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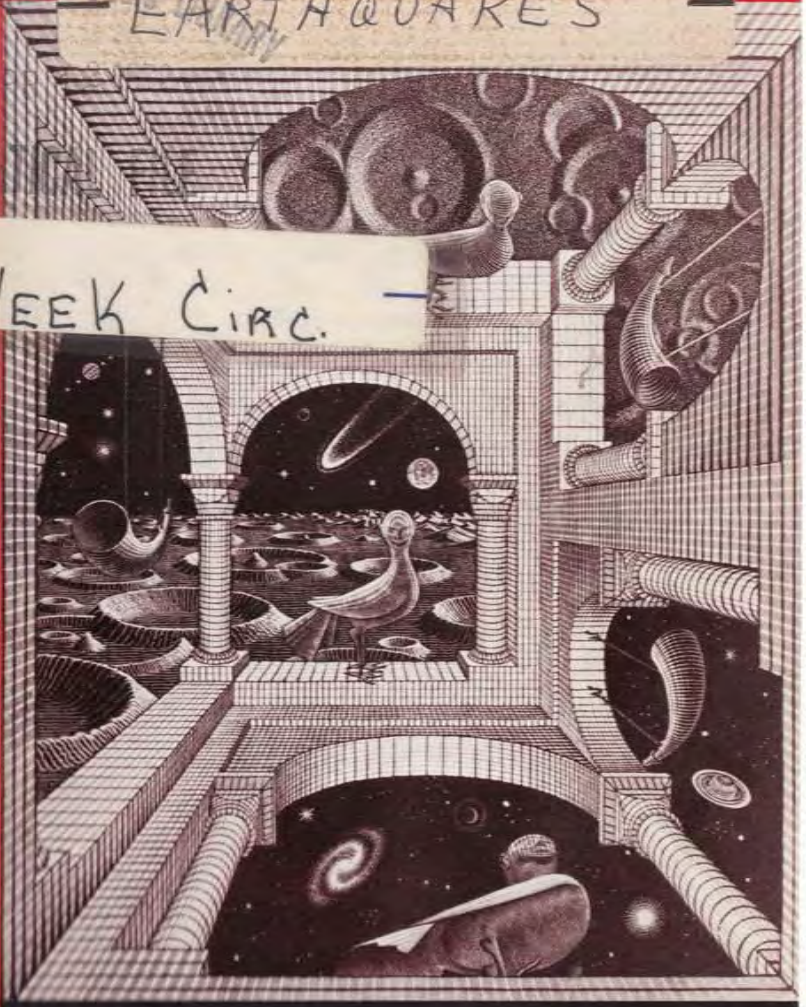
Unnoticed by most citizens of Hollister, Calif., the San Andreas fault creeps through a quiet residential neighborhood, producing the classic offset of curb and sidewalk. NOAA's efforts to measure and comprehend such motions are described in "Every Little Movement Has a Meaning All Its Own," beginning on page 22.

Earthquake Information Bulletin

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration

Environmental Research Laboratories



"Another World" by M. C. Escher
Collection Escher Foundation—Haags Gemeentemuseum
The Hague

Earthquake Information Bulletin

January-February 1972, Vol. 4, No. 1

IN THIS ISSUE

Cover. M. C. Escher's wood-engraving, "Another World," illustrates how a four-dimensional world might blend time and space to form patterns which are impossible in our familiar three-dimensional world. For a description of how modern seismologists are learning to visualize earthquake activity in four-dimensional terms, see "Global Seismicity Studies—Projections of the Hyperspace," beginning on page 4. © *Koninklijke uitgeverij Erven J. J. Tijl, N. V., Zwolle, Holland*

U. S. DEPARTMENT OF COMMERCE
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Wilmot N. Hess, Director

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Stanley B. Eames
Director, NOAA Office of Public Affairs

James F. Lander, Chief
National Earthquake Information Center
Contributing Editor

All communications (except those concerning paid subscriptions) should be addressed to:
Carl A. Posey
Editor, Earthquake Information Bulletin
NOAA Office of Public Affairs
Room 671 RB3
Boulder, Colorado 80302
(Telephone 303-499-1000, ext. 6280)

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Editorially Speaking

THIS year, as last, the volume begins with the *Earthquake Information Bulletin* barely settled in a new organizational home. It is a good vantage point from which to look at the year just ended, and at what can be seen of the year ahead.

During 1971 we stayed close to what might be called "operational seismology," with occasional excursions like the May-June article on earthquakes and astrology, the September-October polar wobble story, and "earthquake lightning" in November-December. We were extremely fortunate in our contributions from outside NOAA: the Apollo 12 seismic results in January-February, Dr. Charles Richter's responses to *Bulletin* questions in July-August, Dr. Hasegawa's September-October article on seismology in Canada.

Now. What of 1972?

Basic coverage will remain about the same. We hope to have special issues more often—specials on earthquake hazard reduction and earthquake prediction (including some of the myth and magic of earthquake prophecy) are planned now—and there will be more photoessays on earthquakes, seismology, and tangentially interesting fields. Major earthquakes will still be covered as fully as possible, as soon after the events as possible.

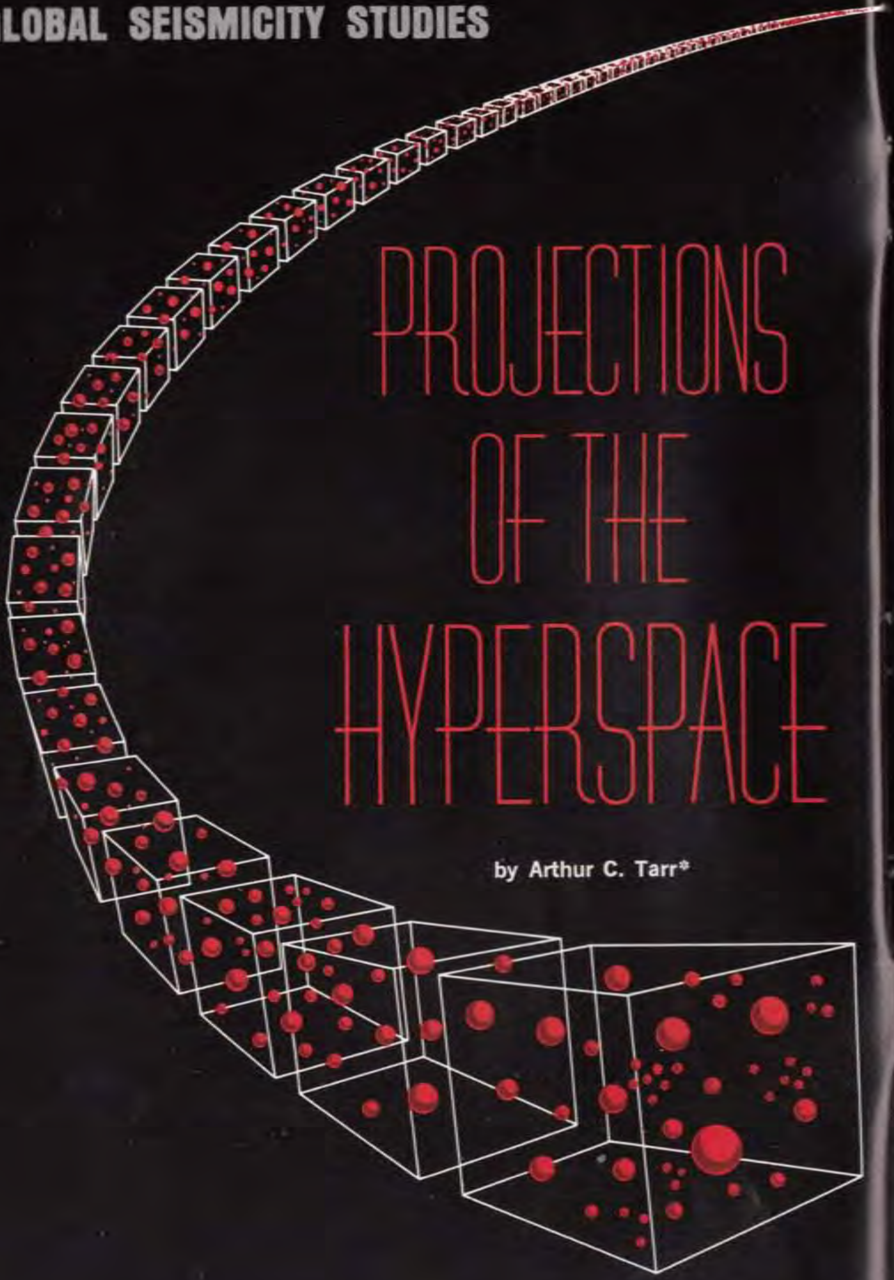
We will expand slightly into areas which touch and influence seismology, especially some of the plate tectonic, continental drift, and geomagnetic work being done by geophysicists in NOAA and elsewhere, on land and at sea. From contributors outside the agency we expect to have a number of interesting articles, among them something on volcanoes, lunar seismology since Apollo 12, and seismology in other nations.

Back-of-the-book departments will change only slightly. The bimonthly earthquake summary and seismic history by state will continue to appear each time, along with meetings. But publications will be listed only in every other issue, beginning with the next one.

"Seismology for the Classroom," a department seen only twice last year, is gone for good; however, we are planning articles on faults, strain, magnitude, and other basics with an eye to possible classroom use, and we will consider any good, short how-to material that comes in.

All in all, it looks like a good year for *Bulletins*. Welcome to volume four.

GLOBAL SEISMICITY STUDIES



PROJECTIONS OF THE HYPERSPACE

by Arthur C. Tarr*

We humans are able to cope with ordinary three-dimensional, or 3-D, space with ease. The reality of solid objects is apparent to all of us, and we have little difficulty in realizing that three quantities (having dimensions of length) are required to describe uniquely the spatial position of any point in this space.

Time may also be considered to be a dimension, and if such a consideration is accepted, it means that each of us is immersed in a four-dimensional, or 4-D, *hyperspace*. Each point in the hyperspace is described by four quantities, three of which are the three spatial dimensions and the fourth is time. The dimensionality of time is not always apparent to us, perhaps due to the difficulty of portraying graphically the temporal aspects of reality. A reel of ordinary movie film depicts the temporal dimension since successive instants of time are preserved in the sequence of frames.

