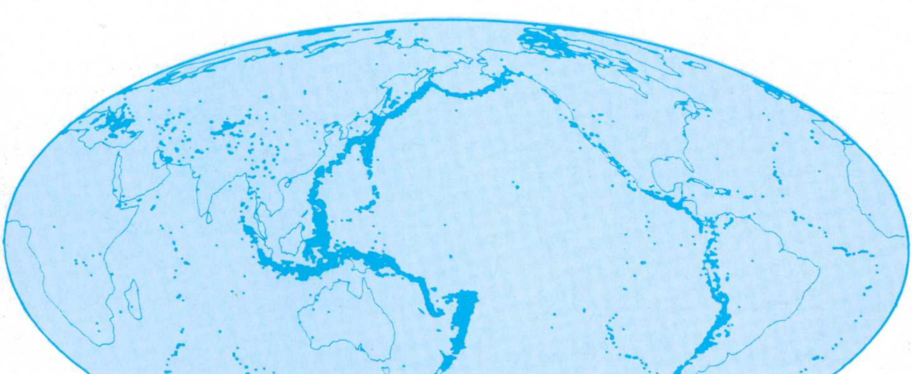
Earthquakes & Volcanoes

Volume 21, Number 1, 1989

Featuring the U.S. Geological Survey's
National Earthquake Information Center
in Golden, Colorado, USA



UNITED STATES DEPARTMENT OF THE INTERIOR
Manuel Lujan, Jr., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

Earthquakes and Volcanoes is published bimonthly by the U.S. Geological Survey to provide current information on earthquakes and seismology, volcanoes, and related natural hazards of interest to both generalized and specialized readers.

The Secretary of the Interior has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this Department. Use of funds for printing this periodical has been approved by the Office of Management and Budget through June 30, 1989. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Subscription orders should be sent to:
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For sale by the Superintendent of Documents. Annual subscription rates—$6.50 (domestic) and $8.15 (foreign). Make check or money order payable to the Superintendent of Documents. To order by VISA or MasterCard, call (202) 783-3238.

Single copy rate—$1.25 (domestic) and $1.65 (foreign). Single copy rate for issues prior to Volume 15, Number 1—$2.25 (domestic) and $2.85 (foreign). Can be purchased from the Books and Open-File Reports Section, U.S. Geological Survey, Federal Center, Building 41, Box 25425, Denver, CO 80225. (Make check or money order payable to the Superintendent of Documents.)

Front Cover: World seismicity, 1978–1986 (map used on cover of all NEIC reports).

Back Cover: Aerial view showing destruction of Juarez Hospital, Mexico City. Photograph by E.V. Layendecker. (See also figure 1, in text.)

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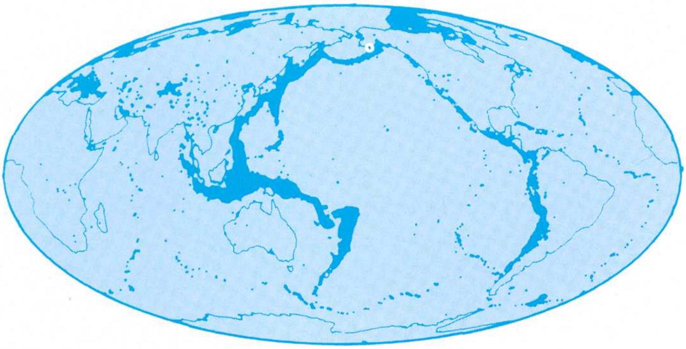

This issue is devoted to earthquakes—How we determine their intensity (*Stover*), where they are (from a previous volume), and their size (*Spence, Sipkin, and Choy*).

Feature article (*Massé and Needham*) describes how the U.S. Geological Survey's National Earthquake Information Center (NEIC) receives, stores, and disseminates earthquake data in a continuing worldwide effort to mitigate the hazard of earthquakes to mankind.

NEIC—The National Earthquake Information Center

by
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The National Earthquake Information Center (NEIC) of the United States Geological Survey (USGS) provides (1) rapid source information for all destructive earthquakes worldwide; (2) determines areal distribution of damage following widely felt, domestic earthquakes; (3) operates modern national and global digital seismograph networks; (4) provides worldwide distribution of seismic waveform data; and (5) pursues an aggressive research program on earthquake sources and Earth structure. All this effort is aimed at mitigating the hazard of earthquakes to mankind. Here is the NEIC story.

Introduction

Mexico was hit by one of the most devastating earthquakes in its history on September 19, 1985 at 7:18 a.m. MDT time. This earthquake, which was centered about 380 kilometers west-southwest of Mexico City, had a surface-wave magnitude of 8.1. In less than a minute, seismic waves from this earthquake had traveled to Mexico City. At this early hour, people were beginning to get ready for the day's work. Without warning, buildings in some sections of the city began to shake violently. A few minutes later, 412 buildings had collapsed and another 3,124 were badly damaged (figure 1). Most communication systems linking Mexico City to the rest of the world were damaged or rendered inoperable.

At least 9,500 people were killed, 30,000 were injured, and 100,000 were left homeless by this earthquake. According to some unconfirmed reports, the death toll from this earthquake may have been as high as 35,000. This earthquake is estimated to have seriously affected an area of 825,000 square kilometers, caused between 3 and 4 billion dollars in damage, and been felt by 20 million people.

Figure 1. Earthquake of September 19, 1985, in Mexico City caused total collapse of the Juarez Hospital. Photograph by E.V. Layendecker.

A few minutes after the destruction in Mexico City, seismic waves from the earthquake reached seismograph stations used by the USGS to monitor earthquake activity. Immediately, these waves triggered an alarm at the U.S. Geological Survey's National Earthquake Information Center (NEIC) in Golden, Colorado. At the NEIC, geophysicists quickly began to review data received in real-time from a number of seismograph stations located across the United States. From these data, the geophysicists were able to determine the location of the earthquake only 17 minutes after it began. This information was quickly relayed to the U.S. Federal Emergency Management Agency (FEMA), to the public, and to the U.S. Embassy in Mexico City. As noted in the chronological log (table 1) of NEIC activities following the earthquake, the first television reporters arrived at NEIC only 37 minutes after the earthquake.

Throughout the history of mankind, major earthquakes have caused the deaths of hundreds of thousands of people and the loss of billions of dollars of property. With the increasing world population and the growing size of large cities, the vulnerability of people

Table 1. SEQUENCE OF EVENTS FOR MEXICAN EARTHQUAKE—19 September 1985

Local time (MDT)	Elapsed time, in hr : min	Event or activity
September 19:		
7:18 a.m.		Earthquake occurs near the coast of Michoacan State in Mexico.
7:21 a.m.	0:03	*P*-waves arrive at southernmost U.S. network stations.
7:23 a.m.	0:05	Short-period alarms trigger at NEIC.
7:25 a.m.	0:07	Geophysicists arrive at NEIC and begin to interpret seismograms.
7:27 a.m.	0:09	*P*-wave arrives at Honolulu.
7:28 a.m.	0:10	Surface wave arrives at NEIC.
7:30 a.m.	0:12	*P*-waves arrive at stations in France and Italy.
7:35 a.m.	0:17	Preliminary locations obtained—lat 17.8° N., long 102.3° W. Telephone callers report that earthquakes were felt at Houston, Texas, and at Mexico City. First inquiries received from news media.
7:43 a.m.	0:25	Surface wave arrives at Honolulu.
7:48 a.m.	0:30	Call made to Pacific Tsunami Warning Center (PTWC). Location and magnitude information exchanged. Magnitude 7.8 determined for event.
7:49 a.m.	0:31	U.S. National Warning Center notified by "HOT LINE" of location and magnitude of earthquake.
7:52 a.m.	0:34	Surface wave arrives at Shemya Island, Aleutian Islands.
7:55 a.m.	0:37	First Denver television crews arrive at NEIC for live and taped broadcasts.
8:00 a.m.	0:42	Earthquake information given to USGS news media services, who pass it on to all wire services.
8:05 a.m.	0:47	PTWC issues tsunami watch for Pacific region.
8:18 a.m.	1:00	Earthquake release issued by NEIC. Messages sent worldwide via World Meteorological Organization/Global Telecommunications System (WMO/GTS) and to United Nations Disaster Relief Organization (UNDRO) and American Embassy in Mexico City. U.S. network data broadcast worldwide over WMO and to European-Mediterranean Seismological Center (CSEM) Strasbourg, France.
8:19 a.m.	1:01	Earthquake information given to U.S. State Department. Data received by telex from CSEM.
8:20 a.m.	1:02	Data received by telex from Istituto Nazionale di Geofisica (ING) Italy.
8:30 a.m.- 12 m. (noon)	1:12- 4:42	Calls made to and data received from seismograph stations/ networks in Guatemala, Costa Rica, Panama, Colombia, and Bolivia. Attempts made to contact Mexican observatories by telephone and telex.
9:18 a.m.	2:00	Location and magnitude of earthquake made available via computer link to Quick Epicenter Determination (QED).
9:30 a.m.	2:12	First of several calls over the next few days from the Mexican Embassy in Washington D.C. asking for information about the earthquake.
10:20 a.m.	3:02	PTWC cancels tsunami watch.
12 m. (noon)	4:42	Revised location obtained using additional data—lat 18.13° N., long 102.31° W.
4:00 p.m.- 5:30 p.m.	8:42- 10:12	Television crews return to film live broadcasts for local and national evening news programs for all national networks, including the CBC in Canada.

and their property to earthquakes is becoming greater each day. Many countries around the world are directly threatened by earthquakes; others are at risk due to a possible tsunami created by a distant earthquake. In order to assess the seismic hazard to mankind caused by earthquakes, a clear understanding is necessary of where earthquakes occur and what the recurrence rates are for the larger earthquakes.

Fairly recent theories of global tectonics have made clear that understanding earthquakes demands a global perspective. It is not sufficient to look at any one country in order to completely understand its seismicity. The origins of this seismicity are commonly related to the motions of continent-size crustal plates and the interactions of these plates with other plates. If the successful prediction of earthquakes is to be achieved, detailed information is needed about both the stress fields within the plates and the source mechanisms of earthquakes caused by the sudden release of this stress. Global seismic data are essential to map the motions of crustal plates and to define the earthquake rupture processes.

The collection and distribution of global seismic data obviously requires excellent international cooperation. Fortunately, such cooperation has always been the hallmark of seismology. For many decades, seismograph station directors around the world have made great efforts to provide valuable data to those who would do research on earthquakes. One of the primary missions of the NEIC is to collect and analyze these earthquake data and to distribute the resulting information as quickly as possible to the international scientific community, to government agencies, and to the general public.

The NEIC has a staff of experienced scientists whose responsibility it is to monitor seismic activity around the world. Scientific research at the NEIC is directed toward improving both the quality of the earthquake information distributed by the center and our understanding of the fundamental nature of earthquake processes.

The NEIC was established in 1966 and is now located in Golden, Colorado. The NEIC has three principal missions (figure 2). The first mission is to obtain rapid and accurate locations of earthquakes and to obtain estimates of magnitude and other parameters that

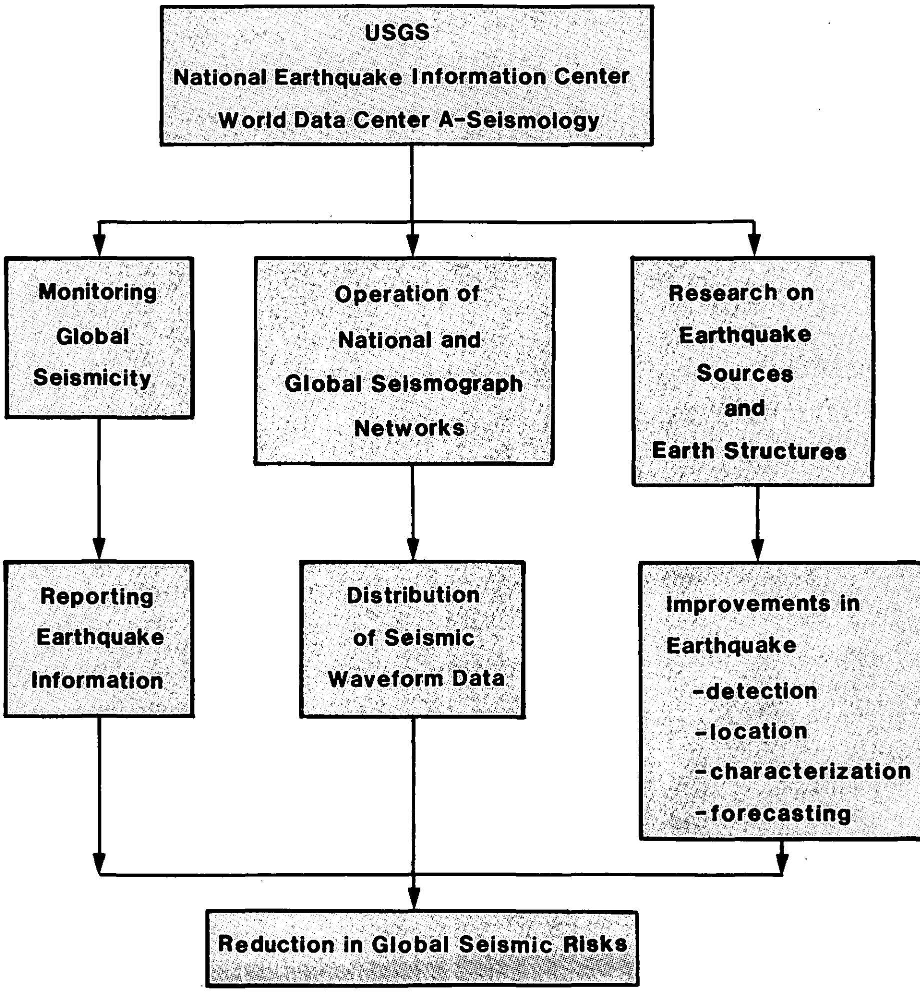

Figure 2. Principal missions of the National Earthquake Information Center.

describe earthquake size. Associated with this mission is the important responsibility to rapidly distribute earthquake information to other Federal agencies, State agencies, disaster relief organizations, and countries around the world. Among the many U.S. agencies that receive prompt notification from the NEIC of damaging earthquakes are the U.S. Federal Emergency Management Agency (FEMA) and U.S. Embassies in all countries that may experience damage from an earthquake. Also important is the notification NEIC gives to all agencies responsible for providing tsunami warning and disaster assistance.

The second mission of the NEIC is to develop, operate, and maintain both a National Seismograph Network (NSN) for the U.S. and a number of Global Seismograph Networks (GSN). Most of the existing global seismograph networks managed today by the USGS were established under the sponsorship of the Defense Advanced Research Projects Agency (DARPA). Maintenance of the NSN and GSN is accomplished by the NEIC's Albuquerque Seismological Laboratory (ASL). The ASL also serves as a data collection center for much of the GSN data. The NEIC functions both as a data collection center and as a data management center to archive digital data from the NSN and GSN operated by the U.S. and by many other countries, and to then distribute these data to the international scientific community. In addition, the NEIC serves as World Data Center-A for seismology.

The third mission of the NEIC pertains to research directed toward improving the capability of detecting and locating earthquakes, toward estimating earthquake size, toward understanding the mechanics of earthquake rupture, and toward forecasting earthquake occurrences. These research efforts include detailed analysis of complex earthquake rupture processes, development of valid statistical models for earthquake recurrence, construction of 3-dimensional models of plates, and synthesis of geophysical data to form comprehensive hypotheses of tectonic processes. Special attention is given to studying U.S. earthquakes and to the compilation, interpretation, and publication of their locations and effects.

Monitoring Global Seismicity

Through the efforts of dedicated scientists in more than 80 countries, data from seismograph stations around the world (figure 3) are routinely reported to the National Earthquake Information Center. In 1987, more than 3,300 stations reported data to the NEIC. For the past two decades, geophysicists at the NEIC have used these data to map the seismicity of the world. Results in the form of seismicity maps for 1971-1986 are shown in figures 4 through 19. Similar seismicity maps were instrumental in establishing the concept of plate tectonics. The global extent of the earthquake hazard problem is obvious from these seismicity maps.

(Text continues on p.16)

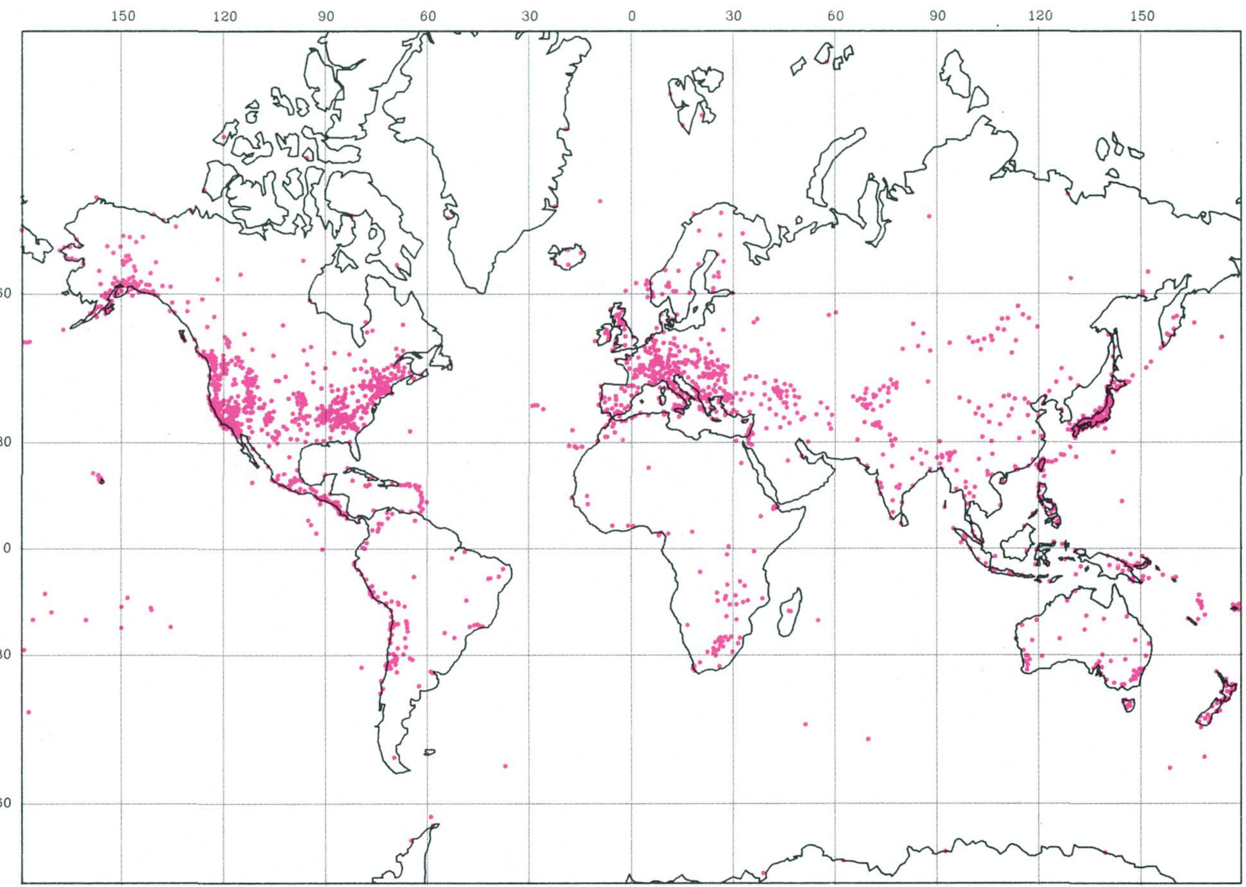

Figure 3. Seismograph stations that contribute data to the NEIC.

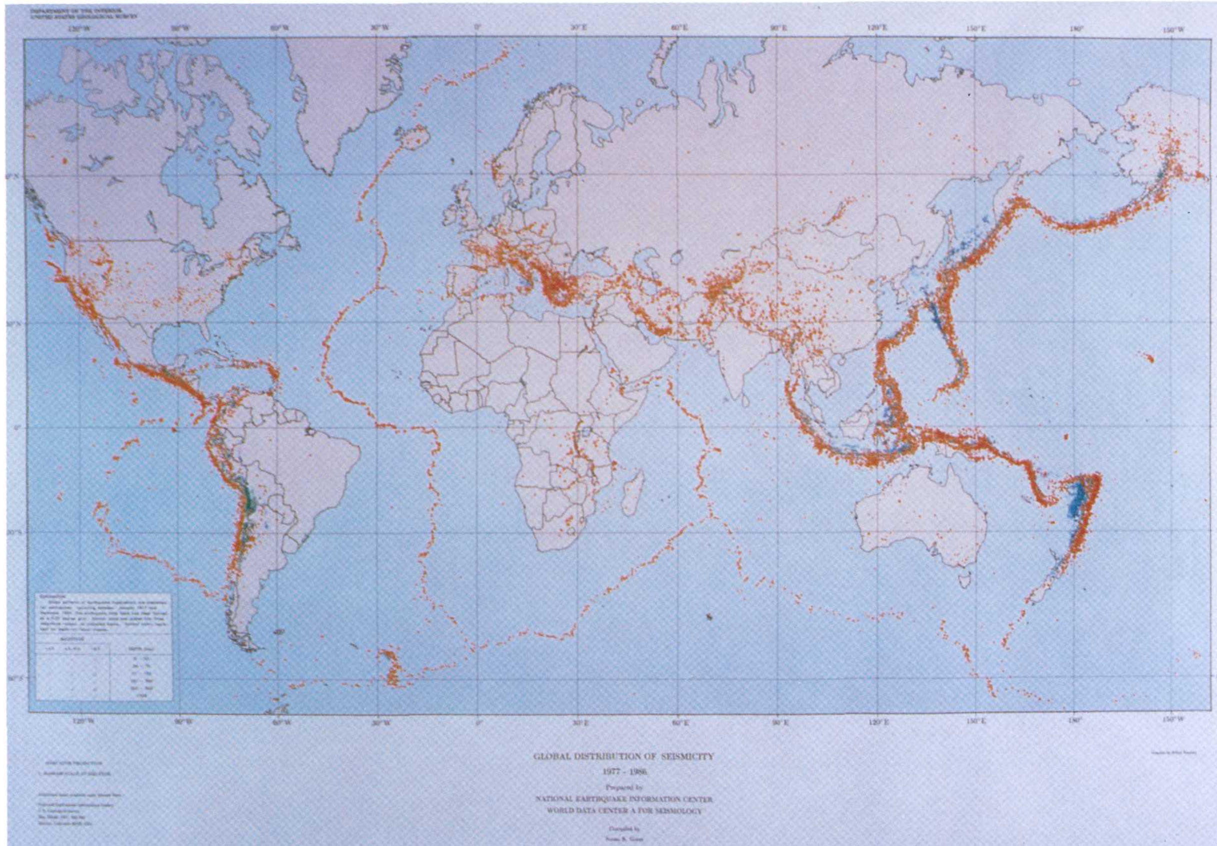

Figure 4. Seismicity of the world, 1977–1986.

