"Parametric" refers to periodic modulation of some parameter of an oscillating system at such a frequency and with sufficient amplitude so that the oscillations become unstable. Presumably the spread F irregularities could be accounted for by an instability, for example, a drift instability (*18*), triggered by anomalously large temperature gradients (*15*) or self-focusing (*19*).

Summary

The ionospheric modification experiments provide an opportunity to better understand the aeronomy of the natural ionosphere and also afford the control of a naturally occurring plasma, which will make possible further progress in plasma physics. The ionospheric modification by powerful radio waves is analogous to studies of laser and microwave heating of laboratory plasmas (*20*). "Anomalous" reflectivity effects similar to the observed ionospheric attenuation have already been noted in plasmas modulated by microwaves, and anomalous heating may have been observed in plasmas irradiated by lasers. Contacts have now been established between the workers in these diverse areas, which span a wide range of the electromagnetic spectrum. Perhaps ionospheric modification will also be a valuable technique in radio communications.

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WWNSS: Seismology's Global Network of Observing Stations

Standardized collection and efficient distribution of earthquake data yield social and scientific rewards.

Jack Oliver and Leonard Murphy

During the early 1960's the World-Wide Network of Standard Seismograph Stations (known as WWNSS) was created. This network consists of some 120 continuously recording stations distributed over much of the land area of the world. Its successful operation depends upon widespread voluntary cooperation by individuals, institutions, and nations. It is by far the finest, general-purpose, global system of seismic monitoring stations ever operated. It has become the essential core of observational seismology; without it, this branch of science would be severely crippled. The WWNSS includes a microfilming service, which makes data from any of the stations of the network readily available to anyone at nominal cost and which is a remarkable improvement over older methods of communicating seismic data. The data from the WWNSS are widely used for applied purposes and for research. The network is very important in the construction of modern maps of global and regional seismicity that are essential in dealing with the earthquake hazard.

Fortuitously, the WWNSS became productive just prior to what has been called the "revolution" in geology based upon the concepts of sea-floor spreading, continental drift, and plate tectonics; thus, data from the WWNSS played a key role in seismology's contribution to the testing and development of those concepts. Curiously, for a system that is so necessary in modern society and that seems to provide social benefit and scientific knowledge of value far greater than the cost of the network itself, the WWNSS has had a perilous history and has followed a rather roundabout course to achieve its present status, which even today is somewhat precarious and irregular. This article presents a brief history of the WWNSS, a short description of the network and of the instrumentation at a single station, a summary of the results of some studies based upon WWNSS data, and a prognosis of what the role of this network may be.

Dr. Oliver is Irving Porter Church Professor of Engineering and chairman of the department of geological sciences, Cornell University, Ithaca, New York; he was formerly with Columbia University, New York, as chairman of the department of geology and chairman of the section of seismology of Lamont-Doherty Geological Observatory. Mr. Murphy is chief of seismology for Environmental Research Laboratories, National Oceanic and Atmospheric Administration (NOAA), Boulder, Colorado; he formerly served NOAA as chief of the seismology division of the National Ocean Survey and as acting associate director of the seismology and geomagnetism division.

The History

During the half century or so prior to 1960, groups of seismologists had managed in some fashion or other to operate sets of seismograph stations that might in a sense be called forerunners of the WWNSS. A notable early global effort was that of the Jesuits who capitalized on the worldwide distribution of their members by installing instruments at a number of their farflung missions; some processed information was collected and analyzed at a center in St. Louis. There were many national networks, such as that of the Coast and Geodetic Survey in the United States, and some regional networks operated by universities and other institutions. During the International Geophysical Year, the Lamont Geological Observatory of Columbia University, in cooperation with local institutions, installed and operated for some time thereafter an international network of special long-period seismographs; in this case, not processed but raw data were collected at a center in Palisades, New York. The form in which the data are collected and are available for distribution is critical for many studies, as we shall see.

