HISTORY OF THE UNIVERSITY OF CALIFORNIA SEISMOGRAPHIC STATIONS AND RELATED ACTIVITIES*

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THE SEISMOGRAPHIC stations at Mount Hamilton and Berkeley present several items of interest in the history of earthquake science, one of which is that according to the available records they were the first seismographic stations set up in America. Furthermore, they have functioned continuously from their founding to the present day, with improvements in instrumental equipment from time to time as the development of the science and opportunity have permitted.

Several outstanding figures in the seismology of the 1880's were impressed with the importance of these stations, and Ewing, Milne, and Gray each took a personal interest in aiding one or both stations to obtain their own best and most modern types of instruments.

It often happens that in the advancement of science the prevailing importance of the current equipment, methods, and theoretical developments makes earlier efforts seem rather unimportant, and the true historic perspective may for many be lost. Several statements that have appeared in print in recent years concerning the earlier period of these stations seem to indicate this influence, and one purpose of the present paper is to attempt to present the early history with a minimum of distortion and error. To quote an example, a publication that has had wide distribution among seismologists, the *Bulletin of the National Research Council*, No. 15 (1921), carries the following entries:

Berkeley, California. Seismologic Station, inaugurated October 30, 1910 (Earlier service with earlier equipment from 1885).

Mount Hamilton, California. Lick Observatory, Seismologic service, inaugurated in 1887, with present equipment May 23, 1911.

This rather definitely indicates that the two stations were quite different and had an entirely different history, and that, while some sort of equipment was set up at Berkeley two years before the Mount Hamilton installation, it was of a character so inferior—perhaps even trivial—that the station cannot be considered as "inaugurated" until twenty-three years after the one at Mount Hamilton. This ignores one of the most important facts in the history of these stations: that they were organized under the same general plan, at the same time, with identical fundamental equipment, to serve as nuclei for a comprehensive seismological study of a region of noteworthy earthquake activity.

Instrumental earthquake recording came to California largely through the

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influence and under the direct operational control of astronomers. The 1880's were an important decade for astronomy in California. In 1875 James Lick[1] set up a trust for the construction of an astronomical observatory on Mount Hamilton, which was to contain the largest refracting telescope ever built, together with other important equipment, and which on completion was to be turned over by the trustees to the Regents of the University of California. The legal transfer was made on June 1, 1888, and the formal ceremonies were held on Commencement Day in Berkeley, June 27, 1888.

In the meantime, the California Legislature of 1882–83 appropriated funds for the purchase of astronomical instruments for an observatory, primarily for the instruction of students, at Berkeley, and the Legislature of 1884–85 followed this up with an appropriation for a building to house these instruments. The astronomical instruments were purchased in the fiscal year 1885–86, and the building was started late in 1885 and completed sometime in 1886, the nearest date found in the record being a report to the Board of Regents, March 2, 1886, that the building was nearly complete. Apparently some volunteer students had observatory practice in the spring of 1886; the first regular class was conducted during the academic year 1886–87.

E. S. Holden was elected President of the University at a meeting of the Regents, October 20, 1885, and was formally inaugurated May 25, 1886. In a letter to the Regents he made it clear that his primary interest was in astronomy and his ambition was to be director of the Lick Observatory. As a service to the University he would be willing to act as President, but only until such time as the Lick Observatory should be completed and officially inaugurated as an operating department. The Regents accepted his resignation, to be effective on the date of the formal transfer of the Lick Observatory, and confirmed his appointment as Director of the Lick Observatory.

These details are given because, as a result of these events, Holden was to have a preponderant influence on the seismographic setup and activity at both Berkeley and Mount Hamilton. During these critical years, 1886–1888, when the Lick Observatory was being completed and equipped and the Students' Observatory at Berkeley was put into commission, he was President of the University, with office at Berkeley, and at the same time Director of the Lick Observatory.

Appreciating that these observatories were situated in an active seismic region, Holden considered it necessary to "keep a register of all earthquake shocks in order to be able to control the positions of the astronomical instruments." He wished to have the best available instruments for this purpose and

[1] The original Lick trust deed was dated July 16, 1874, and provided for an observatory at Lake Tahoe. As a result of a disagreement with the donor, the trustees all resigned. Lick then had another deed of trust prepared which he signed September 21, 1875, designating Mount Hamilton as the site, and providing for the transfer of ownership of the completed observatory to the Regents. It was under this second deed that the Lick Observatory was actually brought into existence.

after some inquiry and investigation of the subject came to the conclusion that "the most satisfactory instruments which I have seen . . . are those invented by Professor Ewing, F.R.S."[2] They were therefore ordered from the Cambridge Scientific Instrument Company, and were constructed under Ewing's personal supervision. The instruments were delivered in the spring of 1887.[3]

The equipment is briefly described as follows in the *Handbook of the Lick Observatory of the University of California* (1888):

1. A Horizontal Seismograph, with clock and driving plate. The clock is started by an electrical contact at the beginning of the earthquake, and the two rectangular components of the horizontal motion are registered side by side on a moving plate.

2. A Vertical Motion Seismograph, to register the vertical movement of the earth on the same plate.

3. A Duplex Pendulum Seismograph, to give independent records of the horizontal motion on a fixed plate, the pencil being free to move in all azimuths.

4. A chronograph attachment which is set in motion at the beginning of a shock, and records the time of its occurrence by one of the standard clocks. It also marks the clock seconds upon the revolving plate of No. 1. An instrument by Professor Milne designed to do the same work as No. 3 is also provided.

Elsewhere he says: "Another complete set, exactly similar, belongs to the University of California at Berkeley, and is installed in the Students' Observatory there, under charge of Professor Soulé. This [Students'] Observatory also has a Gray-Milne seismometer, complete." The *University of California Register* for 1887–88 says: "In a separate building, mounted on a masonry pier, are one Ewing, one Gray, and two duplex seismographs, having both time and electric connections."[4]

[2] Evidently, Professor Joseph LeConte also considered the instruments the best obtainable, for in an article dated June 21, 1887, and printed in *Science*, Vol. 10, p. 24 (July 8, 1887), he said, in reference to seismographs, "The University of California has recently gotten three of these of the best character." (That is, two Ewings and one Gray-Milne.)

[3] Director W. H. Wright stated (in a personal communication dated November 8, 1941): "I have found a copy of the bill by the Cambridge Scientific Instrument Company, the original having been sent to the New York Custom House. It is dated January 26, 1887, and was paid on May 12 of that year by draft on the Bank of California." The bill for the Berkeley instruments was ordered paid by the Regents at their monthly meeting of May 21, 1887. This is all consonant with the idea of Professor Leuschner, who was a student at the Lick Observatory, 1888–1890, that the instruments for both stations were transported in the same shipment. They probably reached their respective destinations in late March or in April, 1887. It is of interest to note that the sum for the purchase of the Berkeley instruments, both the Ewing sets and the Gray-Milne, were charged to the 1886–87 budget of the Geology and Natural History Department, at the head of which was Joseph LeConte. He was instrumental in obtaining the Berkeley instruments and collaborated with Holden in establishing the associated stations, but the Berkeley equipment was set up in connection with the Students' Observatory, and was tended, and the records were kept, by the Observatory personnel until 1910.