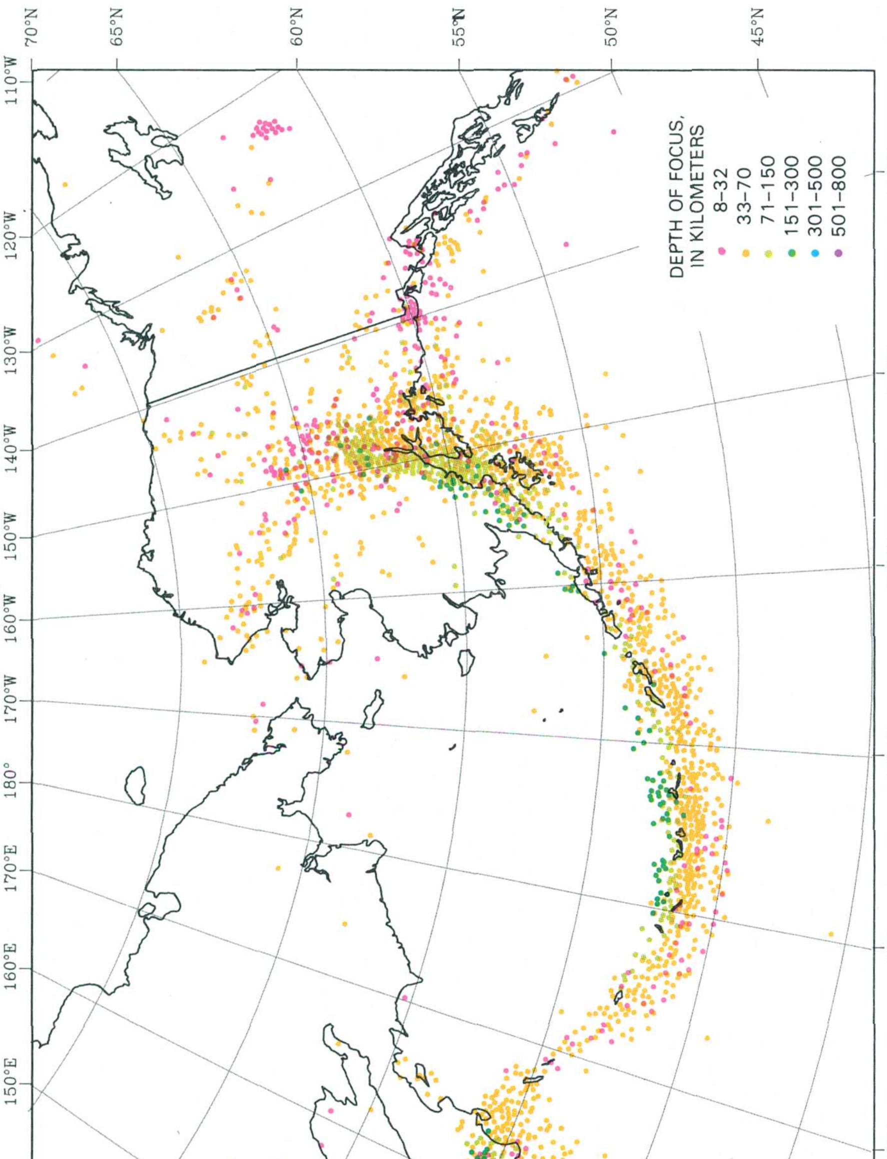

Figure 5. Seismicity of Alaska, 1971–1986.

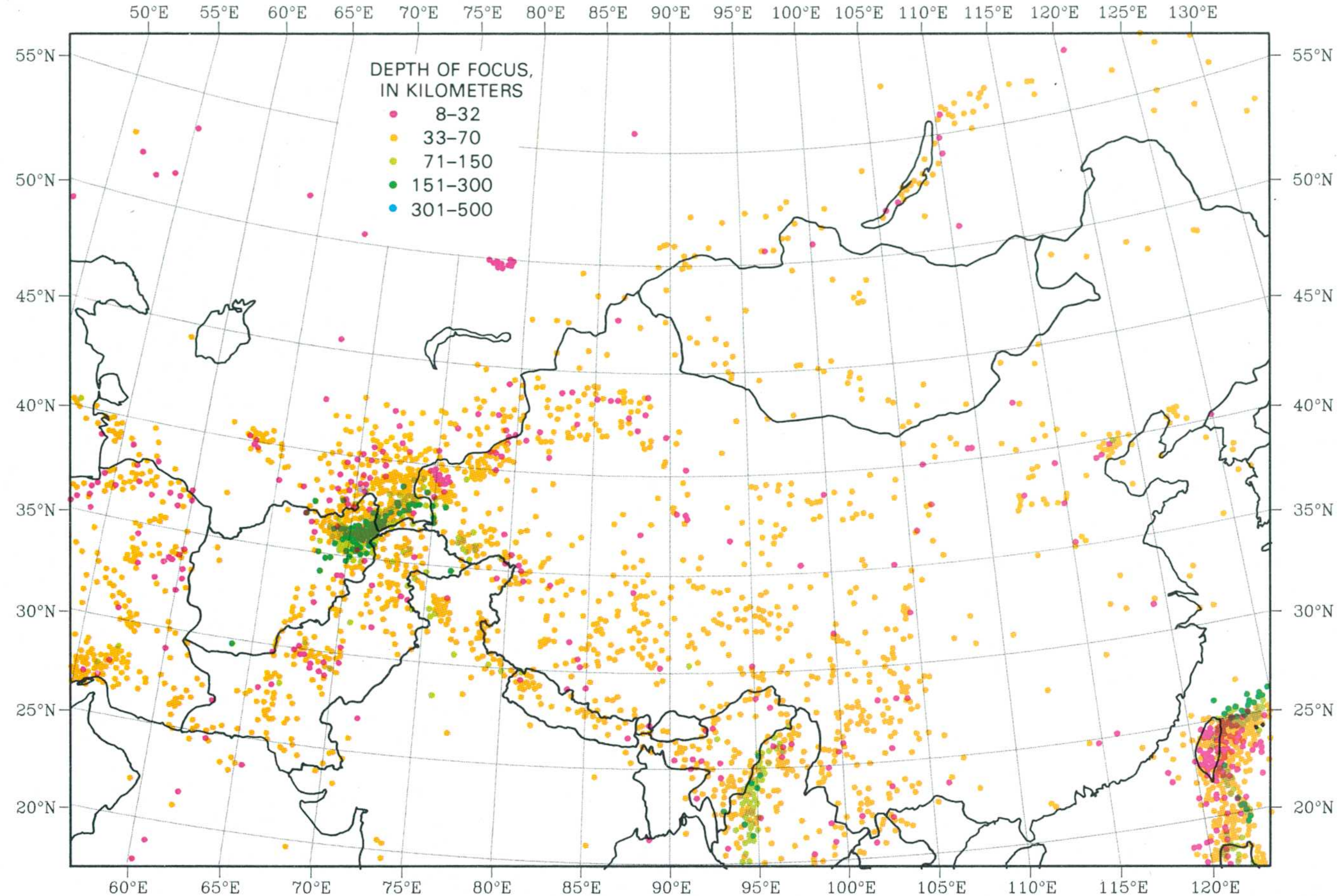

Figure 6. Seismicity of Central Asia, 1971–1986.

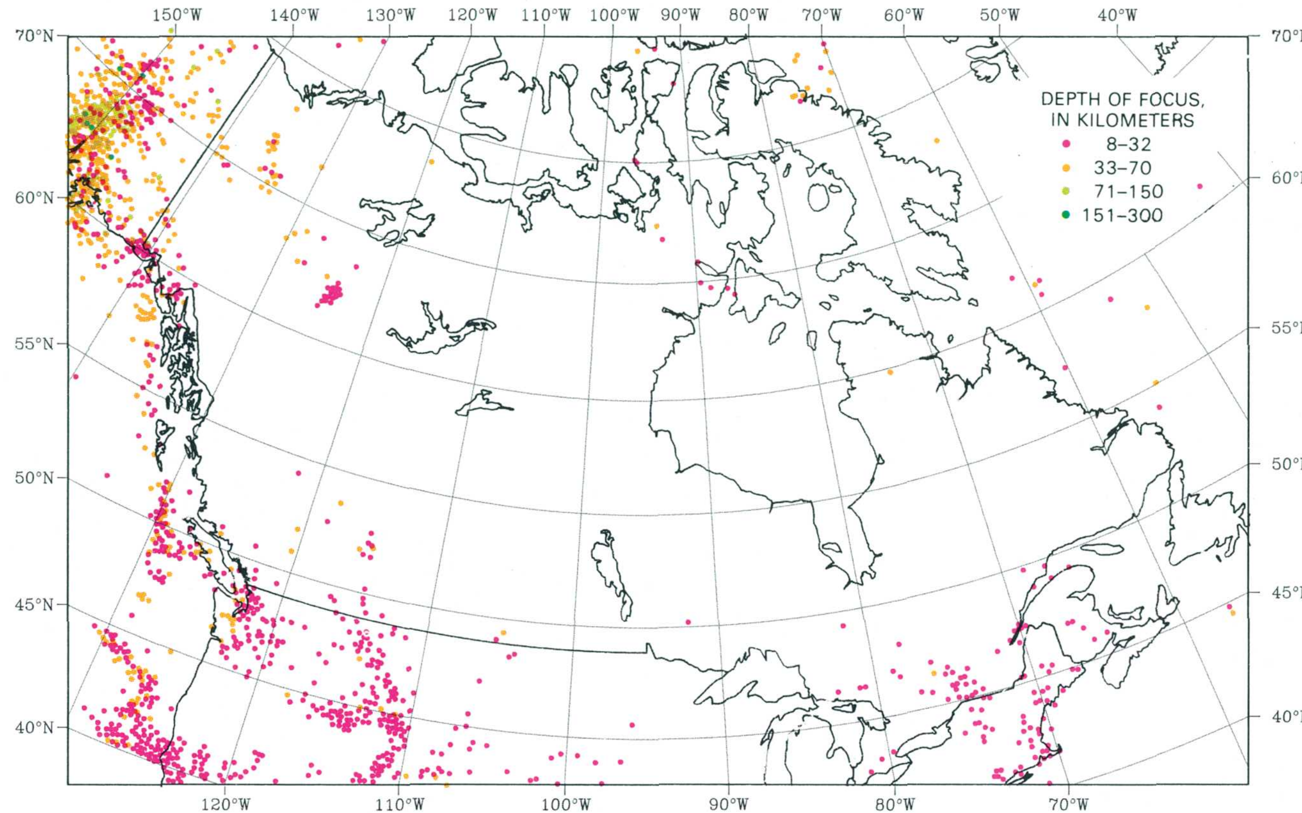

Figure 7. Seismicity of Canada, 1971–1986.

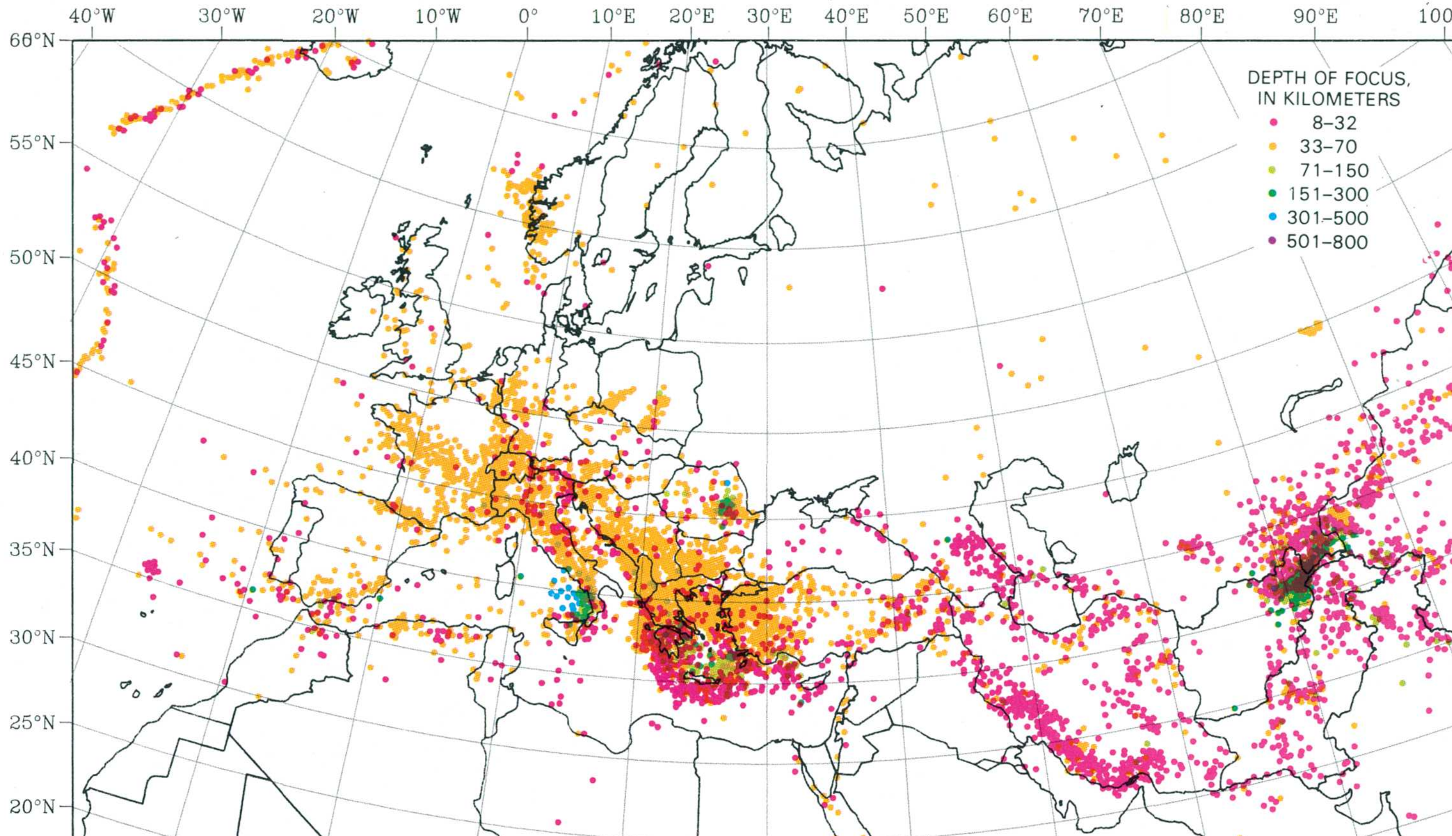

Figure 8. Seismicity of Europe and the Middle East, 1971–1986.

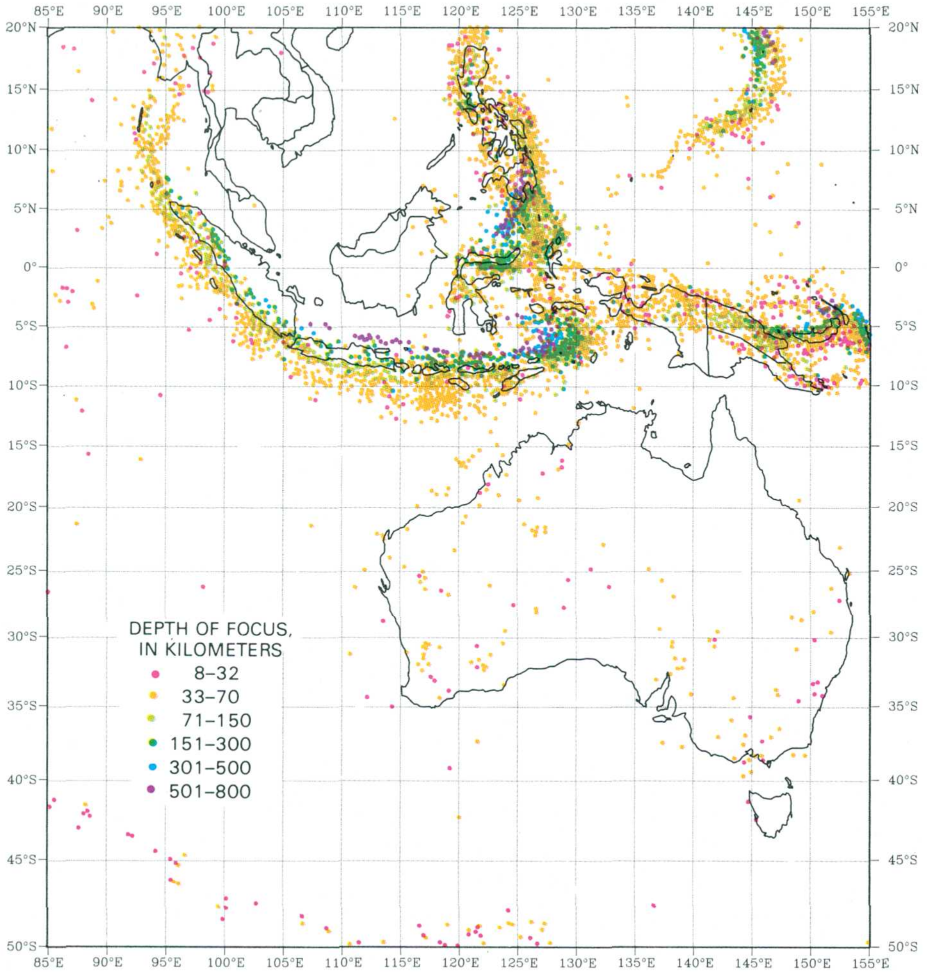

Figure 9. Seismicity of Indonesia, Australia and the Philippine Islands, 1971-1986.

