m. (Mr. Ireland); 1:00:18 p. m. (Mr. Boise).—Mr. Blinn's seismograph makes the disturbance almost entirely in an east and west direction; its amount (maximum double amplitude) was 1.0 mm. The diagram which Prof. Keep sends from Mills



College indicates a slightly smaller disturbance in a direction southwest and northeast.

**SAN FRANCISCO, 1:00:15 p. m.** (Mr. William Ireland).—Intensity=IV, Rossi-Forel scale.

Following is a newspaper account of the shock as felt at San Leandro May 11: "A very heavy shock of earthquake was felt at this place at 1:03 o'clock this afternoon. The oscillations were north and south and the duration 5 or 6 seconds. No damage reported, although many of the older houses in town were loosened up considerably, notably the depot of the Southern Pacific Company."

**May 14.—SANTA CRUZ**—The following general account is taken from the newspaper of even date:

"**SANTA CRUZ, May 14.**—Ever since the big earthquake of the 24th of April there have been daily seismic disturbances along the line between Pajaro and San Juan, where the earthquake was heaviest. Each day three or four small shocks occur, and yesterday six quite pronounced ones were felt. Two were felt at 5 o'clock this morning in this city. The fissure made on the Chittenden ranch, above Pajaro, during the big earthquake has been gradually increasing in depth and width. The railroad company is keeping a force of carpenters in the vicinity of the bridges between Pajaro and Gilroy for fear of damage by the shocks if they get heavier. It is said that there will be no change of the time card on the coast division until the earthquakes cease, as the company does not want to put on the Monterey flyer for fear of accident."

**June 1.—HEALDSBURG, 1:21 p. m.**—Slight shock.

**June 29.—SANTA ROSA, 7:25 a. m.** (newspaper).—"Three distinct shocks; people awakened; vibrations from north to south."

**June 30.**—Our information of this earthquake is comprised in the following three dispatches found in the newspapers:

"**PETALUMA, June 30.**—An earthquake shock passed through this city yesterday morning about 6 o'clock. The vibrations were from east to west."

"**SANTA ROSA, June 30.**—Three earthquake shocks were felt here about 11 o'clock. They were not quite as severe as those in the morning."

"**SANTA CRUZ, June 30.**—Earthquake shocks in this city at 12:30 this afternoon shook all the houses in town. The first shock was slight and was followed in a second by a much heavier shake. No damage was done. The vibrations were east and west. A private telegram from Sargent station, near the center of the seismic disturbance last April, states that the shock was quite severe there, breaking crockery in the houses."

**July 1.**—The following account appears to be from a San Francisco newspaper of even date:

"At 33 minutes past midnight of Monday there was a sharp shock of earthquake felt in this city, lasting ten seconds. The direction of the

vibrations was principally northwest and southeast, with a shock nearly north and south. It was felt in nearly all portions of the city and had the effect of rousing many people from their slumbers. Gas fixtures and windows were set rattling, and in some houses picture frames, loosely fastened on the walls, were thrown to the floors. It was not noticeable by people walking on the streets, and had no distinct violence in the down-town hotels."

GILROY, 12:35 a. m. (newspaper).—"Sharp shock from north to south lasting about one minute."

**July 4.**—EUREKA, 4:30 p. m. (newspaper).—"Quite a sharp shock."

**July 24.**—BAKERSFIELD, 3 a. m. (newspaper).—"Severe shock."

**July 26.**—The Examiner contains the following:

"SISSONS, July 26.—There were three earthquake shocks this morning at 1:45 o'clock. The vibrations were north and south."

"HYDESVILLE, July 26.—Several severe shocks of an earthquake were felt at this place at 1:40 a. m. to-day, lasting about twenty seconds, and another slight shock at 8 o'clock."

**July 28.**—PETALUMA, 12:03:35 a. m. (newspaper).—Two slight shocks from north to south.

**August 17.**—MILLS COLLEGE, 6:50 a. m. (Prof. Keep).—Slight, but distinct shock. The tracing of the seismograph shows three vibrations (averaging 0.3 mm.), in a direction from one point south of east to one point north of west.

