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FILMING SEISMOGRAMS AND RELATED MATERIALS AT THE CALIFORNIA INSTITUTE OF TECHNOLOGY

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ABSTRACT

As part of a world-wide effort to create an international earthquake data bank, Caltech's seismology archive has been organized, labeled, described, and microfilmed. It includes a wide variety of original records, documents, and printed materials relating to local and distant earthquakes. At present, we are filming significant seismograms prior to 1963; more than 50,000 records written between 1924 and 1935 have been filmed to date. Seismograms are the principal source of information about earthquakes and the earth's interior. These records, housed at Kresge Laboratory, the headquarters for Caltech's seismological network of stations, are important because they span so much of the period for which instrumental data exists. The early history of the Laboratory points up the role technology has played in the advancement of the science.

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Judith R. Goodstein[1]

ORIGINS OF THE SEISMOLOGY LABORATORY

Seismology at Caltech arose from an arranged marriage between two different traditions--the American tradition of studying local earthquakes and the European, and particularly German, global interest in earthquakes.[2]

German-born and Gottingen-trained, Beno Gutenberg brought to Caltech the European tradition of viewing seismology as a research tool. Rigorously trained in physics and mathematics, Gutenberg used earthquake records to investigate the physical properties and structure of the earth's interior. Earthquake instruments installed in seismological stations around the world provided the data for his analysis. Seismology, for Gutenberg, was truly a global problem, one in which literally the globe became his scientific laboratory.

Harry Oscar Wood, a mineralogist turned seismic geologist, took a much more pragmatic view of the world as did most of his American colleagues. Few in number, and concentrated in California, where the majority of all earthquakes occur in the United States, they studied earthquake records in the hope of finding a solution to the "California problem" as local earthquakes were then called. The American seismological community, formed largely of geologists, mining engineers, and astronomers, saw their research in terms of a local problem. To a seismologist like Wood, Gutenberg's global problem shrank to the size of southern California.

Gutenberg and Wood made an unlikely scientific pair: Wood, the outsider in the academic world, a veteran of the San Francisco quake and the expert on the seismic history of California, and Gutenberg, the erudite university professor, sufficiently unorthodox to believe in continental drift, and internationally respected for his ability to decipher instrumental recordings of earthquakes. Nevertheless Wood and Gutenberg worked side-by-side in the laboratory, trading seismograms and technical information daily. Seismology at Caltech owes its distinctive character to the marriage of their scientific ideas. Moreover, in bringing these two men together in Pasadena in 1930, Robert A. Millikan set in motion a chain of events that led Charles Richter to develop an earthquake magnitude scale, still the most visible symbol of the Institute's seismological laboratory.

Like so much of the history of seismology in America, the Wood-Gutenberg-Richter story has its roots in the San Francisco earthquake. Harry O. Wood, who hailed from Maine, had come west in 1904 to seek his scientific fortune, following several years of undergraduate and graduate work at Harvard in minerology and geology. He found work as an instructor in the geology department at Berkeley, thanks to its energetic leader, Andrew C. Lawson. Save for the April 18, 1906 earthquake that tossed Wood out of his bed, he might have remained a lab instructor. Instead, Lawson, who directed the work of the State Earthquake Investigation Commission set up to investigate the earthquake, tapped him to study in detail the extent and nature of the earthquake damage within the city. Wood went into the exercise a field geologist and came out a seismologist. Like Lawson, he lobbied for a seismographic station on the campus, and when Berkeley's seismographic station started operations in 1910, under the direction of the geology department, Wood joined the basement-room-of-the-library operation, where he did everything from analyze the seismograms to put out the station's Bulletin.

Hampered by not having a Ph.D., Wood left Berkeley in 1912 for a position at the Hawaiian Volcano Observatory. In 1916, while he was still in Hawaii, he wrote two papers dealing with California earthquakes. His first one collated and cataloged all the known California earthquakes to date. In his second paper, "The Earthquake Problem in the Western United States," Wood stressed the importance of taking a regional approach to the study of local earthquakes. Although he was not the first to note the importance of establishing a network of seismographic stations, Wood's plan spelled out in detail what the systematic study of local earthquakes in California and in neighboring states would involve. Significantly, he suggested that the plan be tested on a modest scale in southern California. These two papers, in fact, later served as the blueprints for the seismology program at Caltech.