Consider the common road map used by all motorists. The map is a two-dimensional, or 2-D, representation (since it is printed on flat paper) of the 4-D hyperspace. It illustrates how one may "freeze" several dimensions for the sake of a convenient, easy-to-produce, usable representation. Here, time has been "frozen" since highways are portrayed as they exist at some recent instant of time. One spatial dimension, depth, has been suppressed because the typical motorist does not care to have the details of the rock strata beneath the highway and the surrounding terrain portrayed on his map. We say,

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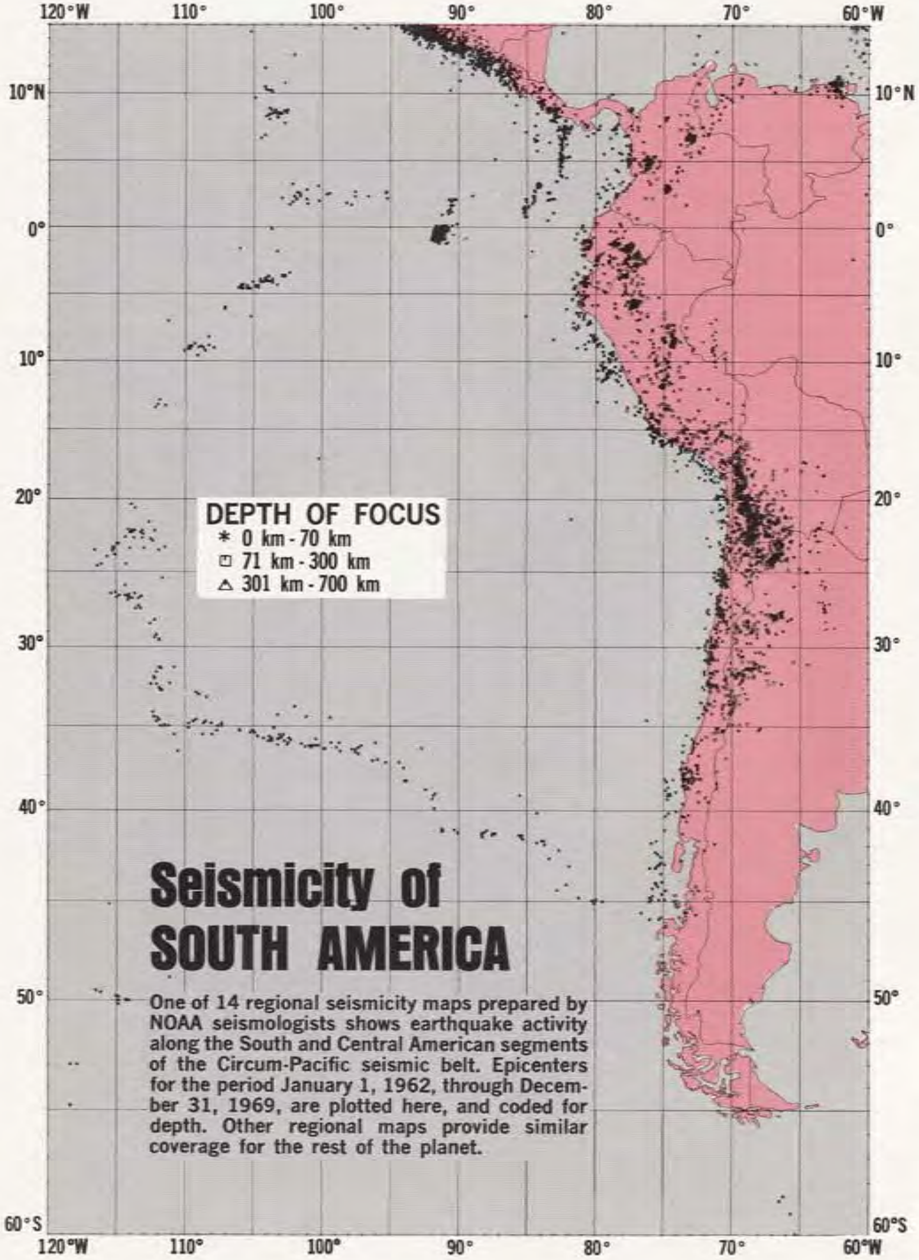
* Dr. Tarr is a research geophysicist in the Earth Sciences Laboratories' Seismology Investigations Group.



Seismicity of SOUTH AMERICA

One of 14 regional seismicity maps prepared by NOAA seismologists shows earthquake activity along the South and Central American segments of the Circum-Pacific seismic belt. Epicenters for the period January 1, 1962, through December 31, 1969, are plotted here, and coded for depth. Other regional maps provide similar coverage for the rest of the planet.

therefore, that the map is a *projection* of 4-D space into a 2-D space lying in the plane of the paper.

Imagine, then, a 4-D hyperspace in which each earthquake event is a unique point, specified by three spatial coordinates, and by its origin time. Three-dimensional representations (such as scale models) of the points in the hyperspace are difficult to construct, but 2-D representations such as maps and graphs are easy to draw, plot, and print. These graphical displays are usually required for meaningful interpretation of earthquake data.

Suppose that we project the events in our seismic hyperspace into various 2-D representations, understanding that the two remaining dimensions must be frozen, and requiring that the three spatial coordinate axes be mutually perpendicular to each other, regardless of orientation. The projection of the events onto the latitude-longitude space is a seismicity *map,* a geographic representation of where the earthquake epicenters are, independent of depth and origin time. The frozen dimensions, depth and time, may be controlled indirectly by specifying on the map legend that the seismicity corresponds to a given time interval and depth interval.

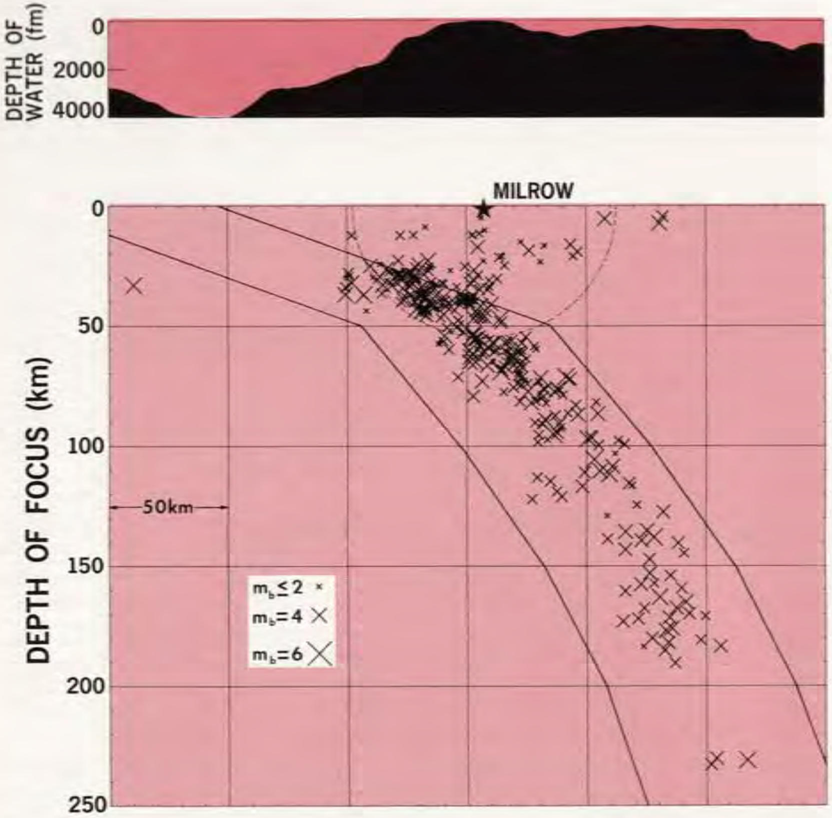
If we project the events in the hyperspace onto the depth-horizontal distance space, the spatial coordinate system consists of an axis along the vertical (depth) direction, and two axes parallel to the surface of the earth, one of which is frozen. The result is a *depth section,* a vertical plane cutting into the earth, upon which the earthquake foci are projected, independent of time and the frozen horizontal distance. The depth section (or *depth profile*) is often used to display the distribution of intermediate- and deep-focus earthquakes.

Finally, suppose that we project onto the time-horizontal distance space. The result is a *time-space diagram,* which permits the display of time-dependent phenomena, such as earthquake sequences following very large earthquakes.

What are some of the results that have been gleaned from studies of earthquake seismicity, utilizing these graphical tools?

The first, and probably most important is the observation that earthquake occurrence is confined, for the most part, to rather narrow belts that are closely associated with geotectonic provinces already defined by geologists, and hence, are thought to delineate the very boundaries of the large, mobile lithospheric plates of global tectonics.

The lithosphere is the uppermost 100 kilometers or so of the earth, and is characterized by relative strength compared to the asthenosphere upon which it rests. The lithosphere is sub-divided into six major plate-like slabs (which are not unlike paving stones) of continental size, and several small sub-plates. The Pacific plate is topped almost entirely by the Pacific Ocean seafloor, whereas both continents and adjacent sea floor lie on the top of each of the other five major plates. Individual plates move relative to one another, driven by forces within the earth that are not yet understood, in directions away from the axis of



Depth profile prepared in conjunction with the Aleutian Seismic Program shows seismic activity as a function of depth along a section through Amchitka Island. This profile was used to illustrate the lack of interaction between MILROW, an underground explosion of about one megaton detonated in 1969, and the area's natural seismicity, which appears to be concentrated in a downthrusting lithospheric plate some tens of kilometers below the island. (See "Preliminary Seismic Results from CANNIKIN," beginning on page 16.)

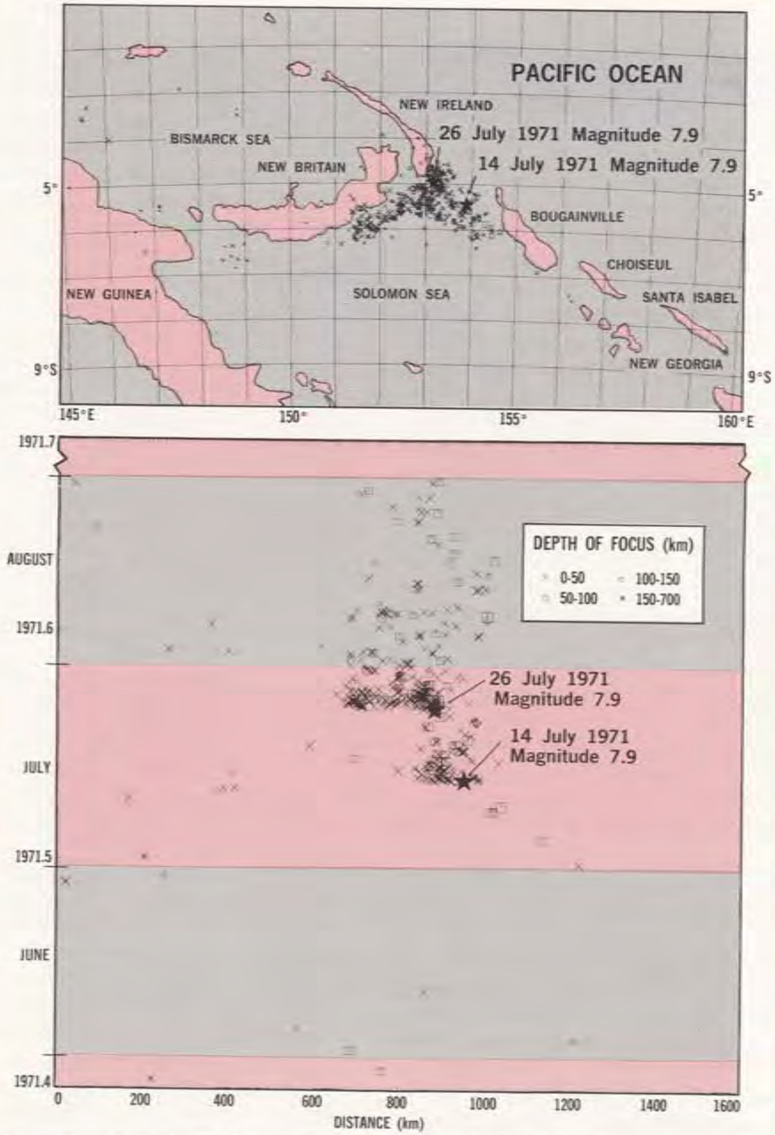
the mid-oceanic ridge where new seafloor is created. Not surprisingly, where the plates collide great distortion and tectonism result. When one of the colliding edges of a plate is sea floor, that edge is pushed (or sinks) under the edge of the other plate, and descends into the asthenosphere. If the colliding edges are both continental, the collision results in great uplift and crustal thickening. The zones of creation of new lithosphere and sea floor, and of destruction of old lithosphere, are characterized by earthquake activity.