**August 23.**—MONO LAKE.—The following is from the Homer Index:

"Remarkable earthquake at Mono.—The southern end of Mono Lake was considerably agitated last Sunday, and dwellers in that shaky locality were much perturbed. Steam was issuing from the lake as far as could be seen, in sudden puffs, and the water was boiling fiercely, like a bean pot, while high waves rolled upon the beach and receding left the sand smoking. In a moment the air was thick with blinding hot sulphurous vapor, and subterraneous moans and rumblings made the witness think that the devil was holding high carnival down below. The fences wobbled up and down and sideways; the wood pile at Nay's ranch locked arms with a big freight wagon and waltzed around the barnyard gleefully to the dismal bellowing of the dismayed cattle and the shrill neighing of terrified horses.

"This appalling fracas lasted about two minutes. Then came a blessed quiet for a moment, followed by a sudden twitch of the earth, as a horse jerks his hide and dislodges a bothersome fly. The shock threw men and animals off their feet with bruising violence, but it was the wind-up of the entertainment, which Mr. Nay hopes will not be soon repeated.

"It was some hours before the lake ceased to emit columns of steam and the water became very hot. Two springs near the house, long noted for the coldness and purity of their water, changed their character and spouted hot mud for two days, when they flowed cold water

again. A stack of 200 tons of hay was moved 70 feet south without disarranging it."

**September 3.**—MOUNT HAMILTON, 2:21:20 p. m. (accurate to one or two seconds), P. S. T.—Felt by Prof. Holden in third story of brick house and estimated by him at II on Rossi-Forel scale. Recorded on duplex seismometer, but did not start Ewing.

A slight shock was also felt at SAN FRANCISCO at 2:30 p. m.; likewise at GILROY.

**September 4.**—MOUNT HAMILTON, 10:06:45 a. m. (E. C. Holden).—"Swung the hanging lamp in my study."—E. S. Holden.

**September 5.**—MERCED, 2:15 p. m.—Vibration east and west.

**September 19.**—The record of earthquakes under this date consists of the following dispatches to San Francisco papers:

"CALICO, September 19.—A severe shock of earthquake occurred at 12:15 last night. There were vibrations east and west. There was another shock fifteen minutes later."

"DAGGETT, September 19.—Two earthquakes were felt here at 12:25 and 12:50 this morning. The vibrations were east and west. No damage was done."

"SAN BERNARDINO, September 19.—A light earthquake shock visited this city a little after 12 o'clock this morning."

"BARSTOW, CALIFORNIA, September 19.—There was an earthquake at 12:15 this morning, with a rumbling sound. No damage."

**October 3.**—HEALDSBURG, 12:05 p. m. (newspaper).—"Sharp shock, accompanied by long and distinct rumbling. Vibrations north and south."

**October 29.**—MOUNT HAMILTON.—Two distinct shocks.

First—8:36:29 a. m.  $\pm$  2s., P. S. T. Rossi-Forel, IV to V.

Second—8:39:29 a. m.  $\pm$  2s., P. S. T. Rossi-Forel, III. (Prof. Holden.)

Prof. Barnard reports as follows: "Coming to the observatory, half-way up the plank walk heard two distinct and heavy jars in the frame cottages as if they were falling down. These followed each other by about one or two seconds. *Did not feel any shock.* The noise of the shaking of the frame houses could have been heard perhaps an eighth of a mile. Reaching the observatory, another shock occurred; did not feel it; heard a rattling. This was at 8:39:35  $\pm$  one or two seconds, P. S. T.<sup>1</sup> I compared the clock in the earthquake instrument case with the Howard (this was for the first shock). Earthquake clock, 7:29:0; Howard 20:42:27."

**December 4.**—LONE PINE, 9 o'clock p. m. Ten distinct shocks felt from 9 to 11. No damage done. This was the seat of the great earthquake of March, 1872, in which many lives were lost.