[4] The statements concerning automatic time recording at both Mount Hamilton and Berkeley give a quite different picture of the setup from that indicated by Gutenberg in his article on "Seismology" in *Geology, 1888–1938*, published by the Geological Society of America in 1941. Gutenberg says, in reference to these apparently first seismographs in the United States (p. 455), "The time of beginning had to be noted on a watch," and gives Holden as authority (*Catalogue of Earthquakes on the Pacific Coast 1769–1897*). But Holden's statement about the use of a watch for timing (p. 22) applied only to some cheap duplex pendulums mounted at private houses and in other locations where instruments for automatic accurate timing were not available, and not to the instruments at either observatory.

The Mount Hamilton instruments were described and illustrated by woodcuts in Volume 1 of the Publications of the Lick Observatory (1886), and elsewhere at later dates.

The California System.—One of the most interesting of Holden's ideas was that of developing a coördinated group of stations, to better learn the mode of action of the earthquakes and the seismic characteristics of the terrain. This latter purpose still appealed to him strongly over a decade later when he stated in his second earthquake catalogue (1898): "It would be of extreme interest if a series of such machines could be distributed around the Santa Clara valley, so as to encircle it on both sides, and so as to be situated on like geological strata. A line of instruments in the valley from Gilroy to San Francisco, and another line on the east side of the bay, would be required. A few years' observations carefully studied would, I think, bring out results of consequence. The basin of Clear Lake should be studied in the same way, as its shocks appear to be of a special class."

Students of earthquake phenomena have often expressed the desire for a liberal distribution of seismographs so that localized variations in earthquake action and relative distribution of intensities could be more definitely and accurately determined than by estimates based on the disturbance, injury, or destruction of a heterogeneous list of objects and structures on which we must usually depend, but the expense of installation and the difficult problem of adequate supervision and servicing have prevented any elaborate development of such a scheme. Holden was faced with the same problem, and concluded that it was not feasible at that time to have the more elaborate instruments installed elsewhere than at Mount Hamilton and Berkeley. The Ewing Duplex Pendulum, however, seemed to be "well suited for general purposes." Holden arranged with an electrical works in San Francisco to construct inexpensive copies of this instrument, which were sold for $15 apiece. His remaining problem was to find collaborators who would be willing to provide space and proper installation and agree to report all earthquake records. The glass plate carrying the record was to be sent to the Lick Observatory, where measurements would be made and blueprints prepared. A set of directions prepared by Holden and Professor Joseph LeConte was sent to each collaborator.[5]

This coöperative scheme, consisting of "two complete seismometric stations, at Berkeley and at Mt. Hamilton," together with the group of stations furnished with duplex seismographs, was called by Holden "The California System."[6] All reports and/or actual records, tracings, or blueprints were to be

[5] Reproduced in *Catalogue of Earthquakes on the Pacific Coast 1769–1897* (1898), pp. 21, 22. The main use of these records was based on the form of the tracing, giving the "magnitude of the earthquake force in any two directions." Time, if noted, was determined by the collaborator's watch, the accuracy of which was to be checked soon afterward at a near-by railroad station. All railroad stations at that time were receiving noon time signals from the Lick Observatory.

[6] Astronomical Society of the Pacific, *Publications*, Vol. 2, p. 73 (1890).

sent to the Lick Observatory, where they were to be studied and arrangements were to be made for their publication. If not the first, this was one of the earliest sets of closely coördinated seismographic stations, and certainly the first in America.

The instrumental equipment, especially of the collaborating stations, when compared with present-day instruments, appears inadequate, but at the time it was considered to represent an important step in seismologic science. Even the results of the Duplex Pendulums in California were considered to be of value, as is shown for example by the statement of Dr. Ehlert in 1897 (p. 363):

> Wir kommen nun zu der geistvollsten Art der Kompensation, welche in unserem Gebiete je erdacht worden ist, und welche die vorigen Methoden an praktischer Vollkommenheit wohl noch übertrifft, wie die zahlreichen Beweise in Tokio selbst, aber auch in Californien darthun. Es ist das Ewing'sche Doppelpendel vom Jahre 1882.[7]

The original list of stations that agreed to coöperate with the Lick Observatory included, according to Holden's statement:

1. San Francisco, near Cliff House, residence of Hon. A. Sutro
2. San Francisco, 917 Pine Street, residence of Hon. J. R. Jarboe
3. Chabot Observatory, Oakland, in charge of Mr. Burckhalter
4. Private observatory of Mr. Blinn in East Oakland
5. Kono Tayee, Clear Lake, residence of Capt. R. S. Floyd
6. Observatory of University of the Pacific, San Jose, in charge of Professor Higbee
7. Students' Observatory, Berkeley, in charge of Professor Soulé
8. Office of the State Weather Bureau, Carson, Nevada, in charge of Charles Friend, Esq.

All stations were prepared to operate in 1888. As far as the printed records indicate, no usable reports were ever received from stations 1 and 5, although they were still listed in Holden's earthquake catalogue published in 1898. Station 2 was very active during 1888, but was not heard from after that year. Station 4 reported regularly for three years and then passed into inactivity. All the other original stations, together with two that were added later, continued reporting until the disintegration of this early "California System," which took place at the end of 1898 shortly after Holden left the Lick Observatory. The two added stations were:

9. Observatory of Mills College near Oakland, in charge of Professor Josiah Keep, which started effective operation in 1889.
10. Alameda, residence of C. D. Perrine (a member of the Lick Observatory staff), 2138 Alameda Avenue, started reporting in 1892.

After the demise of the coöperative system, most of these stations continued to function, but without a central station to which they reported and by which their records were studied and results prepared for publication. It is not the purpose of the present article to follow the later history of the individual sta-

[7] R. Ehlert, "Zusammenstellung, Erläuterung und kritische Beurtheilung der wichtigsten Seismometer mit besonderer Berücksichtigung ihrer praktischen Verwendbarkeit," *Gerlands Beitr. z. Geophysik*, 3:350–474 (3. Heft 1897).

tions that collaborated in the California System, but a few data may be recorded that give some idea of the duration of their later activity.

In the report of the State Earthquake Investigation Commission on the California earthquake of April 18, 1906, Vol. 2, pp. 59–108 (1910), is presented a list of all known stations and their records of this world-shaking earthquake. Of the California stations listed above, the following were reported:

Berkeley, California. Students Astronomical Observatory. Prof. Leuschner, director
Oakland, California. Chabot Observatory. Prof. Charles Burckhalter, director
Alameda,[8] California. Mills College Observatory. Prof. Josiah Keep, director
San Jose, California. University of the Pacific. Prof. J. Culver Hartzell, director.
Mt. Hamilton, California. Lick Observatory. Prof. W. W. Campbell, director
Carson City, Nevada. Carson Observatory. Prof. C. W. Friend, director

It may be noted that the Chabot Observatory, Mills College Observatory, and Carson Observatory were in 1906 still under the direction of the men who made the coöperative arrangement with Holden in the 1880's. Professor Friend died in January, 1907, and the Carson Observatory apparently died with him.

In the 1921 "List of Seismologic Stations of the World," published by the National Research Council (*Bulletin 15*), besides the Berkeley and Mount Hamilton stations, only the University of the Pacific Station at San Jose[9] is mentioned of the old coöperating group. By the time of the Research Council's 1931 list, all but the Berkeley and Mount Hamilton stations were out.