Wood singled out southern California for several reasons. For one thing, the region didn't possess a single recording instrument. For another, he expected the next really large earthquake to occur in the southern half of the state. The 1906 earthquake had struck central California, but the 1857 earthquake along the San Andreas fault in southern California had been the last great shock in that region. For Wood, the earthquake problem in California centered on determining the causes of earthquakes, investigating its effects, and pinpointing where and when large earthquakes might occur in the future.

He was aware that putting his plan into practice would, in fact, make a contribution to the science of geophysics. But this was not the principal reason for undertaking the work. Indeed, Wood had very definite ideas about what his research program should--and should not--do. To begin with, he was not interested in establishing a network of seismographic stations to record distant earthquakes. To use southern California for "the instrumental study of great earthquakes," when Los Angeles and surrounding cities lacked the means to monitor even local ground motion seemed senseless to Wood.

In addition, his research program also stressed the need for a new generation of instruments; there could be no hope of measuring short-period local earthquakes with instruments devised to measure long-period distant earthquakes. Drawing on his own background as a field geologist, Wood also pointed out the need to make extensive field measurements, including first-order triangulation studies, to look for and measure evidence of shifts in the earth's surface, and to verify known faults and identify new ones.

In fact, the field work required to locate the place of origin of the weak shocks played a central role in Wood's plans for seismological research in and around Los Angeles. Like most of his contemporaries, Wood was convinced that if geologists could identify the active faults associated with these weak shocks, they could then "deduce. . .the places where strong shocks are to originate, considerably in advance of their advent." Big shocks, in other words, follow weak shocks. In time, he believed it would be possible to make, in his words, a "generalized prediction" of when and where to expect the next big quake.

This was the compelling reason for setting up branch seismological stations: in order to detect and register the weak shocks systematically. Wood's expectation of a "generalized prediction" based on number and frequency of small shocks did not turn out, in the end, to be very useful to seismologists. The weakness of the hypothesis, indeed, became apparent largely as a result of the work he set in motion in the southland. For in the course of routinely registering hundreds and hundreds of small California earthquakes, the evidence that weak shocks, as he argued, "are indicative of growing strain and are preliminary to failure and faulting with resulting strong shocks" has not materialized. Nevertheless, the lure of that elusive idea drives seismological research to this day.

Wood's research program, as he set it down in Hawaii in 1916, was very ambitious. By the time the proposal reached Carnegie president John Merriam's hands in 1920, he had pared it down from twenty pages of scientific prose advocating field work and tens of earthquake monitoring stations in five western states to a modest seven-page document calling on the Carnegie Institution of Washington to support earthquake research in southern California. Merriam gave Harry Wood the chance he craved.

Southern California's first seismological program began operation in Pasadena in June, 1921 under Wood's direction. For the next six years, Wood ran the project out of an office at the Mt. Wilson Observatory office, located a short distance from the Caltech campus.

The project needed publicity, but even more than publicity it needed the right instrument for recording nearby earthquakes. Fortune favored Wood in the person of John Anderson, one of the ablest astronomers at the Mt. Wilson Observatory. He had no sooner unpacked and settled into his Mt. Wilson office than the two scientists began talking about the kind of instrument the seismologist needed to record local shocks; the Wood-Anderson collaboration had begun.

To do what Wood wanted it to do, the instrument had to be sensitive enough to record shocks having a period varying from 0.5 to 2.0 seconds approximately. Seismometers designed for the purpose of recording distant earthquakes are far less sensitive because the periods of such shocks are much longer. The state-of-the-art in seismological instruments in the early twenties was such that instruments on the Atlantic seaboard could measure with greater precision the time and place of California shocks than comparable instruments located back home in California.

In the fall of 1922, after several false starts, the two men had just what they wanted: a compact, portable, instrument which, when placed in a vertical position, measured with stunning accuracy the east-west and north-south components of the earth's movement during an earthquake. In practice, the Wood-Anderson torsion seismometer turned out to be an ideal instrument for recording the earth's horizontal movements over a short distance during an earthquake; it proved less successful for recording the up-and-down direction of the earth's motion. Shortly before Gutenberg arrived to take up his duties as professor of geophysics at Caltech in 1930, Hugo Benioff, Wood's assistant, designed and built a vertical seismometer to meet Wood's needs. Routine recording of local shocks using Benioff's instrument began in 1931, by which time Wood was predicting the new vertical-component seismometer would surpass, "any [existing] vertical. . .in use for the registration of distant earthquakes" as well. Both the Wood-Anderson and Benioff instruments have since become standard equipment in seismic stations around the world.