Seismologists were aware very early of the need for data collection on a global scale. Therefore, in addition to organizing networks, they developed various means for communication and assembly of data in various forms. The International Seismological Summary in Britain, the Bureau Central Internationale Seismologique in France, and the U.S. Coast and Geodetic Survey's Preliminary Determination of Epicenters service in Washington are examples of centers that collected data (normally after the data had been processed or interpreted once locally) and then performed some operation, usually the precise location of the hypocenter, on the basis of those data. With few exceptions, any individual seismologist could, and still can, write to an organization or a colleague elsewhere in the world for data and anticipate that his request would be honored. This informal worldwide system of data exchange, which depends almost entirely upon the voluntary cooperation of many individuals in many countries, is perhaps a thing of beauty politically, for it avoids the administrative snarls that characterize a more formal, politically recognized system. The system is inadequate, however, from a technical standpoint. Most of the seismograph stations of the world have, like Topsy, "just growed"—and usually with the barest minimum of funds. There is a hodgepodge of instruments operating in different frequency ranges, measuring different components of ground motion, recording in a variety of forms, lacking calibration (or at least standard calibration), and sometimes without accurate timekeeping. Thus, the seismologist of the pre-WWNSS era who, usually after a delay of many months, assembled a worldwide collection of seismograms for the study of a particular earthquake found himself with data so diverse that many important studies were impossible or, worse yet, so inaccurate that he was led astray. In such a situation the WWNSS was a welcome and vital development, and it quickly grew in importance after its inception. The WWNSS continues to draw upon the goodwill and cooperation of people, institutions, and nations throughout the world but does so in a more organized and productive fashion than had previously been the case.

The concept of a WWNSS was generated during a meeting in 1959 of the Panel of Seismic Improvement. This panel was formed by James Killian, special assistant for science and technology to the President of the United States, to consider the need for research in seismology to improve the nation's capability in this discipline, particularly as it related to the detection and identification of underground nuclear explosions. In 1958 the Geneva Conference of Experts had met to consider this subject as a preliminary to a nuclear test ban treaty, and many deficiencies in seismology were bared.

The panel's chairman was Lloyd Berkner, and its report is widely known as the "Berkner report" (*1*). As one response to Berkner's request for novel means for upgrading the science of seismology, Frank Press suggested that the United States spend of the order of $2 million to provide standardized instruments and accurate clocks to a selected group of 100 to 200 existing seismograph stations throughout the world, thereby achieving, at rather modest expense, a vast capability for data acquisition. This idea was immediately accepted with enthusiasm by the panel and was included in its report, although at that time perhaps none of the members clearly visualized the WWNSS system as it finally evolved.

The Berkner report formed the basis for Project VELA Uniform, a program of fundamental and applied research designed to improve the nation's capability for detection and identification of underground nuclear explosions. Project VELA Uniform was funded and administered by the Department of Defense through the Advanced Research Projects Agency. This agency in turn assigned the task of installing and operating the WWNSS to the Coast and Geodetic Survey of the Department of Commerce, an agency that had for many years been involved in seismology through such activities as the operation of a modest network of instruments and a service for location of shocks throughout the world.

Although it was not unfashionable at that time to support large basic research efforts through the Department of Defense, the WWNSS experienced some early political problems because of its association with the military and with the Coast and Geodetic Survey, an agency that had on occasion announced the firing of certain U.S. and foreign nuclear tests. It was falsely claimed by some that with the WWNSS the United States was attempting to set up a network for worldwide surveillance of nuclear testing. Actually, the WWNSS, although its stations as well as all other sensitive stations throughout the world do provide some information on large nuclear tests, is not very effective for detection of small shots in general, because most sites of the WWNSS stations are rather noisy. A far better *detection* network with more uniform coverage can be made by utilizing a smaller number of stations and carefully selecting each site for low background. Such a network will not provide the versatile research capability nor the comprehensive data collection of the WWNSS, however. Fortunately, reason prevailed, and the WWNSS is no longer widely mistaken for a network with detection as its prime goal.

The Coast and Geodetic Survey was guided in its efforts to design and install the WWNSS by a special committee set up for this purpose by the National Academy of Sciences and chaired by James T. Wilson. Starting with the Berkner report and aided by some special surveys by the Coast and Geodetic Survey, the committee developed a strategy for the network that had several main points. The instruments were to be of a reliable, proven type that required no extensive development. The portion of the spectrum to be monitored was that which conventional instruments could manage conveniently. A standard station would consist of six instruments measuring three components of ground motion in the long-period range centered at about 15 seconds and three components in the short-period range centered at about 1 second.