Earliest records.—As stated above, the instruments for the Berkeley and Mount Hamilton stations arrived from England early in 1887. Although work at the Lick Observatory was not officially inaugurated until June, 1888, so that the Secretary of the Regents in his report of 1889 could say (p. 128), "During the first 12 months of the Observatory's existence [June 1, 1888, to June 1, 1889] 5801 persons have recorded their names in the visitors' book at the Lick Observatory," instruments were set up and operating before that time. The Duplex Pendulum must have been set up very soon after its receipt, because the first record was of an earthquake of April 24, 1887. "Slight shock recorded on seismometer," estimated as intensity II R.-F., time given only as "night." Two more were similarly noted in May. The first record giving time was on July 6, 1887, $10^h\ 15^m\ 10^s$ P.M., the direction of motion and amplitude also being noted. This time was apparently not by earthquake clock, but noted by an astronomer (J. E. Keeler) who was on duty as an observer. The first earthquake recorded on the three-component machine was on April 28, 1888.

At Berkeley, the first record of the Duplex Pendulum was due to an explosion at the powder works in North Berkeley, August 11, 1887, at 1:20 P.M. The first earthquake was recorded August 19, 1887, at 1:02 A.M. The first

[8] Alameda is an erroneous location. This observatory was never in Alameda, but in outlying territory east of Oakland, now included in that enlarged city.

[9] The entry, p. 497, says of this station, "Time service: not specified." The reason no point was made of time in the station's report is that it was one of the old duplex-pendulum stations that depended on the observer's watch.

items in the observatory files concerning the three-component seismograph are readjustment and clock readings. The first of these was that of July 18, 1888, by J. E. Keeler. The first earthquake record reported on this instrument was that of July 31, 1889, 4:47 A.M., a shock felt from Gilroy on the south to Santa Rosa on the north, and attaining an apparent intensity of VII R.-F.

From these early beginnings, seismographs have been kept continually in service at Berkeley and Mount Hamilton to the present time. For both stations, station records have been kept of the performance of the instruments, together with copies (or originals) of seismograms.

Early publications.—One of the first important by-products of the setting up of the California stations was the preparation by E. S. Holden of a "List of Recorded Earthquakes in California, Lower California, Oregon, and Washington Territory," published by direction of the Regents of the University of California in 1887, and including entries from April 11, 1769, to December 25, 1887. This book included the Berkeley and Mount Hamilton reports for 1887.

For the earthquakes of 1888, Holden prepared a report that was printed in the *American Journal of Science* in 1889 (3d series, Vol. 37, pp. 392–402), which included reports from the collaborating stations that had come into operation in that year. In the meantime, he had arranged for an official publication medium for the future, and therefore in his report as Director of the Lick Observatory he could state (*Biennial Report of the President of the University of California, 1890*): "A regular series of observations of all earthquake shocks and tremors is maintained at Mt. Hamilton and at Berkeley, and at various other stations in California and Nevada. The results are all sent here, and at the end of the year a report is made to the United States Geological Survey, which report is printed in their *Bulletins*. This work is under the charge of Mr. Keeler."

This arrangement continued throughout the life of Holden's California System. The first Geological Survey publication in the series was "Earthquakes in California in 1889," by James Edward Keeler, *Bulletin 68* (1890).

Keeler, who was in charge of earthquake observations, left the following year to become director of the Alleghany Observatory, before completing the report for the 1890 earthquakes. So Holden again took up the task of earthquake cataloguing, and the earthquakes of both 1890 and 1891 were included in *Bulletin 95* (1892). Then Charles D. Perrine was put in charge of the earthquake work, and the reports thereafter came out regularly:

Earthquakes in California in 1892	*Bulletin 112*	(1893)
1893	*114*	(1894)
1894	*129*	(1895)
1895	*147*	(1896)
1896–97	*155*	(1898)
1898	*161*	(1899)[10]

[10] Two typographical errors may be noted in this bulletin. Professor Leuschner, who was at that time in charge of the Students' Observatory at Berkeley, is referred to as Professor Teuschner, and his assistant Mr. Kuno as Mr. Keno.

As stated above, Holden left the Lick Observatory in 1898, and the publication of *Bulletin 161* of the United States Geological Survey marks the end of his enthusiastically developed "California System" of coöperative earthquake studies. The underlying idea was sound, and in more recent years has been redeveloped with better instrumental equipment and in a more effective way, if not in so complete a way as he envisaged. His was a noble pioneer effort; it produced a considerable amount of information, and it laid the groundwork for future developments.

Besides these "official" publications of the system, Holden published a number of other papers on earthquakes, such as

"Note on Earthquake Intensity in San Francisco," *Am. Jour. Sci.*, Vol. 35 (1888)
"Earthquake Observations in California," *Publ. Astron. Soc. Pacific*, Vol. 2 (1890)
"Earthquake Shocks Felt at Sea Off Cape Mendocino," *Publ. Astron. Soc. Pacific*, Vol. 7 (1895)
"Catalogue of Earthquakes on the Pacific Coast 1769–1897,"[11] *Smithson. Misc. Cat.* No. 1087 (1898)

1899–1906.—From the end of 1898 to the time of the California earthquake of 1906, several of the stations of the former system (as stated above) continued the registration and recording of earthquakes, although they no longer had any regular scientific medium[12] of publication of the results. The two University of California stations maintained both the Ewing three-component seismographs and the Duplex Pendulums in service. The Gray instrument at the Berkeley station, and the Milne instrument at Mount Hamilton, apparently never worked satisfactorily, or at least were never referred to in the reports.

One result of the 1906 earthquake was the generally expressed desire that the list of earthquakes of the Pacific Coast be brought up to date. At the request of the Secretary of the Smithsonian Institution, Alexander G. McAdie of the United States Weather Bureau, who was stationed in San Francisco at the time, undertook this work and prepared a *Catalogue of Earthquakes of the Pacific Coast 1897–1906*,[13] which was published by the Institution in 1907. For the years 1897 and 1898 he used Perrine's *Geological Survey Bulletins Nos. 155* and *161*,[14] which included the reports of the formerly coöperating stations. For the years 1899 to 1906, inclusive, in addition to various other reports and records, he consulted the records of the Lick Observatory (Mount Hamilton), of the Students' Observatory (Berkeley), and of the Chabot Observatory (Oakland), and included the material in brief form in his list. He

[11] This is an exclusive date, for the last earthquake recorded is for December 22, 1896.
[12] Reports of felt or damaging shocks were given to the newspapers and were always recorded and made available to interested persons.
[13] These dates are inclusive, the first listed earthquake being January 1, 1897, the last, December 28, 1906; it therefore takes up where the second Holden catalogue left off.
[14] In McAdie's Acknowledgments a typographical error makes these bulletins cover the years 1886–7–8, instead of 1896–7–8, but this naturally does not affect the body of the list itself.

evidently did not make use of the instrumental records of three others of the old group which were still in existence and which Professor H. F. Reid consulted in regard to the 1906 shock, namely, the Mills College (Oakland), University of the Pacific (San Jose), and Carson, Nevada, stations.

Effects of the earthquake of 1906.—The great California earthquake of April 18, 1906, aroused widespread interest in earthquake studies and very definitely marks the beginning of a new era in the history of seismology in the United States and Canada. It was realized that the science was practically unorganized in America, that seismographic stations were too few and far between and in general not provided with the best modern equipment, and that there was an important field of activity in the development of further knowledge of the physical, geological, and engineering or applied aspects of the subject.

The first visible effect of this realization was the organization of the Seismological Society of America in San Francisco in the latter part of 1906. This society has been active to the present time and has done much to further the science of seismology. Another effect was the stimulation of a demand to set up new seismograph stations and improve those already in existence. With the normal delays incident to such projects—time for the necessary planning, obtaining funds, construction, and installation—these developments followed only after the lapse of a few years, and the general impetus led to still further expansion in later times.