"This is the first disturbance at Lone Pine for eight or ten years."—C. Mulholland.

## CHRONOLOGICAL RECORD, 1891.

**January 2.**—Generally felt throughout the state.

Prof. Holden telegraphed from the Lick Observatory as follows:

"**LICK OBSERVATORY** (Mount Hamilton), January 2.—A violent earthquake shock stopped our standard clock at eighteen seconds after noon to-day. The pendulum swings about north and south.

"Several ceilings were cracked in the observatory, and large pieces of plaster were thrown down in the brick houses. So far as I know no damage was done to the instruments. The earthquake registers indicate by far the severest shock since 1868 in northern California. Its intensity was VII on the Rossi-Forel scale. The pen of the duplex seismometer was thrown completely off the glass plate. Some definite idea of the force may be had when I say that a swinging lamp, making a pendulum of about 15 inches in length, which is suspended in my study, was still in vibration twenty minutes after the shock.

"Framed photographs on my mantel were overthrown. It appears that serious damage would be done to the houses here by a shock of twice this intensity, but it looks as if the observatory would stand considerably more. The large telescope has been secured to its base by four holding-down bolts, and it is as safe as it can be made."

Prof. Davidson's observation will be found among others reported below:

"San Francisco was visited by two distinct shocks of earthquake at noon yesterday (Jan. 2). Both shocks were distinct, but of a different movement, the first being vibratory, the second proving of the type known to seismic observers as undulatory.

"Prof. Davidson states that his chronograph recorded the time of the shock to be 12:00:40, with an entire duration of fifty seconds. A comparison of directions observed by various persons indicates the wave to have moved from southeast to northwest. In the lower portion of the city, from Kearny street to the water front, the shocks are said to have resembled the rumbling of a wagon, while in the more elevated residences the vibratory movement was perceptibly felt.

"**SANTA CRUZ**, January 2.—There was a heavy earthquake here at 12:02 this afternoon. The shock, which passed from southwest to northeast, lasted ten seconds, and was the heaviest felt here in years. Only very slight damage was done, but the people were greatly frightened.

"**SALINAS**, January 2.—A very severe shock of earthquake was felt here at 12 o'clock noon to-day. The vibrations were from north to south.

"**EL VERANO**, January 2.—A severe shock of earthquake was felt here to-day at 12:20 o'clock. It moved from southeast to northwest. Houses were shaken up.

"**LOS GATOS**, January 2.—A sharp shock of earthquake was preceded by a rumbling sound at 12:01 o'clock this afternoon. The duration of the shock was fifteen seconds. No damage.

"GILROY, January 2.—One of the heaviest earthquakes ever felt here occurred at 12:01 this afternoon. The duration was less than half a minute, but it was accompanied by heavy rumblings and a sickening, swaying sensation. Gas fixtures and movables swayed and clattered considerably.

"STOCKTON, January 2.—Rather a sharp shock of earthquake was felt here precisely at 12 noon. The vibrations were south to north.

"LATHROP, January 2.—There was a severe shock of earthquake at 12 o'clock to-day. Houses squeaked, clocks stopped, lamp chimneys were broken, etc. No further damage was done. Apparently the direction of the shock was from east to west.

"MODESTO, January 2.—A sharp earthquake shock was felt here at noon to-day. The shock lasted fifteen seconds. The vibrations were north and south.

"SAN JOSE, January 2.—At 12 o'clock a sharp earthquake shock was felt here, the movement being north and south, and it lasted about fifteen seconds. Clocks were stopped and buildings rocked, but no damage was reported.

"PETALUMA, January 2.—This afternoon, a few minutes past 12, a sharp shock of earthquake passed through Petaluma, with vibrations from east to west.

"SAN LEANDRO, January 2.—A sharp earthquake shock was felt here to-day at 12:02. The oscillations were from northeast to southwest. The duration was about ten seconds.

