Filming Seismograms and Related Materials at the California Institute of Technology

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As part of the worldwide effort to create an international earthquake data bank, the seismology archive of the California Institute of Technology (Caltech) 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. The single largest and most complex component of the task has been the preparation and microfilming of Caltech's vast collection of original seismograms. The original proposal envisioned a modest project in which a selected number of seismographic records at Caltech could be made more generally available to the scientific community. These single-copy records are stored at Kresge Laboratory and comprise thousands of individual photographic sheets, each 30 × 92 cm. In the end, we microfilmed both the Pasadena station records and those written at the six original stations in the Caltech network. This task got underway in June 1981 and was completed in January 1985. In the course of the project, the staff sorted, arranged, inventoried, copied, and refiled more than 276,000 records written between January 10, 1923 and December 31, 1962. The microfilm edition of the earthquake records at the Seismological Laboratory at Pasadena and at auxiliary stations at Mount Wilson, Riverside, Santa Barbara, La Jolla, Tinemaha, and Haiwee (the latter two in the Owens Valley) consists of 461 reels of film. The film archive is cataloged and available to researchers in Caltech's Millikan Library in Pasadena, at the U.S. Geological Survey in Menlo Park, Calif. and at the World Data Center (National Oceanic and Atmospheric Administration) in Boulder, Colo.

Origins of the Seismology Archive

Seismology at the California Institute of Technology (Caltech) arose from an "arranged marriage" between two different traditions: a European interest in global earthquakes and an American concern for local earthquakes [*Goodstein*, 1874]. German-born and Güttingen University–trained, Beno Gutenberg brought to Caltech the European tradition of viewing seismology as a research tool. Rigorously trained in physics and mathematics, he 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. For Gutenberg, the globe was his scientific laboratory.

However, Gutenberg's American colleagues, Harry Oscar Wood included, took a much more pragmatic view of the world. Few in number and concentrated in California, the American seismological community saw their research in terms of finding a solution to the "California problem," as they called regional earthquakes. To a seismologist like Wood, a veteran of the San Francisco quake and the expert on the seismic history of California, Gutenberg's global problem shrank to the size of southern California.

In bringing these two men together in Pasadena in 1930, Robert A. Millikan, the head of Caltech, set in motion a chain of events that was ultimately to lead Charles Richter to develop the first earthquake magnitude scale.

Charles Richter took his Ph.D. in theoretical physics at Caltech. He became Wood's assistant in 1927, 3 years before Gutenberg's arrival. He spent the next several years measuring and filing seismograms. Much of the work was tedious and mechanical, and aside from Wood, Richter's contacts with seismologists remained limited. A theoretical physicist who fell into seismology more or less accidentally, Richter desperately needed a scientific mentor. Gutenberg fit the bill; indeed, if Gutenberg had not come to Richter, Richter would have gone to Gutenberg. As things turned out, they spent 30 years under the same academic roof.

American interest in seismology got its biggest boost from the 1906 San Francisco earthquake. At that time, no American university boasted a department of seismology, let alone any professional seismologists. The quake triggered, among other things, the birth of the Seismological Society of America, an organization dedicated to stimulating interest in geophysical matters in general and earthquake problems in particular. Meanwhile, at the state level, a commission under the direction of Andrew C. Lawson, a Berkeley geologist, investigated the tremblor itself. The Carnegie Institution of Washington, a private philanthropic foundation, supplied the necessary funds when the Sacramento, Calif., state legislators, under pressure from the business community, refused to do so.

Lawson tapped Wood, who was then an instructor in the University of California, Berkeley, Geology Department, to study in detail the extent and nature of the earthquake damage within the city itself. Wood went into the exercise a field geologist and came out a seismologist.

It was Wood who brought seismology to southern California. His campaign began in 1916 with the publication of two papers. Stressing the importance of taking a regional approach to the study of local earthquakes, he suggested that the plan be tested on a modest scale in southern California.