The 1906 earthquake brought the famous Japanese seismologist, Professor Fusakichi Omori, to California, and he kindly extended to the Berkeley station the use of a two-component, horizontal pendulum tromometer designed by him and constructed in Japan. This was mounted with the other instruments at the Students' Observatory and placed in commission as soon as possible. Its first earthquake record was dated June 15, 1906, and this same day was the last day that the Ewing seismograph was mentioned in the station records. Mr. Sturla Einarsson (at present Professor of Astronomy) was designated by the Director of the Observatory, Professor A. O. Leuschner, to have personal care of the Omori instrument, and he maintained the registration, measured the seismograms, and prepared the reports from June, 1906, to late in 1910. The last entry concerning the Omori instrument in the station record was made on November 10, 1910. These complete reports were not published by the University, but were made available to the newspapers and entered on the report forms of the United States Weather Bureau. In the Townley and Allen earthquake catalogue published in 1939 by the Seismological Society of America, data concerning a number of earthquakes are given from the Berkeley Omori seismograph records as obtained from the Bureau report forms.

Following the earthquake of 1906, most of the members of the Department of Geology of the University of California took some part in the investigation

of the phenomena, and Professor Lawson, at that time head of the Department, was Chairman of the State Earthquake Investigation Commission, which prepared an extensive report, published by the Carnegie Institution of Washington. Many important geological relations were established by the investigation, and the members of the Department were enthusiastic about more active development of seismology through the agency of improved instrumental equipment, definite means of regular publication of results, and instruction. The problem of the location of any new and more extensive equipment arose. The old location associated with the buildings of the Students' Observatory was inadequate unless a new and special building were constructed. There was no satisfactory site connected with the location of the Department of Geology or its possible new location. Fortunately, before the instruments became available, construction started on a new large building for the University Library under which was an area in which rather fresh Jurassic bedrock (Franciscan sandstone) was exposed. Permission was obtained in 1909 to construct there a seismographic concrete vault, and this was completed, the instruments installed, and regular continuous service with the new instruments established the year before the new building was completed, stocked, and opened for public use as a library.

The new equipment set up at that time (1910) consisted of two 100-kgm. Bosch-Omori tromometers (made by J. & A. Bosch in Strassburg) and one 80-kgm. Wiechert vertical seismograph (from Spindler and Hoyer, Göttingen). A direct wire connection with the Students' Observatory allowed daily time check with the mean time clock. These new instruments were finally put into routine operation, so that the published record begins October 30, 1910. As had been done in 1906 when the Omori instrument replaced the Ewing, so now when it appeared certain that the new instruments were in dependable operation, the recording on the Omori at the Students' Observatory was stopped (November 10, 1910), and the instrument was dismounted and turned over to the Geology Department, later to be placed in the new vault.

Another result of the 1906 earthquake was a set of new instruments for the Lick Observatory at Mount Hamilton. Mr. W. R. Hearst, learning that much better and more effective instruments were available than those possessed by the Observatory, made a cash gift to provide the most recent forms of seismographs. This was probably in 1907, for the Regents passed a formal vote of thanks on November 1 of that year. But the instruments were not purchased until 1910. A "specially constructed concrete and steel room" had to be built for the new equipment, and this was placed in the basement of the Meridian Circle house. The delay in the purchase was explained by Director Campbell in his report of July 1, 1910, as "in accordance with the advice of experienced seismologists, in order to receive the benefit of pending improvements in the instruments." The installation was actually made "early in the year 1911" and

consisted of a 200-kgm. Wiechert horizontal seismograph and an 80-kgm. Wiechert vertical. Routine operation is said to have started on May 23, 1911, but the first published record is dated July 1, 1911.

With the two University of California stations again both supplied with modern equipment representing a quarter of a century in the advance of seismometry over the period of their inauguration, there was renewed the scheme by which someone at one of the stations should receive all the records, have the measurements and computations made, and prepare the material for publication. This time, Berkeley became the place where the records were worked up, and the University of California set up a publication series of its own, the *Bulletin of the Seismographic Stations*, to carry the reports of its stations. The first number was published January 2, 1912, and presented the record of "Registration of Earthquakes" on the new instruments at the Berkeley Station from October 30, 1910, to March 31, 1911. The numbers were originally intended to cover an interval of six months, and No. 2 was planned to cover the period April 1 to September 30, 1911. The first number was called by the plural name "*Bulletin of the Seismographic Stations*," because it had already been arranged to handle the instrumental data from both stations in the same bulletin, but during the time it covered, the new instruments on Mount Hamilton had not been brought into operation. The second number, issued September 5, 1912, carried the reports of both stations.

This bulletin has been continued up to the present time (now thirty years) and has carried throughout this period the Berkeley and Mount Hamilton records, and has included, as they became available, those of other coöperating or "branch" stations that were later established.

When arrangements were made for newer, more sensitive, continuously recording instruments, it was taken into account that they would give little information concerning strong near-by shocks, that is, shocks within the zone of destruction. One of the early attempts to plan an instrument for getting strong-motion records was that of Professor C. F. Marvin, of the United States Weather Bureau. An instrument according with his drawings was constructed by V. Arntzen in the shops of the Department of Civil Engineering and was completed in 1911. But it was found necessary to make considerable modifications of certain parts of the instrument to overcome certain difficulties[15] and these were not successfully completed until April, 1914, when this strong-motion instrument was added to the group of other instruments in the basement of the Library. On December 15, 1914, two sets of Galitzin prisms (10 each) for intensity determinations were added to the station equipment.

The renaissance of regional seismological programs.—All those engaged in the investigation of the California earthquake of April 18, 1906, became impressed with the importance and desirability of regular and systematic regional earth-

[15] E. F. Davis, "The Marvin Strong Motion Seismograph," *Bull. Seism. Soc. Am.*, 3:195–202 (1913).

quake studies. While Professor Lawson, the chairman of the Earthquake Investigation Commission, was in Washington, D.C., preparing the report of the Commission for publication, he caused to be printed and circulated a three-page statement of a "Plan for a Proposed Seismological Institute," dated April 18, 1907, the first anniversary of the earthquake occurrence. In this statement he pointed out the deficiencies in our knowledge of earthquakes, their causes, the factors controlling the distribution of intensity and the consequent destructive effects, the practical question of minimizing loss of life and property, and he also stressed the lack of a sufficient number of seismologists—men whose chief or only pursuit is the study of earthquakes.

According to his plan, "Such an institute would, of course, take cognizance of the larger shocks, and coöperate with other stations in this and various other countries. But this should not be its primary purpose. It should chiefly be concerned with an intensive study . . . of a region where earthquakes are frequently recurrent, and where, therefore, the greatest variety of seismic phenomena is likely to be met with. In the United States the region best suited for this purpose is California. . . . The general plan . . . would involve a central station, convenient to all means of communication, and various outlying stations. . . . The records obtained would point the way to field studies of the geological structure for various limited areas. . . . A laboratory should be maintained for experimental work." An estimate of costs was also given.

A set of resolutions strongly approving such a plan was signed by 151 physical scientists throughout the United States. The agitation for the establishment of an organization for seismological research continued for several years. At a meeting held March 2, 1910, in San Francisco, the Seismological Society of America passed a series of resolutions[16] giving briefly the reasons for, and urging the establishment of, a National Bureau of Seismology, "under the Smithsonian Institution with the active co-operation of other scientific departments of the government." Copies of the resolutions were sent to "the President, President of the Senate, the Speaker of the House of Representatives, Secretary of the Smithsonian Institution and the members of the House Committee on Library which has this matter now under consideration." Nothing concrete resulted from these efforts at the time, but the fundamental idea would not down, and after a few years again appeared in print.