In order to determine the size and characteristics of an earthquake, more information is required than that needed simply to locate the earthquake. For example, a well-calibrated seismograph system, which can faithfully record the entire range of Earth motion even for large earthquakes, is required for reliable earthquake-magnitude determination. Many seismograph stations currently operating in the U.S. are not calibrated and do not have the dynamic range to record on-scale the moderate to large earthquakes that occur within the U.S. For this reason, the USGS, in cooperation with the U.S. Nuclear Regulatory Commission, has designed

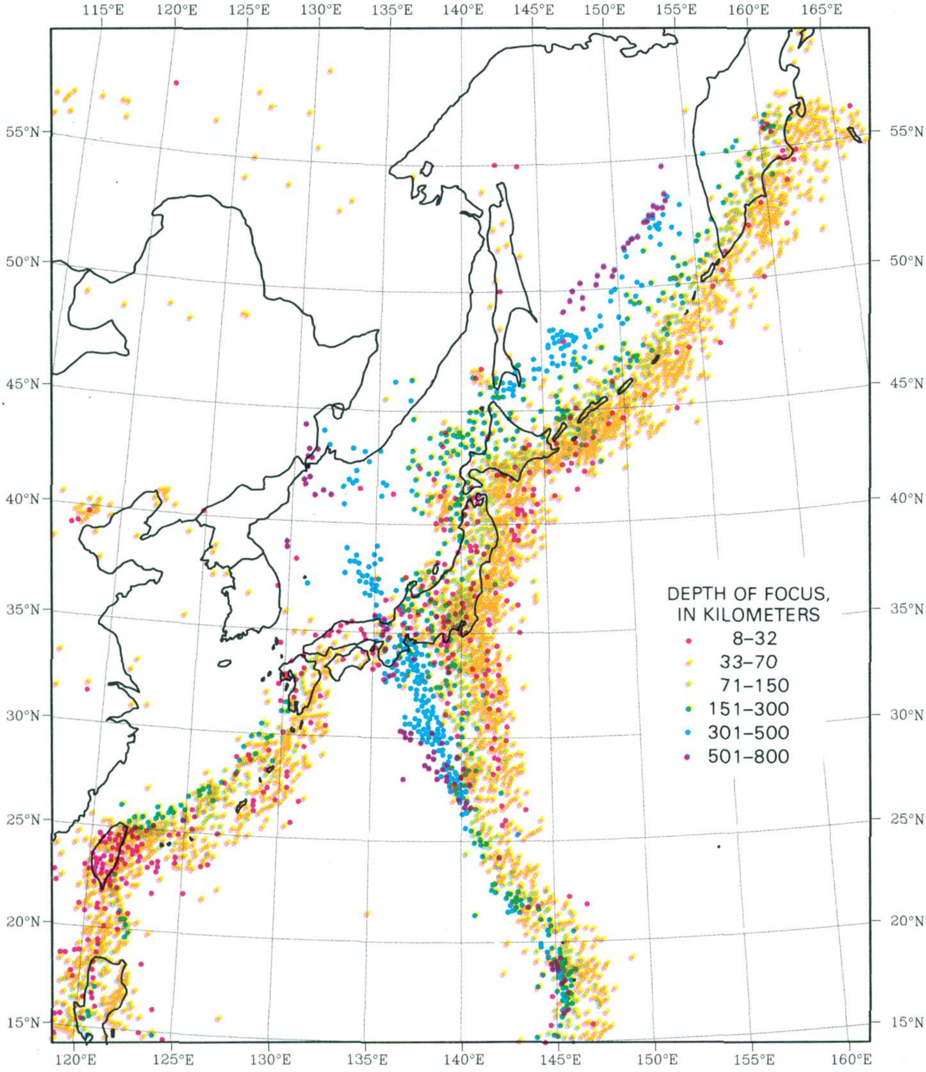

Figure 10. Seismicity of Japan and the Kuril Islands, 1971-1986.

a new digital seismograph network for the U.S. The approximate configuration of the U.S. National Seismograph Network (USNSN) is shown in figures 20 through 23; specific station sites have not yet been selected in many areas. The network will consist of about 150 seismographic stations throughout the contiguous 48 states and across Alaska, Hawaii, Puerto Rico, and the Virgin Islands. The network should provide the capability to detect and locate earthquakes of

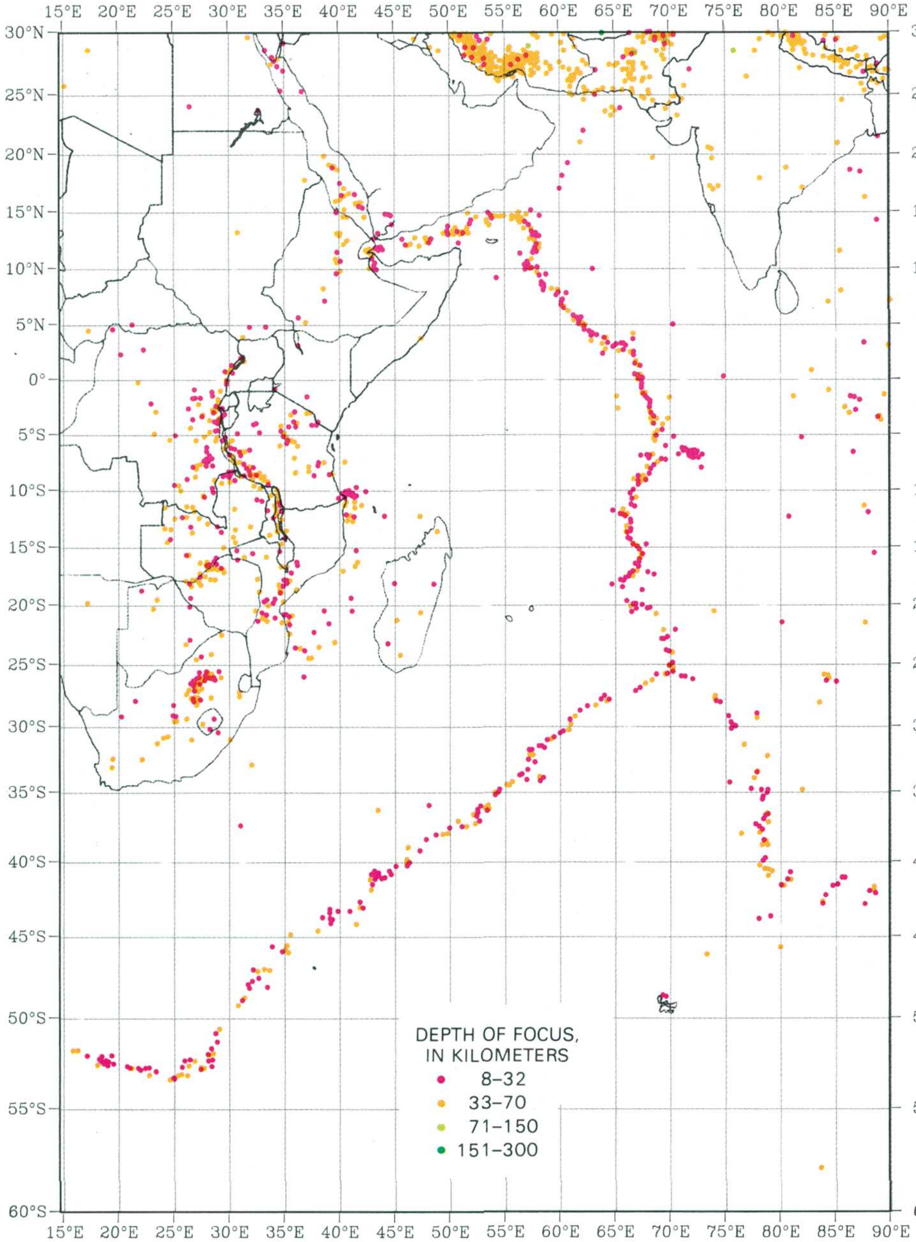

Figure 11. Seismicity of the Indian Ocean, 1971-1986.

magnitude 2.5 and larger in all states except possibly part of Alaska. The network will record three-component information that has a high dynamic range

(210 decibels). The frequency response of each station will be broadband (DC to 15 hertz). Each station will also be equipped with strong-motion sensors. Waveform data from the stations will be transmitted in real-time via satellite (figure 24) to the NEIC. Figure 25 shows broadband and long-period signals recorded at a USNSN station near Denver, Colorado, for the Los Angeles, California, earthquake of October 1, 1987. When the entire USNSN becomes operational, the high-quality, standardized broadband data from the network will provide new research opportunities for understanding earthquakes and the processes that cause them. The network will also furnish near real-time estimates of strong ground motion and damage potential for significant U.S. earthquakes.

In order to analyze the large volume of waveform data arriving in real-time from the USNSN as well as from other seismograph stations around the world, a new operations center has been developed at the NEIC (figures 26 and 27). The goal of this center is to achieve the capability to detect, locate, and characterize all earthquakes having Richter body-wave magnitudes greater than 2.5 in the U.S. and 4.0 worldwide. The ever-increasing availability of real-time seismic data from around the world and the inexpensive computer power now available make these magnitude threshold goals realistic for most of the world.

Processing the large volume of real-time waveform data arriving from around the world requires a high degree of automation in the computer analysis system. Using modern microcomputers and work stations, an automated analysis system has been developed by the NEIC for locating and characterizing earthquakes anywhere in the world. The automated signal-processing system is represented schematically in figure 28. The last step of the data-processing is a review by a geophysicist. This review is important to ensure that all available data have been properly used and that the results are correct. The earthquake information obtained from this process is available immediately in the form of the Quick Epicenter Determination (QED) list. The QED may be obtained by dialing the NEIC computers through an 800 telephone number (1-800-358-2663). An example of the QED is shown in figure 29.

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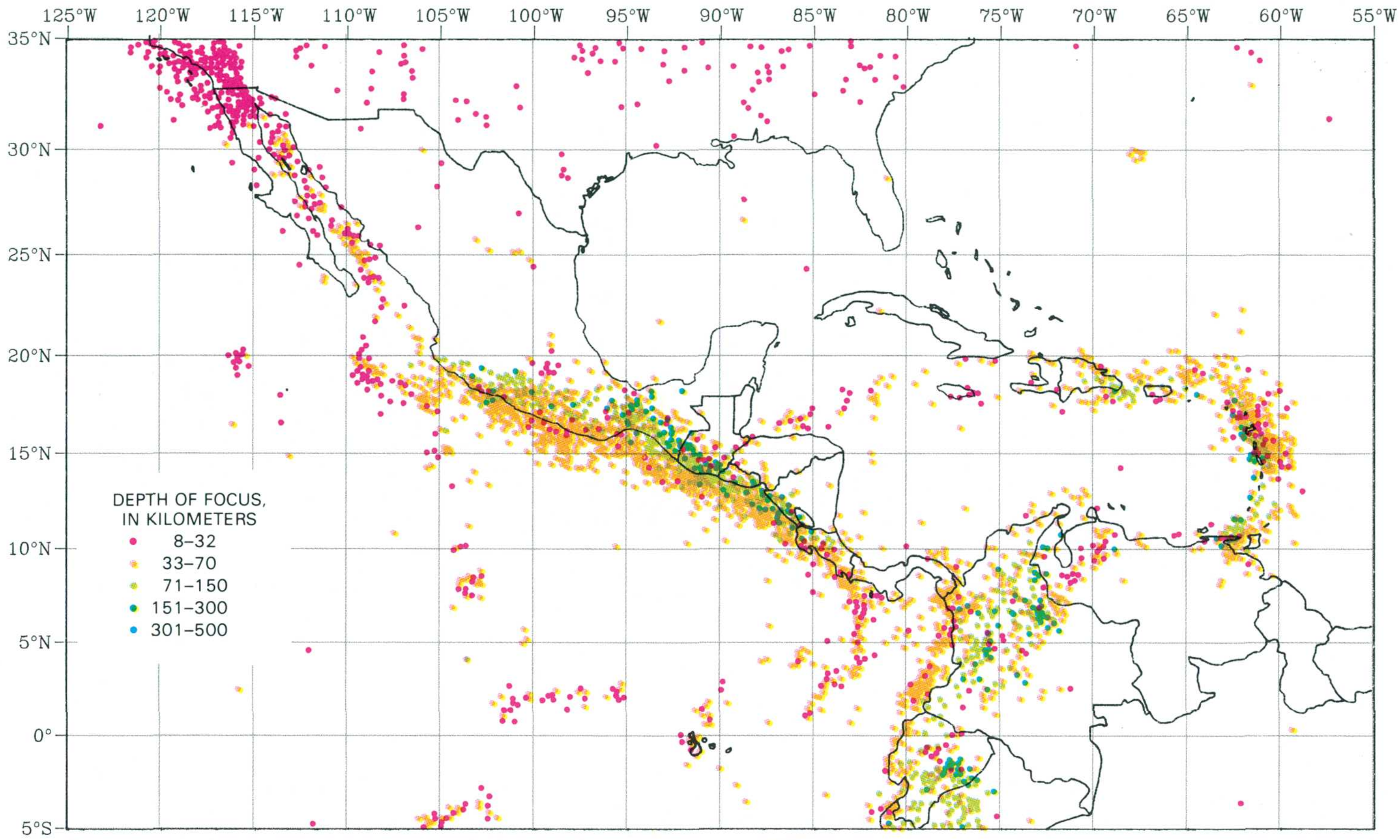

Figure 12. Seismicity of Central America, 1971–1986.

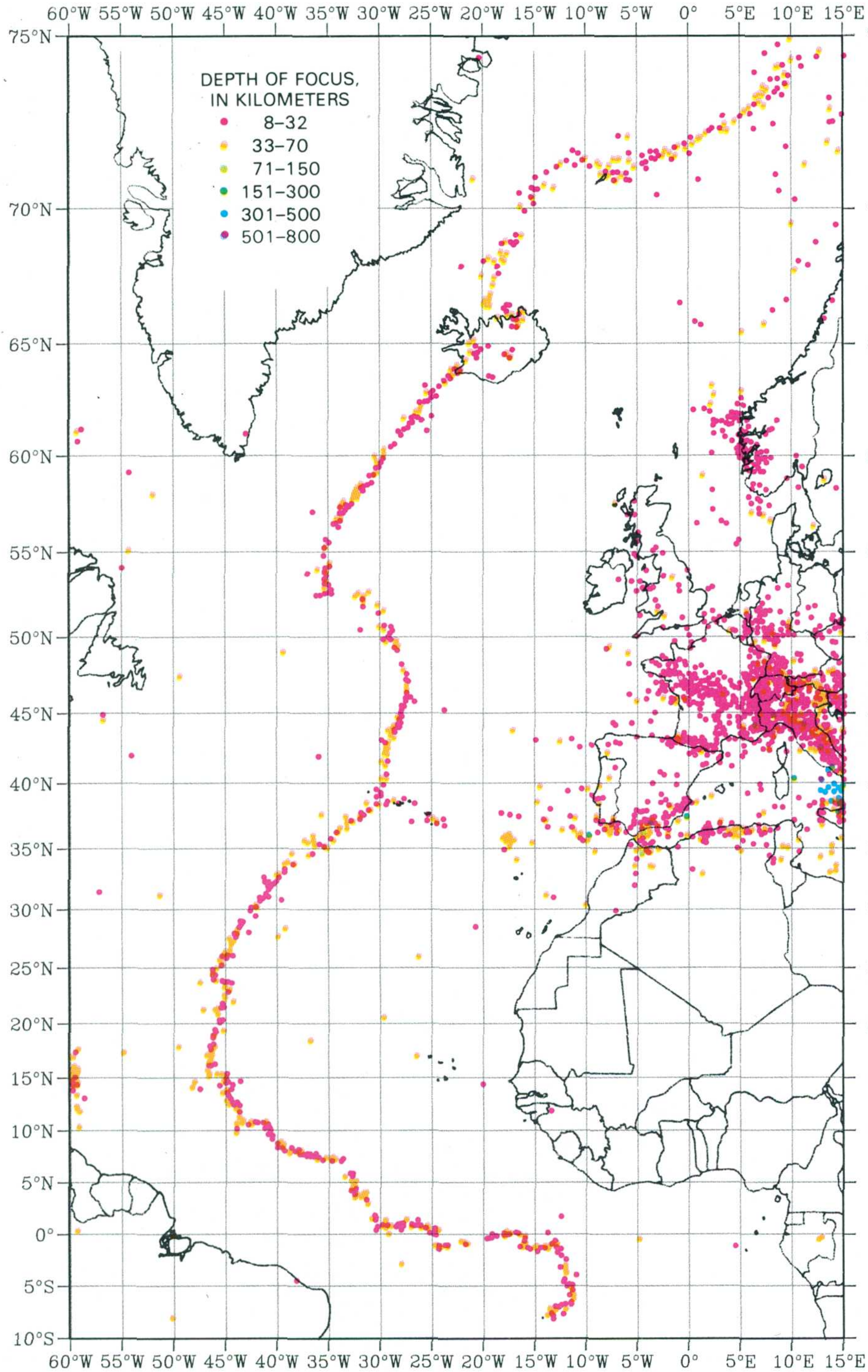

Figure 13. Seismicity of the North Atlantic Ocean, 1971–1986.

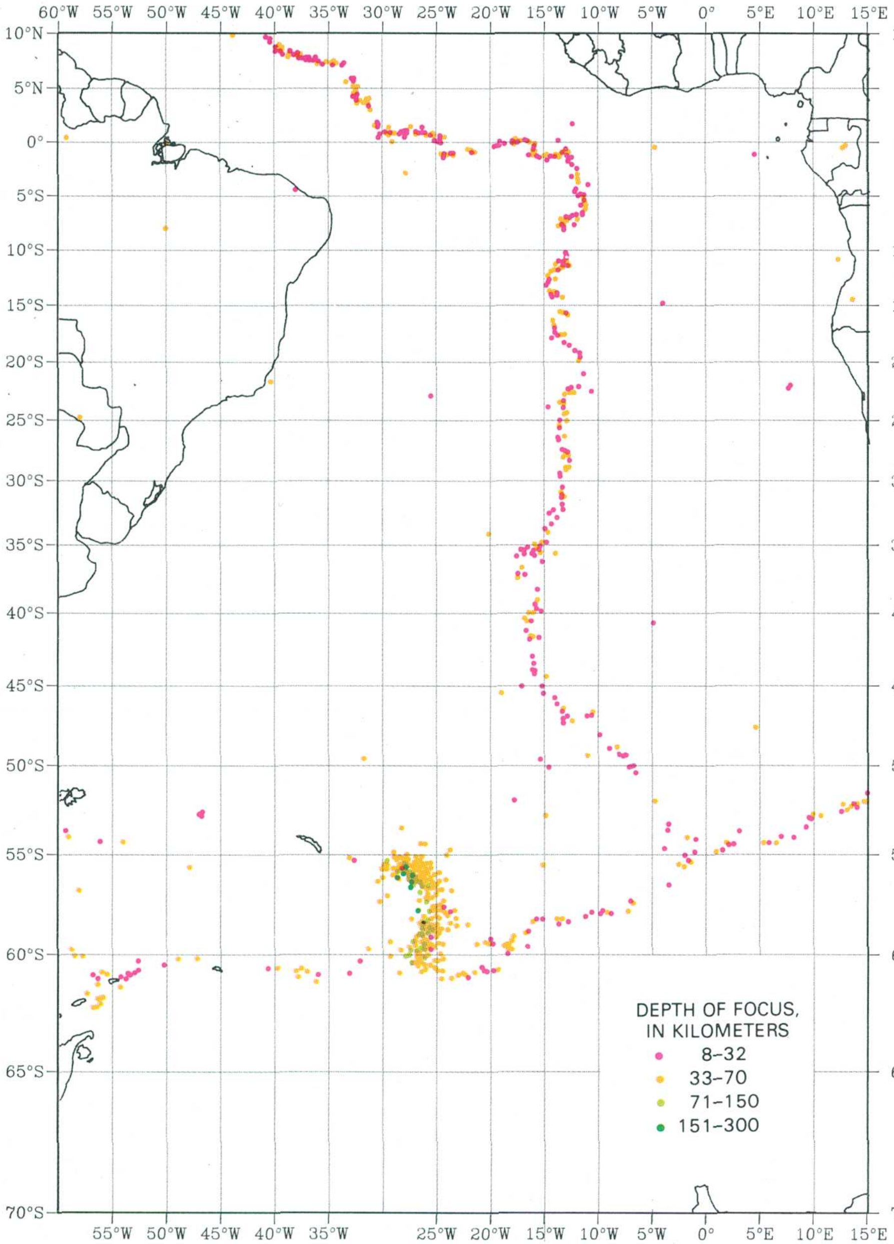

Figure 14. Seismicity of the South Atlantic Ocean, 1971–1986.

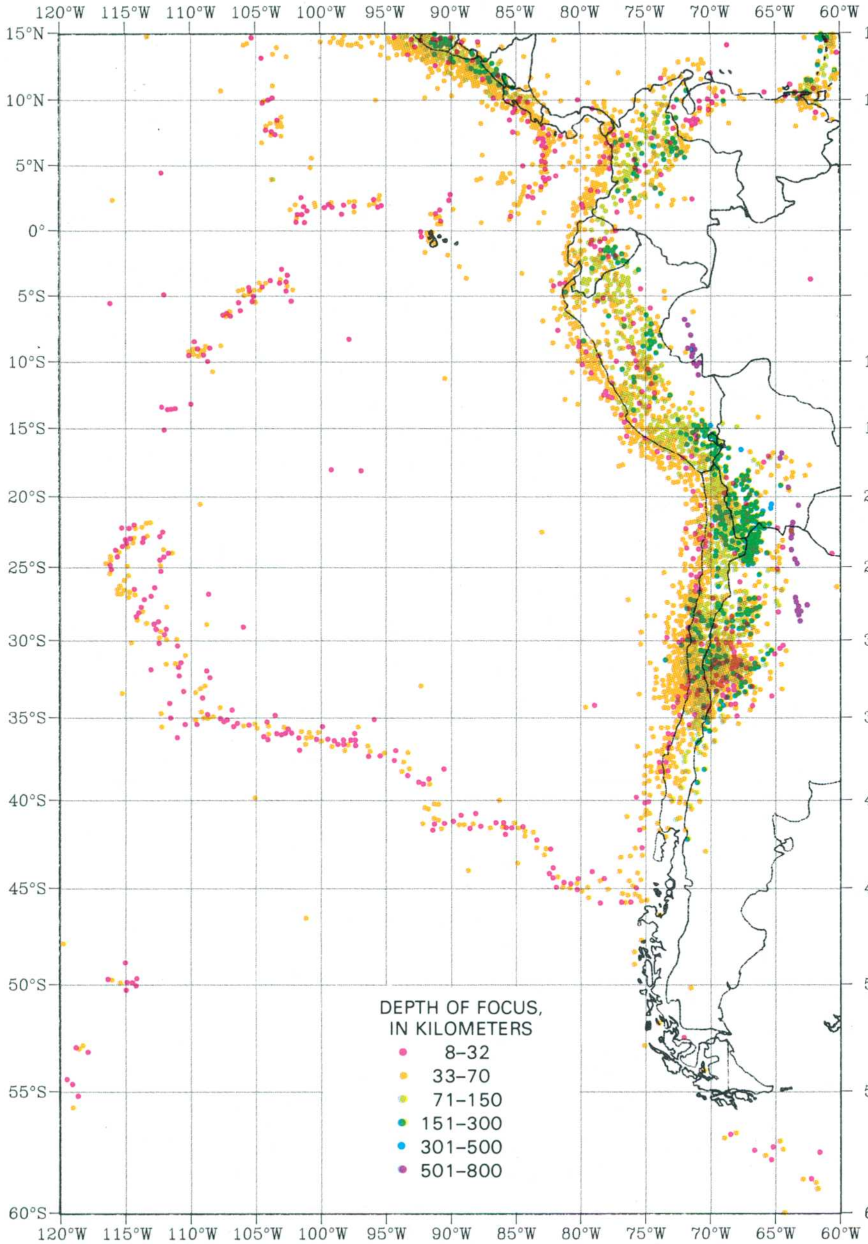

Figure 15. Seismicity of South America, 1971-1986.