Wood singled out southern California for two reasons: because the region had no recording instruments, and because he expected the next large earthquake to occur there. The 1857 earthquake along the San Andreas fault had been the last great shock in southern California.

His research program also stressed the need for a new generation of instruments: there could be no hope of measuring short-

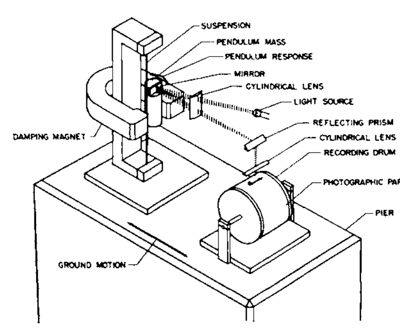

Fig. 1. Schematic drawing of the Wood-Anderson torsion seismometer.

Cover. *Planet Earth:* Twenty-five years ago, scientists from around the world joined forces in a venture of unprecedented scale aimed at achieving a major advance in our knowledge of the earth. The International Geophysical Year (IGY) took place in 1957–1958 and was successful beyond all hopes of the participants. "Planet Earth" is an upcoming major new PBS prime-time series and television course that will explore the multifaceted revolution in scientific thought that came in the wake of IGY. Special previews of this series will be featured at the 1985 AGU Fall Meeting in San Francisco, Calif., December 8–13.

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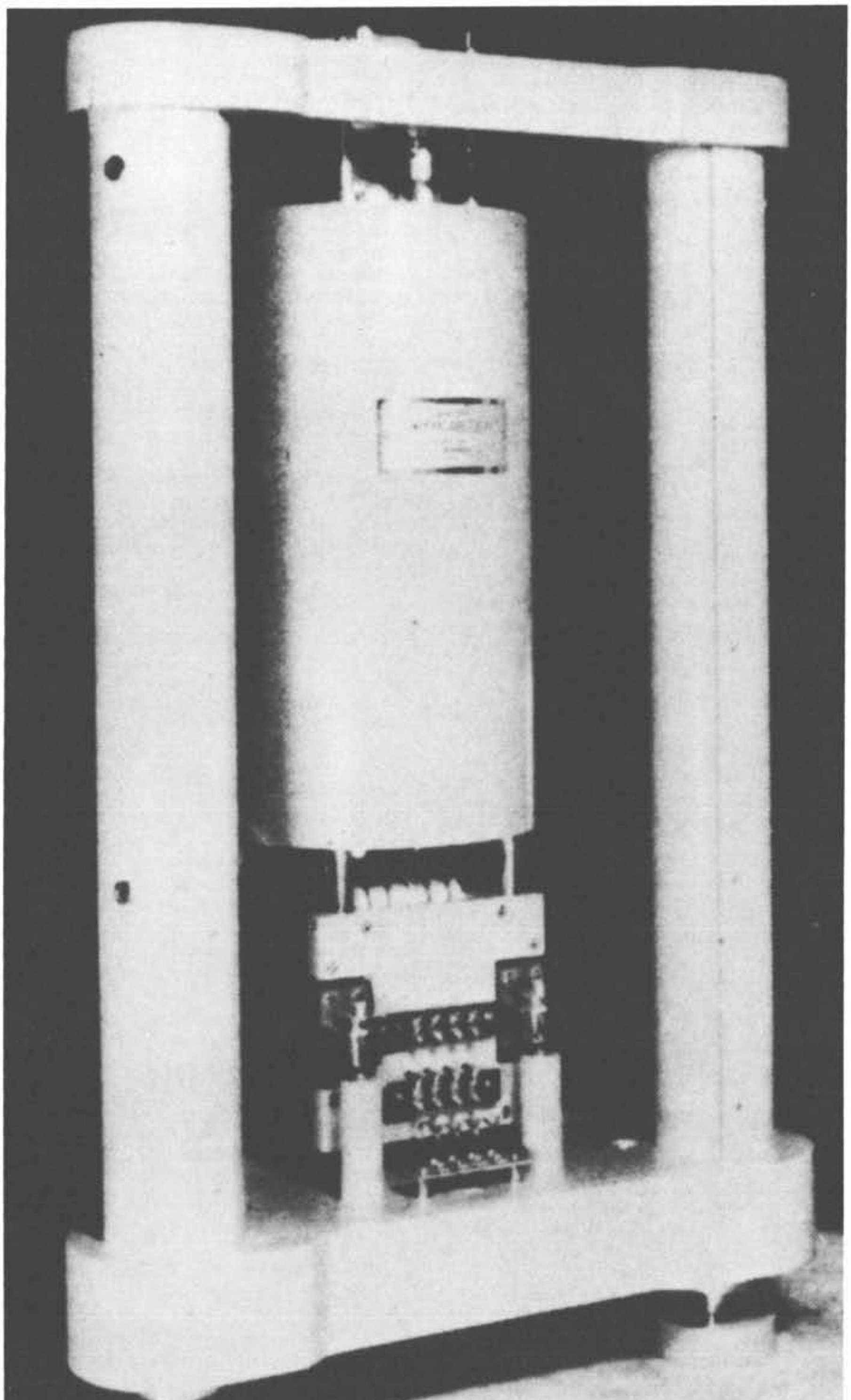