The separation of the frequency spectrum into two bands is commonly assumed by nonseismologists to be due to the difficulty of constructing broad-band instruments. This is not the case; such instruments can easily be built. The cause lies in the level of background noise, which is much lower in displacement amplitude at the short-period end of the spectrum and which has a sharp high peak due to microseisms generated by ocean waves at periods of about 3 to 9 seconds. Both long- and short-period instruments record only at low gain in this microseismic range, and the response curves peak well away from it.

The committee also recommended conventional recording rates and methods and the use of high-quality clocks and radio time signals for clock calibration. (For some details, see the section entitled "Instrumentation.") The important point here is that the strategy was to build a widespread network of conventional reliable instruments and not to attempt to enter poorly explored areas of the seismological spectrum or of instrumentation.

The committee recommended that the instruments be placed primarily at sites where the local personnel had demonstrated a continuing interest in seismology or where there appeared to be great promise for future development of a research program, although it recognized that some stations should go to sites that were particularly interesting because of their geographical location, or low background noise, or some other reason. The committee also recommended that all data be assembled, copied, and made available to qualified investigators.

The policy clearly demonstrates the intent of the committee (i) to provide a *standardized* network (not to the exclusion of nonstandard or non-WWNSS instruments, of course; overstandardization would be as unfortunate as understandardization); and (ii) to foster research in seismology throughout the world. Both goals are being achieved.

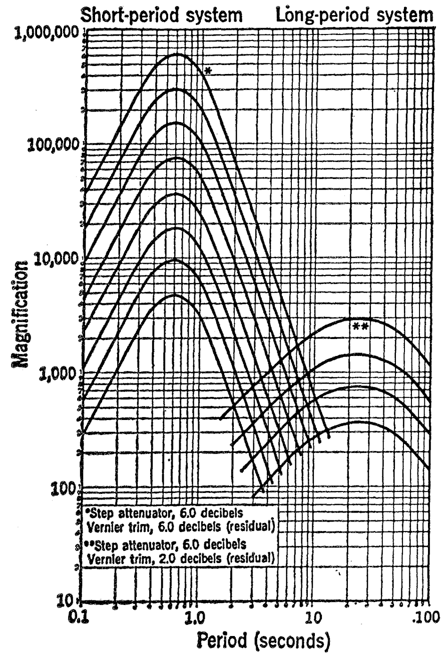


Fig. 1. Families of response curves for short- and long-period seismograph systems of the WWNSS. The upper long-period curve is to be ignored, and recent changes have modified the shape of the long-period curves slightly. Note the minimum of combined curves in the microseismic range.

Final design and construction of the instruments were then carried out by the Geotechnical Corporation under contract with the Coast and Geodetic Survey. There followed a hectic, trying, yet steadily productive period of several years during which instruments were installed at some 120 stations distributed throughout the world. It is difficult to convey the excitement and the adventure experienced by members of the 15 two-man teams who made the installations. The forms of transportation used included multiengined jets, small seaplanes, freighters, skiffs, four-wheel-drive trucks, railroad handcars, rickshas, and dog sleds. One man was trapped for a time in a remote seismic vault by a severe brush fire. As a result of a leak, several instruments at the South Pole were once inadvertently frozen into a solid cake of ice. In Italy, where the instruments are installed in an underground cavern, mountain climbers had to be employed to string the cables behind the stalactites, where they would not detract from the natural beauty of an underground grotto some 90 meters in height. Those who accomplished the actual construction of the WWNSS deserve a great deal of credit and the appreciation and gratitude of their colleagues.

Concurrently with installation, facilities for copying and distributing the data were being developed in Washington, D.C. These facilities were later transferred to Asheville, North Carolina, the present location of the Seismology Data Center. The size and shape of the seismograms, 11½ by 36 inches (29.2 by 91.4 cm), made them difficult to copy with conventional microfilming equipment without serious loss of resolution. A special system was finally developed by the Itek Corporation; it performs very effectively and very reliably, and over 10 million copies have been made to date.