The first Wood-Anderson instrumental records were written in December 1922; the first extant records date from mid-January, 1923. Ironically, the Wood-Anderson torsion seismometer did more than its creators intended. Wood had wanted a short-period instrument to register local earthquakes. But when the instrument was put to the test in 1923, he discovered that it also registered the first phases of distant earthquakes. Wood had unwittingly altered the course of his own program.

By the spring of 1924, the experimental torsion seismometers installed in the basement of the Observatory office and the physics building on the Caltech campus had recorded dozens of earthquakes, near and far, including the initial short-period phases of the devastating Japanese earthquake of September 1, 1923. The fact that Wood had recorded this event on an instrument designed to register local earthquakes gave seismologists something to talk about. When Gutenberg heard the news in Germany, via a colleague who had attended an international gathering of geophysicists in Madrid, he held up the publication of his book on the fundamentals of seismology long enough to insert a diagram of the apparatus. By the end of the twenties, thirteen cities in the U.S., and one overseas, boasted Wood-Anderson instruments.

In 1925, Caltech started a geology program; the following year Millikan formally invited the Carnegie Institution to conduct its earthquake research in the Institute's new Seismology Laboratory, located in the foothills of the San Rafael Mountains, a short drive from the campus. In January 1927, Wood left his temporary quarters at the Observatory office and moved into the new building. The time to go earthquake hunting in earnest had begun. By 1929, six outlying stations, all within a 300-mile radius of the central station in Pasadena, each equipped with automatic horizontal-component torsion instruments and radio-timing equipment, were in place and working. Records were sent weekly to Pasadena for registration and interpretation.

SEISMOLOGY RECORDS IN MICROFORM

Caltech's seismology archive includes a wide variety of original records, documents, and printed materials relating to local and distant earthquakes. In 1979, the Institute Archives prepared, labeled, described, and filmed a group of published and unpublished items including the Bulletin of the CIT Seismological Laboratory, Pasadena and Auxiliary Stations, 1931-1968, various station clock corrections, Beno Gutenberg's annotated copy of the International Seismological Summary, 1918-1942, and the original Gutenberg-Richter worksheets for Seismicity of the Earth (1954). The notepads, more than 100 in all, include calculations and data relating to the magnitude scales used by the two men in their catalog.[3]

Since then, we have concentrated on filming the original documentation on earthquakes registered at the Seismological Laboratory at Pasadena and at auxiliary stations at Mt. Wilson, Riverside, Santa Barbara, La Jolla, and Tinemaha and Haiwee (in the Owens Valley). In 1981, we completed the microfilm publication of the phase cards compiled at the Laboratory and at the auxiliary stations belonging to the southern California network of seismological stations. There are 133 rolls of film, covering the years April 15, 1927-December 31, 1969. We also prepared a microfilm index of the collection.

In addition to the phase cards, the contents of five loose-leaf binders, located in the Laboratory's measuring room were also filmed. This material is contained on a separate roll of film marked, "Richter Notebooks: Local Shocks; Long Beach." Binder No. B is concerned exclusively with the Long Beach shock of March 10, 1933, and contains graphs and tabulations of readings from all stations of the shock and its aftermath, March 1933-June 1936. The other binders contain material relating to instruments and stations in the 1930s, tabulation of local shocks between October 1926 and

December 1930, contemporary accounts of local and distant shocks between 1933 and 1935, and miscellaneous tables, news reports, and geological notes.

SOME GENERAL INFORMATION ABOUT THE PHASE CARDS

The microfilm edition of the phase cards mirrors the arrangement of the original cards in the shock file. Every card was filmed. Remarks, diagrams, calculations, and other information noted on the reverse of the card was also filmed.