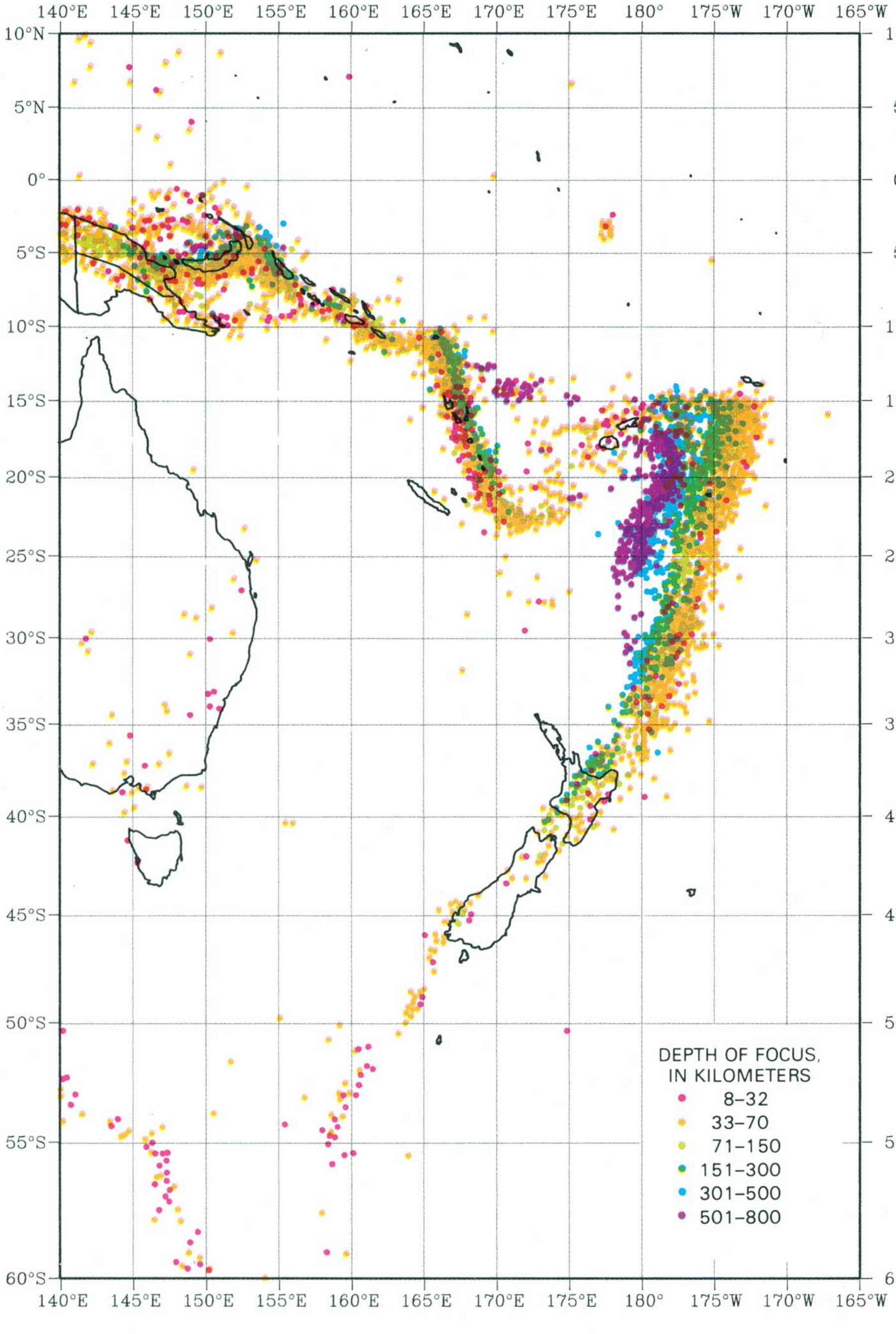

Figure 16. Seismicity of the southwest Pacific Ocean, 1971-1986.

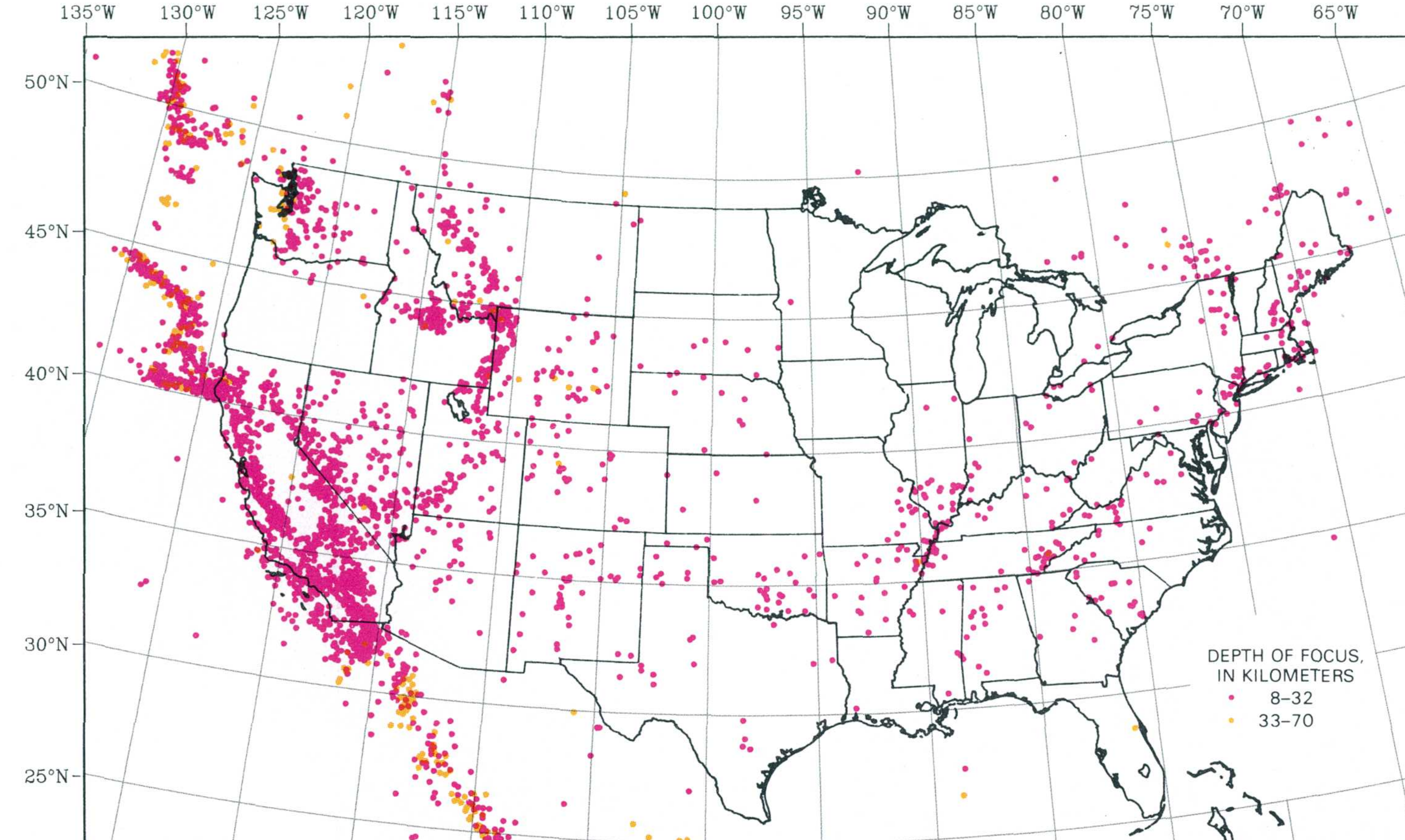

Figure 17. Seismicity of the United States, 1971–1986.

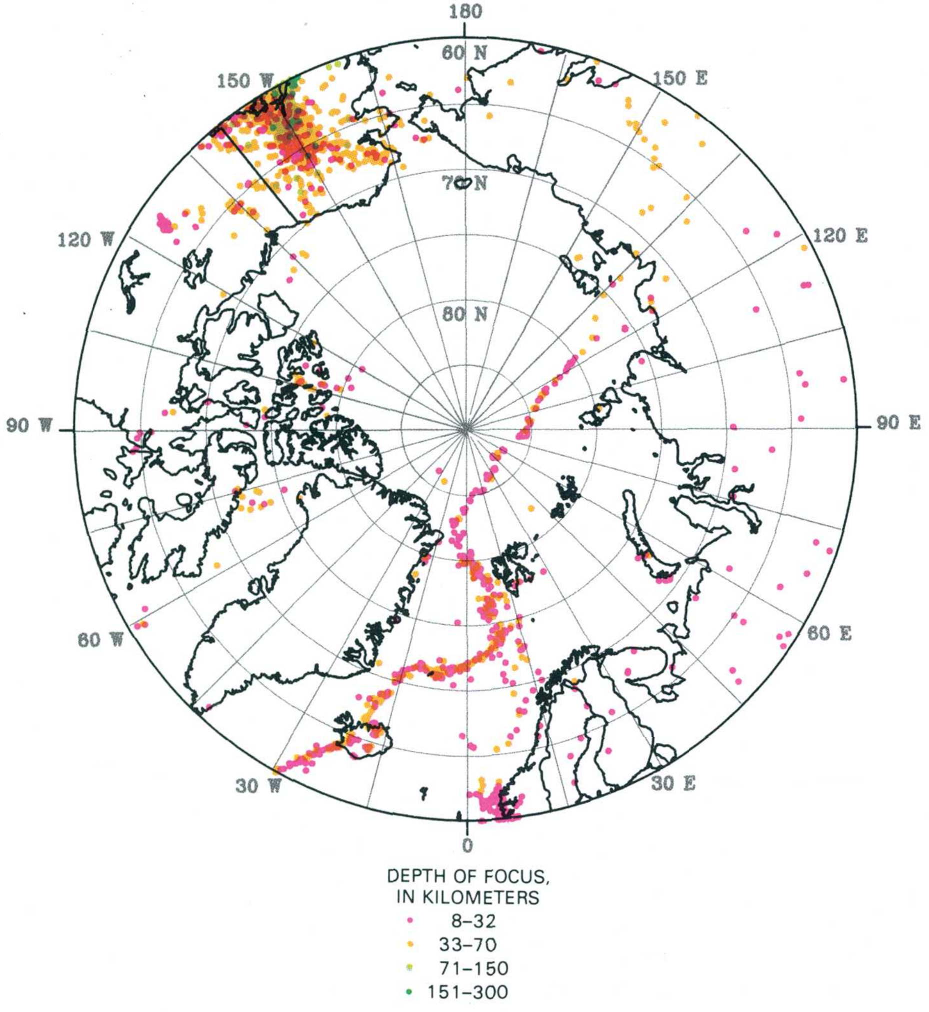

Figure 18. Seismicity of the Arctic region, 1971–1986.

Operation of National and Global Seismograph Networks

The USGS interest in operating national and global seismograph networks stems from its role as the chief seismological agency of the U.S. To meet USGS responsibilities for detecting and locating all felt earthquakes within the U.S., the NEIC is developing and deploying the USNSN. The deployment and operation of the USNSN will be accomplished by working closely with the many Federal agencies, State agencies, and universities that have an interest in seismic monitoring.

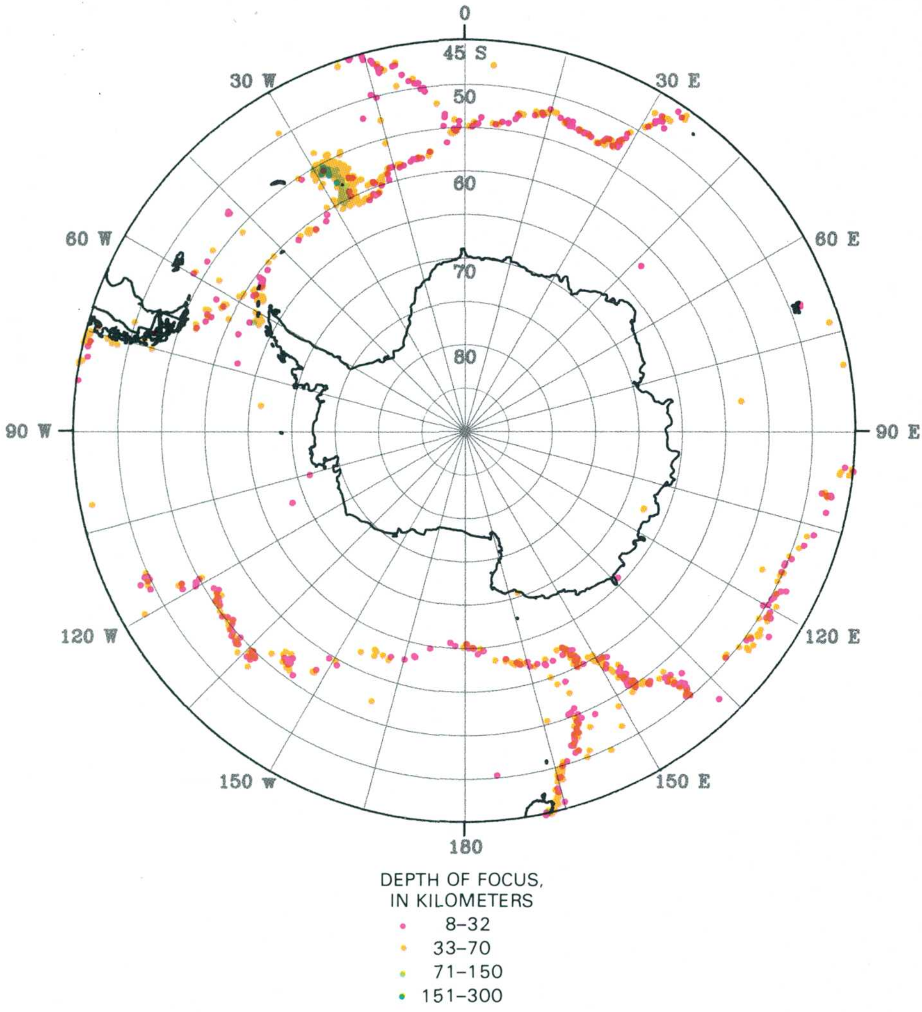

Figure 19. Seismicity of the Antarctic region, 1971–1986.

The NEIC, through its Albuquerque Seismological Laboratory (ASL), has a long history of developing, operating, and maintaining global networks. For many years, the ASL has represented the U.S. to foreign countries and institutions in the deployment, management, and operation of worldwide seismograph networks. Figures 30–32 show global seismograph networks installed by the ASL in cooperation with many foreign countries; figure 33 shows the ASL. The NEIC has also begun a number of new national and global projects to install seismograph networks (figure 34).

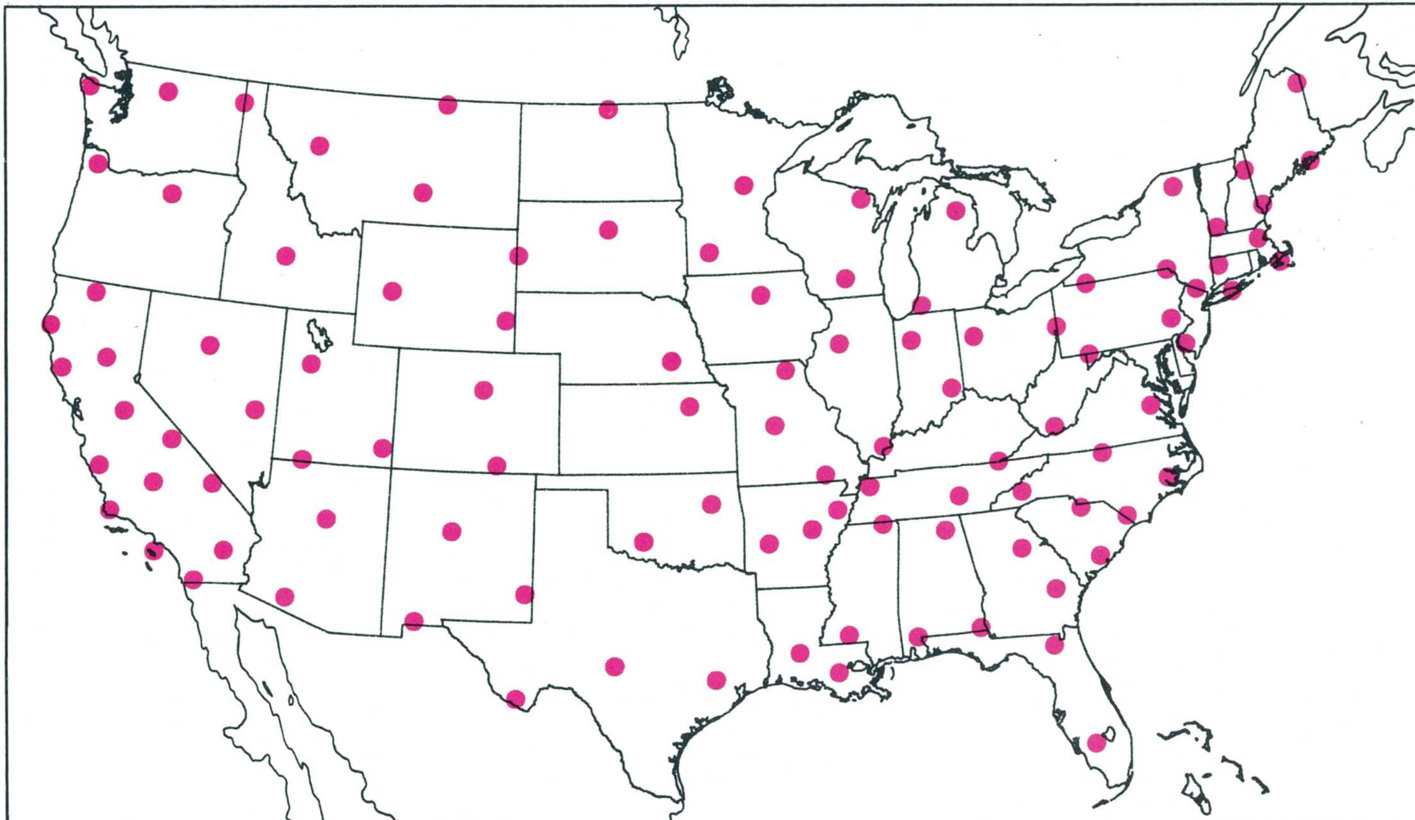

Figure 20. Generalized configuration of the U.S. National Seismograph Network (USNSN) for the conterminous United States.

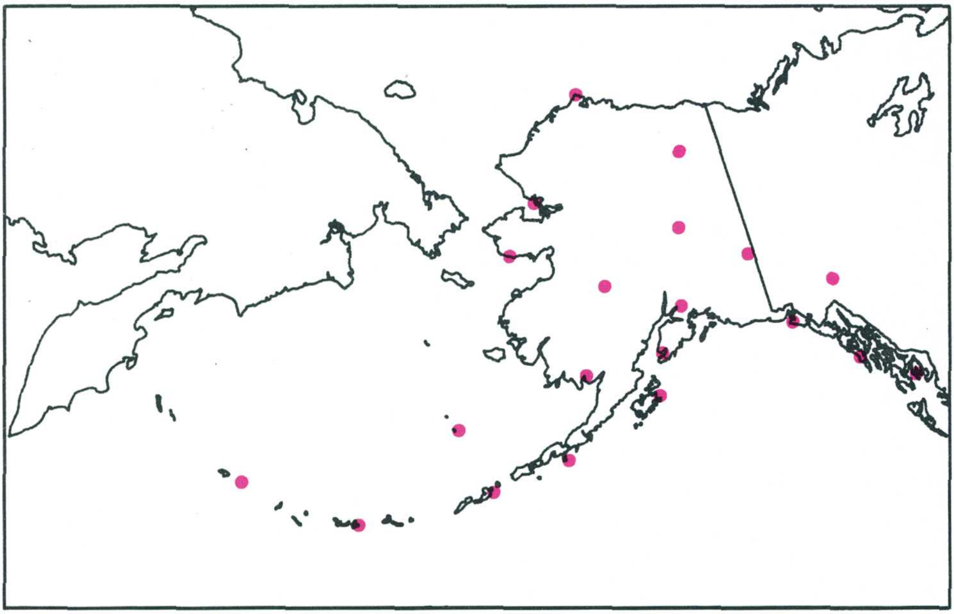

Figure 21. Generalized configuration of the U.S. National Seismograph Network (USNSN) for Alaska.

The largest of these projects is the modern, broadband USNSN with its 150 stations (described earlier). The Global Telemetered Seismograph Network (GTSN) project will bring real-time seismic data to the ASL and NEIC from four stations in Africa, four stations in South America, and one in Antarctica. Through funding and other support provided principally by the National Science Foundation (NSF) and the USGS, the Incorporated Research Institutions for Seismology (IRIS)—a consortium of U.S. universities—plans to develop 50 modern digital broadband seismographs and deploy them at existing or new stations as the IRIS/GSN. The Caribbean project—a cooperative effort involving the NEIC and many Central and South American countries—will surround the Caribbean with a modern, broadband network. The USGS and the State Seismological Bureau of the Peoples' Republic of China have cooperated to develop and deploy of the China Digital Seismograph Network (CDSN)—a network of nine stations and a data collection center in China. The CDSN, which became operational in 1986, records short-period, broadband-event data and continuous long-period and very-long-period data. The WWSSN replacement will upgrade many WWSSN stations with modern broadband equipment.

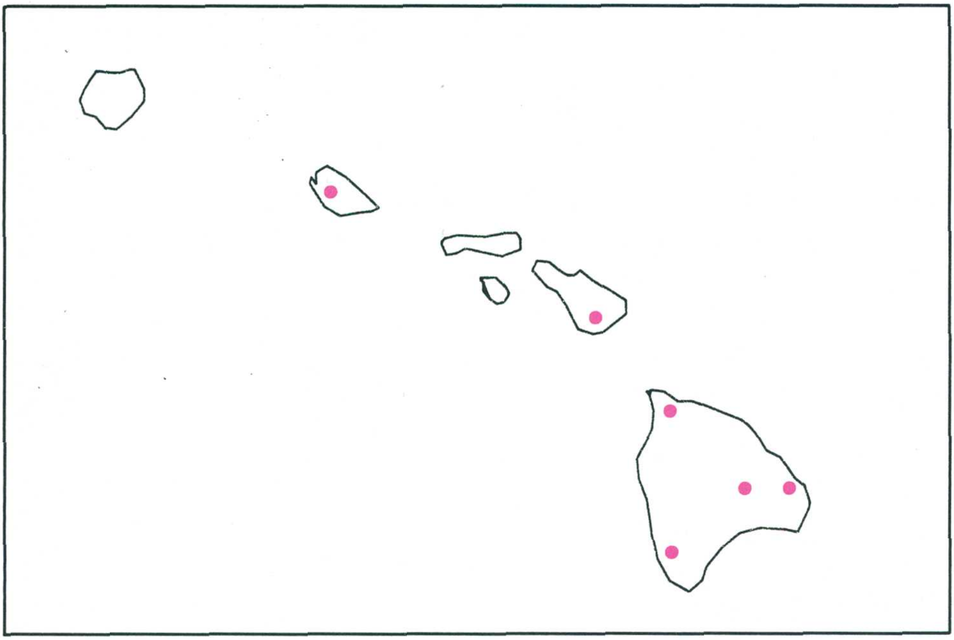

Figure 22. Generalized configuration of the U.S. National Seismograph Network (USNSN) for Hawaii.