By 1967 the WWNSS had essentially reached its present configuration. Just under $10 million had been spent by Project VELA Uniform, and foreign countries had made a large contribution in vaults and manpower. These sums were considerably more than the Berkner panel had recommended but were not an unreasonable amount for the value received. The operating budget was under $1 million per year and included regular yearly visits by teams to the stations for nonroutine maintenance and calibration. At about that time a serious funding problem began to develop. Project VELA Uniform began to phase out, and Department of Defense funds were no longer available for the network. The Environmental Science Services Agency (ESSA), then the parent organization of the Coast and Geodetic Survey, did not obtain congressional support, and hence there were no appropriations for the support of the network. Possibly the congressional attitude was a general reaction against construction of large installations by the Department of Defense, an unfortunate side effect in view of the clear value of the WWNSS to the civilian sector.

After near-failure of the network the funding problem was resolved, temporarily at least, in a patchy and rather unsatisfactory manner. Part of the maintenance and calibration activity was cut back, some support of U.S. stations was undertaken by local institutions, limited ESSA funds were made available, and the National Science Foundation granted partial support to the foreign part of the network. The support by the National Science Foundation is crucial; in fact, it saved the WWNSS from severe curtailment or destruction. It seems incongruous, however, to use basic research funds for support of this general facility, even though one purpose of the operation is to collect data for research, and a better arrangement should be made. To use the foundation's basic research funds in meteorology for support of standard weather stations throughout the world would, for example, be unthinkable, and yet the present funding of the WWNSS is analogous to such a scheme.

Instrumentation

Six seismometers, one vertical and two orthogonally oriented horizontals for monitoring the short-period spectrum and a similar set for the long-period spectrum, are operated at each station. The free periods of the pendulums are 1 and 15 or 30 seconds; for the galvanometers, 0.75 and 100 seconds for the short- and long-period instruments, respectively. Overall response curves are shown in Fig. 1. Special care is exercised to maintain synchronous records through accurate timing. A crystal clock, accurate to 1 part in 10^7, controls the recording drum rate and the time-marking device. In addition, radio time from the standard time broadcast is impressed automatically on the records every 12 hours. Provision is made for 8 hours of operation on storage batteries in the event of power failure. The electrical system is designed to operate over a wide range of input voltages and at either 50 or 60 hertz.

A unique feature of the system is its standardized response. The magnification of the short-period system can be varied from 3,125 to 400,000 in 6-decibel steps by a simple switching mechanism without changing significantly the shape of the response curve. Similarly the long-period magnification ranges from 750 to 6,000. A simple calibration pulse impressed at the beginning and the end of each record permits the seismologist to determine the exact frequency response of each individual instrument and allows him to compare, quantitatively, seismograms from anywhere in the network. This is a refinement that has never before been achieved in the seismometry of network systems.

The locations of the stations of the WWNSS are shown in Fig. 2. They are distributed fairly uniformly over most of the free world. Of course, the ocean floors have no WWNSS stations, and therefore much of the earth's surface is not monitored. Canada has no official WWNSS stations, but it operates a network of its own that is designed to be compatible with the WWNSS and hence is a valuable contributor to the data pool. The Iron Curtain countries do not participate in the WWNSS, but seismological data from their own national networks, although not strictly compatible with WWNSS data, are rather readily available.

Opinions on policy for selection of the WWNSS sites varied between two extremes. One group held that the stations should be distributed insofar as possible in the form of an evenly spaced grid. The other held that, since earthquakes and land, sea, and various geological features are not distributed in gridlike fashion, the network should not be fixed by simple geometry but should be laid out to take maximum advantage of these features. The present pattern represents a compromise between these two views and also reflects the important factor of distribution of interested personnel and institutions.

Results Based on WWNSS Data

Results in great number and variety have appeared as a consequence of operation of the WWNSS. To attempt to summarize them here would be inappropriate, but some general comments plus a few representative examples will be given to demonstrate the great utility of the network and its data distribution system.

In part, the success of the WWNSS has resulted from the increase in the quantity, quality, and means for distribution of the data. To some extent successes occurred because the new data became available at the "right" time in history, just when the concepts of sea-floor spreading, continental drift, and plate tectonics were appearing, or reappearing, and undergoing development.

The very earliest stages of the development of the sea-floor spreading hypothesis depended in only a limited and secondary way on seismology, for it was geomagnetism that held the key. Seismic activity was used to map the spreading zones, but the linear magnetic anomalies were the source of information on spreading and rates of spreading. Very shortly, however, the contributions of seismology grew in importance, and this discipline was able to play an important role in the testing and development of the hypothesis. The contributions fall into three general categories that might be titled seismicity, source mechanisms and fault plane solutions, and wave propagation.