"SAN RAFAEL, January 2.—A rather sharp earthquake shock was felt here at 12 noon to-day, lasting several seconds. The vibrations were from east to west.

"BOULDER CREEK, January 2.—A severe shock of earthquake was felt here at 12 o'clock, continuing for several seconds. The vibration was from southwest to northeast. There was a general rush for the streets, but no damage was done.

"SPANISHTOWN, January 2.—A severe shock of earthquake occurred at three minutes before noon to-day. The vibrations were from east to west.

"MERCED, January 2.—A slight shock of earthquake was felt here at 12 o'clock to-day with vibrations from east to west. The shake was heavy enough to cause the glassware on the shelves to rattle.

"REDWOOD CITY, January 2.—Two sharp shocks of earthquake were felt here to-day at two minutes past noon. The vibrations were east and west."—San Francisco Examiner.

SAN JOSE, January 2.—"Buildings shaken so that their motion was plainly visible. Many clocks stopped at 12:00:30 p. m."—San Jose Herald.

Seismographic records obtained at Mills College by Prof. Keep and at Oakland by Mr. Blinn show the greatest disturbance to be in a direction running from northeast to southwest.

Mr. Blinn's seismometer gives a diagram indicating that the maximum double amplitude of the pendulum was 3.8 mm. The diagram consists of many (not less than 25) intersecting loops. So far as one may judge from the tracing, the instrument was in good adjustment.

Prof. Keep's tracing is of the same general character, but with a maximum double amplitude of 5.8 mm.

These maximum double amplitudes probably indicate very little in a diagram of this kind, in which the pendulum makes so many vibrations; for one can not tell to what extent it is a "resonance" phenomenon.

The Carson City seismometer (C. W. Friend) gives a tracing even more complicated than either of the preceding; it is the smallest of the three, but every azimuth is filled with fine lines.

The glass plate of the San Jose instrument was jarred by the earthquake and the record spoiled.

A third shock of intensity III on Rossi-Forel scale is reported by Prof. Holden as occurring at the Lick Observatory at 8:18:21 p. m.

**January 12.**—BERKELEY, 1:36 a. m.—Prof. Hilgard reports a "light earth-tremor lasting a little less than a second, but preceded by a marked rumbling from the southwest."

**January 13.**—MOUNT HAMILTON, 2:58 p. m., I to II Rossi-Forel scale; observed by Mrs. Breseno.

**February 15.**—DOWNIEVILLE.—Quite a shock felt between 2 and 3 a. m.

**January 21.**—SAN FRANCISCO, 2:24:35½ p. m.—Artificial earthquake, caused by the explosion of 3,000 pounds of blasting powder, for the purpose of clearing away a hill in San Francisco.

But few rocks were scattered; the hill collapsed and the earth in the neighborhood showed deep crevices.

No disturbance was observed on the San Jose seismograph, which was watched by Prof. George. Nor was any record obtained at Mount Hamilton, where it was looked for with mercury basins.<sup>1</sup>

**February 24.**—INDEPENDENCE, 3:10 a. m.—Reported by Mr. C. Mulholland as follows: "A strong earthquake shock. The tremor was preceded an instant by a rumbling sound. The motion appeared to be a little east of south to west of north, i. e., parallel to the Sierra Nevada Mountains. The house shook so that the pans and dishes rattled. A strong breeze from the south had been blowing all night, but at the time of the tremor there was a brief but complete lull; then the breeze set in as before."

**April 4.**—MOUNT HAMILTON, 4:30 a. m.—"A light, but prolonged shock from east to west," reported by Prof. Holden.

**April 12.**—MOUNT HAMILTON, 9:29 (?) 41.—"A sudden, slight earthquake of intensity II, Rossi-Forel scale," reported by Prof. Holden.

**April 13.**—HEALDSBURG.—A sharp shock at 11:40 p. m.

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<sup>1</sup>Publications Astronomical Society of the Pacific, vol. III, page 132.