Fig. 2. Hugo Benioff's vertical component seismometer.

period local earthquakes with instruments designed to measure long-period distant earthquakes. Finally, he emphasized the importance of field work, in particular, to locate weak shocks. Like most of his contemporaries, Wood was convinced that if geologists could identify the active faults associated with weak shocks, they could then "deduce. . .the places where strong shocks are to originate, considerably in advance of their advent," [*Woods,* 1916]. Big shocks, in other words, follow weak shocks. He believed that, in time, it would be possible to make, in his words, a "generalized prediction" of when and where to expect the next big quake.

The compelling reason for setting up branch seismological stations was therefore to detect and register the weak shocks systematically. Yet the routine registration of hundreds and hundreds of small California earthquakes did not confirm Wood's hypothesis. Nevertheless, the lure of that elusive idea drives seismological research to this day.

Like Lawson before him, Wood ultimately found a patron in the Carnegie Institution. Southern California's first seismological program began operation in Pasadena in June 1921, under Wood's direction. For the next 6 years, Wood ran the project from an office at the Mount Wilson Observatory, located a short distance from the Caltech campus.

To succeed, the project needed the right instrument for recording nearby earthquakes. Fortune favored Wood in the person of John Anderson, one of Mount Wilson's ablest astronomers. As part of the school's defense effort during World War I, Anderson had worked on submarine detection instruments sensitive enough to record short vibrations. The apparatus made use of the piezoelectric properties of crystals, including Rochelle salt and quartz, to produce and detect supersonic waves. Anderson's war-honed skills matched Wood's peacetime needs. The Wood-Anderson collaboration began immediately after Wood had settled into his office.

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 s. Seismometers designed for recording distant earthquakes typically have longer period response. In the case of Berkeley's station, the instruments in use had periods of 15 and 6 s, respectively. In the early 1920's, instruments on the Atlantic seaboard could measure the time and place of California shocks with greater precision than could comparable instruments located in California.

In the autumn of 1922, after several false starts, Wood and Anderson had designed a reliable, compact, portable instrument that, when placed vertically, consistently recorded the east-west and north-south components of the earth's motion during an earthquake. In practice, the Wood-Anderson torsion seismometer was an ideal instrument for recording the earth's horizontal movements over a short distance during an earthquake; it proved less successful for recording the earth's up-and-down motions. 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 with Benioff's instrument began in 1931, by which time Wood was predicting the new vertical component seismometer would surpass any existing vertical then 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.

All seismographs consist of a damped mechanical oscillator of some type, along with a mechanical, optical, or electromagnetic recording apparatus. In the case of the Wood-Anderson instrument (Figure 1), a permanent magnet provides critical damping of the pendulum motion. The pendulum mass is mounted on a taut wire suspension and rotates about the wire against the restoring force of torsion. This rotation is optically magnified and photographically recorded by means of a mirror attached to the pendulum and the recording drum.