During the 1960's the numbers of events routinely located and the precision of those locations increased by something like a factor of 3 to 5. This was an important development that greatly improved knowledge of seismicity and that made correlation of geology and seismicity much more precise and informative. Not all of the improvement can be attributed to the WWNSS, however, for locations of epicenters are based largely upon the arrival times of the first wave, and instruments need not be standardized to provide good data of this type. Thus, other first-class stations were and are of comparable importance to WWNSS stations for epicentral location. Accurate timekeeping is vital, however, and here the WWNSS made a substantial contribution. Sometimes the new WWNSS stations were far more sensitive than earlier instruments had been at that site. In many areas, WWNSS stations supplemented the preexisting network and contributed important data; in a few areas that were already well instrumented, the added contribution of the WWNSS was smaller, although the ease of distribution of WWNSS data made rechecking for errors much simpler. At any rate, the combined effect of the new WWNSS data, the improvement and addition of other stations, and the adoption of modern data-handling techniques caused a marked improvement in our knowledge of seismicity. Whereas less than 1000 epicenters per year were located previously, 5000 or more are located at present. A map of worldwide seismicity (*2, 3*) based only on data of the 1960's was a vital piece of information in the development of plate tectonics. It showed, more clearly than ever before, the consistency of the global pattern of seismicity with nearly continuous, narrow, major seismic belts outlining the stable areas that define the plates of plate tectonics. Probably this information—the locations of the active seismic zones and the stable areas—is the most important contribution that seismology has made to the study of tectonics and global geology in general. Data on seismic activity covering most of the 1960's are also available now in the form of regional maps. Figure 3 contrasts a map of the Arctic region [from Gutenberg and Richter (*4*)] based on data for approximately the first half of the century with a map of