In 1916 Mr. H. O. Wood published in the *Bulletin of the Seismological Society of America* a comprehensive plan[17] for the study of local earthquakes, ground displacements, and all related phenomena and conditions throughout the

[16] Printed in *Science*, n. s., Vol. 31, p. 534 (April 8, 1910).

[17] Harry O. Wood, "The Earthquake Problem in the Western United States," *Bull. Seism. Soc. Am.*, 6:197–217 (1916). This plan received the approval and endorsement of the Executive Committee of the American Geophysical Union and the Division of Geology and Geography of the National Research Council.

western part of the United States, and he included tentative locations of a great network of seismographic stations to cover the area. At the same time, he advised that the inquiry be started not on the wide scale outlined as ultimately desirable, but by the establishment of "one station of the first class and several subordinate stations located in a restricted district of this great area. Then as experience dictates, the network can be extended, either gradually or rapidly, and both equipment and the placement of stations can be modified in accordance with accumulating knowledge." He recommended a portion of southern California as a suitable subprovince in which to initiate this undertaking. This area was in large part a thickly settled district of much economic importance, subject to earthquakes, without any appropriate seismographic installations, and not included in any other project of research related to earthquakes.

At the time of the California earthquake of 1906 the Carnegie Institution of Washington made possible the extensive work of the State Earthquake Investigation Commission by financial aid, and later published the report of the Commission, but it did not follow this up by any further undertakings in the field of seismology. When Dr. John C. Merriam became President of the Carnegie Institution in 1921, Mr. Wood presented to him his plan as a possible project. A widely representative committee was set up to advise the president of the Carnegie Institution whether in its opinion the Institution should enter the field of seismology, and, should it be favorable to such activity, to present plans for the project. This Advisory Committee on Seismology consisted of Arthur Day, chairman, J. A. Anderson, Ralph Arnold, W. W. Campbell, A. C. Lawson, R. A. Millikan, Harry Fielding Reid, and Bailey Willis.

When the action of the Carnegie Institution became known, resolutions of endorsement were passed by the San Francisco Section of the American Institute of Mining Engineers, the Board of Directors of the Seismological Society of America, the Executive Committee of the American Geophysical Union, and the Commonwealth Club of California.[18] The Advisory Committee on Seismology recommended that the Carnegie Institution should enter the field of seismology, and there was inaugurated a project which had the benefit of the active interest and financial aid of the Institution for a period of two decades, and which resulted in the establishment of agencies and activities that are still directed toward the cultivation of the field under other auspices.

Before outlining some of the events which followed, it would appear appropriate to note the relation of the background of some of the active participants in this project to the earlier history already covered in this paper.

H. O. Wood originally prepared himself at Harvard University for a career in mineralogy and petrography and at the time of the California earthquake of 1906 was a member of the Department of Geology and Mineralogy at the

[18] Carnegie Institution of Washington, *Year Book No. 20*, p. 175 (1921).

University of California pursuing his chosen line of teaching and research. Then, in aid of the work of the State Earthquake Investigation Commission, he undertook a detailed study of the distribution of intensities as shown by the varying phenomena throughout the city of San Francisco. He became an ardent student of seismology, and when the Berkeley station was placed under the administration of the Department of Geology and Mineralogy in 1910, he was put in immediate charge of the new instruments, and it was he who prepared the first reports for the newly established *Bulletin of the Seismographic Stations*. He continued in this work until 1912, when he became Research Associate in Seismology at the Hawaiian Volcano Observatory. It was while there that he prepared the paper, referred to above, that outlined the plan for regional seismographic studies in the western United States. The war brought him back to the mainland in 1917, and he was in Washington when Dr. Merriam was called to the presidency of the Carnegie Institution, a happy circumstance for seismology in California.

John C. Merriam at that time had been on the faculty of the University of California for some twenty-seven years, a period during which he had been a member of or closely associated with the Department of Geology and Mineralogy. He had experienced the 1906 earthquake and, although his own line was paleontology, he had an active appreciation of the scientific and practical value that the development of research in seismology promised.

It may be added that three of the members of the Advisory Committee had served on the State Earthquake Investigation Commission: W. W. Campbell, A. C. Lawson (as chairman), and Harry Fielding Reid, and that these men had reason to be greatly impressed with the importance of regional studies in connection with their investigation of the 1906 shock.

Without going into the less obvious influences, it would seem fair to assert that the undertaking by the Carnegie Institution of a regional seismologic program in California was, through a lucky concatenation of events, a direct, even if delayed, result of the California earthquake of 1906, and the investigation that immediately followed it.

The Advisory Committee expressed the opinion[19] in 1921 that "in the State of California there is probably a more favorable opportunity for the study of crustal movements in great variety than in any other region, save possibly Japan." It recommended five different projects, some of which were to be urged on other appropriate agencies and were not to be undertaken by the Carnegie Institution itself.

1. Study of geological formations along the California fault lines (especially by the United States Geological Survey and the Geological departments of California universities).

2. Surface displacements (by the United States Coast and Geodetic Survey).

3. Southern California: "that, as soon as suitable instruments are available, a beginning

[19] Carnegie Institution of Washington, *Year Book No. 20*, pp. 175–178 (1921).

be made of continuous seismologic observations at selected points in this region for the study of local earth movements, both tremors and displacements."

4. Development of Instruments. "It happens that no instruments appropriate for recording local earthquakes of short period and locating their sources has yet been developed, although instruments for recording of shocks of distant origin have been in continuous operation at many stations for a number of years. . . . Your committee is of the opinion that for a study of local earth movements it is indispensable that appropriate agencies be invited to take up this instrument problem as soon as practicable." The committee particularly recommended "the coöperation of the California Institute of Technology, the Mount Wilson Observatory, and other agencies, if necessary, in the development of seismometric recording apparatus for study of local earthquakes."

5. Isostasy (by the United States Coast and Geodetic Survey).

In the meantime H. O. Wood was appointed Research Associate in Seismology by the Carnegie Institution (1921) and was engaged in field studies in southern California, with headquarters at the Pasadena Office of the Mount Wilson Observatory.

Within the next two years H. O. Wood and J. A. Anderson had developed a seismograph, "an instrument of the utmost simplicity, adaptable to the measurement of any one of the three components of movement and capable of detecting short waves as well as long ones."[20] "The early and remarkable success attained in the development of suitable instruments for the study of regional seismology has placed the committee in position to recommend the immediate establishment of the first group of stations and the systematic study of local earth tremors in southern California."[21]

In testing the instruments for routine service, experimental runs (1923–1925) were made with installations in the basement of the Mount Wilson Observatory Office and in the Norman Bridge Laboratory of Physics, both in Pasadena. Later an arrangement was made for the California Institute of Technology to build a seismological laboratory to serve as the center for the research work in seismology of the Carnegie Institution of Washington and also as the central unit of a group of seismographic stations. The research work was to be under the general direction of the Advisory Committee, but under the immediate supervision of H. O. Wood and J. A. Anderson "with competent assistants." "On the other hand the station will be enrolled in the newly established Department of Geology of the California Institute of Technology."[22]

It is of interest that in the development of the coöperating stations, "the destructive earthquake at Santa Barbara on June 29, 1925, had the effect of stimulating vigorous local coöperation throughout the region where, before the earthquake occurred, our efforts were looked upon with some indiffer-

[20] "Seismology: Report of the Advisory Committee," Carnegie Inst. of Wash., *Year Book No. 22*, p. 366 (1923). Later experience justified the enthusiasm of the committee as regards the recording of the horizontal components. For the vertical component, the problem still remained to be solved.