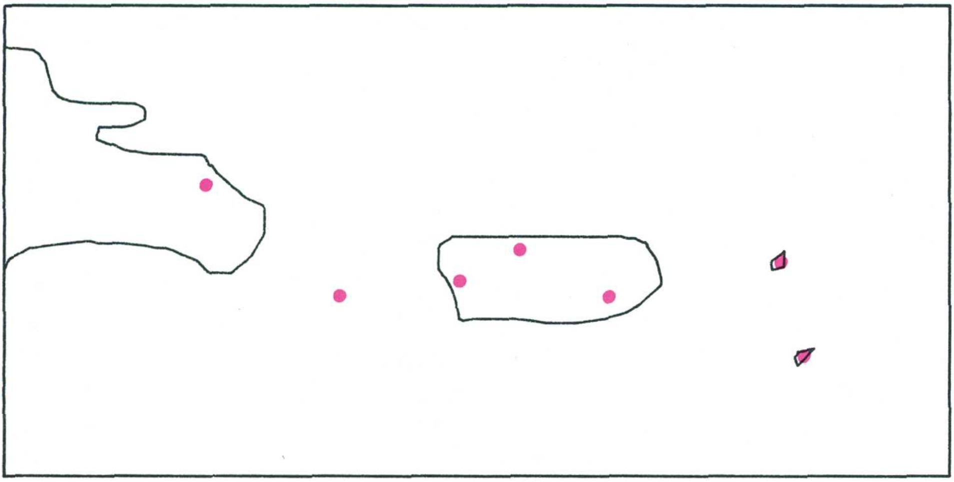

Figure 23. Generalized configuration of the U.S. National Seismograph Network (USNSN) for Puerto Rico.

Figure 24. Satellite transmitting dish for typical USNSN station. Photograph by J. McMillan.

For a seismograph network to have optimum value, data from the network must reach the scientific community rapidly and in an easily accessible form. The NEIC has led the way in providing digital seismic data to the international scientific community. Figure 35 shows how digital seismic data flows from global networks to the NEIC and from the NEIC to scientists around the world. This flow chart demonstrates very well the degree of cooperation that exists in the international seismological community.

Until recently, the only reasonable way to provide digital seismic data to the scientific community was on magnetic tape. Now the contents of about 25 magnetic tapes can be stored on a single Compact Disc-Read Only Memory (CD-ROM). The NEIC pioneered the use of CD-ROM technology for storing and distributing seismic data (figure 36). The NEIC has stored broadband digital seismic data on CD-ROMs beginning with data recorded in 1980. These CD-ROMs have been provided to scientific institutions across the U.S. and around the world (figures 37 and 38). Cooperation with international organizations such as ORFEUS, Geoscope, and the Federation of Digital Broadband Seismograph Networks have made digital data on

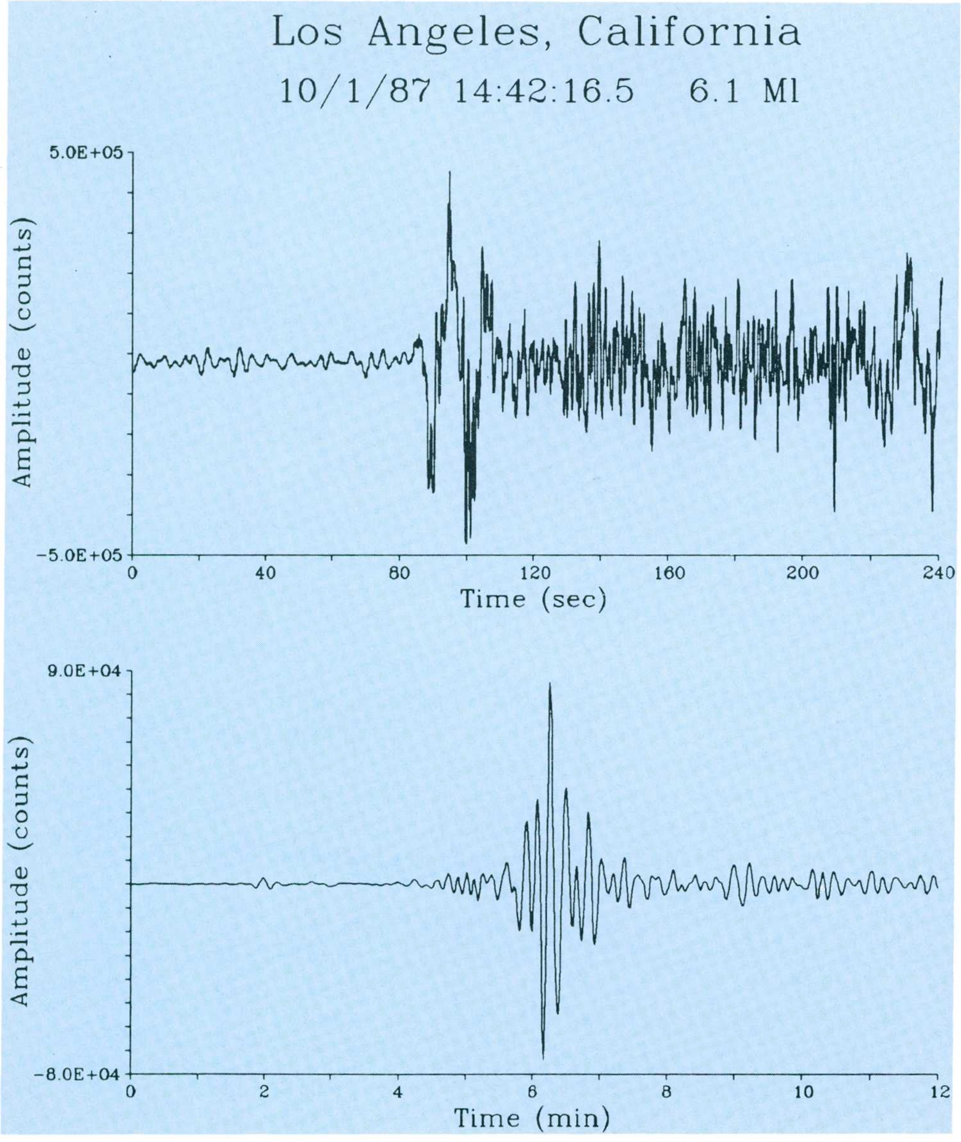

Figure 25. Broadband and long-period signals recorded at a USNSN station near Denver, Colorado, for the Los Angeles, California, earthquake of October 1, 1987.

CD-ROM easy to access by scientists throughout the world. The collection and distribution of seismic data is a joint function of NEIC and the World Data Center A-for seismology. Planned high-speed dial-up and satellite links will provide the scientific community with rapid access to all USNSN waveform data stored on the mass store systems at the NEIC.

Figure 26.
Analyst workstation in the operations center at NEIC.

Research

A wide range of research is conducted at the NEIC, utilizing seismic data from both NSN and GSN stations. Investigations range from resolving the internal structure of the Earth to understanding the mechanics of earthquake rupture. All these efforts are aimed at improving the data services provided by the NEIC to the scientific community and to the general public. For instance, in addition to location and depth, the NEIC now reports other parameters that describe the mechanics of an earthquake, including focal mechanism, radiated energy, and moment. Some of the data services and products of the NEIC are summarized in figures 39 and table 2. A promising application of research toward the goal of mitigating seismic hazard is the production of maps like that in figure 40—seismic potential maps that show comparative earthquake risk (or of recurrence interval for great earthquakes). These results were made possible by the accumulation and analysis of statistics of earthquake location and occurrence. The information on a map such as that in figure 40 provides a guide for scientists and emergency-preparedness agencies as to which regions require the most immediate attention. In the future, such maps could provide the basis for accurate forecasting of large earthquakes.

(Article concludes with "Summary" on p. 44)

Figure 27. Heliocorder drums in the operations center at NEIC.

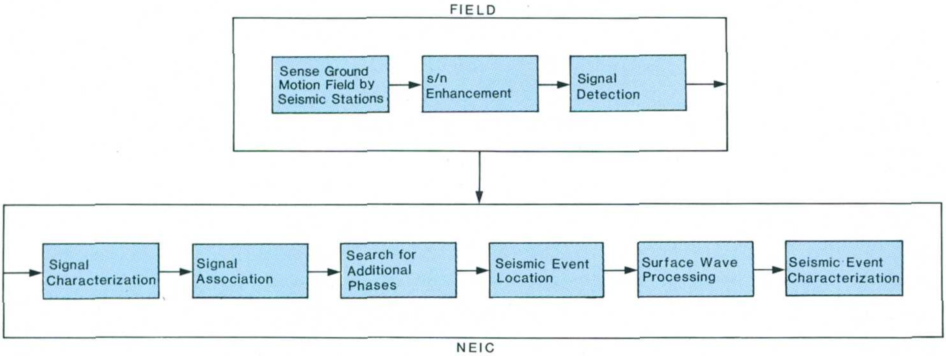

Figure 28. Automated-signal processing system.

U.S. DEPARTMENT OF THE INTERIOR — NO. 8-075
GEOLOGICAL SURVEY — MAR 15, 1988

NEIC QUICK EPICENTER DETERMINATIONS

FEB 1988

DAY	ORIGIN TIME UTC HR MN SEC	GEOGRAPHIC COORDINATES LAT	LONG	DEPTH	MAGNITUDES GS MB	Msz	SD	NO. STA USED	REGION, CONTRIBUTED MAGNITUDES AND COMMENTS
19	00 13 25.5•	37.556 S	58.938 E	10 G	5.2	5.2	0.9	7	ATLANTIC-INDIAN RISE
19	02 33 51.7•	51.531 N	174.797 E	33 N	4.8		1.0	21	NEAR ISLANDS, ALEUTIAN ISLANDS
19	04 14 59.7•	7.890 S	127.821 E	33 N	5.5		1.3	12	BANDA SEA
19	04 53 26.8	58.634 N	142.942 W	10 G	4.9		1.2	19	GULF OF ALASKA
19	11 39 22.4?	42.93 N	146.15 E	33 N	5.0		1.3	12	OFF COAST OF HOKKAIDO, JAPAN
19	12 42 10.0•	33.785 N	118.256 W	5 G			0.7	6	SOUTHERN CALIFORNIA. ML 2.5 (NEIS), 2.8 (PAS). Felt in the Long Beach-Pasadena-Signal Hill area.
19	14 07 44.0•	33.245 N	137.530 E	365 •	4.4		1.0	13	NEAR S. COAST OF HONSHU, JAPAN
19	19 07 43.0	10.185 S	161.441 E	86 D	5.6		1.0	34	SOLOMON ISLANDS
19	22 37 11.7	52.780 N	158.280 E	120 D	5.2		0.7	91	NEAR EAST COAST OF KAMCHATKA
19	23 17 15.0	18.346 N	95.061 E	69 D	5.4		0.8	21	BURMA
20	01 25 50.7	7.176 S	127.120 E	327 •	5.7		1.2	53	BANDA SEA
20	08 39 55.0	36.789 N	121.512 W	6 G	4.6		1.3	33	CENTRAL CALIFORNIA. ML 5.3 (BRK). Felt from Monterey to San Francisco.
20	12 51 33.9?	6.22 N	126.01 E	150 •	4.1		0.6	10	MINDANAO, PHILIPPINE ISLANDS
20	13 19 07.7?	34.08 S	70.50 W	98 ?			0.2	10	CHILE-ARGENTINA BORDER REGION
20	13 46 08.9?	33.80 S	72.12 W	7			0.7	9	OFF COAST OF CENTRAL CHILE
20	14 48 50.8•	61.852 N	141.267 W	10 G	4.5		0.8	10	SOUTHERN ALASKA
20	22 12 00.1	46.649 N	152.534 E	54 D	5.6		0.9	93	KURIL ISLANDS
20	22 51 13.4	4.381 N	73.654 W	33 N	5.1		1.1	26	COLOMBIA. Felt strongly in the Bogota area.
21	01 05 14.3•	28.873 N	139.423 E	442 ?	4.5		0.5	28	BONIN ISLANDS REGION
21	05 20 13.5•	15.580 S	173.022 W	33 N	5.3		0.5	24	TONGA ISLANDS
21	05 44 06.8	44.441 N	115.759 W	5 G			0.6	17	WESTERN IDAHO. ML 3.8 (NEIS).
21	08 34 18.7?	15.01 S	173.56 W	33 N	5.0		1.0	11	TONGA ISLANDS
21	09 22 09.9	6.847 S	129.302 E	118 ?	5.3		0.9	20	BANDA SEA
21	09 46 18.5?	33.52 S	71.97 W	33 N			0.6	9	NEAR COAST OF CENTRAL CHILE
21	16 55 21.6	13.234 N	145.676 E	63	5.2		0.8	25	MARIANA ISLANDS. Felt (IV) on Guam.
21	19 03 19.6•	11.543 N	86.812 W	33 N	5.2	4.7	1.4	23	NEAR COAST OF NICARAGUA
21	19 27 13.6?	0.15 N	121.91 E	222 ?	5.0		1.7	10	MINAHASSA PENINSULA
21	22 00 07.8?	32.29 S	72.11 W	5 G			0.5	10	OFF COAST OF CENTRAL CHILE
21	22 49 07.5?	31.91 S	72.50 W	5 G			0.7	10	OFF COAST OF CENTRAL CHILE
22	01 58 49.2	1.045 S	14.020 W	10 G	5.2	5.1	1.0	65	NORTH OF ASCENSION ISLAND
22	07 43 12.0	35.477 N	119.620 W	5 G			0.8	12	CENTRAL CALIFORNIA. ML 3.8 (NEIS), 3.9 (PAS). Felt in San Luis Obispo County.
22	08 45 46.5	4.337 S	102.904 E	81	5.2		0.9	24	SOUTHERN SUMATERA. Felt (III) in the Kepahiang area.
22	14 51 51.3	27.297 N	53.233 E	33 N	4.7		0.6	31	SOUTHERN IRAN. Felt at Lar.
22	15 42 03.6•	52.674 N	173.087 W	33 N	4.6		0.5	21	ANDREANOF ISLANDS, ALEUTIAN IS.
22	18 30 43.2	17.225 N	120.228 E	33 N	4.5		0.8	16	LUZON, PHILIPPINE ISLANDS
22	19 13 16.2•	21.005 S	69.891 W	65 D	6.2		1.3	32	NORTHERN CHILE. Felt (V) at Iquique. Felt in many areas of northern Chile. Also felt in southern Peru.
22	20 24 20.8?	51.69 N	16.40 E	10 G			0.7	5	POLAND. ML 3.0 (VKA).
23	00 48 44.6	35.912 N	114.947 W	5 G			0.5	11	CALIFORNIA-NEVADA BORDER REGION. ML 3.7 (NEIS). Felt strongly in the Boulder City-Henderson area, Nevada.
23	06 40 56.1?	26.65 N	54.71 E	33 N	4.8		1.3	29	SOUTHERN IRAN
23	07 35 26.1?	53.83 N	161.13 E	33 N	4.8		1.1	16	OFF EAST COAST OF KAMCHATKA
23	08 10 22.5	38.791 N	122.628 W	5 G			1.1	9	NORTHERN CALIFORNIA. ML 3.1 (NEIS).
23	08 14 11.2?	53.78 N	161.54 E	33 N	4.9		0.8	18	OFF EAST COAST OF KAMCHATKA
23	16 06 28.3•	2.244 N	127.103 E	124 ?	5.0		1.1	11	MOLUCCA PASSAGE
23	16 18 41.4?	35.46 N	36.44 W	10 G	5.0		0.8	22	NORTH ATLANTIC RIDGE
24	01 56 32.8	1.311 N	126.177 E	87 ?	5.3		1.1	17	MOLUCCA PASSAGE
24	02 54 23.1	51.697 N	176.894 W	`64	5.4		1.0	54	ANDREANOF ISLANDS, ALEUTIAN IS.
24	03 52 04.3	13.425 N	124.606 E	33 N	6.0	7.0	1.1	102	LUZON, PHILIPPINE ISLANDS. Slight damage (VIRF) at Virac. Felt (VRF) in the Naga-Legaspi-Catbalogan area and (III RF) at Cebu and Manila.
24	06 11 23.7•	46.717 N	152.800 E	3 G	5.2		0.9	17	KURIL ISLANDS
24	10 04 39.5•	0.133 S	91.601 W	10 G	5.1		0.7	21	GALAPAGOS ISLANDS
24	10 42 36.5•	50.841 N	173.671 E	33 N	5.2		1.1	15	ALEUTIAN ISLANDS REGION
24	14 01 42.7?	1.40 S	91.45 W	10 G	4.8		0.7	12	GALAPAGOS ISLANDS
24	14 07 28.5•	23.410 N	94.229 E	71 ?	4.9		1.3	9	BURMA-INDIA BORDER REGION
24	15 43 15.6	0.487 S	91.678 W	10 G	5.6	4.4	0.9	65	GALAPAGOS ISLANDS
24	17 18 01.1	13.452 N	124.628 E	33 N	4.9	5.2	1.2	24	LUZON, PHILIPPINE ISLANDS
24	20 22 44.7	0.397 S	91.657 W	10 G	5.2	4.0	0.9	44	GALAPAGOS ISLANDS
24	22 08 40.8•	0.666 S	91.503 W	10 G	5.3	4.0	0.9	38	GALAPAGOS ISLANDS
24	23 44 42.7•	0.191 S	91.520 W	10 G	5.0		0.8	17	GALAPAGOS ISLANDS
24	23 50 57.2?	0.31 S	91.41 W	10 G	5.1		1.0	15	GALAPAGOS ISLANDS
25	06 40 38.9•	30.026 N	69.913 E	33 N	4.8	4.4	1.3	14	PAKISTAN
25	10 47 48.4•	8.173 N	71.549 W	33 N	4.7		0.6	10	VENEZUELA
25	11 45 04.9•	41.855 N	133.541 E	457 ?	4.3		0.8	9	SEA OF JAPAN
25	14 22 07.8•	21.119 S	173.973 W	33 N	5.0	4.5	0.6	12	TONGA ISLANDS
26	02 31 22.1	18.047 S	69.697 W	144	5.4		1.2	62	NORTHERN CHILE. Felt (V) at Arica, Chile. Also felt at Tacna, Peru.
26	06 17 30.9	37.399 S	47.868 E	10 G	6.2	6.7	1.3	85	ATLANTIC-INDIAN RISE
26	09 30 09.7?	37.44 S	47.66 E	10 G	4.8		1.0	6	ATLANTIC-INDIAN RISE
26	09 36 22.9•	18.244 S	68.987 W	149 D	4.5		0.9	22	CHILE-BOLIVIA BORDER REGION
26	09 55 35.5•	17.758 S	172.083 W	33 N	5.5	5.3	1.1	26	TONGA ISLANDS REGION
26	13 42 26.7•	37.302 S	47.762 E	10 G	5.4	5.2	1.0	29	ATLANTIC-INDIAN RISE
26	17 31 54.9?	34.73 N	6.31 W	10 G			1.3	8	MOROCCO. MC 3.2 (MDD).
26	17 52 34.4•	37.287 S	47.797 E	10 G	5.4	5.2	1.1	24	ATLANTIC-INDIAN RISE
27	00 55 11.7•	42.402 N	23.851 E	10 G			0.7	5	BULGARIA
27	04 50 26.9	6.825 N	72.934 W	156 D	5.0		0.6	20	NORTHERN COLOMBIA
27	05 32 55.9•	37.328 S	48.040 E	10 G	5.2		0.9	13	ATLANTIC-INDIAN RISE
27	07 28 27.5	5.287 S	131.143 E	33 N	5.2		0.9	20	BANDA SEA

Figure 29. Example of an NEIC Quick Epicenter Determination (QED) listing.