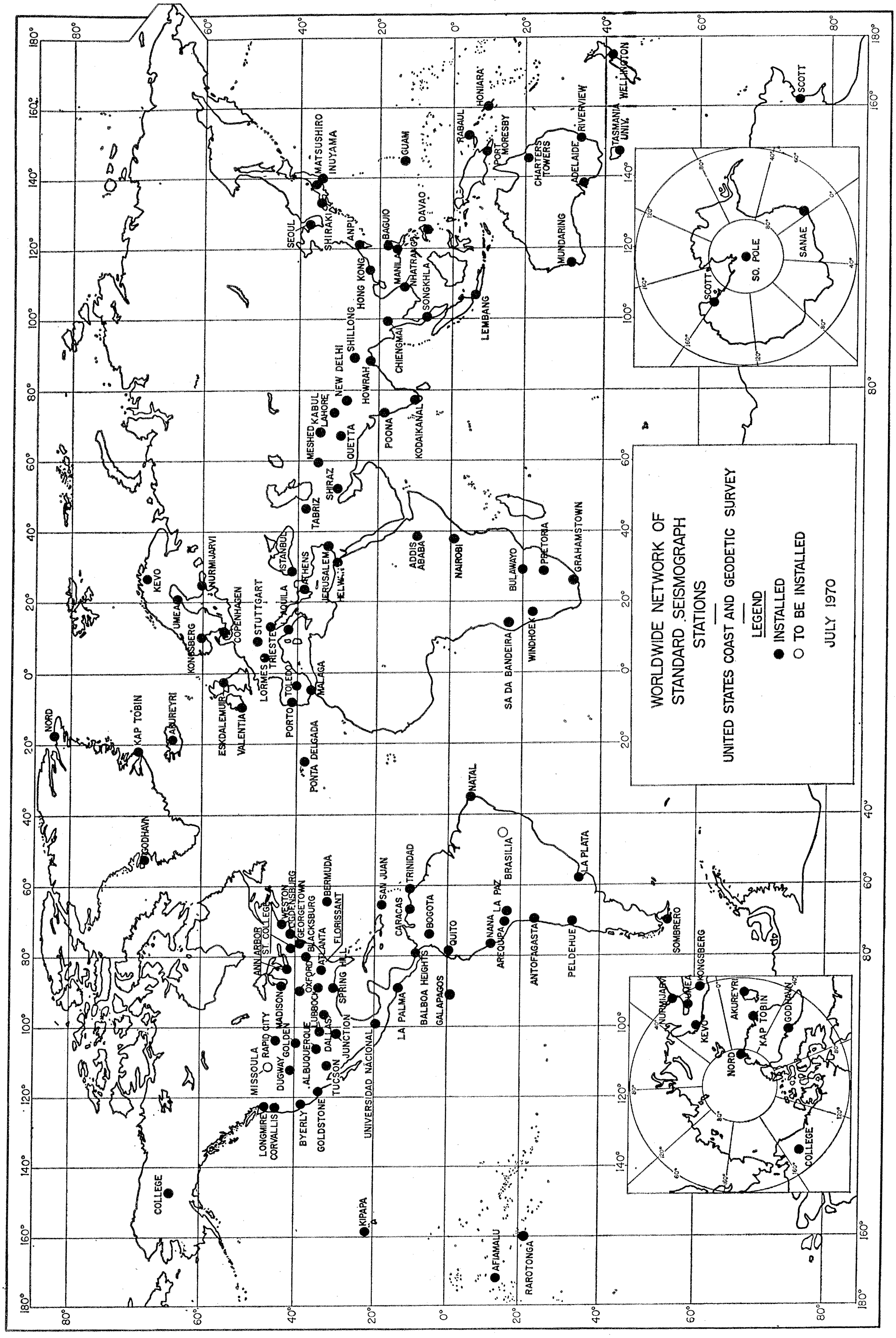
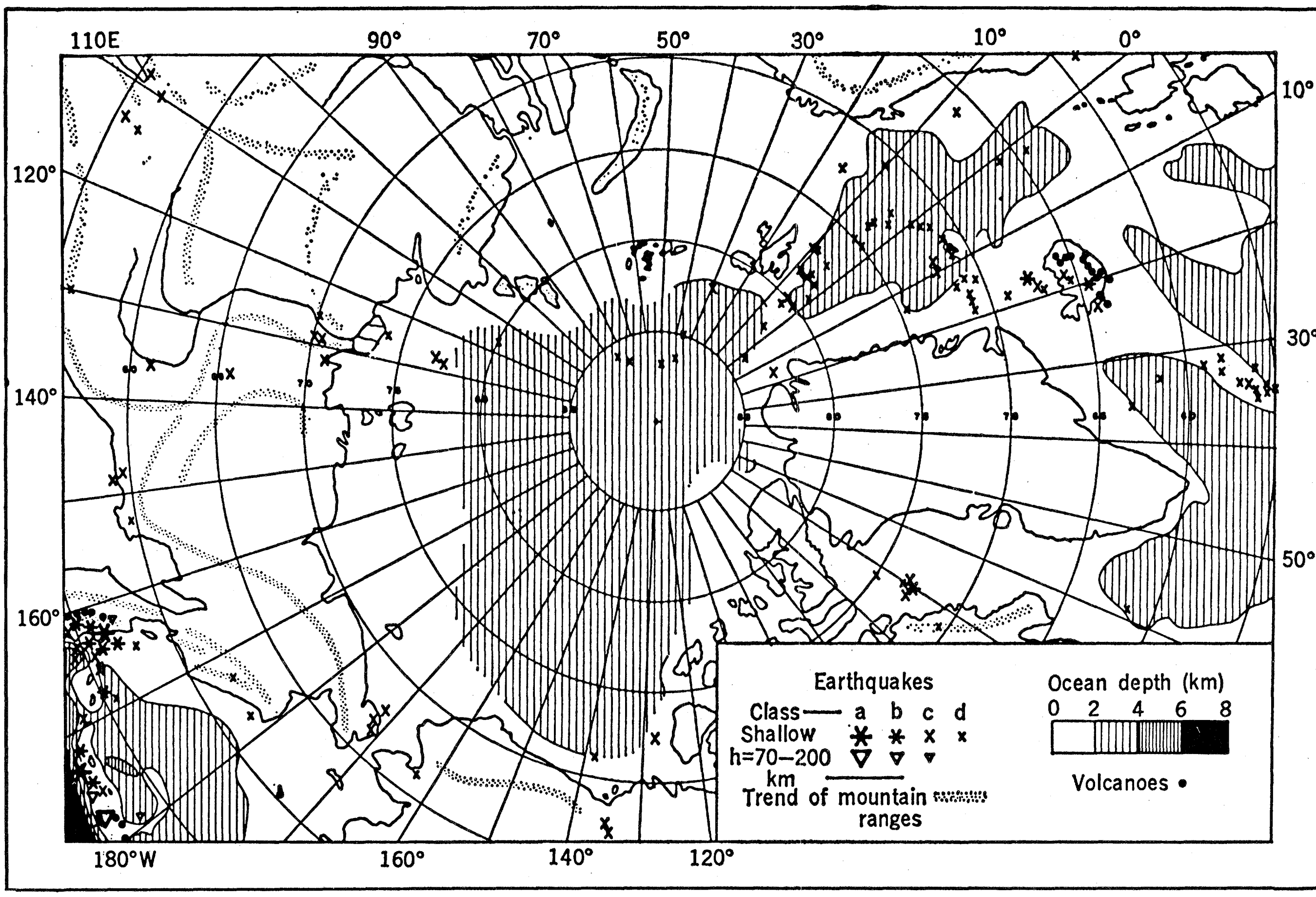