VISALIA.—Earthquake at 10:30 p. m. Vibrations from north to south.

**May 8.**—BERKELEY, 6:10 p. m.—Prof. Frank Soulé writes: "Very slight in San Francisco and Oakland, so much so that comparatively few people noticed it. The Ewing and Gray-Milne instruments, though in excellent order and very sensitive, were not set off. The duplex gave a small record indicating that the direction of the shock was from northwest to southeast. From individual accounts, I should rate it as II in the Rossi-Forel scale."

SAN RAFAEL, 6:08 p. m.—A heavy shock lasting about six seconds. The vibrations were from west to east.

**May 19.**—SUSANVILLE.—Seven shocks felt; two very heavy; time not reported.

**May 20.**—MILLS COLLEGE.—Prof. Keep writes: "An earthquake was felt here last night about 10 o'clock. The shock was slight, but was preceded by a peculiar sound which made me brace myself for a severe shock."

The seismographic record accompanying this letter shows the greatest disturbance to have been in a north and south direction.

**June 22.**—PASADENA AND SAN FERNANDO.—Slight shocks felt between 8 and 9 o'clock in the evening.

**June 28.**—SAN FRANCISCO, 3:02:45 a. m.—Reported in San Francisco Chronicle as follows: "A double shock of earthquake occurred early yesterday morning. It was not heavy, and was of such brief duration that not many of the citizens who were awake at the time could have noted it. F. W. Edmonds, the assistant in Prof. Davidson's observatory, was at work when the shock came and noted its features, afterward comparing his figures with those recorded by a small seismograph. The first shock began at 3:02:45, Pacific standard time, and ended five seconds later. The vibrations were east and west. Then at 3:03:05 there was another shock, so brief that the duration was not recorded. It was sharper than the first shake, but had the same motion."

"Prof. Davidson remarked to a Chronicle reporter yesterday that one night last week, while he was making observations for latitude, there was an almost imperceptible quake. He was reading the level of the instrument at the time and noticed that it was suddenly shaken, the bubble moving backward and forward several times in quick succession. The extremes of this motion as marked by the bubble were three or four millimeters apart. The vibrations were north and south."

MOUNT HAMILTON.—Waked sleepers, set hanging lamps in vibration, rattled windows, pictures, stoves, etc. Ewing seismograph clock did not start; components were therefore recorded as straight lines. The actual displacements of the earth were as follows: North and south = 0.24 inches; east and west = 0.39 inches; vertical = 0.15 inches.

Prof. Holden makes the time 3:02:08<sup>1</sup> ± 20s. P. S. T.

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<sup>1</sup>The first time here given is probably wrong. E. S. H.

Mr. Campbell makes the time 3:02:36  $\pm$  2s. P. S. T.

Mr. Schaeberle makes the time 3:02:35 (watch). P. S. T.

Intensity on Rossi-Forel scale, V.

MAYFIELD.—“A slight shock of earthquake was felt here at 3 o'clock this morning. It lasted four seconds. Trembling vibrations were followed by two shocks.”—Telegram to San Francisco Chronicle.

**June 29.**—MOUNT HAMILTON, 8:06:31  $\pm$  2 a. m. (W. W. Campbell); 8:06:32 (J. M. Schaeberle).—One quick shock lasting for less than half a second; Rossi-Forel I or II. “Recorded on duplex, but not on Ewing seismometer.” No record of measured displacements.

**July 13.**—MONTEREY, 4:27 p. m.—A sharp shock with vibrations from southwest to northeast. Clocks were stopped and crockery thrown from the shelves.

**July 17.**—HOLLISTER, 1 a. m.—Quite a severe shock; no damage.

**July 30.**—LERDO, MEX., was the center of a very severe earthquake about 6 o'clock a. m. It appears to have caused a tidal wave of considerable height at the head of the Gulf of California. The country is so thinly and poorly settled that no damage was done. The reports of this earthquake are so indefinite and contradictory that we have really very little reliable information regarding what must have been at least a very widespread disturbance. One newspaper report from Yuma, Arizona, makes the direction of the shock from east to west. Among other curious freaks a number of salt springs are said to have been made fresh; but judging from later investigations made by a Chronicle reporter who visited the scene, no reliance is to be placed on any statement of this kind.