Almost all earthquakes occur in one of three major seismic zones, the Circum-Pacific Belt, the Alpine-Himalayan (or Alpide) Belt, and the Mid-Oceanic Ridge Belt. Each of these belts is sub-divided into smaller arcs, linear segments, and diffuse zones, corresponding to variations in shape, alignment, and rate of activity. In the case of the Circum-Pacific Belt, the segments are narrow and arcuate in shape, and each is closely associated with a parallel trench and island (or mountain) arc nearby. Most segments in the Alpine-Himalayan Belt are somewhat more diffuse and are associated with the trends of the Alps, Himalayas, and the mountain ranges of the Middle East. The sharply delineated segments of the Mid-Oceanic Ridge Belt are associated with the crest of the world-girdling mid-oceanic ridge system and the connecting links between the ends of offset ridge crest segments.

The second important result is provided by depth sections, in which we see that foci in most segments of the Circum-Pacific Belt (and a few segments of the Alpine-Himalayan Belt) are distributed in relatively thin, planar zones which are inclined to the earth's surface and extend from the arcs to depths as great as 700 kilometers. According to the proponents of global tectonic theories, the intermediate and deep foci comprising the inclined seismic zone are located *within* a downgoing lithospheric plate.

A third class of evidence is found in the gaps and clusters of foci which are observed on detailed seismicity maps and on depth sections taken perpendicularly to inclined seismic zones. One gains the impression from such maps and sections that considerable seismic energy is continually being dissipated in dense knots and localized nests of earthquakes. Some of these clusters of intense activity have been associated with volcanic activity (swarms), and with contortions and tears in the downgoing lithospheric slab. Gaps are not easy to interpret, for in addition to the possibility of genuine quiescence, the absence of activity may indicate defects in the data—for example, the time period of observation may be too short or the location and detection capability of the world network of seismograph stations may be low.

The fourth important result comes from a collection of observations of aftershocks following large earthquakes. Most large earthquakes are followed by an extensive series of smaller aftershocks, owing to extensive distortions in the stress field surrounding the focal region during and after the principal rupturing, and to the large volume of lithosphere that is involved when slip occurs along a fault zone. It is thought that the spatial distribution of aftershocks on a map is indicative of the large extent of this distortion. Aftershock sequences of very large earthquakes tend to fill in gaps in the natural seismicity patterns, and tend to abut the aftershock zones of former large earthquakes. Large aftershocks in some sequences have been observed to migrate along the aftershock zone, away from the location of the main shock, and it has been suggested that the very largest earthquakes tend to migrate sequentially around the Circum-Pacific Belt. Time-space dia-



Recent burst of Solomon Sea earthquake activity is displayed here in a conventional latitude-longitude seismicity map (top) and in the innovative time-space display (bottom). The time-space diagram "deepens" the seismicity map's content by making the vertical axis the time period 1971.4 to 1971.7 (May 27—Sept. 15, 1971), and shows how this activity was distributed through time. The horizontal axis of 1600 kilometers corresponds at this latitude to the 15 degrees of longitude covered by the upper map. Of particular interest to researchers are such features as seismic activity preceding major earthquakes, small gaps in the time distribution of earthquakes and aftershocks, and clustered tremors which show distributions of stress-field adjustments following seismic energy release. Symbols denote earthquake depth of focus; their size indicates relative magnitude.

grams show patterns of these migrations along the time dimension, and illuminate the geographic and depth patterns which appear on conventional seismicity maps.

Why are studies of seismicity important? Perhaps the topic of seismic risk as applied to densely populated areas is of greatest interest to the general public. Suppose that the earthquake hazard for the city of San Francisco is to be evaluated. The answers to the questions of where and how often earthquakes occur in the San Francisco Bay area must come partially from our analysis of a catalog of historical earthquakes in California. Or suppose that an electrical power company proposes that a nuclear reactor be built on an earthquake-prone region. Estimates of the frequency of recurrence of potentially damaging shocks may be made from a regional catalog of seismicity and used in establishing design criteria for the reactor facility.

The topic of earthquake prediction is of increasing interest, particularly as it relates to the reduction of loss of life and property. The accurate prediction of origin time and location of potentially damaging earthquakes is a long-range goal of many seismologists, and a considerable research effort has already been mounted to reach this objective in the next few decades. Again, seismicity studies of a particular region are obviously going to be important in the development of an earthquake prediction system, and in fact, in understanding those larger processes, on regional and global scales, which are responsible for the very evolution of the earth.

A Glossary of Seismicity Terms

Aftershock–An earthquake, usually a member of an aftershock series, following the occurrence of a large earthquake (main shock). The magnitude of an aftershock is commonly much smaller than the main shock.

Depth-of-focus class–A set of earthquakes occurring within a specified depth interval. Three common classes are shallow (0 to 70 kilometers), intermediate (70 to 300 kilometers), and deep (300 to 700 kilometers).

Epicenter–Point on the earth's surface directly above the hypocenter. It is specified by latitude and longitude.

Foreshock–An earthquake occurring prior to a large earthquake and having a smaller magnitude than the main shock.

Gap–The absence of earthquake foci in an active seismic region.

Hypocenter (or focus)–The hypothetical point location at which an earthquake begins, specified by latitude, longitude, and depth.

Inclined seismic zone–A thin, nearly planar zone of foci inclined to the surface, and extending from a tectonic zone at the surface to depths as great as 700 kilometers.

Magnitude–The "size" of an earthquake, the value of which is related to the actual ground motion measured by a seismograph. Several magnitude scales (local, body wave, and surface wave) are employed for the ranking of earthquakes.

Main shock–The largest magnitude earthquake in a series.

Multiplet–Several earthquakes occurring close together in space-time, with comparable magnitudes.

Nest–A tight spatial cluster of earthquakes, usually at intermediate and deep depths.

Series–A sequence of earthquakes which are assumed to be associated because of proximity both in spatial location and origin time.

Swarm–An earthquake series in which no one event is sufficiently larger than the others to be classified as the main shock.

Zone (or belt)–A spatial grouping of earthquakes, not necessarily related by time of occurrence.

GLOBAL SEISMICITY IN RETROSPECT

SEISMICITY is a word so common in the vocabulary of earth scientists, that it is forced to carry a great burden in its various connotations and implications. Seismicity literally means "quality, state or degree of being seismic," which implies that the word refers strictly to characteristics of earthquakes at their source, and therefore, has little to do with the passage of seismic waves through the earth and with their detection. The word must do heavy duty in its implication of earthquake geography and earthquake history, since the elements of place and time are involved in the state and degree of being seismic, and the word must serve as a catchall in which other descriptive characteristics (such as earthquake magnitude) are collected—that is, the seismicity of an area must be a complete description of the individual earthquakes that have occurred there.

In the first half of this century, the young science of modern seismology developed slowly, owing, in part, to a lack of good observational data. It is not surprising, then, that considerable emphasis was placed upon developing sensitive seismographs which would provide the essential raw seismological data, and upon developing techniques for the processing and analysis of this data as sufficient quantities became available. The development of accurate travel-time tables and theories concerning details of the internal structure of the earth were among the important advances of this period which permitted the accurate location (within several degrees of arc) of most of the largest earthquakes occurring since 1900. Simultaneously, earthquake catalogs were compiled which now constitute the data base for seismicity studies. The goal of collecting large quantities of relatively high-quality seismological data has been achieved in the present global network of sensitive seismographs, and the computerized determination of epicenters ensures the availability of large and growing catalogs for detailed studies in most of the planet's seismic areas.

It would be wrong to conclude that the description of the seismicity of an area is merely the collection and tabulation of earthquake hypocenter parameters and associated data in a catalog. It also involves the meaningful interpretation of patterns in the data drawn from the catalog, and relating these patterns to other non-seismological information; this is where the emphasis of current research is concentrated.