Fig. 2. Map showing locations of stations of the WWNSS.



the same Arctic region based on data for 1961 to 1967 (*5*).

In the determination of focal mechanisms the contribution of data from the WWNSS is vital. The seismologist frequently uses, as a simple representation of the focal mechanism of an earthquake, a model in which two masses of rock separated by a finite planar surface undergo abrupt linear displacement relative to one another. From the radiation pattern of the first motion of the fastest seismic wave (the compressional wave) the orientation of the surface in space and the direction of slip can be determined with a minor ambiguity. Data from a large part of the earth's surface are normally required or are desirable. Although the principle of the method had been known for many years from the work of Byerly (*6*), who developed it for worldwide studies, it was not until the 1950's that Hodgson (*7*), who recognized the value of large quantities of this information to the study of tectonics, tried to apply it on a large scale. He set out to amass information in quantity and first studied about 100 selected large earthquakes in detail. In that pre-WWNSS era, however, he was forced to collect his first-motion data

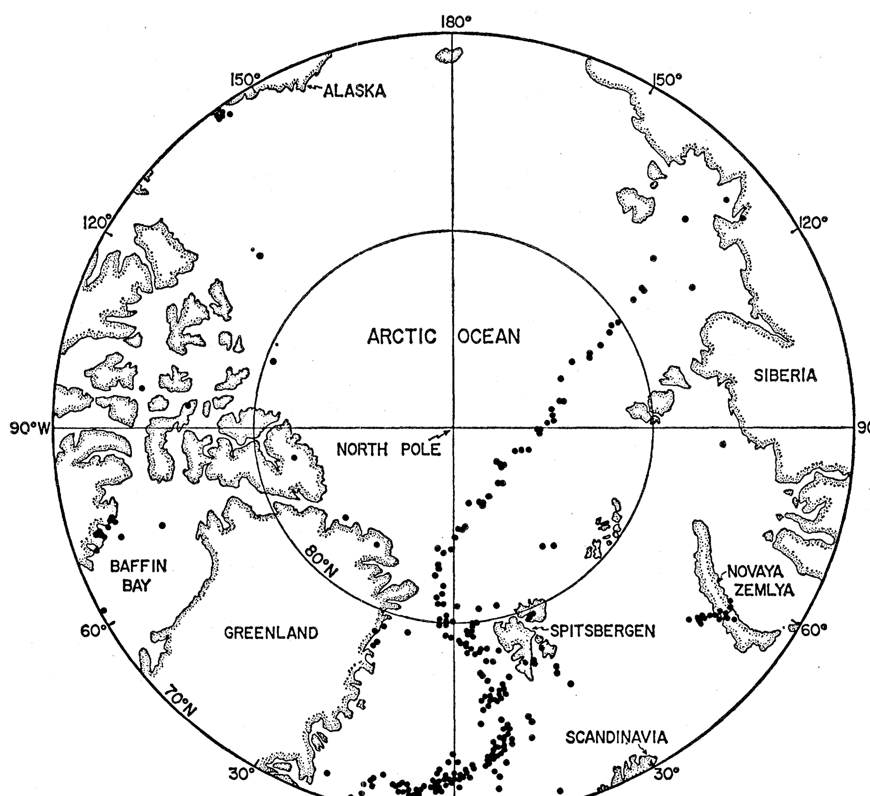


Fig. 3. Two maps of the Arctic regions which demonstrate improvements in knowledge of patterns of seismicity during the 1960's. (Top) In this map from Gutenberg and Richter (*4*) the data shown cover approximately the first half of the century. (Bottom) In this map from Barazangi and Dorman (*5*) the data are for the 1960's only.