Benioff's vertical component seismometer (Figure 2) works on the same principle as the telephone transmitter. Pendulum movement is converted into electric current by means of a variable reluctance transducer. A galvanometer, activated by this current, records the up-and-down component of ground motion.

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 was not lost on seismologists elsewhere. When Gutenberg heard the news in Germany, from a colleague who had attended an international gathering of geophysicists in Madrid, Spain, 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 1920's, 13 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, which was 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-mi (480-km) radius of the central station in Pasadena were in place and working. Each station was equipped with a pair of horizontal component torsion instruments and recording drums, as well as with radio-timing equipment. Records were sent weekly to Pasadena for photographic processing, registration, and interpretation.

Historical Seismogram Filming Project

Why develop a historical file of seismograms? Aside from the practical consideration that there is always the danger of fire destroying the present single copies, there is no doubt that the records are scientifically important. One reason, certainly, is that the art and science of interpreting such records has improved considerably since the end of the last century, when instrumental data first came into existence. There is still much to be learned about the physics of the earth and of earthquakes from analyzing old seismograms.

Consider the problem of earthquake prediction and the assessment of risk due to large earthquakes. Progress in this area depends, in part, on knowledge of seismicity rates and historical changes of seismicity in a certain region. The understanding of the seismic cycle of the local shocks and the recurrence time of large earthquakes requires seismicity data over a long period of time. This applies to distant earthquakes also. Pasadena's historical file is important here because it is a continuous long-term record for both kinds of events. Since the seismic cycle itself is a long-term process, and since no two earthquakes are ever identical, the need to consult old records remains vital.

Over the last several decades, researchers at Hokkaido University (Japan), the University of Tokyo, and the Japan Meteorological Agency, as well as at Stanford University (Stanford, Calif.), Caltech, and other places, have used historical seismograms to attack a wide range of geophysical problems. Such studies include accuracy of earthquake catalogs, seismic gaps, global and regional seismicity, tsunami earthquakes, some previously unstudied great earthquakes around the world, and patterns of foreshocks and aftershocks associated with large earthquakes.

In the absence of field work or a good local network, seismologists have found other ways to expand the data base for regions that have strong earthquakes. For example, distant earthquake records can be used to supply the fault orientation, rupture mechanics, and related information through the use of a computer modeling technique known as "synthetic seismology." This is one way in which researchers utilize Caltech's distant earthquake seismograms. Still another technique involves the use of unpublished primary accounts in archival repositories, such as diaries and reports, to document the effects of great earthquakes in the past and prepare comprehensive catalogs.

Nuclear test detection has also focused attention on seismology archives. The problem of discriminating earthquakes from explosions in connection with the nuclear test ban treaty led to improvements in the worldwide network of seismic stations. Locally, many users of Caltech's historical file seek out records of nuclear tests, both ours and those of other nations. In their day, Gutenberg and Richter used nuclear explosion records for scientific reasons: they measured their size and the travel time of the seismic waves. They are still used for this purpose today.

Caltech's historical file of seismograms has been filmed as part of an international program to preserve records written prior to the creation in 1963 of the World-Wide Network of Standardized Seismographs (WWNSS) and to make them more accessible to the scientific community. The World Data Center A for Solid Earth Geophysics in Boulder, Colo., administers the program in the United States, working with the International Association of Seismologists and Physicists of the Earth's Interior (IASPEI) and the United Nations Educational, Scientific, and Cultural Organization (UNESCO) in other countries. Financial support for the filming in the United States has been provided by the U.S. Geological Survey, the National Oceanic and Atmospheric Administration (NOAA), and the Nuclear Regulatory Commission. The 35,235 seismograms recorded at Mount Hamilton, Calif., between 1911 and 1962 have also been microfilmed as part of this project, as have seismograph station records from College, Alaska; Honolulu, Hawaii; and the University of Tokyo. The long-term goal is to film several million pre-WWNSS seismograms.