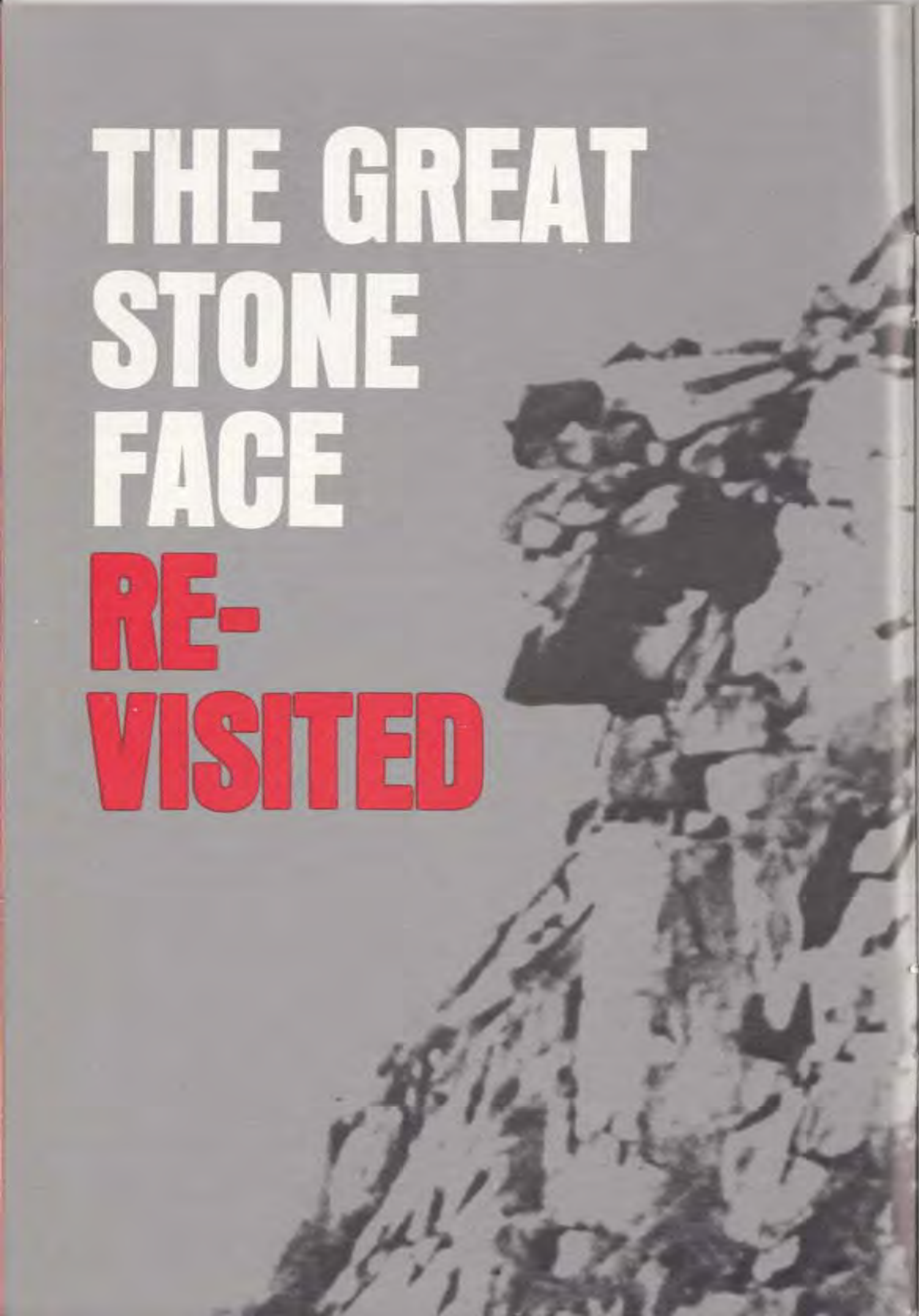
An important landmark was reached at mid-century (1949) when the first great synthesis of seismicity data was accomplished by Professors Beno Gutenberg and Charles Richter of the California Institute of Technology in their book, *The Seismicity of the Earth and Associated Phenomena*. These eminent seismologists described the varied and distinctive patterns of regional earthquake activity in detail, and were able to associate these patterns with geological and geophysical information available to them. Their classic study is perhaps most important for its global viewpoint, which unified many disparate pieces of information and which foreshadowed the remarkable developments in geotectonics a decade and a half later. It has not yet been superseded by a study of comparable importance.

CALIFORNIA INSTITUTE OF TECHNOLOGY PHOTO

This 1956 photograph assembles key figures in the development of basic global seismicity theory. The late Dr. Beno Gutenberg (second from left) did the pioneering work in this field, working with Dr. Charles F. Richter (at right), whose magnitude scale permitted comparisons of earthquakes by size. Dr. Richter is professor emeritus of seismology at the California Institute of Technology. The late Dr. Hugo Benioff (second from right) invented the short-period Benioff seismograph, a high-gain device which was the most popular seismographic instrument for decades, and, in a sense, marked the beginning of modern seismic instrumentation. Dr. Frank Press (at left), who in 1959 succeeded Dr. Gutenberg as director of the California Institute of Technology's seismological laboratory, had worked on the development of long-period instruments; he is now chairman of the Department of Earth and Planetary Sciences at the Massachusetts Institute of Technology.

Advances in tectonophysics, a new discipline drawing on other disciplines such as seismology, geology, and oceanology, have had a powerful impact on seismicity studies. The explanation of the tectonic evolution of a region often requires the detailed investigation of the patterns of earthquake occurrence in that region, perhaps even to the extent of deploying a temporary network of seismographs for the purpose of monitoring low-level (micro-earthquake) activity. Conversely, seismicity studies have played an important role in tectonophysics. Perhaps the best example is the association of global seismicity patterns with the interacting edges of mobile lithospheric plates which figure prominently in the hypotheses of global tectonics. Seismicity studies have been important in delineating the edges of plates and in understanding the tectonic processes at work there.

THE GREAT STONE FACE RE-VISITED



A study of New Hampshire's Great Stone Face begun in 1969 by NOAA seismologists (*Earthquake Information Bulletin*, January-February 1970) has ended, and indicates that wind—not blasting for a proposed interstate highway, not earthquakes, not distant underground explosions—poses the greatest threat to the chronically unstable granite profile.

The Face has been known to be unstable for at least a century—it has been 100 years since mountain climbers first warned that the rocks were ready to fall—and New Hampshire has spared nothing to keep her foremost tourist attraction together. In 1956, the state gave nature a major assist in the form of some 20 tons of steel and concrete material, transported to the profile by helicopter, and installed to hold the granite blocks in place.

The seismic vibration monitoring project was arranged by New Hampshire, which defrayed its cost, to determine whether construction of a proposed highway through Franconia Notch would endanger the Old Man of the Mountain, who presides over Franconia Notch from his perch 1200 feet above Profile Lake. After taking preliminary measurements, the survey team installed four seismometers at the top of the profile, two near the edge in a crevasse at the back of the forehead boulder and two more about 300 feet back from them on the mountain. Each pair of instruments combined a vertical and horizontal seismometer, to record all vibrations experienced by the profile rocks. Signals from the seismometers were telemetered over cables to recorders at the base of the mountain. Film records in the instruments were changed daily by New Hampshire Highway Department personnel, who then developed and forwarded them each week to NOAA for analysis. A daily log showed principal seismic phenomena observed.

In their final report, seismologists Alfred V. C. Meyer and James Devine concluded that wind blowing on the boulders and turnbuckles holding them together had the greatest effect on the Great Stone Face. The turnbuckles were installed four years ago to help keep the granite formation from disintegrating, but had begun to vibrate in the wind. The seismologists recommended that supports be wedged under the turnbuckles to reduce vibrations, and this seemed to help.

To determine the effect of blasting along the proposed route of the highway through Franconia Notch, the survey team detonated an 11-pound dynamite charge 3750 feet from the Profile on the valley floor. It had no appreciable effect on the boulders.

After carefully examining the area's earthquake history, Meyer and Devine reported that earthquakes seemed to offer "a remote hazard" to the Old Man of the Mountain. "Inspection of the history of earthquake occurrences in the eastern part of the country as well as New Hampshire itself suggests that the Profile happens to be in a location of much less than average seismic activity," they wrote, adding that while "earthquakes strong enough to cause the Old Man to tumble are rare in the area . . . records show that quakes of appreciable strength have occurred in New England since the early settlers arrived."

This means, apparently, that the Great Stone Face, although still on his mountain, is not yet out of the woods.

Preliminary Seismic Results From

CANNIKIN

AEC PHOTO

Cannikin, the nuclear explosion detonated beneath the Aleutian island of Amchitka November 6, produced some of the most precise seismic data ever recorded for a tremor, natural or manmade. That, at least, is the consensus among earth scientists in NOAA.

From the rich harvest of seismic data obtained by instruments crowded around the Amchitka test site, and by instruments around the world, scientists have begun assembling their comprehensive portrait of the Cannikin event's seismic nature. Although the full picture awaits thorough analysis of present data and data being gathered through the coming year, this seismic sketch of Cannikin has emerged.

The Main Shock

An estimate of the body-wave magnitude based on the average of values reported by 43 observatories worldwide is 6.8 for Cannikin, and 5.7 for the surface wave magnitude from the average of seven observatories. The cavity collapse 38 hours after the detonation caused a tremor with a body-wave magnitude of about 4.9.

Body-wave magnitudes are obtained by measuring maximum amplitudes caused by seismic waves that travel deep through the planet's interior. Surface-wave magnitudes are obtained by measuring maximum displacements caused by waves which travel through the earth's shallow surface layers and arrive after the body waves.

Because underground explosions are a point source—not a regional source like a fault—they release less energy in the form of surface waves and have a lower surface-wave than body-wave magnitude.

Also, explosions release most of their energy in a burst lasting only fractions of a second, as against periods of minutes in very large natural earthquakes. The latter appear to be a succession of earth-shaking ruptures, rather than a single event.

Maximum transient vertical ground motion at the control point on Amchitka 22½ miles from ground zero amounted to 8 centimeters (4 up, 4 down), four-tenths of a centimeter at Adak Island, 180 miles to the west, and four one-hundredths of a centimeter at Anchorage, about 1350 miles to the east. Maximum transient horizontal motion at the control point was 11.8 centimeters (5.9 push, 5.9 pull) along a radius from the explosion.

The Aftershocks

A series of numerous aftershocks was recorded following the Cannikin detonation, and aftershock activity continued until the explosion-created underground cavity collapsed 38 hours later. Most aftershocks appeared to be shallow, within a few miles of the surface, and close to ground zero. All aftershocks were less than body-wave magnitude 4—that is, all were less than one one-thousandth the amplitude of the main shock.

Cavity collapse appears to have terminated aftershock activity, just as it did in Milrow, the approximately one-megaton predecessor to Cannikin, detonated in 1969. This suggests that here, as in Milrow, the scale of the aftershock-generating mechanism at Amchitka is small enough to be completely relaxed by cavity collapse.

An interesting set of contrasts between natural and manmade earthquakes in the same area and magnitude range is provided by a magnitude 7¾ shock that occurred near Amchitka on February 4, 1965. This tremor generated more than 1300 detectable aftershocks in a 450-mile-long zone which generally followed the trend of the Aleutian arc. Many of these were in the magnitude 6 class, one of which would release more energy than all of the Cannikin aftershocks combined.

Effects on Natural Earthquake Activity in the Amchitka Region

It appears that global processes and processes involving the entire Aleutian Island arc are more important to earthquake activity here than such localized events as underground explosions.

The emergent theory of plate tectonics holds that a spreading seafloor, constantly replenished by material rising from the earth's mantle through oceanic rift zones, drives large crustal plates.

Where these "floating" plates converge, as along the western rim of the Americas, the oceanic plate thrusts under the continental plate. The high level of earthquake activity found in such zones is believed to be caused by stresses built up in the crustal material. When these stresses exceed the capacity of the supporting rocks, underground ruptures occur, releasing the energy of strain in the form of earthquake waves and dislocations along faults.

The Aleutian Island arc is a typical zone of convergence, and earthquake activity in the Amchitka Island region appears to be deeply rooted in the structural behavior of the entire arc and to global movements in general. Also, most of the natural earthquake activity occurs along a major thrust fault zone some tens of miles beneath the island; shallow earthquakes near Amchitka fall primarily where the oceanic plate begins its oblique downward thrust.