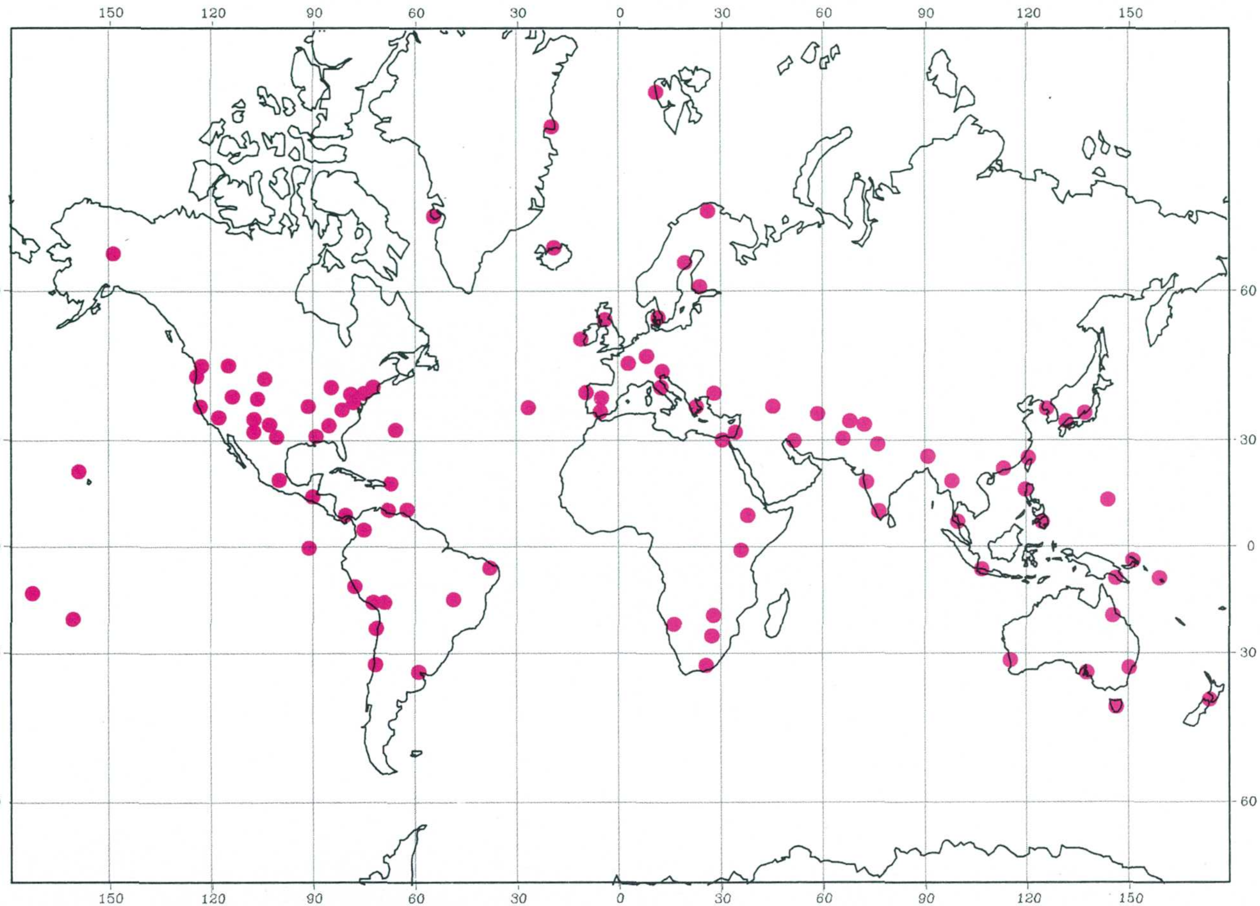

Figure 30. Worldwide Standardized Seismograph Network.

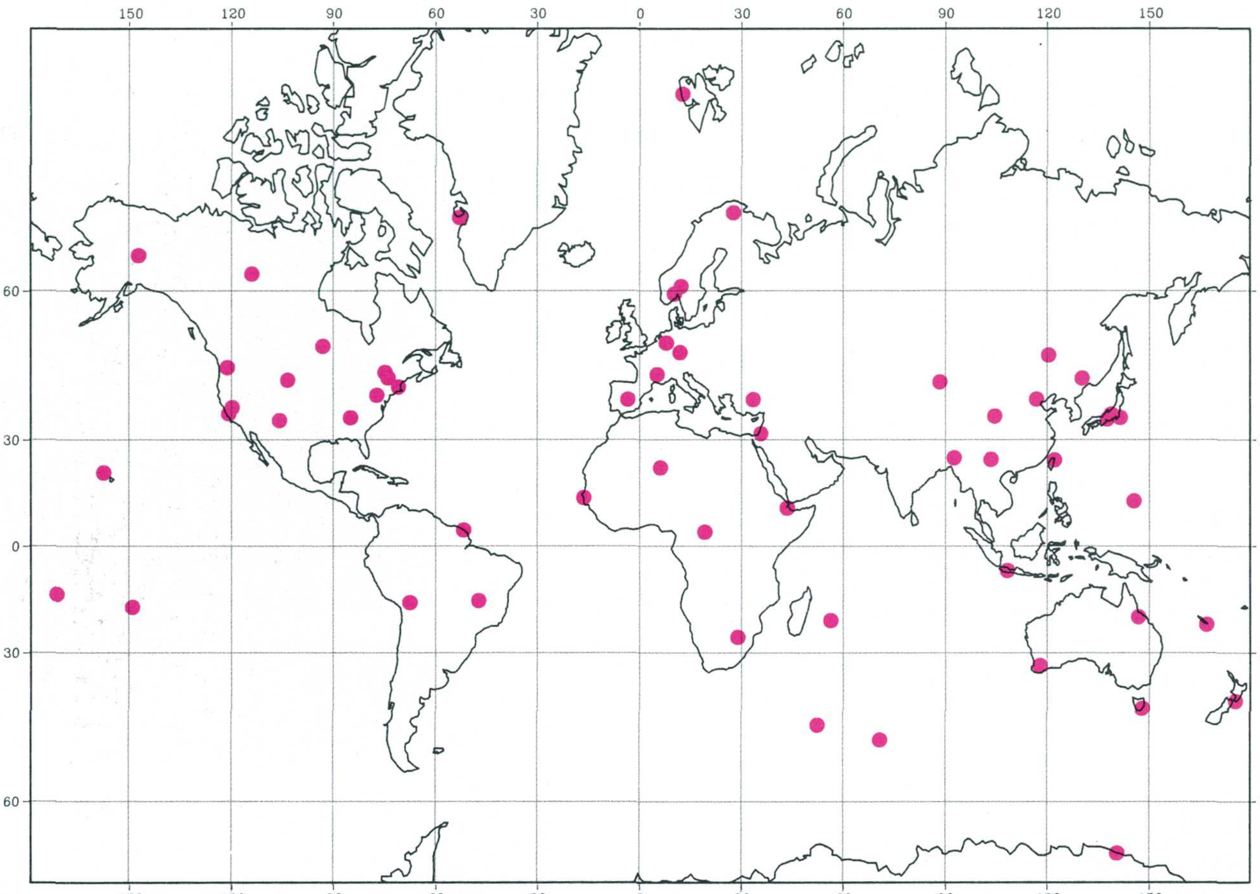

Figure 31. Global digital seismograph stations.

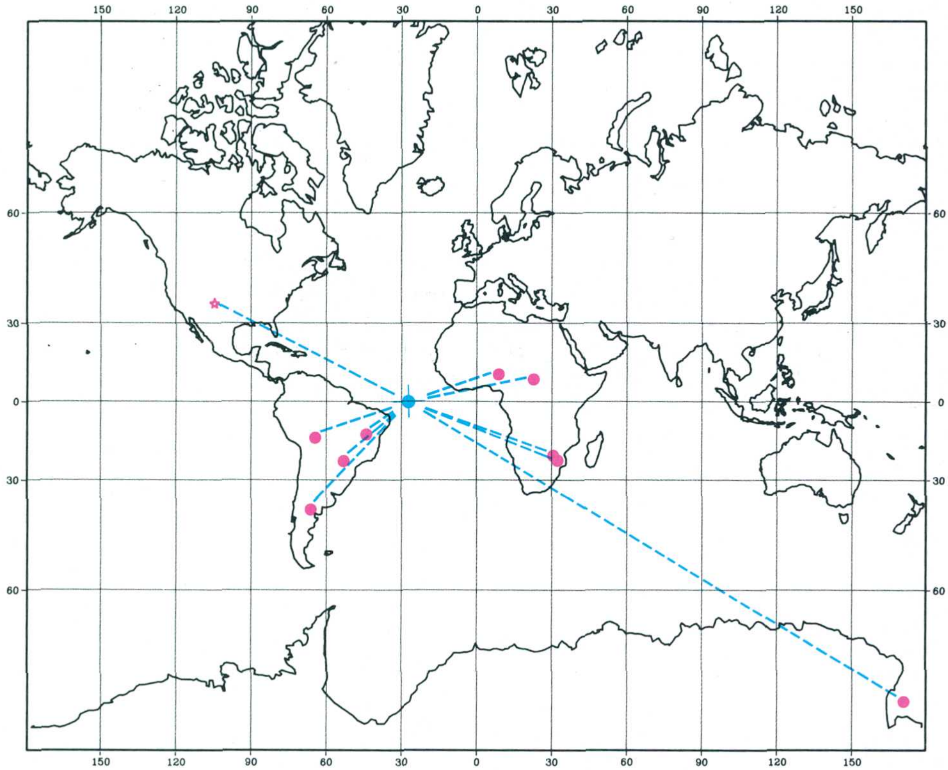

Figure 32. Planned U.S. Geological Survey global network (satellite data transmission). Star marks location of Albuquerque Seismological Laboratory.

Figure 33. Albuquerque Seismological Laboratory (ASL), New Mexico.

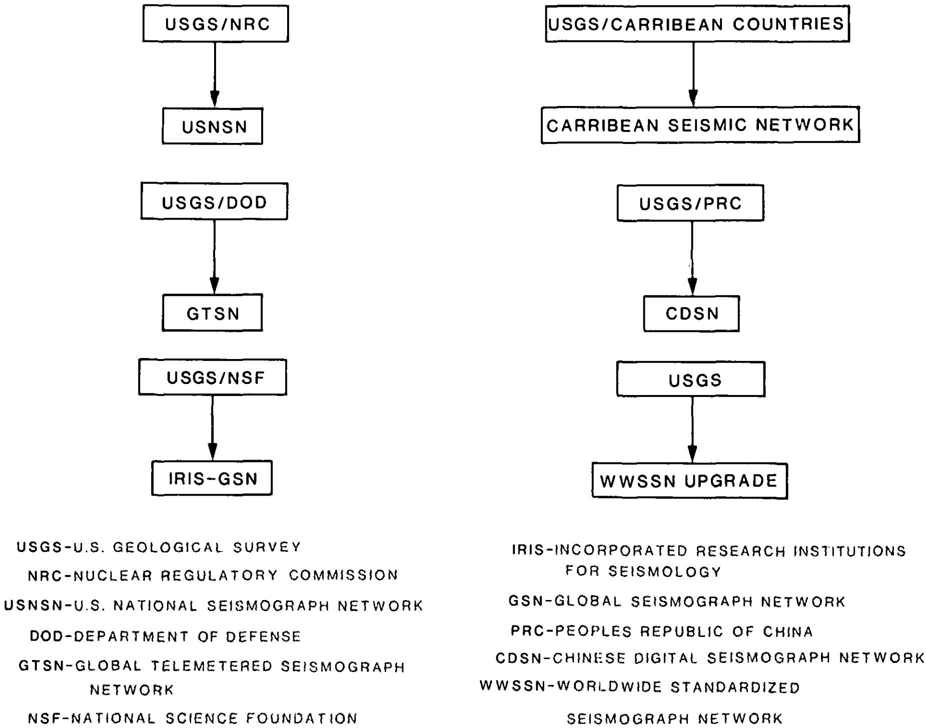

Figure 34. U.S. Geological Survey current seismograph network projects.

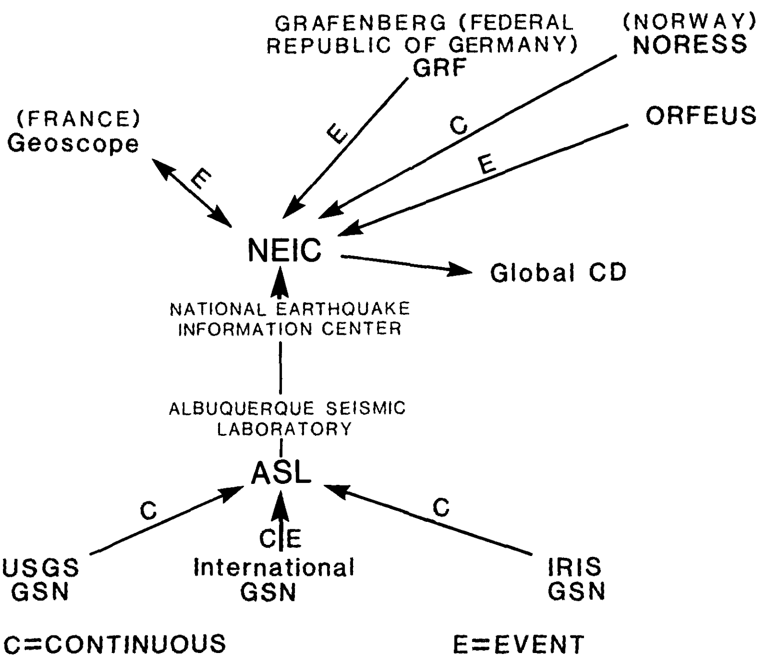

Figure 35. Global seismic data flow.

Figure 36.
Example of NEIC CD-ROM disk that contains digital data about earthquakes.

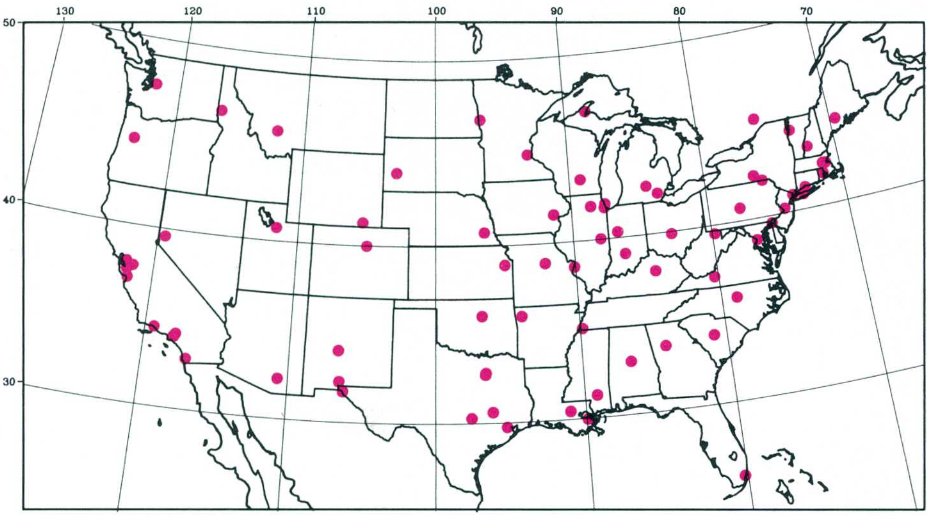

Figure 37. Distribution of the NEIC CD-ROM for the conterminous United States.

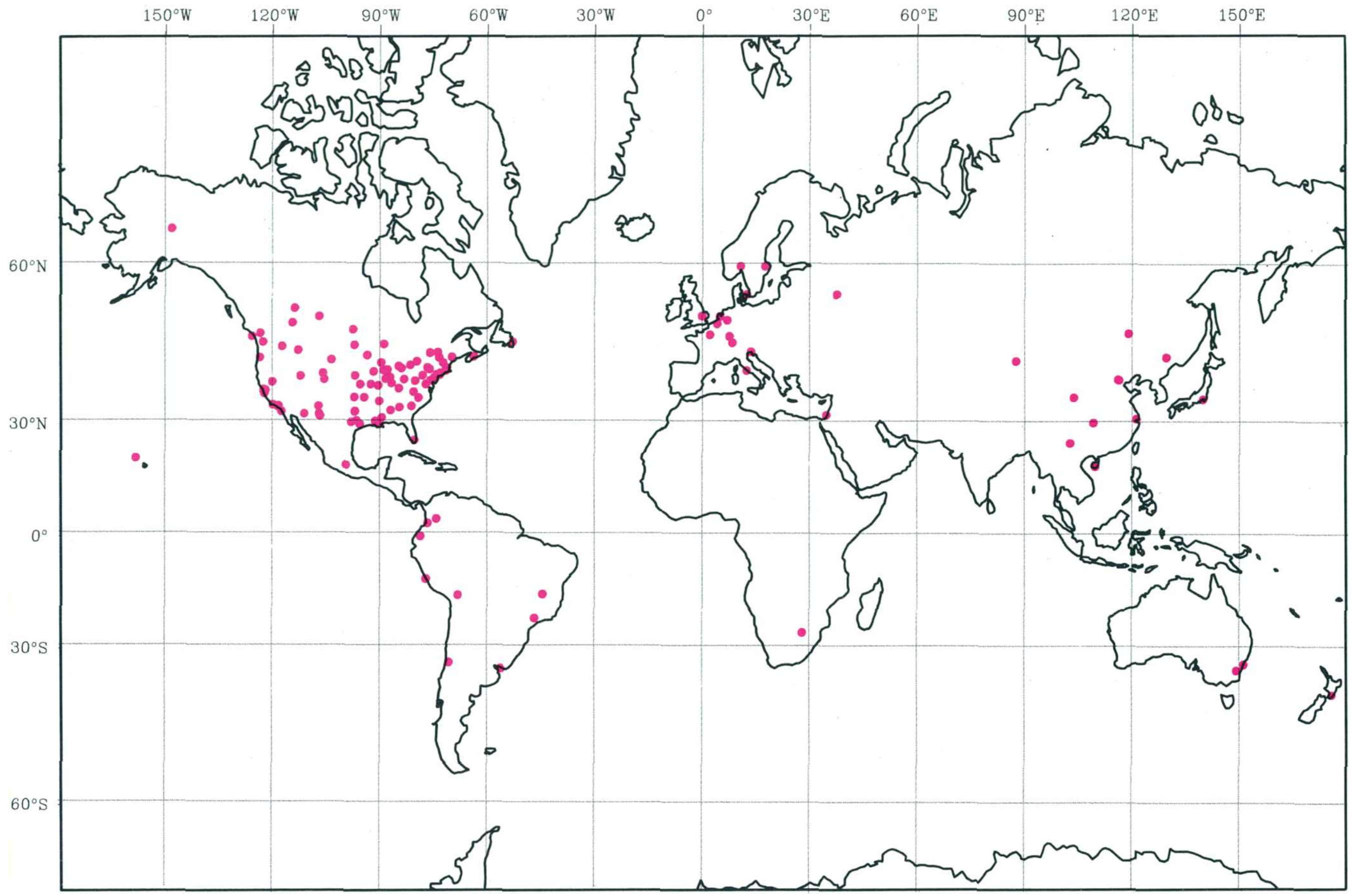

Figure 38. Distribution of the event CD-ROM.

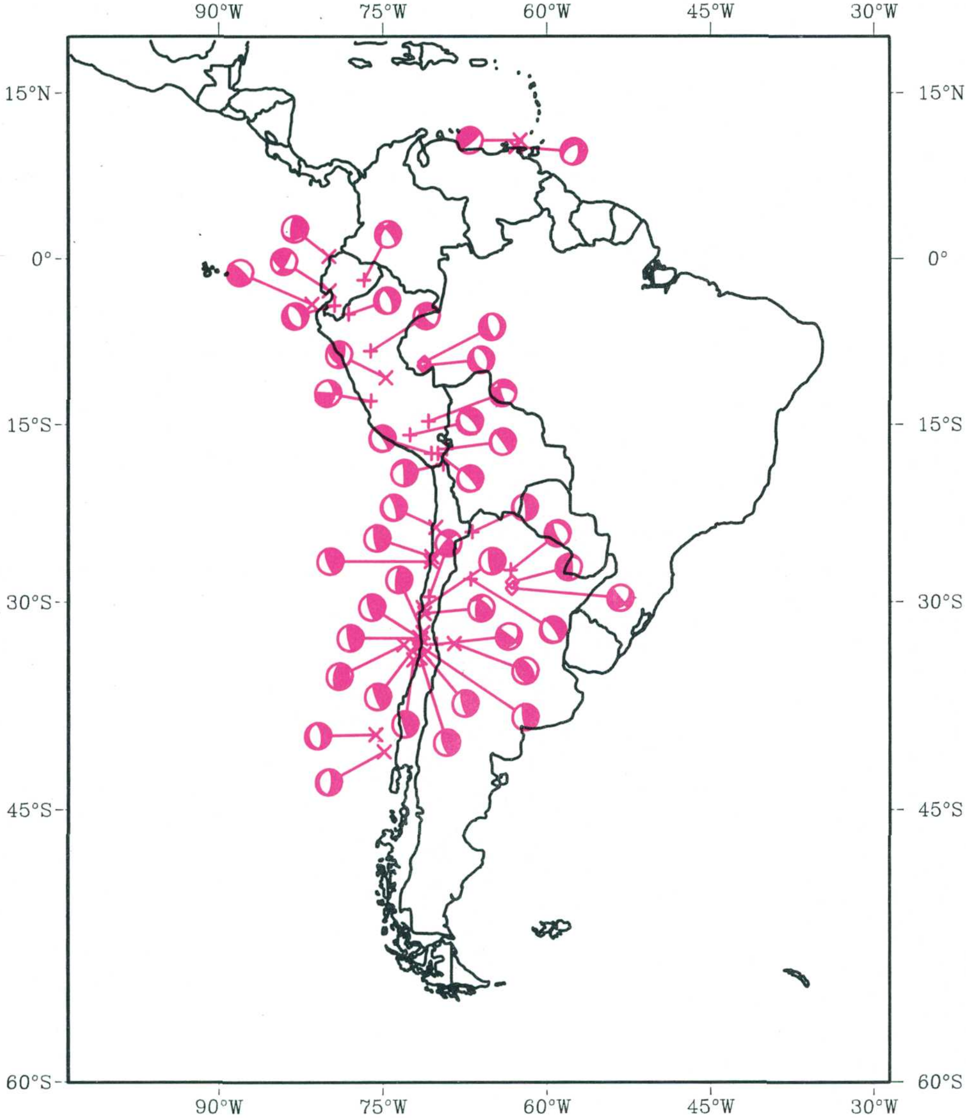

Figure 39. First-motion focal mechanism solutions for South American earthquakes, 1981–1985.