The arrangement of the shock file, composed of guide and file cards, was established by C. F. Richter in 1929; and while changes in the earthquake measuring routine have occurred over the years, the phase card layout remains largely intact. The cards themselves are filed in chronological order within each drawer. Each shock is represented by a primary guide card, followed by a series of color-coded file cards. The primary guide card has a center, right, or left tab. Center tab cards contain information about local shocks; right-hand tab cards about teleseismic shocks. For a time, left-hand tabs indicated uncertainty as to whether the shock was teleseismic or local; this practice has been discontinued. By 1955, the left-hand tab served as station markers, showing the point to which measurements for the auxiliary stations were completed. In addition, the primary guide card includes information pertaining to the character of the shock, epicenter, time (P.S.T. and G.C.T.), date, and recordings at other stations. Since January 1, 1951, only G.C.T. is used.

Each station that registered the shock has a file card indicating the date, and the character of the shock. Each card contains the measurements of one instrumental record of one earthquake. The original file cards are colored buff, white, and blue, the color of the card indicating the direction of the particular instrument recording each shock. Although these colors do not show up on the black-and-white microfilm, the components of the direction are indicated on the card by a pair of letters: N-S, S-N, E-W, W-E, U-D, D-U.

To assist researchers in using the microfilmed phase cards, each roll includes a standard introductory section that contains the following information: site information, site instrumentation, a brief description of the records microfilmed, a station chronology, and a time-on/time-off index. The actual card index for the stations in the network was filmed alone. Richter's basic set of instructions governing the shock file, and subsequent procedure manuals is also available.

After we had finished this project, we found in the attic of the central station records pertaining to the measurement of local and distant earthquakes for the period covering January 17, 1923-April 24, 1927. This group of records is now microfilmed and available separately on 4 rolls of film.

PROCEDURES FOR PREPARING AND MICROFILMING SEISMOGRAMS

The project to copy Caltech's archive of original seismograms is in a class by itself. In size and complexity alone, it surpasses any of the projects already described. These records, housed at the Kresge Seismological Laboratory, comprise more than 500,000 individual photographic sheets--each 30 x 92 cm. As records go, they are important because they span so much of the period for which instrumental data exists. We are microfilming both the Pasadena station records, as well as those written at the six outlying stations in the Caltech network. The project got underway in June 1981; and since then, we have sorted, arranged, labeled, inventoried, copied, and refiled more than 50,000 records written between January 10, 1923 and December 31, 1935.

At the beginning of every roll of film, we have inserted general information about the station site, station instrumentation, a description of the records, a historical chronology of the stations, and monthly seismogram inventory sheets. The inventory sheets indicate records filmed, missing, incomplete, and unreadable.[4]

GUIDELINES AND EXPERIENCES

Preparing the records for microfilming is, by far, the most time-consuming part of the project. The seismograms are filed in boxes and stored on shelves. As the microfilming is done by station, the seismograms must be sorted accordingly. To prevent confusion, each station's records are kept in boxes labeled by date and station.

After the records have been organized by station, they are put in chronological order. Each day's seismograms are arranged by component direction. The sequence for "outside" stations generally is: NS, EW, Z, and Time record, depending on the stations' compliment of components. For example, in August 1932, HAI and TIN have NS, EW, Z, T; all the other stations have NS, EW, T. On any day that one or more of these components are missing, this information is noted on the inventory sheet, and those remaining are arranged as closely as possible to the above sequence.

For the PAS station, the sequence is different because there are more recording instruments. The response and direction of some of the instruments also changes occasionally. Daily sequence for the PAS seismograms is arranged so that the longest continuously-recording seismograph is first, and those running for shorter periods are last. The different instruments in use are also listed at the top of every inventory sheet. As instruments are changed, the "older" records are deleted from the sequence, the remaining records are "moved up," and the "new" records are added to the inventory sheet.

Pasadena's seismograms are identified by letter, Roman numerals, or Arabic numbers on the back, along with date and component directions. The letter "G", for example, refers to an instrument. Originally, the instruments were identified by letters; as new instruments were installed, they were assigned Roman numerals; in more recent times, all the instruments were given Arabic numbers. Sometimes, instrument responses and type are also indicated on the back of the seismogram. What is written on the reverse side is, indeed, the principal source (the station information cards have been microfilmed separately) for the information written on the labels affixed to the front of the seismogram. If the instrument responses and types are not written on the back of the record, we have used the instrument number to determine what they are. In some cases, this information is given on the first seismogram for the month, and not repeated for the rest of the month. The response and instrument type noted on the first record is repeated on subsequent records until changes are noted on the back of the seismogram. In effect, the monthly inventory sheets summarize the recording history of each instrument.