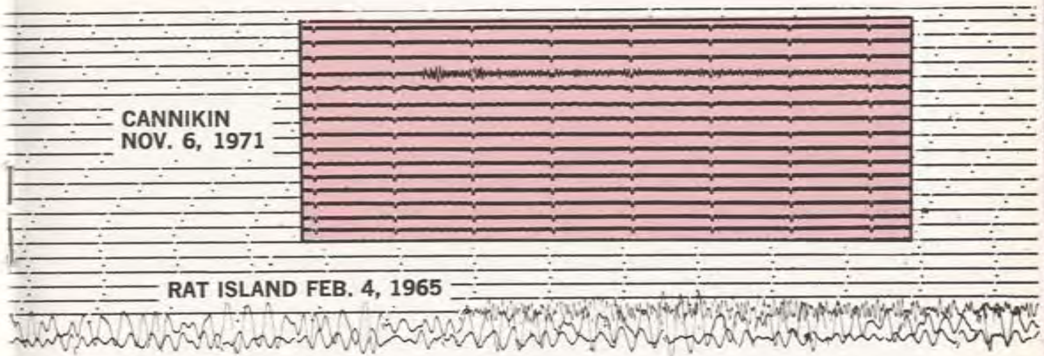
Apparently, Cannikin, did not interact with the large-scale processes which control the region's major natural earthquake activity.

Measurements of stress (force) and strain (physical deformation) in Amchitka rocks also point to little or no serious interaction. Milrow results showed a sudden "step" in the strain record, probably produced by the forces that created the underground cavity; most of this increase was transient, however, and the stress field in the rocks soon relaxed to essentially pre-explosion levels. Some minor permanent deformation occurred, and local surface faulting.

Cannikin strainmeter data taken at two sites, each six miles away from the shock, show the same general pattern—a sharp increase in stress levels during and immediately after the explosion, then relaxation. Permanent deformation six miles from the shock amounted to about one part in ten thousand—about six inches per mile. These were not symmetrical, but were larger toward the north and east than toward the northwest, suggesting that some faulting occurred near ground zero.

Geomagnetic Effects

To detect any quasi-static geopiezomagnetic effects associated with the Cannikin event, four proton total-field magnetometers were placed in near-continuous operation for several months on Amchitka. At 36 kilometers northwest and 15 kilometers southeast of ground zero, magnetometers of 0.12-gamma sensitivity were used; at 3 and 9 kilometers southeast of ground zero, magnetometers with 0.5-gamma sensitivity were used. Sets of pre- and postshot data were also taken at 200 locations across and along the White Alice fault, whose surface trace passes within a kilometer of ground zero.



The Cannikin shock (color block) and a natural, magnitude 7¾ earthquake which occurred near Amchitka in 1965 were detected on the same seismograph at the Tucson Observatory. While more than 870 aftershocks were located in the first 45 days after the 1965 event, only the collapse of the Cannikin cavity was recorded by enough distant stations for location. (Both seismograms above have been greatly truncated and are merely meant to illustrate the comparative shocks recorded at the Tucson Observatory.)

Within 30 seconds after the detonation, the instrument 3 kilometers away showed a 9-gamma increase in the magnetic field strength. Within five hours this value decreased almost linearly to 7 gammas. No similar step-like change was observed when the crater collapsed. In the White Alice fault-study area, centered about a kilometer and a half from the epicenter, the difference between readings taken two days before and nine days after the test decreased from +13 gammas in the fault block containing the shot to −11 gammas northwesterly across the fault. Magnetic mapping shows this pattern repeating along the fault trace rather than distributing radially from the shot.

Initial interpretation strongly suggests *magnetic detection* of stress release within the shot-containing block, a stress increase across the fault, and a stress pattern consistent with a dislocation along the White Alice fault.

Effect on Global Earthquake Activity

Apparently, Cannikin had no effect on earthquake activity elsewhere on the planet. According to NOAA's National Earthquake Information Center, the week preceding and the two weeks following the test were unusually quiet, seismically speaking, with no magnitude 6½ class earthquakes anywhere in the world. (Magnitude 6½ and larger earthquakes trigger an alarm at the National Earthquake Information Center.)

The first natural earthquake of any significance reported after the test followed the detonation by over four hours, was a magnitude 5.2 shock over 5400 miles away near Timor in Indonesia. The largest shock reported after the explosion came about 16 hours after CANNIKIN. It was a magnitude 5.3 earthquake centered in the Pacific about 1700 miles west of Ecuador. Other small shocks have been reported from Japan, Guatemala, off the Oregon Coast, the New Hebrides Islands in the South Pacific, the Leeward Islands in the Caribbean, and the North Atlantic Ocean.

These post-CANNIKIN tremors are part of normal global seismic energy releases and are not related to the test. Since approximately 5000 epicenters are determined annually, an average of more than 13 earthquakes per day can be expected which will be large enough to be located; on the average 140 magnitude 6 and larger shocks occur annually.

Seismic Sea Wave (Tsunami) Activity

Because CANNIKIN was expected to be close to the threshold magnitude for tsunami generation—in the Aleutians a magnitude 7 earthquake is necessary to generate a major tsunami — NOAA's Honolulu-based Pacific Tsunami Warning System and the Regional Tsunami Warning System at Palmer, Alaska, watched the test very closely. Palmer observatory continuously monitored incoming data from automated seismic and tide stations dispersed along the Aleutian chain and down into southeast Alaska for any evidence of abnormal wave activity.

Wave and other short-period water motions appear on a tide gage record, or marigram, as small disturbances on the generally smooth curve of the rising and falling astronomic tides. The tsunami wave train set in motion by some large earthquakes is readily discernible as a set of wave motions that have longer periods than wind waves, but shorter periods than the ocean tides. This unique tsunami "fingerprint" is used to confirm the existence of a potentially hazardous wave after a major ocean area earthquake has occurred.

After CANNIKIN, no wave activity was observed on tide gages that could be distinguished from surf action.

Significance to Earth Sciences

Underground nuclear tests have provided earth scientists with a unique opportunity to study seismic events of known yield, origin, and time of occurrence, and have done much to advance the states of the various seismological arts.

CANNIKIN, one of the largest manmade tremors thus far detonated underground, provided a source of energy—and seismic information—that is unsurpassed. As one NOAA seismologist put it, "Everybody who had an instrument had it running for this one."

Scientists in the United States and in other nations used the seismic waves emanating from Amchitka as a "window" to the earth's interior. How well the experiment illuminated this hidden region will not be known for some time; but these probable results can be seen.

Island arc tectonics. The island arc structures which characterize trench-rise features in oceanic areas are highly seismic, intensely interesting to paleogeologists and other geophysical historians—and poorly understood. Seismic and other geophysical data from Amchitka will do much to characterize one segment of the Aleutian Island arc in substantial detail, and provide important clues to the structure and behavior of similar geologic features elsewhere.

Aftershock causal mechanism. The clustered seismographs on Amchitka and nearby islands produced extremely clear records of CANNIKIN's aftershock activity. The test also provided a record of an entire aftershock sequence, permitting scientists to view the beginning, middle, and end of the series over a comparatively short period. NOAA seismologists expect to extract significant new information on the causal mechanisms of aftershocks, and hope to be able to apply that knowledge to an improved understanding of natural earthquake source mechanisms. Because this work might apply to natural earthquakes, it holds particular promise for scientists studying earthquake prediction and mitigation techniques.

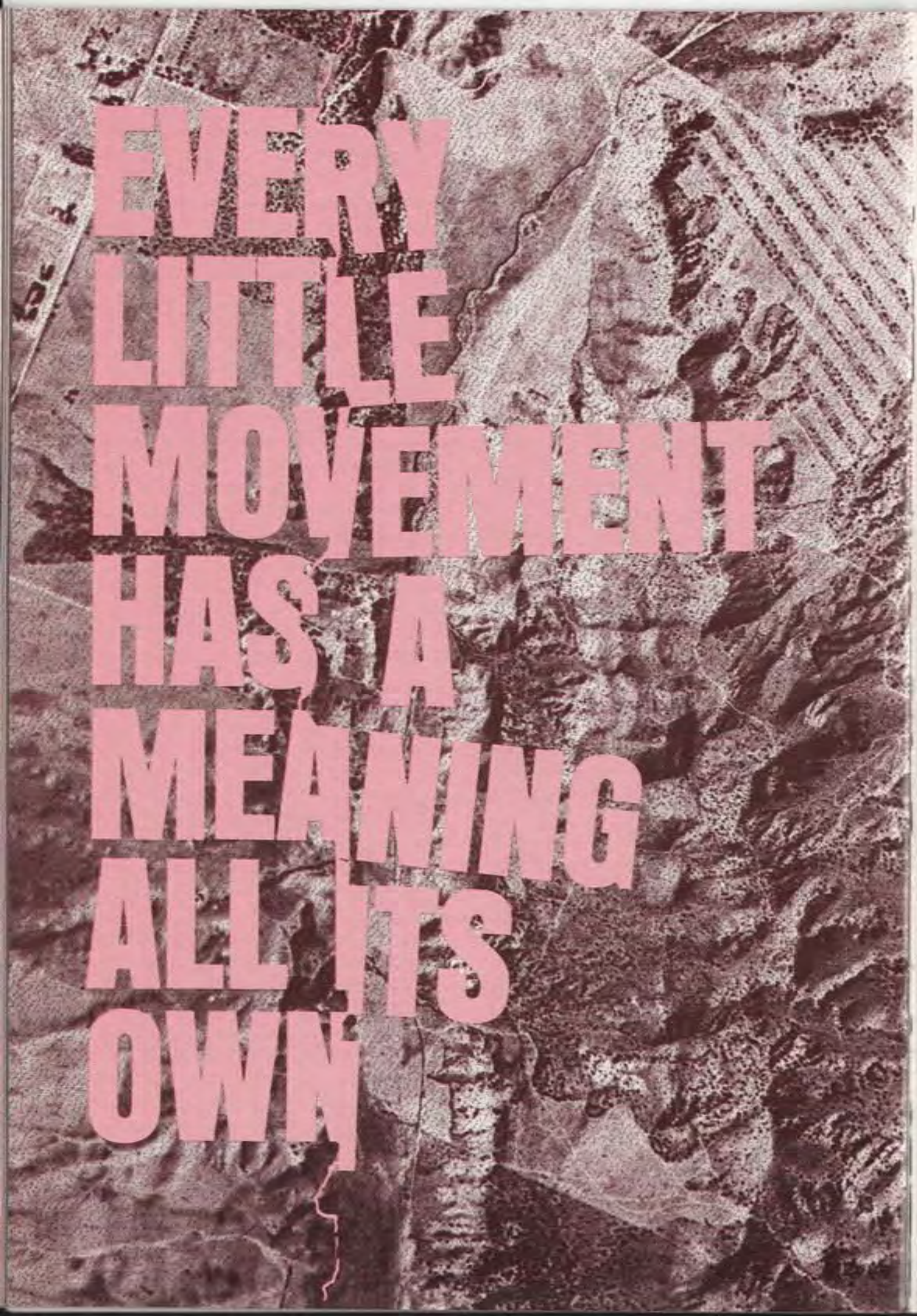
Earthquake engineering data. Instruments set up at various distances from ground zero measured the dynamic response of the earth's surface to the shocks. The resulting body of information is unique in that it provides insights into some important aspects of what structures can expect from earthquakes in this magnitude range. It is the kind of information usually acquired from the catastrophe of a large natural earthquake in a populated area.