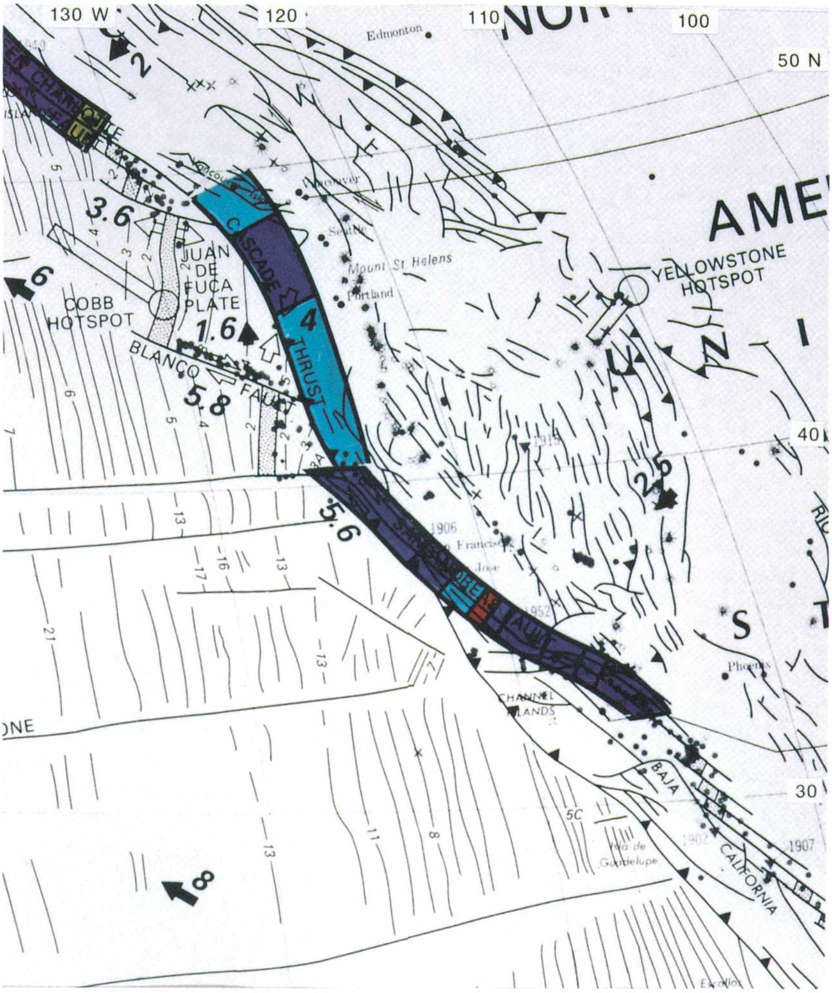

Figure 40. Seismic hazards forecast map, 1988-1999, prepared by Stuart P. Nishenko. See also "Circum-Pacific Seismic Potential, 1989-1991"—another map by Nishenko (U.S. Geological Survey Open-File Report 89-85).

Table 2. NEIC PRODUCTS

Product	Availability
Earthquake Early Alert Service (EEAS)	Immediate.
Quick Epicenter Determination (QED)	Daily.
Preliminary Determination of Epicenters (PDE)	Weekly.
PDE monthly listing	Monthly.
Earthquake Data Reports (EDR)	Monthly.
Moment tensor and first-motion fault-plane solutions	Monthly.
Radiated energy computations	Monthly.
Focal spheres of moment-tensor and first-motion solutions with selected GDSN wave forms	Monthly.
GDSN station day tapes	Monthly.
GDSN network day tapes	Monthly.
Event tapes and waveform plots	Monthly.
Event CD-ROMs	Quarterly.
U.S., Alaska, and world seismicity maps	Monthly.
Hypocenter data file tape	Monthly.
Hypocenter data file CD-ROMs	Yearly.
United States Earthquakes	Yearly.
Global seismicity maps	Yearly.
State seismicity maps.	
U.S. Geological Survey reports.	
Outside publications.	
Presentations at meetings of professional societies.	

Summary

The National Earthquake Information Center of the U.S. Geological Survey has three main missions. First, the NEIC determines as rapidly and as accurately as possible, the location and size of all destructive earthquakes that occur worldwide. The NEIC disseminates this information immediately to concerned national and international agencies, scientists, and the general public. Second, the NEIC collects and provides to scientists and to the public an extensive seismic database that serves as a solid foundation for scientific research, principally through the operation of modern digital national and global seismograph networks and through cooperative international agreements. Third, the NEIC pursues an active research program to improve its ability to locate earthquakes and to understand the earthquake mechanism. These efforts are all aimed at mitigating the risks of earthquakes to mankind; and they are all made possible by the fine international cooperation that has long characterized the science of seismology.

Evaluating the Intensity of United States Earthquakes

by
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Intensity Scales

Intensity scales have been used to measure the strength of earthquakes for more than 200 years. They were first devised so that comparisons of a series of earthquakes could be classified. One of the earliest was the Pignataro Scale (Davison, 1933), which divided the effects into five classes. Dr. D. Pignataro devised the scale to study the Calabria, Italy, earthquakes of 1782–1786 and published it in 1788. At least 44 scales (Barosh, 1969) are known to have been used to measure earthquakes.

Intensity estimates were the only representation of the size of an earthquake until the magnitude scale was devised and published by Charles F. Richter in 1935. However, intensity remained a primary scale for estimating the size of earthquakes until the early 1960's when computers and the installation of many seismograph stations in the United States and other countries made routine calculations of magnitude feasible for most earthquakes. Historically, intensity scales, in addition to representing size, also were a measure of the effects from shaking. Thus, intensity was a way to compare the damage caused by earthquakes in different areas of the United States. Intensity is used today as a measure of the shaking effects and (or) damage from an earthquake based upon reports from people who live in the affected area. The effects of present-day earthquakes in terms of the damage caused may be compared with those of historical earthquakes by comparing the intensities. Intensity is also a factor in determining the seismic risk in the United States because it is a means of mapping a geographic area showing the degree of relative shaking and (or) damage from individual earthquakes.

The evaluation of intensity for U.S. earthquakes cannot be done in a mathematical sense. The basic data consists of information from a mail questionnaire, supplemented by field surveys when an earthquake causes significant damage. Therefore, the interpretations of intensity are based upon effects that people report they experienced, saw, or were told about. These effects of seismic shaking are objective. All observers can agree these are real effects and not subjective speculation. Reliable intensity evaluations are based not on a single factor on any scale, but on consistent combinations of several factors.

The Modified Mercalli Intensity Scale of 1931 (MM scale) is used by the U.S. Geological Survey to measure the effects from seismic shaking. Because the MM scale was published in 1931, it was designed to evaluate the effects on people, buildings, other man-made structures, and automobiles of that era. Other than people, all the other categories have changed significantly. Buildings, bridges, highways, dams, and such are designed to resist earthquakes. Although automobiles still serve the same function, their suspension has been altered considerably so that they are much more likely to "bounce" due to softer suspension. In the 1931 MM scale, "noticed by persons driving motor cars" is at the intensity VII level; however, in modern automobiles, this effect is at a lower level of shaking and should not be evaluated at the 1931 intensity. Also, the 1931 MM scale has no category for mobile homes, which are quite common now. These examples illustrate the problems of applying the 1931 MM scale to present times. Obviously, the 1931 MM scale needs updating to reflect the industrial changes in materials, manufacturing, and building practices.

NEIC Questionnaire Survey

As soon as an earthquake in the United States is geographically located, NEIC mails computer-addressed questionnaires to postmasters, selected government personnel, and volunteers who have agreed to complete the questionnaire. Questionnaires are also mailed to police and fire departments when damage has occurred. These addresses are selected from geographic locations within the area to be canvassed—an area determined by the radius of a circle with its center at the earthquake epicenter. The larger the earthquake, the larger the canvassed area; canvassed areas usually have a radius of 20–700 kilometers. When the questionnaires are returned, NEIC personnel evaluate information supplied by the addressee according to the MM scale and assign discrete values to represent the intensity. This questionnaire, formally called Earthquake

Report, has gone through many revisions; both sides of the version now used is shown in figure 41 (see p. 52-53).

Results from Damage Surveys

All the completed Earthquake Report questionnaires are usually returned to the NEIC about one month after the earthquake. These questionnaires are evaluated daily as they are received and are later published annually in *United States Earthquakes*. For larger earthquakes, the preliminary results may have to be published quickly in special reports. In either case, the evaluated MM intensities are assigned to the geographic location of each report, using a computer, and an intensity file is created. This file is used to plot the intensities geographically in order to make an isoseismal map (see figure 42) that shows the geographic extent and severity of the shaking.

In addition to the questionnaire survey, the USGS conducts a field survey of damaging earthquakes in order to evaluate the damage on-site in terms of assigning intensities and defining the areal extent of the damage. These results are incorporated with the questionnaire data into the intensity file to make an isoseismal map.

References Cited

Barosh, P.J., 1969, Use of seismic intensity data to predict the effects of earthquakes and underground nuclear explosions in various geologic settings: U.S. Geological Survey Bulletin 1279, 93 p.

Davison, Charles, 1933, Scales of seismic activity—Supplemental paper: Seismological Society of America Bulletin, v. 23, no. 4, p. 158-166.

Modified Mercalli Intensity Scale

The Modified Mercalli Intensity Scale of 1931 was developed at the California Institute of Technology Seismological Laboratory, Pasadena, California. It was first published in the *Bulletin of the Seismological Society of America* in 1931 and placed in use that year. The authors were Harry O. Wood of the Carnegie Institution of Washington; Seismological Research, Pasadena, California; and Frank Neumann of the U.S. Coast and Geodetic Survey, Washington, D.C. The MM scale was developed to replace the Rossi-Forel (RF) scale of 1873, because the RF scale was inadequate for 1931 needs; for example, the RF scale had no provision for evaluating intensity based on effects to tall structures, behavior of 1931 motor cars and trucks, or damage to underground pipes.

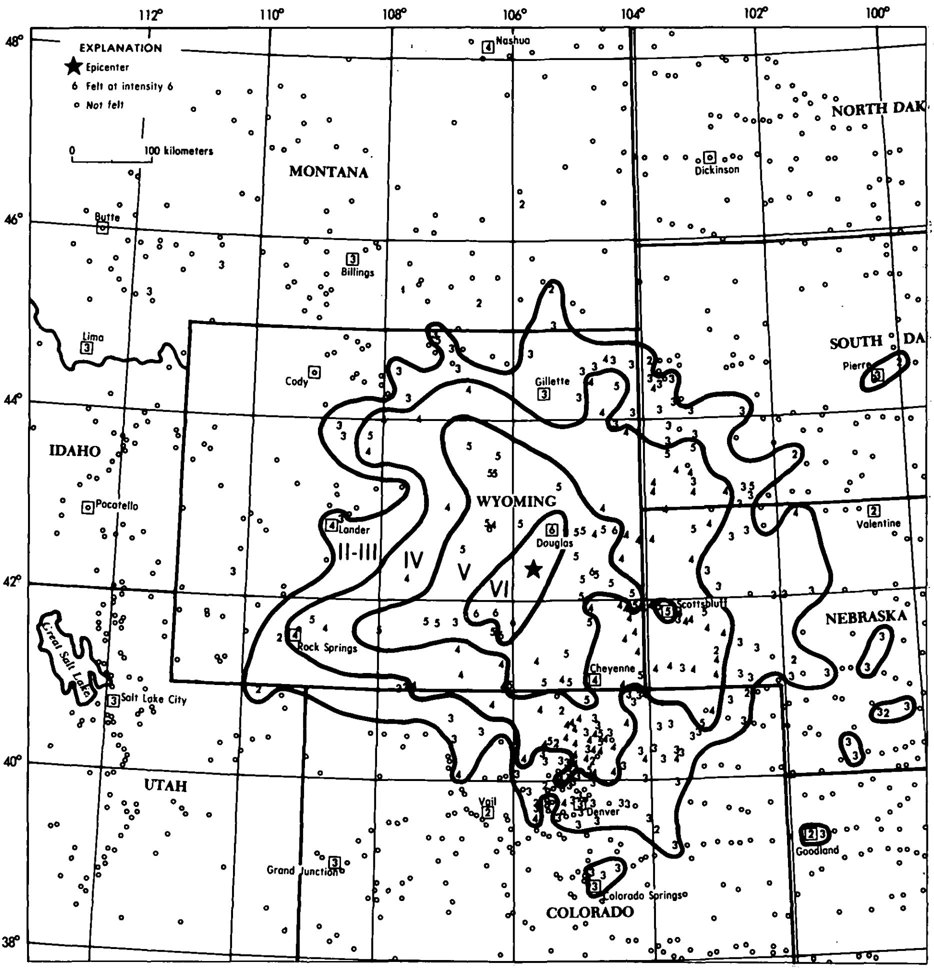

Figure 42. Example of an isoseismal map. II-VI, MM intensities.

Modified Mercalli Intensity Scale of 1931

[Adapted from Sieberg's Mercalli-Cancani scale, modified and condensed]

I. Not felt—or, except rarely under especially favorable circumstances.
Under certain conditions, at and outside the boundary of the area in which a great shock is felt:
sometimes birds, animals, reported uneasy or disturbed;
sometimes dizziness or nausea experienced;
sometimes trees, structures, liquids, bodies of water, may sway; doors may swing, very slowly.

II. Felt indoors by few, especially on upper floors, or by sensitive or nervous persons.

Also, as in grade I, but often more noticeably:

sometimes **hanging objects may swing,** especially when delicately suspended;

sometimes trees, structures, liquids, bodies of water, may sway, doors may swing, very slowly;

sometimes birds, animals, reported uneasy or disturbed;

sometimes dizziness or nausea experienced.

III. Felt indoors by several, motion usually rapid vibration.

Sometimes not recognized to be an earthquake at first.

Duration estimated in some cases.

Vibration like that due to passing of light or lightly loaded trucks or heavy trucks some distance away.

Hanging objects may swing slightly.

Movements may be appreciable on upper levels of tall structures.

Rocked standing motor cars slightly.

IV. Felt indoors by many, outdoors by few.

Awakened few, especially light sleepers.

Frightened no one, unless apprehensive from previous experience.

Vibration like that due to passing of heavy or heavily loaded trucks.

Sensation like heavy body striking building or falling of heavy objects inside.

Rattling of dishes, windows, doors; glassware and crockery clink and clash.

Creaking of walls, frame, especially in the upper range of this grade.

Hanging objects swung, in numerous instances.

Slightly disturbed liquids in open vessels.

Rocked standing motor cars noticeably.

V. Felt indoors by practically all, outdoors by many or most; outdoors direction estimated.

Awakened many, or most.

Frightened few, slight excitement, a few ran outdoors.

Buildings trembled throughout.

Broke dishes, glassware, to some extent.

Cracked windows, in some cases, but not generally.

Overturned vases, small or unstable objects, in many instances, with occasional fall.

Hanging objects, doors, swing generally or considerably.

Knocked pictures against walls or swung them out of place.

Opened or closed doors, shutters, abruptly.

Pendulum clocks stopped, started, or ran fast or slow.

Moved small objects, furnishings, the latter to slight extent.

Spilled liquids in small amounts from well-filled open containers.

Trees, bushes, shaken slightly.

VI. Felt by all, indoors and outdoors.

Frightened many, excitement general, some alarm, many ran outdoors.

Awakened all. Persons made to move unsteadily.

Trees, bushes, shaken slightly to moderately.

VI. **Felt by all**, indoors and out—Continued
- Liquid set in strong motion.
- Small bells rang, church, chapel, school, and so forth.
- **Damage slight** in poorly built buildings.
- **Fall of plaster**, in small amounts.
- **Cracked plaster** somewhat, especially fine cracks **chimneys** in some instances.
- **Broke dishes**, glassware, in considerable quantity, also some windows.
- **Fall of knick-knacks, books, pictures.**
- **Overturned furniture** in many instances.
- **Moved furnishings** of moderately heavy kind.

VII. **Frightened all**, general alarm, all ran outdoors.
- Some or many found it difficult to stand.
- Noticed by persons driving motor cars.
- **Trees, bushes shaken moderately to strongly.**
- Waves on ponds, lakes, running water.
- Water turbid from mud stirred up.
- Incaving to some extent of sand or gravel stream banks.
- Rang large church bells and so forth.
- Suspended objects made to quiver.
- **Damage negligible** in buildings of good design and construction, **slight** to moderate in well-built ordinary buildings, **considerable** in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, and so forth.
- **Cracked chimneys** to considerable extent, **walls** to some extent.
- **Fall of plaster** in considerable to large amounts, also some stucco.
- **Broke numerous windows, furniture**, to some extent.
- Shook down loosened brickwork and tiles.
- Broke weak chimneys at the roof-line, sometimes damaging roofs.
- **Fall of cornices** from towers, high buildings.
- Dislodged bricks and stones.
- **Overturned heavy furniture**, with damage from breaking.
- **Damage considerable** to concrete irrigation ditches.

VIII. **Fright general**, alarm approaches panic.
- Disturbed persons driving motor cars.
- **Trees shaken strongly**, branches, trunks, broken off, especially palm trees.
- Ejected sand, mud, in small amounts.
- Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters.
- **Damage slight** in structures (brick) built especially to withstand earthquakes.
  - **Considerable** in ordinary substantial buildings, partial collapse; racked, tumbled down, wooden houses in some cases; threw out panel walls in frame structures, broke off decayed piling.
  - **Fall of walls.**
  - **Cracked, broke, solid stone walls seriously.**
  - **Wet ground** to some extent, also ground on steep slopes.
  - **Twisting, fall, of chimneys, columns, monuments**, also factory stacks, towers.
  - **Moved conspicuously, overturned, very heavy furniture.**

IX. **Panic general.**
Cracked ground conspicuously.
Damage considerable in (masonry) structures built especially to withstand earthquakes;
threw out of plumb some wood-frame houses built especially to withstand earthquakes;
great in substantial (masonry) buildings, some collapse in large part;
or wholly shifted frame buildings off foundations, racked frames;
serious to reservoirs; underground pipes sometimes broken.

X. **Cracked ground,** especially when loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks.
Landslides considerable from river banks and steep coasts.
Shifted sand and mud horizontally on beaches and flat land.
Changed level of water in wells.
Threw water on banks of canals, lakes, rivers, and so forth.
Damage serious to dams, dikes, embankments.
Severe to well-built wooden structures, bridges, some destroyed.
Developed dangerous cracks in excellent brick walls.
Destroyed most masonry, frame structures, also their foundations.
Bent railroad rails slightly.
Tore apart, crushed endwise, pipe lines buried in earth.
Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.

XI. Disturbances in ground many, widespread, varying with ground material.
Broad fissures, earth slumps, land slips in soft, wet ground.
Ejected water in large amount charged with sand and mud.
Caused sea waves ("tidal" waves) of significant magnitude.
Damage severe to wood-frame structures, especially near shock centers.
Great to dams, dikes, embankments, often for long distances.
Few, if any (masonry), structures remained standing.
Destroyed large well-built bridges by the wrecking of supporting piers, pillars.
Affected yielding wooden bridges less.
Bent railroad rails greatly, thrust them endwise.
Put pipe lines buried in Earth completely out of service.

XII. **Damage total,** practically all works of construction damaged greatly or destroyed.
Disturbances in ground great, varied, numerous shearing cracks.
Landslides, falls of rock of significant character, slumping of river banks, etc., numerous, extensive.
Wrenched loose, tore off, large rock masses.
Fault slips in firm rock, with notable horizontal, vertical offset displacements.
Water channels, surface, underground, disturbed and modified greatly.
Dammed lakes, produced waterfalls, deflected rivers, and so forth.
Waves seen on ground surfaces (actually seen, probably, in some cases).

U.S. DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

EARTHQUAKE REPORT

Form Approved
OMB No. 42-R1700

Please answer this questionnaire and return as soon as possible

1. Was an earthquake felt by anyone in your town near the date and time indicated on the opposite page?

☐ No: Please refold and tape for return mail.

☐ Yes: Date ________ Time ________ ☐ AM ☐ PM ☐ Standard time ☐ Daylight time

Name of person filling out form ________

Address ________

City ________ County ________

State ________ Zip code ________

If you felt the earthquake, complete the following section. If others felt the earthquake but you did not, skip the personal report and complete the community report.

PERSONAL REPORT

2. Did you personally feel the earthquake? ☐ Yes ☐ No

Were you awakened by the earthquake? ☐ Yes ☐ No

Were you frightened by the earthquake? ☐ Yes ☐ No

Were you at ☐ Home ☐ Work ☐ Other? ________

Town and zip code of your location at time of earthquake ________

Check your activity when the earthquake occured:

☐ Walking ☐ Sleeping ☐ Lying down ☐ Standing

☐ Driving (car in motion) ☐ Sitting ☐ Other ________

Were you ☐ Inside or ☐ Outside

If inside, on what floor were you?

Did you have difficulty in standing or walking ☐ Yes ☐ No

Vibration could be described as ☐ Light ☐ Moderate ☐ Strong

Was there earth noise? ☐ No ☐ Faint ☐ Moderate ☐ Loud

Direction of noise ☐ North ☐ South ☐ East ☐ West

Estimated duration of shaking ☐ Sudden, sharp (less than 10 secs) ☐ Short (10-30 secs) ☐ Long (30-60 secs)

Continue on to next section which should include personal as well as reported observations.

COMMUNITY REPORT

Town and zip code ________

DO NOT INCLUDE EFFECTS FROM OTHER COMMUNITIES/TOWNS

Check one box for each question that is applicable.

3 a. The earthquake was felt by ☐ No one ☐ Few ☐ Several ☐ Many ☐ All?

b. This earthquake awakened ☐ No one ☐ Few ☐ Several ☐ Many ☐ All?

c. This earthquake frightened ☐ No one ☐ Few ☐ Several ☐ Many ☐ All?