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* (Princeton University Press, Princeton, N. J., 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. (See *Goodstein et al.* [1980] for a more detailed description of this project.)

Since then, we have concentrated on filming the original documentation on earthquakes registered at the Seismological Laboratory at Pasadena and at auxiliary stations at Mount Wilson, Riverside, Santa Barbara, La Jolla, Tinemaha, and Haiwee. 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, which cover data from April 15, 1927 to 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 that were 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 *B* is concerned exclusively with the Long Beach shock of March 10, 1933, and contains graphs and tabulations of readings from all stations recording the earthquake and its aftershocks, March 1933–June 1936. The other binders contain material relating to instruments and stations in the 1930's, 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 were 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 tabs 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 (Pacific Standard Time and Greenwich Civil Time (GCT), date, and recordings at other stations. Since January 1, 1951, only GCT has been 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 (north-south. . .down-up).

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 are 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 January 17, 1923–April 24, 1927. This group of records is now microfilmed and is available separately on four 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 close to 500,000 individual photographic sheets, each 30 × 92 cm. Seismograms are the principal source of information about earthquakes and the earth's interior. As records go, they are also important because they span so much of the period for which instrumental data exists. We microfilmed both the Pasadena station records and those written at the six outlying stations in the Caltech network. The project got underway in June 1981 and was completed in January 1985. During that time, we sorted, arranged, labeled, inventoried, copied, and refiled more than 276,000 records written between January 10, 1923 and December 31, 1962.

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.

Guidelines and Experience

Preparing the records for microfilming was by far the most time-consuming part of the project. The seismograms are filed chronologically in boxes and stored on shelves, with the seismograms for all stations filed together by date. As the microfilming was done by station, the seismograms had to be sorted accordingly. To prevent confusion, each station's records were kept in boxes labeled by date and station.

After the records had been organized by station, they were put in chronological order. Each day's seismograms were arranged by component direction. The sequence for "outside" stations is generally: NS, EW, Z (vertical component of the motion of the earth), and T (time) record, depending on the equipment at the stations. For example, in August 1932, HAI (Haiwee) and TIN (Tinemaha) 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 components remaining are arranged as closely as possible to the above sequence.

For the PAS (Pasadena) station the sequence is different because there are more recording instruments. The response and direction of some of the instruments also changes occasionally. The 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 is not repeated for the rest of the month. The response and instrument type noted on the first record are 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 more or less described on the back. Since only the front of each record was filmed, the information on the back had to be transferred to the labels that are affixed to the front. The labeling process involved circling the component directions, writing in the date (including the month, day on/day off, and 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 were crossed out, and the corrections were 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 or curled, or if handwritten information appeared in this area, the label was placed nearby.

The earliest records, in particular those for the years 1923–1927, were made with what were essentially 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 1920's 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. [taken from a letter by Wood to William C. Repetti, June 27, 1927; available from the Harry O. Wood papers, Caltech Archives.]

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 in this way:

> 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. [letter, Wood to Repetti, July 7, 1927; available as above.]

An inventory of the records is essential. The inventory form indicates records present, missing, unreadable, or incomplete. Unreadable seismograms are those either blank or black, those with very faint lines, or those fogged so badly that the lines are barely visible. Incomplete seismograms have lines that are readable but have conspicuously fewer lines than is "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 crosses are 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 (30.5-m) roll. The deciding factor as to the actual number of seismograms filmed is the number of whole months of records that can fit on a roll. Each roll, in other words, starts at the beginning of a month and stops at the end of a month.

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 were filmed for completeness.

Afterward, an index and general appendix were prepared and filmed as a separate roll of film. This roll contains procedures and information on the project, seismogram recording and station technical data, notes made during the project, and the complete inventory of all seismograms filmed.