Plate tectonics and continental drift. Although the general scheme of plate tectonics is beginning to be well understood, the details of how and where the plates collide are not. The intensive data-gathering effort in the Aleutians is providing those details for this segment of the Aleutian Island arc (which marks the intersection of the Pacific and Bering crustal plates) and, by extension, for similar boundary zones elsewhere in the world.

Further Work in the Aleutians

The Aleutian Seismic Program (*Earthquake Information Bulletin,* January-February 1971) undertaken by what is now the National Oceanic and Atmospheric Administration was intensified in 1969, at the request of the Atomic Energy Commission, and is now conducted by the Earth Sciences Laboratories of NOAA's Environmental Research Laboratories, headquartered in Boulder, Colorado.

With the experiment concluded, the program now turns to a year of intensive data-gathering and analysis, to assess what effects, if any, CANNIKIN had on the way stresses, strains, thrusting plates, and other processes interact to produce earthquakes in this highly seismic corner of America.



EVERY LITTLE MOVEMENT HAS A MEANING ALL ITS OWN

So the old song tells us. And so it has, especially when the little movement may hold important clues to the collisions of gigantic crustal plates, and to the occurrence–or dearth–of major earthquakes in California's crowded coastal zone. Accordingly, scientists at NOAA's Earthquake Mechanism Laboratory in San Francisco search for the meaning of movements along the San Andreas fault in general, and a small, slow movement called "fault creep" in particular.

The San Andreas fault is now viewed in the context of plate tectonic theory. In a series of complex geologic processes begun perhaps 30 million years ago, the eastern rim of a Pacific crustal plate rammed into and under the western rim of the North American plate, ultimately producing the visible boundary region defined by the San Andreas and the other fault systems which crisscross California.

Today, the process continues, with the North Pacific plate drifting to the northwest with respect to the continental plate, at rates estimated at between one and three inches per year, depending on the method of measurement. This differential movement produces stresses in portions of the fault that are finally relieved by rock failure, resulting in violent earthquakes.

Creep is a non-seismic slip motion —that is, a motion that does not generate seismic vibrations—along certain segments of faults in the earth's crust, such as the San Andreas fault system in California. The creep mechanism is not yet fully understood. Among scientists opinion is divided as to whether creep is a rupture process or a process linked to the deformation of clay material along a fault. But there is agreement that creep appears to occur in episodes, or "steps," like the larger fault movements associated with earthquakes.

But creep is a slower, gentler process than earthquake-generating fault breaks. A creep event travels at a rate of only several miles per day, as against the 7,000-mile-per-hour speed of some seismic ruptures. Creep dislocations usually amount to several millimeters over a period of hours or days, whereas earthquake-producing fault movement may amount to tens of feet in seconds.

The existence of this non-seismic fault motion on California's San Andreas fault was first discovered in 1956 by Edwin Zacher and Karl Steinbrugge, structural engineers, at the Cienega Winery. The winery straddles the fault zone south of Hollister and is being slowly torn in half by the fault movement. Dr. Don Tocher, director of the Earthquake Mechanism Laboratory, did the pioneering research on the phenomenon while he was with the University of California, and continues this work with his associates in the San Francisco laboratory.

The effect of fault creep on man's works is distinctive. Everything on one side of the fault has shifted relative to everything on the other side, the shift usually occurring across a narrow zone about 15 feet wide. In cities like Hollister, California, the offsets produced by creep are evident in sidewalks, curbs, cracked pavement, crooked streets, kinks and

Dr. Robert D. Nason, in charge of NOAA's field studies of fault creep, checks the offset of a concrete-lined irrigation ditch at the Cienega Winery, where this non-seismic fault movement was first identified.

bumps in fences, foundations, walls, and other structures, and in land formations.

Scientists at the Earthquake Mechanism Laboratory have set up instruments wherever creep is revealed by these characteristic distortions. The laboratory's network of continuously recording creepmeters includes eight instruments on the San Andreas fault near Hollister, eight on the Calaveras fault near Hollister, and six on the Hayward fault in Hayward and Fremont. The laboratory also measures creep in oil fields—for example, along the Buena Vista thrust fault near Taft, California—and measures the creep that occurs along faults after some earthquakes.

The instruments use invar metal rods installed across the fault. Compression and elongation of the rods indicate the amount and direction of creep and are recorded by electronic gear near the installations.

Survey lines several hundred yards long are also run by the laboratory. The objective here is to define a very straight line across the fault, and then to measure offsets in the line caused by fault creep. NOAA's National Geodetic Survey (of the National Ocean Survey) shares this interest in horizontal distortions caused by fault creep, which move geodetic markers, change the direction of property lines, and otherwise affect the geodetic network's precision. The Survey has been measuring these displacements along the San Andreas since 1906, when the major fault break associated with the San Francisco earthquake occurred.

Dr. Robert D. Nason, a research geophysicist with the Earthquake Mechanism Laboratory, conducts the field program of creep measurement, and the related effort to identify additional areas where there is evidence of fault creep. Dr. Chi-Yu King, another Earthquake Mechanism Laboratory geophysicist, has been working on the development of creep theory, using data from the network to construct mathematical models of fault behavior.

Present creep movement is occurring along the central San Andreas fault between the two portions of the fault that were broken by the earthquakes of 1857 (to the south) and 1906 (to the north). This pattern suggests to some scientists that the central segment of the San Andreas fault is "unlocked"; and that the fault segments to the north and south, where no creep is now observed, are locked.

The great bend of the San Andreas fault near Los Angeles would help to lock the fault in that area. It is not clear if the northern San Andreas fault is locked or is inactive because of large strain release in the 1906 earthquake.

Fault creep is almost certainly related to earthquakes, but the details of this relationship are not fully understood. For example, the fault creep rate almost doubled for two years before a significant (magnitude 5.6) earthquake near the Cienega Winery, then ceased for two years after the earthquake. And the spatial distribution of current fault creep seems to be closely related to the 1857 and 1906 earthquakes.

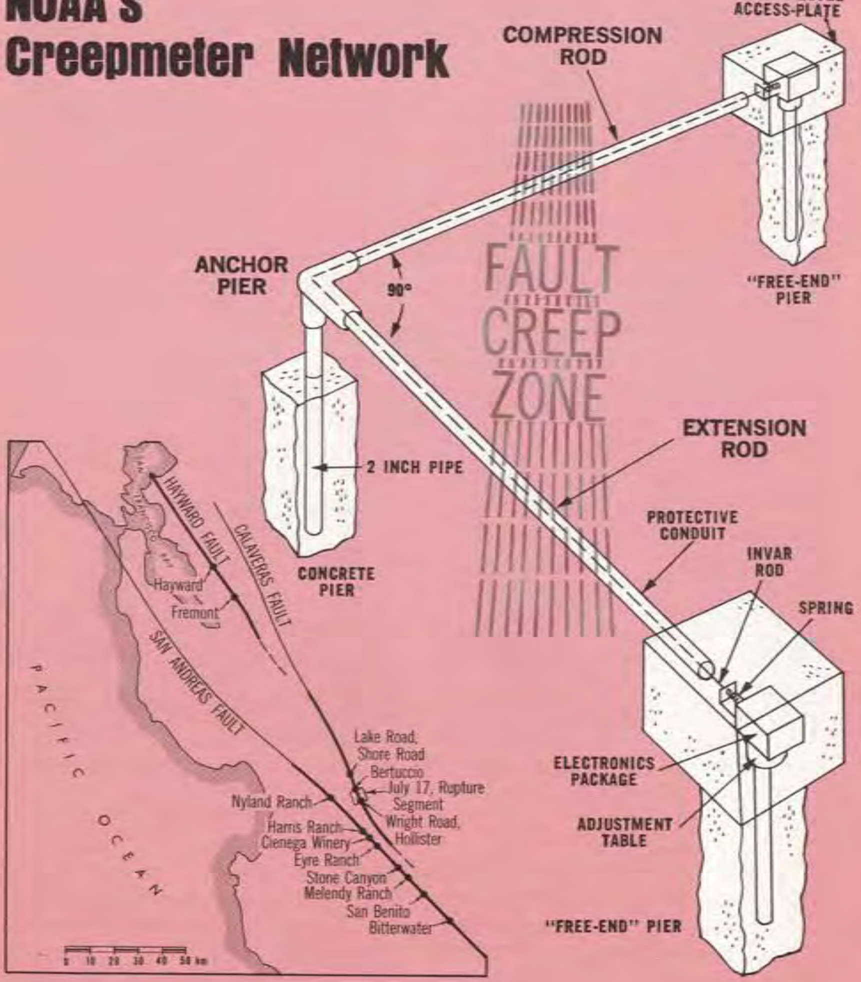
Scientists believe that strain—the elastic deformation caused by internal stresses (forces)—is relieved by creep. The question is, how much is relieved?

Some investigators feel that creep relieves enough strain to reduce the possibility of a major earthquake on that part of the fault. This would also mean that earthquake-producing stresses are building up where there is no evidence of fault creep.

An alternative theory developed by Dr. Nason holds that in certain cases the absence of creep slippage may indicate an absence of strain buildup along that part of the fault, and vice versa; that is, the more creep, the greater the stress and the more likely a strain-relieving adjustment in the form of an earthquake.

Scientists at NOAA's San Francisco laboratory will continue to ponder the significance of these little movements of the enormous San Andreas fault.

NOAA's Creepmeter Network



Creepmeters use invar metal rods arranged at definite angles across the fault creep zone with associated electronics. As shown here, two meters are anchored to a common pier on one side of the fault, and to two recording units on the other. The 90-degree angle of the invar rods permits one rod to measure compression, and the other rod to measure elongation, for computation of creep movement. Instruments are several feet underground, with recording electronics in shallow excavations; man-hole covers permit access to the underground instruments. The map shows where creepmeters are installed along the Calaveras, Hayward, and San Andreas fault systems.

Record Creep Event Detected

On July 17, NOAA's creepmeter network detected the largest creep event on record along the Hayward-Calaveras fault in and to the north of Hollister. The record event produced maximum fault movement of nine-millimeters (slightly more than a third of an inch), a large amount of motion in view of the annual average fault creep in Hollister of about 10 millimeters.

The July 17 event was the first whose rupture length—about six kilometers, or about three and three-quarter miles—was directly measured, the result of installing a relatively dense network of instruments over the past several years.