**August 9.**—MONTEREY, 9:41 a. m.—A heavy shock, causing buildings to rock. The vibration was from north to south.

**September 12.**—CEDAR CITY, UTAH, 8:48 p. m. (C. Mulholland).—“Shock heavy and accompanied by a sound like that of a heavily loaded wagon passing over a street paved with granite blocks. Its duration was brief, and there was but one shock.”

**September 16.**—SALEM, OREGON, 8:30 p. m.—The shock was brief and distinct, and was followed by a wave-like motion lasting several seconds. It was felt in all large buildings; windows rattled.

**September 21.**—PORT ANGELES, WASH.—Reports differ as to time, some claiming that the shock occurred at 4:10 a. m., others at 5 a. m. It is possible there were two distinct shocks. The direction of vibration was from northwest to southeast. Many people were awakened from sleep. Houses trembled and chinaware rattled.

PORT TOWNSEND.—Shock felt shortly after 4 o'clock a. m. Dishes rattled and sleeping people were awakened.

**September 22.**—VICTORIA, B. C., 3:40 a. m.—Sharp shock felt all over city; lasted about seven seconds.

**September 23.**—HEALDSBURG, 1:30 p. m.—“Very severe and long-continued shock; one of the most severe ever felt in this vicinity.”



**October 2.**—MOUNT HAMILTON.—Prof. Barnard reports as follows: "From one and one-half to two seconds' duration. A very decided shock. Gradually increased in intensity. 7:19:55 P. S. T. end of shock."

Prof. Holden gives the time as 7:19:55. Intensity II on Rossi-Forel scale. No record on seismometers.

**October 11.**—Felt generally over the central portion of the state. Following are the newspaper accounts:

"SAN FRANCISCO.—A slight earthquake shock was felt throughout the city last night. It seemed like the heavy, noisy rumble of a cart, and was perceptibly felt in every part of the town. Prof. Davidson was at work in his observatory when it occurred. He did not consider it severe enough to disturb him in his investigations, as the pier upon which his instrument is placed was not thrown out of level in the slightest degree. The earthquake lasted for thirteen seconds, beginning at twenty-seven minutes and thirty-two seconds after 10 o'clock and ending at twenty-seven minutes and forty-five seconds after 10 o'clock. An unusual feature of the shock was that it began light and gradually increased until it was greatest during the last three seconds. The direction was southeast to east-southeast. Prof. Davidson had no means of ascertaining the velocity of the shock, but he did not consider it in any way severe."

Mr. Burckhalter reports from the Chabot Observatory that the mean time clock was stopped at 10:27:49 p. m. His seismograph shows the actual displacement of the earth to have been 2.5 mm. in an east and west direction.

"SUISUN, October 11.—At 10:29 o'clock to-night a heavy shock of earthquake shook up this quiet little city in a frightful manner. The shock lasted nearly half a minute. It was the heaviest earthquake known of here for years. The damage is slight, but the fright of the people was extreme.

"OAKLAND, October 11.—A sharp shock of earthquake was felt here last night at 10:26, the vibrations being from north to south. Windows were shaken, but no damage done.

"SACRAMENTO, October 11.—A pretty lively shock of earthquake, or a double shock, was felt here at 10:28 to-night, but it was not heavy enough to do any damage. Many persons did not feel it.

"SAN JOSE, October 11.—A slight shock of earthquake was felt here at 10:28 this evening. The movement was from northeast to southwest.

"WINTERS, CAL., October 12.—There was a heavy shock of earthquake here last night about 10:30 o'clock. It was heavy enough to wake people from a sound sleep. The vibrations were from east to west and lasted two or three seconds.