4. What indoor physical effects were noted in your community?

Windows, doors, dishes rattled ☐ Slightly ☐ Loudly

Walls creaked ☐ Slightly ☐ Loudly

Building trembled (shook) ☐ Slightly ☐ Moderately ☐ Strongly

Hanging pictures (more than one) ☐ Swung ☐ Out of place ☐ Fallen

Windows ☐ Few cracked ☐ Some broken out ☐ Many broken out

Small objects overturned ☐ Few ☐ Many

Small objects fallen ☐ Few ☐ Many

Glassware/dished broken ☐ Few ☐ Many

Light furniture or small appliances ☐ Overturned ☐ Damaged seriously

Heavy furniture or appliances ☐ Overturned ☐ Damaged seriously

Did hanging objects or doors swing? ☐ Slightly ☐ Moderately ☐ Violently

Can you estimate direction? ☐ North/South ☐ East/West ☐ Other ________

Items thrown from store shelves ☐ Few ☐ Many

Continued on the reverse side

Figure 41. Example of the U.S. Geological Survey's EARTHQUAKE REPORT questionnaire.

5. **Indicate effects of the following types to interior walls if any:**

Plater/stucco	☐ Hairline cracks	☐ Large cracks (many)	☐ Fell in large amounts
Dry wall	☐ Hairline cracks	☐ Large cracks (many)	☐ Fell in large amounts

6. **What outdoor physical effects were noted in your community?**

Trees and bushes shaken	☐ Slightly	☐ Moderately	☐ Strongly
Standing vehicles rocked	☐ Slightly	☐ Moderately	
Moving vehicles rocked	☐ Slightly	☐ Moderately	
Water splashed onto sides of lakes, ponds, swimming pools	☐ Yes	☐ No	
Elevated water tanks	☐ Cracked	☐ Twisted	☐ Fallen (thrown down)
Tombstones	☐ Displaced ☐ Fallen	☐ Cracked	☐ Rotated
Chimneys	☐ Cracked ☐ Broken at roof line	☐ Twisted	☐ Fallen ☐ Bricks fallen
Railroad tracks bent	☐ Slightly	☐ Greatly	
Stone or brick fences/walls	☐ Open cracks	☐ Fallen	☐ Destroyed
Underground pipes	☐ Broken	☐ Out of service	
Highways or streets	☐ Large cracks	☐ Large displacements	
Sidewalks	☐ Large cracks	☐ Large displacements	

7a. Check below any structural damage to buildings.

Foundation	☐ Cracked		☐ Destroyed
Interior walls	☐ Split	☐ Fallen	☐ Separated from ceiling or floor
Exterior walls	☐ Large Cracks		☐ Bulged outward
	☐ Partial collapse		☐ Total collapse

b. What type of construction was the building that showed this damage?

☐ Wood	☐ Stone	☐ Brick veneer	☐ Other ________
☐ Brick	☐ Cinderblock	☐ Reinforced concrete	☐ Mobile home

c. What was the type of ground under the building?

☐ Don't know	☐ Sandy soil	☐ Marshy	☐ Fill
☐ Hard rock	☐ Clay soil	☐ Sandstone, limestone, shale	

d. Was the ground: ☐ Level ☐ Sloping ☐ Steep?

e. Check the approximate age of the building:

☐ Built before 1945 ☐ Built 1945-65 ☐ Built after 1965

8. Check below any structural damage to

Bridges/Overpasses	☐ Concrete	☐ Wood	☐ Steel	☐ Other
Damage was	☐ Slight	☐ Moderate		☐ Severe
Dams	☐ Concrete	☐ Large earthen		
Damage was	☐ Slight	☐ Moderate		☐ Severe

9. What geologic effects were noted in your community?

Ground cracks	☐ Wet ground	☐ Steep slopes	☐ Dry and level ground
Landslides	☐ Small	☐ Large	
Slumping	☐ River bank	☐ Road fill	☐ Land fill
Were springs or well water disturbed?		☐ Level changed ☐ Muddied	☐ Flow disturbed ☐ Don't know
Were rivers or lakes changed?		☐ Yes ☐ No	☐ Don't know

10a. What percentage of buildings were damaged?

Within 2 city blocks of your location	☐ None ☐ Many (about 50%)	☐ Few (about 5%) ☐ Most (about 75%)
b. In area covered by your zip code	☐ None ☐ Many (about 50%)	☐ Few (about 5%) ☐ Most (about 75%)

Thank you for your time and information. Refold this card and tape for return mail.

Seismographs—Keeping Track of Earthquakes

(Abridged from Earthquake Information Bulletin, *vol. 2, no. 5, September-October 1970)*

Throw a rock into a pond of lake and watch the waves rippling out in all directions from the point of impact. Just as this impact sets waves in motion on a quiet pond, so an earthquake generates seismic waves that radiate out through the Earth.

Seismic waves lose much of their energy in traveling over great distances. But sensitive detectors (seismometers) can record these waves emitted by even the smallest of earthquakes. When these detectors are connected to a system that produces a permanent recording, they are called seismographs.

There are many different types of seismometers, but all are based on the same fundamental principle—that the differential motion between a free mass (which tends to remain at rest) and a supporting structure anchored in the ground (which moves with the vibrating Earth) can be used to record seismic waves.

This principle is illustrated in figure 43. Vertical support AB holds mass M in position by wire AM and by strut BM that pivots at point B; the system becomes a seismometer when the vertical support is embedded in a concrete pier attached to the Earth. If there is no friction at point B and mass M is reasonably large, the movement of the pier and the attached upright support in response to an earthquake wave will set up a differential motion between the mass and the pier (the inertia of the mass will make it remain at rest). This motion—the signal of an earthquake wave—can then be recorded on a revolving drum. When the pier is steady, the pen attached to the mass writes a straight line. But when the pier shakes, the mass and strut wiggle, recording waves from the earthquake that started the boom in motion.

Usually, the drum rotates on a screw-threaded axle so that the recording pen moves on a continuously advancing record and does not simply repeat the same circle over and over. Because time—both the time of day and the synchronization of events—is an important element in seismology, clocks are always part of a seismograph system.

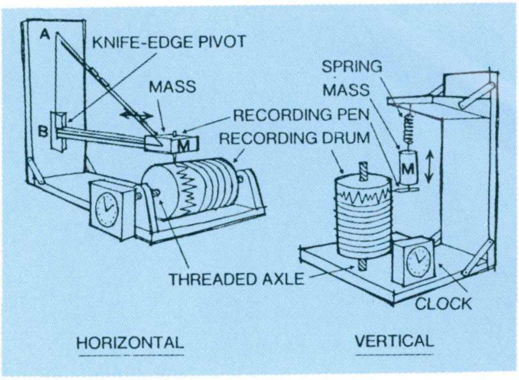

Figure 43. Diagram of horizontal and vertical seismographs.

A single seismograph pendulum works in only one direction and cannot give a complete picture of wave motions from other directions. To overcome this problem, modern seismograph stations have three separate instruments to record horizontal waves—(1) one to record the north-south waves, (2) another to record east-west waves, and (3) a vertical one in which a weight resting on a spring tends to stand still and record vertical ground motions. The spring-suspended mass lags behind the motion caused by the earthquake, making the pen record waves on the drum. This combination of instruments tells a seismologist the general direction of the seismic wave source, the magnitude at its source, and the character of the wave motion. Instruments at other stations must be used to get a precise fix on the earthquake's epicenter.

An earthquake generates a series of waves that penetrate the entire Earth and travel at and through its surface. Each wave has a characteristic time; each has its own mode of travel. They are quite complex, but a few basic facts will explain how they travel through the Earth and how an earthquake's epicenter can be determined from seismograph records.

There are four basic types of seismic waves: two preliminary body waves that travel through the Earth and two that travel only at the surface (*L* waves). Combinations, reflections, and diffractions produce an infinity of other types, but body waves are the main interest in this discussion.

Body waves are composed of two principal types; the *P* (primary) wave, comparable to sound waves, which compresses and dilates the rock as it travels forward through the Earth; and the *S* (secondary) wave, which shakes the rock sideways as it advances at barely more than half the *P* - wave speed.

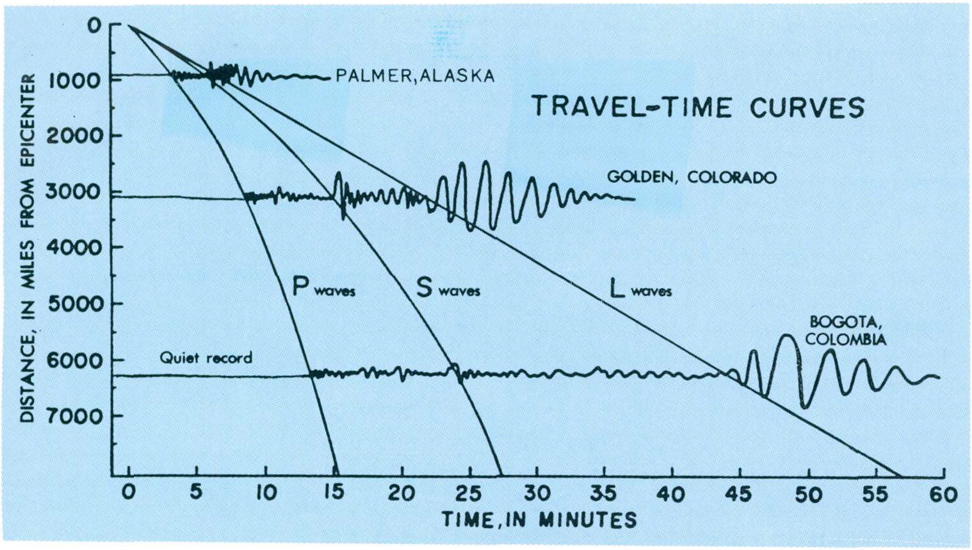

Figure 44. Travel-time curves with idealized seismograms (earthquake records superimposed).

The P wave is designated the primary preliminary wave because it is the first to arrive at a seismic station after an earthquake. It travels at a speed usually less than 6 km/s (kilometers per second) in the Earth's crust and jumps to 13 km/s through the core.

The S wave is the second preliminary wave to be recorded. It follows paths through the Earth quite similar to those of P - wave paths, except that no consistent evidence has yet been found that the S wave penetrates the Earth's core.

The lines labeled P, S, and L in the curves shown on figure 44 represent the travel time required for each phase at distances of 0–1300 km from the earthquake's epicenter. They mark the points on the record at which these waves first arrive at the station.

The simplest method of locating an earthquake on a globe is to find the time interval between the P - and S - wave arrivals at several seismograph stations. The distance to the earthquake from each station is then determined from standard travel-time tables and travel-time curves. Great-circle arcs are drawn on the globe using the distance of the earthquake to the station as a radius. All the arcs should intersect at a common point—the epicenter.

Another method of locating an earthquake is to use the *P* - wave arrival-time minus origin-time (*P* - *O*) interval instead of distance. This method is more common because the time can be taken directly from surface focus travel-time tables assuming an origin of 00 hours. This method, however, requires that travel-time tables be available for various depths of focus. For locating a deep shock, one 700 km deep, for example, travel-time tables and travel-time curves for that depth have to be used to calculate the origin time and distances.

Other wave types can be generated inside the Earth by *P* and *S* waves, as shown in figure 45. As many as five different wave groups or phases can emerge when a *P* or an *S* wave encounters a discontinuity or interface within the Earth.

At NEIC, most of the important information about an earthquake is now received, stored, and calculated on computers.

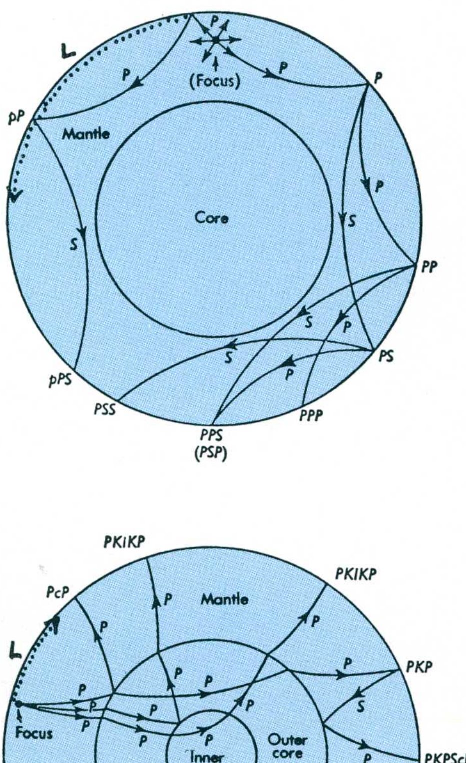

Figure 45. Propagation paths of combinations of *P*, *S*, and *L* waves from an earthquake focus.

Measuring the Size of an Earthquake

by
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Earthquakes range broadly in size. A rock-burst in an Idaho silver mine may involve the fracture of 1 meter of rock; the 1965 Rat Island earthquake in the Aleutian arc involved a 650-kilometer length of the Earth's crust. Earthquakes can be even smaller and even larger. If an earthquake is felt or causes perceptible surface damage, then its intensity of shaking can be subjectively estimated. But many large earthquakes occur in oceanic areas or at great focal depths and are either simply not felt or their felt pattern does not really indicate their true size.

Today, state-of-the-art seismic systems transmit data from the seismograph via telephone line and satellite directly to a central digital computer. A preliminary location, depth-of-focus, and magnitude can now be obtained within minutes of the onset of an earthquake. The only limiting factor is how long the seismic waves take to travel from the epicenter to the stations—usually less than 10 minutes.

Magnitude

Modern seismographic systems precisely amplify and record ground motion (typically at periods of between 0.1 and 100 seconds) as a function of time. This amplification and recording as a function of time is the source of instrumental amplitude and arrival-time data on near and distant earthquakes. Although similar seismographs have existed since the 1890's, it was only in the 1930's that Charles F. Richter, a California seismologist, introduced the concept of earthquake magnitude. His original definition held only for California earthquakes occurring within 600 km of a particular type of seismograph (the Wood-

Anderson torsion instrument). His basic idea was quite simple: by knowing the distance from a seismograph to an earthquake and observing the maximum signal amplitude recorded on the seismograph, an empirical quantitative ranking of the earthquake's inherent size or strength could be made. Most California earthquakes occur within the top 16 km of the crust; to a first approximation, corrections for variations in earthquake focal depth were, therefore, unnecessary.

Richter's original magnitude scale (M_L) was then extended to observations of earthquakes of any distance and of focal depths ranging between 0 and 700 km. Because earthquakes excite both body waves, which travel into and through the Earth, and surface waves, which are constrained to follow the natural wave guide of the Earth's uppermost layers, two magnitude scales evolved—the m_b and M_s scales.

The standard body-wave magnitude formula is

$$m_b = \log_{10}(A/T) + Q(\Delta, h) ,$$

where A is the amplitude of ground motion (in microns); T is the corresponding period (in seconds); and $Q(\Delta, h)$ is a correction factor that is a function of distance, Δ (degrees), between epicenter and station and focal depth, h (in kilometers), of the earthquake. The standard surface-wave formula is

$$M_s = \log_{10}(A/T) + 1.66 \log_{10}(\Delta) + 3.30 .$$

There are many variations of these formulas that take into account effects of specific geographic regions, so that the final computed magnitude is reasonably consistent with Richter's original definition of M_L. Negative magnitude values are permissible.

A rough idea of the frequency of occurrence of large earthquakes is given by the following table:

M_s	Earthquakes per year
8.5–8.9	0.3
8.0–8.4	1.1
7.5–7.9	3.1
7.0–7.4	15
6.5–6.9	56
6.0–6.4	210

This table is based on data for a recent 47-year period. Perhaps the rates of earthquake occurrence are highly variable and some other 47-year period could give quite different results.

The original m_b scale utilized compressional body *P*-wave amplitudes with periods of 4–5 s, but recent observations are generally of 1-s-period *P* waves. The M_s scale has consistently used Rayleigh surface waves in the period range from 18 to 22 s.

When initially developed, these magnitude scales were considered to be equivalent; in other words, earthquakes of all sizes were thought to radiate fixed proportions of energy at different periods. But it turns out that larger earthquakes, which have larger rupture surfaces, systematically radiate more long-period energy. Thus, for very large earthquakes, body-wave magnitudes badly underestimate true earthquake size; the maximum body-wave magnitudes are about 6.5–6.8. In fact, the surface-wave magnitudes underestimate the size of very large earthquakes; the maximum observed values are about 8.3–8.7. Some investigators have suggested that the 100–s mantle Love waves (a type of surface wave) should be used to estimate magnitude of great earthquakes. However, even this approach ignores the basic fact that the excitation level at any period is not truly related to the fundamental processes that determine earthquake size. Thus, modern seismologists are increasingly turning to seismic moment as such a measure.

Fault Geometry and Seismic Moment, M_o

The orientation of the fault, direction of fault movement, and size of an earthquake can be described by the fault geometry and seismic moment. These parameters are determined from waveform analysis of the seismograms produced by an earthquake. The differing shapes and directions of motion of the waveforms recorded at different distances and azimuths from the earthquake are used to determine the fault geometry, and the wave amplitudes are used to compute moment. The seismic moment is related to fundamental parameters of the faulting process.

$$M_o = \mu S \langle d \rangle ,$$

where μ is the shear strength of the faulted rock, S is the area of the fault, and $<d>$ is the average displacement on the fault. Because fault geometry and observer azimuth are a part of the computation, moment is a more consistent measure of earthquake size than is magnitude, and, more importantly, moment does not have an intrinsic upper bound. These factors have led to the definition of a new magnitude scale based on seismic moment, M_w, where

$$M_w = 2/3 \log_{10} (M_o) - 10.7 .$$

The two largest reported moments are 2.5×10^{30} dyn·cm (dyne·centimeters) for the 1960 Chile earthquake (M_s 8.5; M_w 9.6) and 7.5×10^{29} dyn·cm for the 1964 Alaska earthquake (M_s 8.3; M_w 9.2). M_s approaches its maximum value at a moment between 10^{28} and 10^{29} dyn·cm.

Energy

The energy radiated by an earthquake is a measure of the potential for damage to man-made structures. Many attempts have been made to relate earthquake magnitude to seismic energy as a convenient and meaningful interpretation of magnitude. By manually integrating many seismograms from a reference set of earthquakes, Beno Gutenberg and Charles Richter arrived at the following empirical relationship:

$$\log_{10} E = 11.8 + 1.5 M_s ,$$

where energy, E, is expressed in ergs. Thus, for every increase in M_s by 1 unit, the associated seismic energy increases by about 32 times. The press commonly makes misleading statements such as a "magnitude 7 earthquake is 10 times more powerful than a magnitude 6 earthquake." As can be seen from the magnitude formulas, a unit increase of magnitude implies only that seismograph trace amplitude should increase by a factor of 10 for the same wave period and for a given epicentral distance and earthquake focal depth. With digitally recording seismograph systems, computerized methods make accurate and explicit estimates of energy on a routine basis for all major earthquakes.

Intensity

The increase in the degree of surface shaking (intensity) for each unit increase of magnitude of a shallow crustal earthquake is unknown. Intensity is based on an earthquake's local accelerations and how long these persist. Intensity and magnitude thus both depend on many variables that include exactly how rock breaks and how energy travels from an earthquake to a receiver. These factors make it difficult for engineers and others who use earthquake intensity and magnitude data to evaluate the error bounds that may exist for their particular applications.

An example of how local soil conditions can greatly influence local intensity is given by catastrophic damage in Mexico City from the 1985, M_s 8.1 Mexico earthquake centered some 300 km away. Resonances of the soil-filled basin under parts of Mexico City amplified ground motions for periods of 2 seconds by a factor of 75 times. This shaking led to selective damage to buildings 15–25 stories high (same resonant period), resulting in losses to buildings of about $4.0 billion and at least 8,000 fatalities.

The occurrence of an earthquake is a complex physical process. When an earthquake occurs, much of the available local stress is used to power the earthquake fracture growth to produce heat rather than to generate seismic waves. Of an earthquake system's total energy, perhaps 10 percent to less than 1 percent is ultimately radiated as seismic energy. So the degree to which an earthquake lowers the Earth's available potential energy is only fractionally observed as radiated seismic energy.

Determining the Depth of an Earthquake

Earthquakes can occur anywhere between the Earth's surface and about 700 kilometers below the surface. For scientific purposes, this earthquake depth range of 0–700 km is divided into three zones: shallow, intermediate, and deep.

Shallow earthquakes are between 0 and 70 km deep; intermediate earthquakes, 70–300 km deep; and deep earthquakes, 300–700 km deep. In general, the term "deep-focus earthquake" is applied to earthquakes deeper than 70 km. All earthquakes deeper than 70 km are localized within great slabs of shallow lithosphere that are sinking into the Earth's mantle.

The evidence for deep-focus earthquakes was discovered in 1922 by H.H. Turner of Oxford, England. Previously, all earthquakes were considered to have shallow focal depths. The existence of deep-focus earthquakes was confirmed in 1931 from studies of the seismograms of several earthquakes, which in turn led to the construction of travel-time curves for intermediate and deep earthquakes.

The most obvious indication on a seismogram that a large earthquake has a deep focus is the small amplitude, or height, of the recorded surface waves and the uncomplicated character of the *P* and *S* waves. Although the surface-wave pattern does generally indicate that an earthquake is either shallow or may have some depth, the most accurate method of determining the focal depth of an earthquake is to read a depth phase recorded on the seismogram. The depth phase is the characteristic phase *pP*—a *P* wave reflected from the surface of the Earth at a point relatively near the hypocenter (see figure 45 in the preceding article). At distant seismograph stations, the *pP* follows the *P* wave by a time interval that changes slowly with distance but rapidly with depth. This time interval, *pP-P* (*pP* minus *P*), is used to compute depth-of-focus tables. Using the time difference of *pP-P* as read from the seismogram and the distance between the epicenter and the seismograph station, the depth of the earthquake can be determined from published travel-time curves or depth tables.

Another seismic wave used to determine focal depth is the *sP* phase—an *S* wave reflected as a *P* wave from the Earth's surface at a point near the epicenter. This wave is recorded after the *pP* by about one-half of the *pP-P* time interval. The depth of an earthquake can be determined from the *sP* phase in the same manner as the *pP* phase by using the appropriate travel-time curves or depth tables for *sP*.

If the *pP* and *sP* waves can be identified on the seismogram, an accurate focal depth can be determined.

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