The nine-millimeter creep event occurred as one of a cluster of fault creep motions observed during July and early August by the Earthquake Mechanism Laboratory. A few days before the large event, on July 11, a four-millimeter creep was observed at the northern end of the six-kilometer segment ruptured by the July 17 movement; on July 14, fault creep of 0.2 millimeter was detected at the southern end of that segment. On August 2, movement of 0.8 millimeter was recorded about five kilometers to the north.

During the same period, five other creep events were recorded by instruments deployed over a 60-kilometer (37-mile) segment of the main San Andreas fault immediately to the south of Hollister:

- ■ July 3, 4.2 millimeters at Melendy Ranch;
- ■ July 12, 4.9 millimeters, and July 19, 1.7 millimeters, both at Cienega Winery;
- ■ July 21, 2.3 millimeters at Bitterwater; and,
- ■ July 26, 1.4 millimeters at Harris Ranch.

Only tentative conclusions are possible on the basis of present knowledge and data, among them:

- ■ The July-August cluster of creep events, especially the nine-millimeter event of July 17, probably relieved significant amounts of strain along the ruptured segment of the fracture zone near Hollister.
- ■ The creep episodes involved both the main San Andreas fault and the Hayward-Calaveras fault near Hollister, where the surficially unconnected fracture zones branch, suggesting some form of interaction between the two faults.
- ■ If this interaction is real, the creep activity observed along the Hayward-Calaveras fault may be relieving stress along the main San Andreas fault north of Hollister, providing a "safety valve" for stresses developing where that fault system cuts through San Francisco.

EARTHQUAKES

SEPTEMBER-OCTOBER 1971

THE earthquake activity for the period of September and October in the United States was marked by a number of mild shocks. Small but unusual earthquakes occurred at Spotsylvania, Virginia, on September 12; Lawrence, Massachusetts, on October 20; and Hanford, Washington, on October 25.

On October 1 a small shock in Arkansas was felt in nine states. Wide felt areas are characteristic of mid-continental earthquakes.

The strong series of earthquakes in the Rabaul area in July and August continued into this period with over 50 shocks felt at Rabaul. Although three exceeded magnitude 6, none did damage.

Major earthquakes occurred near Sakhalin Island north of Japan on September 5, in New Guinea on September 25, and in the New Hebrides Islands region on October 27. No important damage was reported for the earlier two earthquakes. A local tsunami resulted from the Sakhalin tremor. Two were killed and damage was reported at Santo in the New Hebrides. Five fatalities resulted from an earthquake in the Peruvian Andes on October 15 but few details are available.

Sakhalin Island

A magnitude 7.1 earthquake occurred on September 5 west of the southern tip of the Russian-held Sakhalin Island, the large island north of Hokkaido, Japan. It was felt with intensity VII on the 12-point scale on nearby Moneron Island, and in the southern part of Sakhalin. A one-meter tsunami was reported at Moneron Island and a half-meter wave was reported at Nevel'sk on Sakhalin Island. It was strongly felt at Wakkanai, less severely elsewhere on Hokkaido, where a 64-centimeter tsunami was observed. This is an unusual location for large shallow earthquakes, and, although there were relatively few aftershocks, three were over magnitude 6.

Montana

An intensity V shock struck Polson on September 8 knocking items from store and household shelves. The shaking was preceded by loud, explosive-like sounds.

California

A sharp shock caused small objects to fall at Gasquet and a shelf to fall breaking jars of food at Happy Camp in northern California on September 12. Windows cracked at Scott Bar Mountain Lookout. It was felt as far as Rio Dell to the south, a distance of nearly 100 miles.

New Guinea

A major earthquake with magnitude 7 occurred in the jungle-covered mountains of New Guinea on September 25. Intensity VI-VII was experienced at Siassi and intensity VI with minor damage at Lae. No details were received from Rabaul, the reporting station for this area.

South Atlantic Ocean

On September 30 a magnitude 6.0 earthquake occurred at 0.5°S, 4.8°W believed to be the first instrumentally determined epicenter in this area. It is 850 kilometers east northeast of the nearest active zone of the Mid-Atlantic Ridge.

California

On September 30 some glass was broken and goods fell off shelves in the epicentral area of a magnitude 5.1 earthquake in the Imperial Valley. A vase "went clear across the room" and a woman was knocked to the floor near Westmoreland. It was felt over much of the southwest, from San Onofre, California, on the coast to Ehrenberg, Arizona, a distance of 200 miles, and from Palm Springs into Mexico.

Arkansas

On October 1, an earthquake of approximate magnitude 4.5 occurred in northeastern Arkansas which "shook wall and rattled teeth in Trumann." Small objects fell and some cracking of concrete was noted at Sedgwich and Lake City. Elsewhere in 80 communities in Arkansas, Missouri, Mississippi, Kentucky, Tennessee, Alabama, Illinois, Indiana, and Texas the shock was compared to a sonic boom, or dynamite explosion. Earthquake noise was described as a roar at Bay, Arkansas.

U. S. ACTIVITY*

California	**21**
Alaska	**13**
Montana	**5**
Washington	**1**
Massachusetts	**1**
Utah	**1**
Arkansas	**1**
Tennessee	**1**
Virginia	**1**
Total	**45**

* Felt earthquakes as reported from many sources.

FATALITIES

Peru	**5**
New Hebrides	**2**
Total	**7**

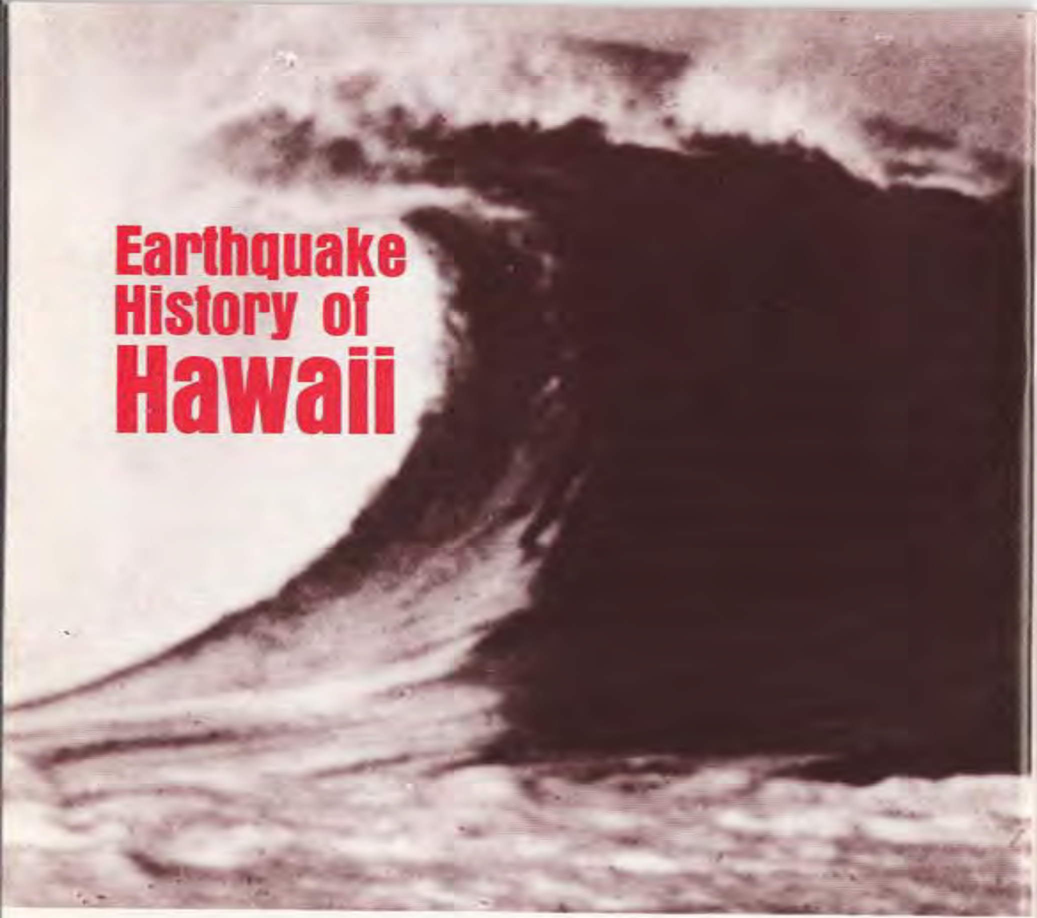
Peru

At least five people were killed and twenty injured in a magnitude 5.1 earthquake on October 15 in southern Peru. Communications were out in the epicental area of the Andes and relief trucks from Cusco were hindered by roads blocked by landslides.

New Hebrides Islands

Two were killed by a magnitude 7.4 earthquake on October 27. One, a fisherman, was killed by a boulder. Serious damage was reported in Santo.

Earthquake History of Hawaii



THE earthquake history of Hawaii begins shortly after the arrival of the missionaries in 1820, and much of the early record comes from the diary of Mrs. Sarah J. Lyman, a missionary's wife at Hilo, on the Big Island of Hawaii. Mrs. Lyman began her account in 1833 and continued it until her death in 1885; this record was then continued for eleven more years by her descendants. About four or five earthquakes per year were reported.