"FAIRFIELD, CAL., October 12.—There was a heavy shock of earth-

quake here last night at 10:30 p. m. and another at 4 a. m., but no serious damage was done.

"SPANISHTOWN, CAL., October 12.—Quite a heavy shock of earthquake was felt here at 9:29 last evening.

"SONOMA, October 12.—Sonoma and vicinity were visited last night at 10:28 o'clock by the severest earthquake ever felt in this section of the State. The people were shaken out of their beds, chimneys were demolished, windows broken, and the interior of almost every plastered house in the town shows effects of the shock, which lasted about eight seconds. The temblor was a series of vicious twisters. Pickett's residence and wine cellar at the outskirts of town were badly damaged, the interior of the house presenting a scene of desolation. On S. F. Ringstrom's farm a large chimney fell and went crashing through the roof to the floor below. Several chimneys in town were also overthrown, but fortunately no one has been injured. Reports from all over the valley show more or less damage. On the Polpula ranch, which contains a number of warm-water springs, the earthquake caused the water to gush forth in perfect torrents. The first shock of the evening was slight and felt at 9:15. Then came the heavy one, after which, at intervals of an hour or so, there were eight or ten other shocks. More or less damage was done to every building in Sonoma Valley. People are greatly excited and everybody is talking 'earthquake.'

"PETALUMA, October 12.—At twenty-five minutes past 10 last night the heaviest earthquake shock since 1868 passed through Petaluma. Door-bells were rung and some plastering badly cracked. The heavy shock was preceded a few minutes by a light one, and after it came six or seven other shocks, the last one being at 5 o'clock this morning. Many people were kept awake most of the night. The main shock lasted fully nine seconds.

"NAPA, October 12.—The heaviest earthquake shock ever felt here was experienced at 10:34 o'clock last night. The people rushed out into the streets greatly frightened, and the whole town was in commotion. The shock was especially heavy at the insane asylum, and the inmates were almost uncontrollable.

"The first shock came at 9:16, but it was light. At 10:29 came the heavy shock, which lasted forty-six seconds. It was a twisting motion from right to left. Some people fainted, and all were greatly exercised, but no fatalities are reported. Lighter shocks followed during the entire night. Some say there were twelve shakes, while others profess to have counted as high as seventeen. Some people remained in the street all night, and others did not sleep for fear of a repetition of the dread sensation. The damage will not be very heavy on any one building, but in the aggregate is considerable. Scores of chimneys are thrown down or turned three-fourths around. Many brick build-

ings are badly cracked, and the wall decorations in most of the fine houses are badly damaged, while nearly every house had some bric-a-brac and crockery destroyed. The insane asylum reports some damage to the walls and tower, but nothing serious.

**"ST. HELENA, October 12.**—The heaviest earthquake shock ever experienced here occurred at 10:30 o'clock last evening. Houses shook, crockery rattled, and clocks stopped. The vibrations appeared to be south to north, followed half an hour later by a light shock, and one also at 5 o'clock this morning.

**"SANTA ROSA, October 12.**—The severest earthquake shock felt here in four years occurred last night at 10:32 o'clock. The oscillations lasted forty-five seconds. A slight trembling was perceptible for three or four minutes.

**"SAN RAFAEL, October 12.**—The most severe earthquake experienced here for years was felt last night at 10:26 o'clock. The shock lasted about twelve seconds. It was preceded by a dull rumbling noise like a heavy wagon rolling over the pavement. Much excitement was caused, and saloons and business places open at the time were soon relieved of their patrons, everybody seeking refuge in the street. Two shocks of lesser power were felt this morning about 4 o'clock."

**October 13.**—MOUNT HAMILTON, 11:0:30 (Prof. Holden).—"Intensity II, Rossi-Forel scale."

Prof. Barnard reports as follows: "Three shocks of earthquake were felt in rapid succession. Interval between the individual shocks about one and a half seconds. The last of these three was the most severe. This occurred at 11:00:09 P. S. T. The shocks were simply quick jerks, and ought to have been powerful enough to wake a person from ordinary sleep."