Each seismogram is described more or less on the back. Since only the front of each record is filmed, the information on the back has to be transferred to the labels that are affixed to the front. The labeling process involves circling the component directions, writing in the date, including the month, day-on/day-off/, year, and indicating the instrument responses. Occasionally, information on the reverse side conflicts with the standard printed notation on the label. When the component directions are reversed, S-N rather than the standard N-S, for example, the printed letters have been crossed out and the corrections written in. We have not filled in the space provided for time corrections as this information is already available on microfiche. The label, in any case, reflects only the information originally written by Richter and others on the back of the record.

The labels are usually placed in the margin (where the paper overlaps when wrapped around the seismograph drum) at the left side, in the lower corner. If the paper was torn, curled, or handwritten information appeared in this area, the label was placed nearby.

The earliest records, in particular those for the years 1923-1927, were made basically with experimental instruments. There were not only a good many interruptions, but the instruments also underwent many changes and adjustments. Wood's own scientific correspondence in the 1920s is worth noting in this connection. To the seismologist who wrote and asked for records of the earthquake in China on May 22, 1927, Wood replied that he had no useful ones. He explained why in some detail:

> We have not yet any reasonably good time at the head station or at any of the outlying stations except the experimental pier at the Mt. Wilson Observatory office. Unfortunately the record. . .[there] is defective for the day in question.
>
> There is not much use in determining constants until after the instruments have had a little opportunity to settle down. . .to their environment. . . . I have five graphs of the shock, two written with short-period local earthquake instruments operating at Riverside, two written with short-period local earthquake instruments operating at the head station, and the defective record written by instrument G. . . . There are no time marks whatever on that, which is due to a change. . .in the timing circuit. . . . There is no value whatever to the time marks on any of the other four records. They are placed on the records only to indicate the character of the running, and the constants are only crudely approximate.[5]

Indeed, in marking the records in pencil on the back in the early years, Wood noted only the station, the date, and the letters E-W or N-S. He explained the meaning of the letters like this:

> If you transpose them to the face of the record so that E on the face is at the same edge as E on the back, and so on, then a shift of the line of the seismogram towards the edge marked E means a shift of the earth towards the east.[6]

An inventory of the records is essential. The inventory form indicates records present, missing, unreadable, or incomplete. Unreadable seismograms are those that are either blank, black, or those with very faint lines, or fogged so badly that the lines are barely visible. Incomplete seismograms have lines that are readable but have conspicuously fewer lines than "usual."

Occasionally, two sheets of paper were used per day per instrument component. An effort is made to determine the order of the sheets; they are then labeled sheet 1 and sheet 2, and two Xs written on the inventory sheet for that day.

Seismographic records are microfilmed in chronological order with each station's records filmed on separate rolls of film. On average, 600 seismograms can be filmed on a 100 ft. roll. The deciding factor as to the actual number of seismograms filmed is the number of whole months worth of records that can fit on a roll. Each roll starts at the beginning of a month and finished and the end of a month after approximately 600 records have been filmed.

Since seismograms vary in darkness and quality of line and background, exposure corrections are made during the filming of each seismic record to compensate for variation. A resolution chart with scales is also filmed, along with the roll number, station name, and the starting and ending dates. Unreadable seismograms are filmed for completeness.

REFERENCES

1. I wish to thank John Lower, Paul Roberts, Graham McLaren, and Yoram Meroz for technical assistance.

2. The historical material in this paper is based on a larger work, "Beno Gutenberg and the Rise of Seismology at Caltech," a chapter from my book on Caltech's History, now in preparation.

3. This microfiche publication project, and the subsequent phase card project, were supported by the U.S. Geological Survey as part of its effort to document the history of California earthquakes. A more detailed description of the 1979 project is given in "Seismology Microfiche Publications From the Caltech Archives," J. Goodstein, H. Kanamori and W. Lee, eds., BSSA (1980), 70: 657-658.

4. Funds for the filming of Caltech's records are provided by the USGS and the National Oceanic and Atmospheric Administration.

5. Wood to William C. Repetti, 27 June 1927, Harry O. Wood Papers, Caltech Archives.

6. Wood to Repetti, 7 July 1927.