[21] *Ibid.*, p. 367.

[22] "Seismology: Report of the Advisory Committee," Carnegie Inst. of Wash., *Year Book No. 24*, p. 377 (1925).

ence."[23] It not only awakened interest "throughout the region," but also throughout the State, and greatly aided the movement to develop a new northern California group of stations as will be described below.

Thus there resulted a center of seismologic research and a group of coöperating stations under central direction, appropriately located for the study of regional seismology in southern California. At the present time this integrated group (which Holden might well have called the Southern California System) includes the central station at the Seismological Laboratory in Pasadena (registration of earthquakes from March 17, 1927) and associated stations at Riverside (October 19, 1926), Santa Barbara (May 10, 1927), La Jolla (March 24, 1927), Mount Wilson (April 24, 1928), Tinemaha (September 4, 1929), Haiwee (September 11, 1929), and Palomar (September 7, 1939). The Carnegie Institution of Washington has recently retired from the field of seismology, and the California Institute of Technology through its Division of Geological Sciences administers the Seismological Laboratory, its research activities, and the coöperative arrangement with the associated stations.

After the Wood-Anderson seismograph had passed through the experimental stage, arrangement was made for its manufacture and sale to stations not connected with the southern California group. The fact that it was particularly adapted to the registration of the smaller local earthquakes and that it was obtainable at a comparatively modest cost led a number of stations to install it. Its availability immediately implemented the long-standing desire to reestablish on a modern basis a regional group of stations for the San Francisco Bay region. The initiative was taken by the Seismological Society of America, and especially by its president, Bailey Willis, who was also a member of the Advisory Committee of the Carnegie Institution of Washington and had therefore been fully informed of the developments of instrumental construction and performance under the Committee's general direction.

In the spring of 1925 the Section on Scientific Research of the Commonwealth Club of California, at the suggestion of Mr. C. B. Lastreto, invited Dr. Willis to suggest some way in which the Club might promote the investigation of earthquakes, especially with reference to their bearing on San Francisco. Dr. Willis suggested that they consider the feasibility of establishing a group of seismographic stations in the San Francisco Bay region "similar to that which is now being installed by the Carnegie Institution in southern California." Dr. Barton W. Evermann, chairman of the Section, called a meeting for March 5, 1925, at which Dr. Willis elaborated on the proposal and Dr. J. B. Macelwane spoke for the University of California. It was recognized that definite general supervision of the operating stations should be provided for, and President W. W. Campbell of the University of

[23] "Seismology: Report of the Advisory Committee," Carnegie Inst. of Wash., *Year Book No. 24*, p. 370 (1925).

California was approached to learn if he was willing to have the University of California undertake this responsibility provided suitable equipment and installations were donated. President Campbell, who, it will be recalled, was Director of the Lick Observatory, a member of the Advisory Committee on Seismology of the Carnegie Institution, and also of the State Earthquake Investigation Commission, was greatly interested in the project. After consultation with the Department of Geological Sciences at Berkeley, he agreed that if equipment and installation of two seismological stations in the University of California (Mount Hamilton and Berkeley) were supplied, "I shall see to it that the University of California will allot funds . . . for the administration of the two stations in the University. I should want the Department of Geological Sciences to be in technical charge of the two stations in the University in order that they may have homogeneous administration."

The activity of the Commonwealth Club produced favorable publicity for the program, and a number of other organizations requested that their members be informed about the project. It was finally decided to conduct a campaign for funds, directly under the auspices of the Seismological Society of America, for four sets of instruments and appropriate, economically planned housing.

Dr. Arthur L. Day, Chairman of the Advisory Committee, and Dr. Willis, in June, 1925, discussed the matter with Mr. Clay Miller, President of the San Francisco Chamber of Commerce. Mr. Miller appointed a committee of the Chamber with Mr. S. M. Haslett as chairman. The Oakland Chamber of Commerce, represented by Mr. A. W. Moore, and the Berkeley Chamber of Commerce, through Mr. Charles Keeler, also assisted.[24] A number of public-spirited businessmen gave their support to the project, and in a short time a sum was pledged that justified detailed planning and institutional arrangements for four stations. The coincidence of the destructive Santa Barbara earthquake and the consequent aroused public interest in earthquakes with the campaign for funds for the San Francisco Bay region project was very definitely effective in the campaign's success and the comparative ease and rapidity with which it was completed.[25]

To complete the project, the Directors of the Seismological Society of America appointed a Committee on Seismometric Stations, April 10, 1926, consisting of Perry Byerly, Henry D. Dewell, James K. Moffitt (treasurer),

[24] Bailey Willis, "Report of the President," *Bull. Seism. Soc. Am.*, 16:73–76 (1926).

[25] It was originally estimated that the four stations could be constructed and equipped for about $5,500 apiece, and contributions were solicited on that basis. Specific groups were asked to contribute toward specific stations, and at the end of the campaign all appeared to be provided for. When the final collections were reported, it was found that the public utilities had contributed $5,500 (assigned to the station at Stanford University), the San Francisco banks, $4,614.29 (assigned to the Mount Hamilton station), the insurance companies, $4,000 (assigned to the San Francisco station). A friend of the University undertook personally to construct and equip the station at Berkeley, but this was ultimately financed by the University of California.

S. D. Townley, Bailey Willis (chairman), and H. O. Wood. This committee was "authorized to solicit and collect funds for the construction and equipment of stations and to expend these funds for the purposes named." Later (August 26, 1926), as Dr. Willis was leaving for extensive travels, George D. Louderback was appointed to take his place as chairman, and the Committee as so reconstituted continued in charge of the project until all the proposed installations were completed. Considerable time was given to an inquiry into the best locations for the stations with respect to effective "seismographic triangulation" of local epicenters, and to appropriate geological conditions. As usual in such undertakings, proposals based purely on such considerations had to be modified by such conditions as availability of site, availability of necessary services, and local administrative oversight.

The first installation completed (November 21, 1927) was on the campus of Stanford University at a location so selected that the instrument piers could be founded on bedrock. This required the erection of a specially designed station building. This station has been referred to as both the Palo Alto and the Stanford University station, the former name coming from the town (and post office), and the latter from the branch post office on the University campus which appears to be firmly established now but has varied through the years in Post Office Department nomenclature. The University named the station the Branner Station in honor of the former Professor of Geology and later President of the University, and also former President of the Seismological Society of America, John C. Branner. Professor S. D. Townley has been in charge of this station from its inception.

The Mount Hamilton and Berkeley installations were both delayed because the quarters of their already operating teleseismic stations did not have sufficient space for the new equipment, and new locations under other buildings had to be found and approved by the institutional authorities, and appropriate vault construction had to be planned and completed. The Mount Hamilton Wood-Anderson instruments were installed February 16, 1928, but routine registration did not satisfactorily get under way until April 8. At the Berkeley station, one component was installed August 28, 1930, and regular registration started (October) before the second was installed October 31, 1930.

The fourth station proved to be the most difficult to locate satisfactorily. An attempt was made to get a suitable site in Marin County on bedrock west of the San Andreas fault (all the other stations being on the east side), but no satisfactory location where both electric service and appropriate supervision were available could be found. An effort was then made to arrange for a location in Golden Gate Park in San Francisco, but the proposed use of a feasible bedrock site conflicted with the developments undertaken by the park management. It was finally decided to place the instruments at the California Academy of Sciences, where housing and the tending of instruments could be

provided. At this location no bedrock foundation was available, but it was hoped that the station might nevertheless prove useful in seismographic triangulation, and at the same time it was thought that it might be possible to determine the free period of a mass of water-bearing sand overlying the bedrock. This matter of possible free periods for surficial masses of alluvium, and so on, was at that time suspected of being of great importance with respect to earthquake-resistant construction and earthquake damage. The instruments were installed in April, 1931. However, they proved so sensitive to artificially produced vibrations which kept the ground on which they were based in a state of almost constant disturbance, that it was finally decided to seek a new location. A satisfactory site not far away was found at the University of San Francisco and the new station was installed in November, 1935, and is still operating.