MILLS COLLEGE, 10:28 p. m.—Prof. Keep sends a very complicated diagram from his seismograph, indicating disturbances in all directions. Maximum north and south = 3.0 mm.; maximum east and west = 4.0 mm.

The above figures are for the actual displacements of the earth.

**October 14.**—SAN FRANCISCO.—Felt in all parts of the city. Prof. Davidson says: "The last shake was similar to the one of the 11th instant in its wave-like vibrations. Its greatest force was during the first seven seconds, and its entire duration was ten seconds. Time of beginning, 4:33:23 o'clock. Direction of the vibration, north and south."

Following are newspaper accounts:

**"NAPA, October 14.**—The earth continues to tremble. Four shocks have been felt here this morning. At 4:30 a. m. the people were startled with quite a heavy shock, and several lighter ones have followed. The damage done by Sunday night's shock is much more than

was at first supposed and will amount to several thousand dollars. Many of the people here are so terrorized that they have hardly slept since Sunday evening, and the slightest shock now starts many into the streets."

"PETALUMA, CALIFORNIA, October 14.—Another lively earthquake shock passed through Petaluma this morning about 4:30 o'clock, and a much lighter one about 7. The vibrations were north to south."

"SUISUN, October 14.—Shortly after 4 o'clock this morning the people here were aroused from their slumbers by another sharp, severe shock of earthquake. It was not as severe as the first one that occurred on Sunday night."

"SAN RAFAEL, October 14.—Quite a severe earthquake shock was felt here this morning at 4:25 o'clock. The shock lasted about ten seconds. The vibrations were from west to east."

Prof. Keep reports that the seismograph at Mills College indicated an actual displacement of the earth in an east and west direction amounting to 1 mm.

**October 27.**—MOUNT HAMILTON, 6:35:43  $\pm$  1s. (Prof. Holden).—Intensity I or II on Rossi-Forel scale. Prof. Barnard reports this as "a decided shock," occurring at 6:35:44.

**November 8.**—ASHLAND, OREGON.—Following is the newspaper account: "The first time an earthquake shock has been felt in Ashland for years was last night about 8 o'clock, when a distinct shock, though light and lasting only a very few seconds, caused a general rattling of window panes in many buildings in town. Though the shock was not heavy enough to cause even timid people any alarm, many unused to such occurrences did not realize what the disturbance was at the time."

**November 29.**—SEATTLE.—At 3:21 o'clock this afternoon two shocks of earthquake, lasting about five seconds each, were felt here. No damage was done.

The direction of the vibrations was southeast to northwest. One building swayed so much that the elevator bumped against the side of the shaft and could not move until the shock was over. Lake Washington, on the east side of town, was lashed into a foam, and the water rolled on to the beach 2 feet above the mark of the highest water and 8 feet above the present stage.

Reports from Snohomish and Bellingham Bay towns say the shock was plainly felt there.

**PORT TOWNSEND, November 29.**—A distinct shock of earthquake was felt here at 3:14 this afternoon. The shock continued fully twenty seconds. Buildings shook, windows rattled, and many persons rushed out of their houses. There was no damage done.

**TACOMA, November 29.**—A slight earthquake was felt all over the city at 3:16 this afternoon. No damage was done. Dispatches say there was a severe shock but no damage done at Olympia.

MENDOCINO, November 29.—Two shocks of earthquake were felt last night at 10:45 o'clock, preceded by a rumbling noise. There were two-minute intervals.

**December 16.**—MOUNT HAMILTON, 8:28:12 a. m.—Prof. Schaebarle estimates the intensity at I on the Rossi-Forel scale.

**December 21.**—MOUNT HAMILTON, 6:15:41  $\pm$  p. m. (Prof. Holden).—Intensity II on Rossi-Forel scale.

**December 29.**—MOUNT HAMILTON, 3:26:56  $\pm$  3s. a. m.—Intensity I to II on Rossi-Forel scale.



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