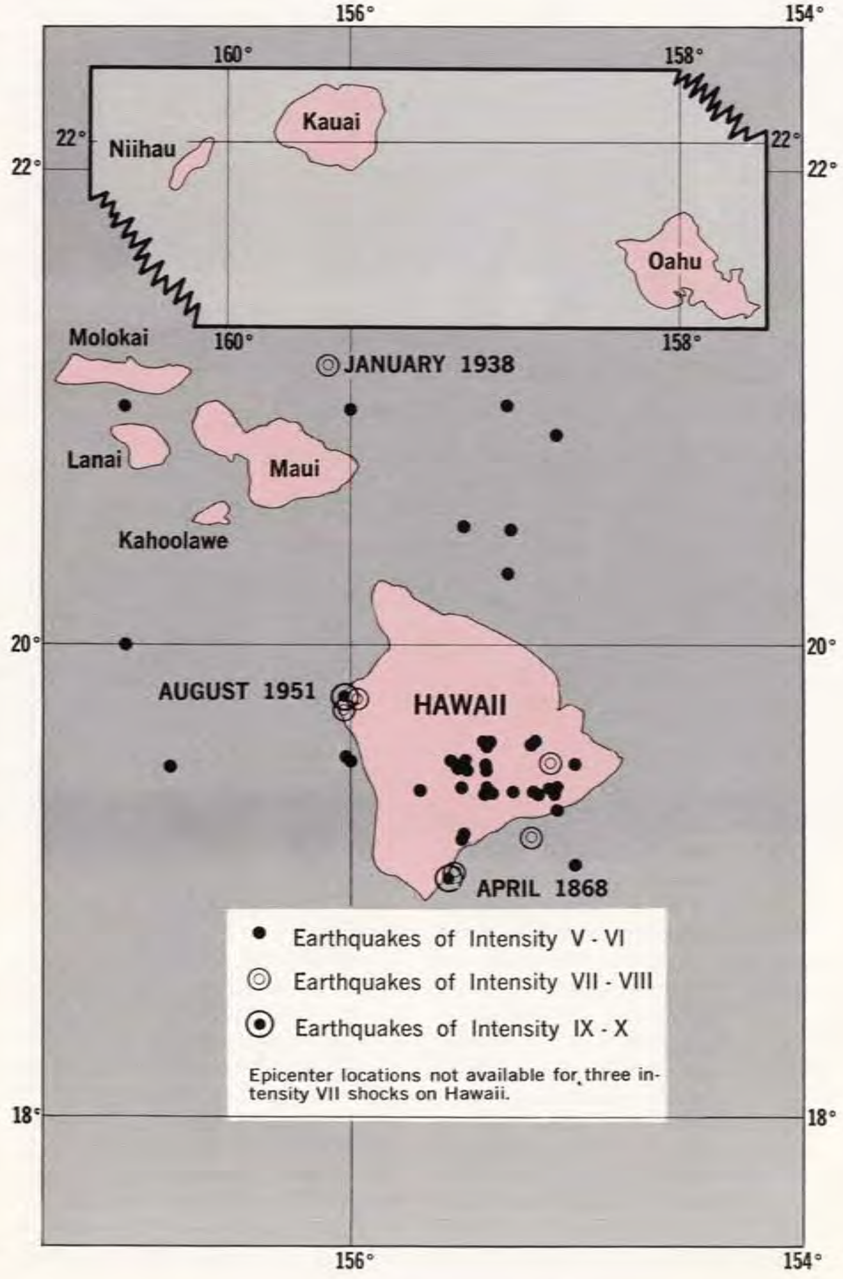
On February 19, 1834, a strong shock threw down stone walls, stopped clocks, upset bottles, and sloshed milk out of half-full pans. Standing and walking were rendered difficult. A similar earthquake occurred on December 12, 1838. No volcanic activity was noted for either event.

On March 27, 1868, whaling ships at Kawaihae on the west coast of Hawaii observed dense clouds of smoke rising from Mauna Loa's crater, Mokuaweoweo, to a height of several miles and reflecting the bright light from the lava pit. Slight shocks were felt at Kona on the west coast and Kau on the flanks of the volcano. On the 28th, lava broke out on the southwest flank and created a 15-mile flow to the sea. Over 300 strong shocks were felt at Kau and 50 to 60 were felt at Kona. At Kilauea the surface of the ground quivered for days with frequent vigorous shocks that caused lamps, crockery, and chairs to spin around as if animated. One shock resembled that of a cannon projectile striking the ground under the proprietor's bed, causing him to flee, according to the narrative published by C. H. Hitchcock in the *Bulletin of the Seismological Society of America* in 1912. Between March 28, 1868, and April 11, over 2000 distinct shocks were felt at Kona.

The main shocks struck on April 2, at 4:00 p.m., and again on April 4 at 12:30 a.m. A magnitude of 7¾ was estimated for this earthquake (by Augustine Furumoto in his February 1966 article on the Seismicity of Hawaii in the *Bulletin of the Seismological Society of America*) based on the extent of intensity reports. Instrumental recording, the usual basis for computing magnitudes, were not available at this early date. The shock was felt throughout the islands as far as Niihau some 350 miles away. The ground rolled like a ship at sea and many walls tumbled down. A landslide three miles long and thirty feet thick swept down the hill carrying trees, animals, and men. Thirty-one people and thousands of cattle, sheep, horses, and goats were killed in the one slide. A seawave struck the coast from Hilo to South Cape, being most destructive at Keauhou, Puna, and Honuapo; 180 houses were washed away, and 62 lives were lost to the wave alone. A 10-foot-high wave struck Hilo. At Kaalualu a 25-foot wave carried wreckage inland 800 feet. Not a house survived at Honuapo. A stone church and other buildings were destroyed at Punaluu. Maximum wave heights were 65 feet, the highest observed on Hawaii to date.

The next most severe earthquake occurred on August 21, 1951, and had a maximum intensity of IX and a magnitude of 6.9. Scores of homes were wrecked or damaged on the Kona coast on the west side of Hawaii. Rocks fell from the cliffs causing a 12-foot wave. A landslide covered the famed Pali Kapu o Keoua burial grounds of Hawaiian royalty. Cracks six inches wide opened on the coastal highway. Walls of churches were thrown down in Hookena and houses moved from their foundations at Napoopoo and Kealakekua. Telephone service was out through most of the area. The collapsing of water tanks along the dry Kona coast faced with a two-month dry season made it necessary to truck water from Hilo.

The third most intense earthquake occurred on January 22, 1938, with a magnitude of 6¾ and a maximum intensity VIII on Mauna Loa. The epicenter, located under the ocean about 40 miles east of the island of Molokai, was about as far north as earthquakes occur in the Hawaiian chain. On Maui there was general panic with people rushing from theaters. Flashing lights were reported by many. Landslides blocked roads and



Much of the island state's earthquake activity is associated with the geologically young Big Island of Hawaii, and its two active volcanoes, Mauna Loa and Kilauea, which is shown here during an eruption in 1969.

cut water pipes. Several reservoirs and water tanks were damaged. A chimney fell and a transformer was thrown down at Hana. Windows were broken and walls were cracked at Kula.

It was felt widely on the other islands with some damage on Molokai (pipes broken), Lanai (bottles thrown from shelves), Oahu (organ pipes out of sockets at Honolulu and the seismograph at the University was dismantled), and Hawaii (dishes broken, some chandeliers fell). The earthquake was distinctly felt by two ships at sea.

Since 1918 nine earthquakes have reached intensity VII resulting in felled chimneys and water tanks, broken pipe lines, cracked walls and reservoirs, etc. Scores of small earthquakes are reported felt each year.

Hawaii is also exposed to another earthquake threat. In addition to the tectonic and volcanic local earthquakes it is a frequent victim of tsunamis from distant earthquakes. The *Catalogue of Tsunamis in the Hawaiian Islands* by George Pararas-Carayannis lists 85 tsunamis since the earliest reported in 1813 or 1814, of which 15 have caused significant damage. Only four of these, including the 1868 earthquake and tsunami described above, have originated near Hawaii. Most have originated in the northwest Pacific and near South American coasts.

In 1837 an earthquake in Chile sent waves 20 feet high against Hilo, Hawaii. Initially the sea receded and several were drowned by the returning wave while they were attempting to collect fish stranded on the exposed sea bottom. In all, 62 people were killed and over a hundred homes destroyed.

The most destructive tsunami in Hawaii occurred on April 1, 1946, following an Aleutian Islands earthquake. Waves 55 feet high, crest to trough, struck the northeast coast of Hawaii. At Hilo, 173 were killed, 163 injured, 488 buildings were demolished and 936 more were damaged. Damage was estimated at $25 million. The waterfront was washed out and breakwater and wharves badly damaged.

This tragic loss of life prompted the formation of the Tsunami Warning System so that Hawaii and the countries bordering the Pacific would never again be surprised by the large destructive waves.

Meetings

1972

March 7-9: International Conference on the Core-Mantle Interface, Florida Inst. of Technology, Melbourne, Fla., AGU. (Joseph C. Cain, Secretary, Scientific Program Committee, International Conference on the Core-Mantle Interface, NASA, Goddard Space Flight Center, Code 645, Greenbelt, Md. 20771.)

March 30-April 1: Sixty-seventh annual meeting of the Seismological Society of America, Honolulu, Hawaii. (William K. Cloud, Secretary, SSA, P.O. Box 826, Berkeley, Calif. 94701.)

April 7-8: National Association of Geology Teachers, Eastern Section Annual Spring Meeting, Rutherford, N.J. (S. Averill, 8 Willow Brook Road, Hillsdale, N.J. 07642.)

April 7-11: National Science Teachers Association annual meeting, New York, N.Y. (Fred Blumenfeld, NSTA Headquarters, 1201 16th St. N.W., Washington, D.C. 20036).

April 17-21: American Geophysical Union, annual meeting, Washington, D.C. (AGU, 2100 Pennsylvania Ave., N.W., Washington, D.C. 20037.)

August 21-30: Twenty-fourth session of the International Geological Congress, Montreal, Canada. (Secretary-General, 24th International Geological Congress, 601 Booth St., Ottawa 4, Ontario, Canada.)

August 22-24: International Symposium on Earth Gravity Models and Related Problems, St. Louis Univ., St. Louis, Mo., AGU. (AGU, 2100 Pennsylvania Ave., N.W., Washington, D.C. 20037.)

November 13-15: Fall national meeting of the Seismological Society of America, Minneapolis, Minn. (William K. Cloud, Secretary, SSA, P.O. Box 826, Berkeley, Calif. 94701.)

The Earthquake Observatory is a 26-minute, full-sound, 16-millimeter color motion picture produced by the Department of Geology and Geophysics, University of California, Berkeley, in the summer of 1970. The film was designed to introduce undergraduate students in geology, geophysics, physics, and earthquake engineering to the work of modern seismological observatories. Subjects covered include the history of earthquake recording, how earthquakes are located, how a seismograph works, types of seismic waves, probable relationships between faulting, fault creep, and earthquakes, and how the observatory provides a window to the planet's hidden interior. *The Earthquake Observatory* is available at a $35-per-day rental, or can be purchased at $312 a copy. For further information, or to order, write: The Director, Seismographic Station, University of California, 475 Earth Sciences Building, Berkeley, California 94720.

Smithsonian Seismology Exhibit

James Smithson, an Englishman who never visited America, left his fortune to the American people to found an institution dedicated to 'the increase and diffusion of knowledge among men." Since its establishment 125 years ago, the Smithsonian Institution has become a wonderfully eclectic organization actively pursuing a wide variety of activities.

The Smithsonian's most popular branch, attracting five million visitors each year, is the National Museum of History and Technology. Exhibits on the first floor of this museum concern the history of technology and science, their internal development, and their social impact. One particularly interesting exhibit depicts the history of our study of the earth, its oceans, and its atmosphere.

Seismology is depicted in this exhibit mainly in terms of its instruments. In the center is a reconstruction of an ancient Chinese seismograph; an earth tremor causes the lightly poised center vertical bar to fall, knocking a ball from a dragon's mouth to the frog below. The seismograph at left, designed by J. E. Wiechert, was used at Georgetown University, in Washington, D.C. The instrument shown at right was designed by John Milne in Tokyo around 1895.

In addition to the public exhibits, the museum houses extensive "reference collections," protecting our material heritage for the future. Other museums borrow objects from the Smithsonian for special exhibits. Behind the scenes, scholars use museum objects, like books in a library, to unravel the history of science and technology.

The Smithsonian Institution's collections are built up primarily through donations. If you have, or know of, any historic scientific instruments, please contact Mrs. Deborah Jean Warner, curator at the National Museum of History and Technology, Washington, D.C. 20560.