These four installations, established primarily for the better acquisition of regional seismological data in the San Francisco Bay region, were integrated into a unified system in which all the seismograms are transmitted to the Berkeley station, where they are measured and compared and the results, including the determination of epicenters, are published in the *Bulletin of the Seismographic Stations*, and in which adjustments and repairs, so far as it may not be feasible to handle them at the local stations, are attended to by a representative of the Berkeley station.

Since the establishment of the San Francisco Bay region system through the good offices of the Seismological Society of America, three other coöperating stations have been arranged for in key positions for northern California by the Department of Geological Sciences (the name given to the former Department of Geology and Mineralogy when its scope was enlarged in 1921) of the University of California in Berkeley, especially through the agency of Dr. Perry Byerly, who is in charge of the seismological field of the department.

With the enthusiastic coöperation of Mr. Joseph Bognuda, who arranged with the City Council of Ferndale, California, for the housing of the instruments in a municipal building, and who has had personal charge of the equipment from the time of its installation, a station was set up in Ferndale especially for the registration of the many earthquakes which originate in the Pacific Ocean area west of the Humboldt County coastal region of California. The instruments used were two 25-kgm. Bosch-Omori horizontal-component seismographs which were received by the University as a gift of the Navy Department when it discontinued its station at Mare Island Navy Yard. One instrument was installed in January, 1933, but the second-component instrument not until October, 1935. Routine registration was satisfactorily begun as of one component in November, 1933, and as of two components in January, 1936.

A single horizontal-component Wood-Anderson seismograph was placed in

operation at the Fresno station (in coöperation with Fresno State College, Dr. W. M. Tucker in charge of the instrument), November 28, 1935, and similar equipment at the Mineral station (in coöperation with the National Park Service, Lassen Volcanic National Park, Dr. Carl Swartzlow in charge of the instrument), November 5, 1938.

Later developments at the Berkeley station.—At the time of the campaign of the Seismological Society of America for increased instrumental equipment it was evident that the vault under the University Library furnished inadequate space for the new development. Furthermore, it was desired that a set of more sensitive teleseismic instruments be added to the station equipment. A new housing arrangement was imperative. Mr. F. W. Bilger of Oakland, whose interest was particularly aroused by an address made by Dr. Willis in the course of the campaign, offered to construct an ideal station at Berkeley and equip it with the desired sensitive instruments. These were to be two horizontal-component and one vertical-component Wilip-Galitzin seismographs manufactured by Hugo Masing in Dorpat (Tartu), Estonia. A geological examination of the campus was therefore made to determine the best location, and a detailed plan was developed for an underground vault in the hillock on which the Students' Observatory was situated, to be entered by a tunnel from the sub-basement of Haviland Hall, the comparatively new building housing the School of Education. Mr. Bilger made a first payment of half the cost of the new teleseismic instruments, but before final arrangements for actual construction of the station could be made, financial exigencies (at the time of the Depression) blocked the carrying out of the original plan. In the meantime the geological studies had shown that the sub-basement of Haviland Hall offered an excellent location for a quiet station located on bedrock, and satisfactory housing was arranged there. The older vault and its instrumental contents were undisturbed and they have been continued in operation up to the present time. The new instruments, all supplied with photographic registration, were installed in the Haviland Hall vault. The three Wilip-Galitzin instruments, two horizontal components and one vertical component, together with one of the Wood-Andersons, were put in operation August 28, 1930, the second Wood-Anderson, October 31, 1930. Later on, a very sensitive Benioff vertical-component instrument was installed (October 17, 1933), and with this the present seismographic equipment of the Berkeley station was completed.

At the time that the second Wood-Anderson was put into operation (October 31, 1930) a radio receiving set and an electric time switch were installed which at predetermined intervals permit the direct registration of the Mare Island radio time signals on the recording drums of the Wood-Anderson instruments. Similar registration was arranged for the Benioff instrument when it was installed (1933). Thus these drums are used as chronographs and, with the intro-

duction of this improvement, the station time service became independent of the periodic time check with the Students' Observatory clocks which had been in use for twenty years (1910–1930). Time corrections can be measured as accurately as the beginning of the phases of the earthquake motion.

The two vaults which now house the Berkeley station instruments are under two different buildings but are only about 800 feet apart, the photographic registration room under Haviland Hall being northwest of the vault under the Library. The Haviland Hall location is about 290 feet southwest of the original location of the station equipment associated with the Students' Observatory.

In retrospect.—We have seen how what appear to have been the first seismographic stations in the Western Hemisphere were set up in California at the instigation of an astronomer (Holden) aided and abetted by a geologist (LeConte). While arranged for at an earlier date, the original stations were equipped with what were considered the best instruments available, which arrived from Cambridge, England, in the same shipment and were placed in operation at approximately the same time in 1887, one set on Mount Hamilton in connection with the Lick Observatory and one set at Berkeley in connection with the Students' Observatory. The first group of stations particularly planned to coöperate for obtaining regional seismographic data was set up, including these first stations and in association with them, and was in operation in 1888. This, called by Holden the "California System," remained in operation, with a center for measurements and reports at the Lick Observatory and with an official medium of publication, until Holden severed his connection with the University of California in 1898, when for twelve years the individual stations operated independently and kept their own station records, but had no integrating center and no regular medium of publication of their routine data.

Under the influence of the experiences in connection with the California earthquake of 1906, the two University of California stations were supplied with modern equipment and the Berkeley station became the center of seismograph measurements and the interpretation and preparation of reports, the periodical publication of which was provided for by the establishment of the *Bulletin of the Seismographic Stations* published in Berkeley beginning January 2, 1912 (Berkeley earthquake records from October 30, 1910, Mount Hamilton records from July 1, 1911), and continued to the present time. A new regional group to carry out the purposes of the old "California System," with more adequate equipment than was available in Holden's time, was not definitely projected until 1925 after an appropriate instrument had been invented (the Wood-Anderson seismograph) and a regional group had been set up in southern California under the guidance and aid of the Carnegie Institution of Washington. The actual installations in the San Francisco Bay region were made during

the years 1927–1931. For these and for coöperating stations later set up in other parts of northern California the Berkeley station has acted as the integrating agency and has published the results.[26]

Throughout its history the Mount Hamilton station has been operated under the general administration of the Director of the Lick Observatory.[27] The station was established in 1887 by Edward S. Holden, who served as Director until 1898 and was followed by J. M. Schaeberle (interim appointment, 1898), James E. Keeler (1898–1899), W. W. Campbell (1900–1930), R. G. Aitken (1930–1935), and W. H. Wright (1935–1942).

The Berkeley station was installed and was originally operated as an activity of the Department of Civil Engineering, under the direction (and personal attention) of Frank Soulé, Professor of Civil Engineering and Astronomy from 1887 to 1898,[28] then under Professor A. O. Leuschner as Director of the Students' Observatory, 1898–1910, then under the direction of the Department of Geology and Mineralogy (Department of Geological Sciences from 1921) with the following administrative officers: Andrew C. Lawson, 1910–1918, 1920–1923, 1924–1925; George D. Louderback, 1918–1920, 1923–1924, 1925–1937; N. L. Taliaferro, 1937 to date.