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News

Solwind Instrument Destroyed in Test

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The U.S. Air Force's destruction of one of its own satellites last month ended what had been the longest continuous stream of data from an instrument observing the sun's corona. Satellite P78–1 served as the target in a test of antisatellite (ASAT) weaponry on September 13, 1985. The satellite carried Solwind, a white light coronagraph that observed the solar corona at distances of 3–10 solar radii, according to Robert M. MacQueen, director of the High Altitude Observatory at the National Center for Atmospheric Research (NCAR) in Boulder, Colo.

P78–1 was launched in February 1979, carrying Solwind and five other instruments, all but two of which had ceased to work by the time the satellite was destroyed. Solwind gathered data during the period of "solar maximum" in 1980–1981; scientists had hoped it would continue to function at least until the sun's 11-year activity cycle reaches its minimum a year or two from now. "That's why I hate to see the mission terminated prematurely," said MacQueen.

The coronagraph was used in the study of coronal mass ejections, one of the few kinds of solar activity recognized to have a direct impact on earth and near-earth space. When material is ejected from the sun in the direction of the earth, it can trigger a geomagnetic storm, causing disruptions in communications and power transmission. Solwind data also demonstrated that while the corona is uniformly distributed during solar maximum, it is mostly confined to the equator as the cycle heads toward solar minimum. In addition, data from the coronagraph had been responsible for the detection of five "sun-grazing" comets, small comets that seemed to have been headed into the sun. Finally, Solwind had been used to study "coronal holes," which are the source of high-speed solar windstreams that also result in geomagnetic storms.

Scientists at the Naval Research Laboratory in Washington, D.C., were the primary users of Solwind data, which they shared with several other research groups. Recently, NRL had responded to requests for data from the National Oceanic and Atmospheric Administration's (NOAA) Space Environment Services Center (SESC) in Boulder, Colo. SESC used the data on an experimental basis in an effort to improve the accuracy of the hourly forecasts of solar and geomagnetic activity that they provide to government agencies and to the public. At the time of the ASAT test, SESC had yet to determine whether the additional data improved their accuracy.

The Air Force had not originally planned to use P78–1 as a target so early in their test program. Instead, they had intended to start by using the "Instrumented Test Vehicle" (ITV), little more than a sensor-equipped balloon, which they would send into space solely to serve as an ASAT target. Lightning at the ITV launch site resulted in short circuits that caused the launch to be called off, according to Air Force Col. James F. Shunk, a military assistant for strategic analysis in the office that oversees the ASAT program. That office asked the Air Force to consider "reversing the schedule" for ASAT targets so that the tests would not be delayed.

It is unclear whether the Air Force decisionmakers knew that Solwind was still providing useful data to researchers and to agencies like NOAA. Press accounts quoted officials in the Department of Defense as calling P78–1 "burned-out" and saying the satellite had "outlived its useful life." Although the Air Force presumably can do as it wishes with its own satellite, some researchers were asking whether a less useful object could have served just as well as a test target. Shunk said P78–1 probably was chosen over other potential targets because its size and orbit posed more of a challenge to the ASAT instruments. He added that to his knowledge, no other working research satellites will be destroyed in the ASAT tests.

The ASAT program, which has existed for more than a decade, uses no nuclear weaponry; in fact, it does not even use explosives, Shunk said. A "non-nuclear kinetic energy kill" is achieved simply by the force of the target's collision with a 17-kg object about the size of a coffee can. "We call them 'smart rocks,'" Shunk said. The ASAT program is not part of the Strategic Defense Initiative (SDI), but SDI will borrow some of the ASAT technology.

The loss of P78–1 will not end the work on Solwind data. "We still have about 2 years' worth of data left to process," said Neil R. Sheeley, Jr., of the Naval Research Laboratory. For the present, the National Aeronautics and Space Administration's Solar Max satellite "would be best classified as a partial substitute" for Solwind, according to NCAR's MacQueen, because Solar Max examines a more restricted area of 1.6–6 solar radii, which limits its usefulness to perform some of Solwind's functions. Meanwhile, SESC's evaluation of Solwind's usefulness for their forecasts is no longer a high priority. In the words of one SESC scientist, "The question is sort of moot."—*JAK*