It may be emphasized that irrespective of changes in administration, or in the location or character of the instruments, both of the original California stations have remained continually in operation, and have kept an unbroken series of station records from their beginnings in 1887. Whenever any new instrumental installation was intended to replace an older one for routine registration, the old was continued in service (and in station record) until the new was found to be in practical operation.

Since the geological department took over the administration of the Berkeley

[26] The readings from the Wiechert records of the Mount Hamilton station have not been published in the *Bulletin of the Seismographic Stations*, starting with registration of October 1, 1930. The Wood-Anderson instrumental registration has continued in publication to the present time.

[27] The Wood-Anderson seismographs at Mount Hamilton are not considered by the Director to be part of the Observatory equipment, and are given space and are tended as a courtesy to the Department of Geological Sciences at Berkeley. Routine supplies, and payment for a nonprofessional attendant, are the responsibility of the Berkeley department.

[28] The Department of Astronomy became independent of the Department of Civil Engineering with the fiscal year 1897–98, by action taken on December 22, 1896, by the Regents, who named it the "College Astronomical Department" to distinguish it from the "Lick Astronomical Department" at Mount Hamilton, but Professor Soulé, the head of the Department of Civil Engineering, remained head of the College Astronomical Department until 1900. In the meantime, Professor A. O. Leuschner, who from 1894 was in personal charge of the courses in astronomy, was made Director of the Students' Observatory in 1898, and in 1900, when Professor Soulé withdrew from the Department of Astronomy, became head of the department ("under the charge of Professor Leuschner" is the Regents' wording), the name of which had been changed to the "Berkeley Astronomical Department" by the Regents, December 12, 1899. The system of yearly appointed "chairmen" of departments was not introduced at the University of California until 1919. These details are given because the peculiar complication of the successive changes has given rise to confusion and conflicting published statements.

station, the following have had direct charge of the instrumental equipment and the preparation of the reports for publication: Harry O. Wood, 1910–1912; E. F. Davis, 1912–1919; Lewis A. Bond, 1920–1921; James B. Macelwane,[29] 1921–1925; Perry Byerly, 1925 to the present time, except that during the year 1928–29, while he was absent on leave, the station was under the care of V. C. Stechschulte.

It may be of interest to note that while an astronomer who became enthusiastic about earthquake studies was responsible for the establishment of the early California stations, and while in the course of years a number of astronomers both at Berkeley and Mount Hamilton have personally worked with the seismographs and have attended to them and to the records with care, conscientiousness, and often with considerable interest, no one of them ever decided to make seismology his chief interest. They have all remained primarily astronomers, with seismology strictly a subordinate sideline.

When the Department of Geology took up seriously the cultivation and advancement of seismology, it was convinced that it was a field worthy of selection as a professional career and gave its encouragement to that end. Furthermore, seismology as a scientific pursuit and in its practical applications was soon to experience a definite expansion in this country. Of the six men who have had direct charge of the instruments of the Berkeley station since the department took over in 1910, four, H. O. Wood, J. B. Macelwane, V. C. Stechschulte, and Perry Byerly, have made seismology a major scientific interest or have adopted it as a career, and have made important contributions to the science.

Other seismologic activities at Berkeley.—To this history of the stations it seems appropriate to add that the Department of Geology, in its desire to further seismologic studies, did not limit its plan to the establishment of satisfactory seismographic stations, but also aimed to organize instruction and encourage research in seismology. An undergraduate course on earthquakes was set up first in 1910 (H. O. Wood in charge), a course in instrumental seismology was added in 1913 (first organized by E. F. Davis), and graduate work was inaugurated in 1923 (first organized by J. B. Macelwane). Many students have profited by this instruction, taken in part for the broadening of their geologic knowledge, in part to prepare themselves to work in applied geo-

[29] During the years 1921–1923, when the Rev. J. B. Macelwane, S.J., was a graduate student at the University of California, he kindly agreed to help the Department by serving as a part-time student assistant in care of the instruments, the study of the seismograms, and the preparation of the results for publication. After receiving his Ph.D. degree in 1923, he was appointed Assistant Professor of Geology and placed in charge of the station. This note is to explain the apparent inconsistency of dates between the present account and certain published statements, which place Dr. Macelwane's official connection with the station as beginning in 1923. It was during the period 1921–1923 that Dr. Macelwane determined the constants of the seismographs at Berkeley and Mount Hamilton so that ground motion could be published in the reports. Constructional alterations were required in the instruments, and standardization was accomplished with instruments borrowed from the Department of Physics.

physics, and a number have received training in research and have entered the field of professional seismology. Professor Perry Byerly has had charge of the instruction and research since 1925, and is the first person at the University of California to receive the title Professor of Seismology. Under his direction of their research, the following students have received the degree of Ph.D. with a major in seismology:[30] Miss H. H. Sommer, 1930 (at present Mrs. Karl Dyk); the Rev. V. C. Stechschulte, S.J., 1932 (now Professor of Physics, Director of the Department of Mathematics and Physics, and Director of the Seismological Observatory, Xavier University, Cincinnati, Ohio); Dean Samuel Carder, 1933 (at present in seismologic work for the United States Coast and Geodetic Survey, Boulder City, Nevada); Karl Dyk, 1934 (at present geophysicist with the Stanolind Oil Company, Tulsa, Oklahoma); John N. Adkins, 1939 (at present with the Naval Air Service); James T. Wilson, 1939 (now in the Department of Geology at the University of Michigan, in charge of their work in geophysics); the Rev. Alexis I. Mei, S.J., 1941 (now of the Department of Physics at the University of San Francisco).

The United States Coast and Geodetic Survey.—Any account of the regional seismographic agencies in California as detailed as the present paper would be inexcusably incomplete if it did not make mention of the important work in this field of the United States Coast and Geodetic Survey.

For many years (since 1923) this organization has performed a useful service in the circulation and compilation of postcard questionnaires on the effects of felt earthquakes. In more recent years it started seismographic instrumental work (from 1932), soon called the California Seismological Program (1934), and from June 1, 1936, this work was officially organized as the Seismological Field Survey, which, under the direction of Mr. Franklin P. Ulrich, has not only continued the questionnaire program but has also been active in the collection of seismographic and field data on important earthquakes, the installation and operation of strong-motion seismographs at various locations, the installation of a group of tiltmeters adjacent to the Haywards fault and their continuous operation in connection with the Berkeley station, the prosecution of vibration measurements in various buildings and on a variety of engineering structures, and in a number of other ways aiding in the acquisition of knowledge of local earthquakes and their effects. This is not the place to describe these activities, nor to detail the effective coöperation of the Survey with the other seismologic agencies in California. It may be noted, however, that the results are published in a series of yearly reports on *United States Earthquakes*,

[30] Before the Department of Geological Sciences was prepared to offer graduate work in seismology, the Rev. J. B. Macelwane, S.J., and Perry Byerly, in 1923 and 1924 respectively, received Ph.D. degrees at the University of California, with physics as the major subject, and theses in the field of seismology. Their research was carried out under the direction of Professor E. E. Hall, who had himself designed a vibration meter, and had carried out interesting researches in the vibration of buildings due to street traffic, running machinery, and wind gusts.

and in other Survey publications, and in the *Bulletin of the Seismological Society of America*. Other important activities of the Survey in relation to regional seismologic studies include triangulation and leveling for the purpose of determining ground displacements.

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