by questionnaire. Different styles of interpretation, contrasting instrumentation, and other factors affected the results to the point where, typically, 15 to 20 percent of the data were inconsistent with the final solution. Many even doubted that the method was useful, and some incorrect mechanisms were published. But Hodgson was ahead of his time, for when WWNSS data became available it became apparent that, if all interpretations were made consistently by the same observer and if only clear long-period information were used, the inconsistencies normally dropped below 1 percent. The trouble was in the data, not the method. Few, if any, now doubt the utility and validity of the method, which has become so popular that most of the earthquakes that have occurred since the installation of the WWNSS and that were adequately recorded have now been analyzed in this way.

Let us review briefly some of the key results. Sykes (*8*) used this method and data from midocean shocks to show that the transform fault hypothesis of Tuzo Wilson (*9*), which predicted a sense of motion on ocean fracture zones exactly opposite to that of the conventional interpretation, was indeed correct. McKenzie and Parker (*10*) showed that the focal mechanisms of earthquakes in the Aleutians were in accord with the concept of the underthrusting by an oceanic plate of that arc. Isacks *et al.* (*3*) extended this approach over the entire globe; they used 100 reliable determinations for shallow shocks of arc, ocean ridges, and fracture zones as a major part of their comprehensive study of seismological data in support of plate tectonics. Few shocks showed more than a 30° departure from the directions predicted by Le Pichon's (*11*) simplified six-plate model based primarily on geomagnetic and geomorphological data. It was an era of remarkable discoveries. A few years earlier, who would have guessed that direction of relative movement of two rock masses during an earthquake would bear a simple relation to a pattern of ancient and weak magnetic anomalies located halfway round the world! Other more detailed studies of focal mechanisms of shocks of selected regions—Stauder's (*12*) work on the Aleutians is one—provide further support of the plate tectonics hypothesis. A small percentage of shocks do not fit the model well, but these seem merely to indicate a need for refinements of the simple model.

With the grand principle now rather well established, studies in plate tectonics have turned to the problem of the driving mechanism. Isacks and Molnar (*13*) produced a key result through study of the focal mechanisms of intermediate and deep earthquakes in island arcs throughout the world. They related the focal mechanisms to stresses within the slab of lithosphere beneath the arcs. They found that the pattern of stresses was consistent with sinking of the lithospheric slab under its own weight at intermediate depths beneath island arcs, with some resistance to further sinking occurring at greater depth. This evidence supports the idea of a density minimum at some modest depth in the mantle and continues to play an important role in evaluation of all proposed driving mechanisms.

Within the last few years a number of new techniques have been developed and applied to determine parameters of the seismic source such as seismic moment, fault dimension, stress, and stress drop. In the exploitation of this promising new direction, data from the WWNSS have been and will be crucial. Kanamori (*14*) determined a number of source parameters such as fault plane orientation, rupture length and velocity, moment, average slip, stress and strain drop, and source time function for the Alaskan earthquake of 1964 and for the Kurile earthquake of 1963. Wyss and Hanks (*15*) recently demonstrated the effectiveness of teleseismic WWNSS data for determining fault dimensions and seismic moment in the case of the Borrego Mountain earthquake. More such studies based on WWNSS data can be anticipated.

The uniform response of the WWNSS stations has made possible a number of studies of wave propagation that could not conveniently have been made and would probably not have been made at all if the only data available had been those from the heterogeneous non-WWNSS network. By a rather simple comparison of wave character at various stations (not all WWNSS), Oliver and Isacks (*16*) found evidence that indicated the existence of a slab of lithosphere that apparently had been thrust beneath Tonga and other island arcs. Molnar and Oliver (*17*) used WWNSS data exclusively to extend this type of investigation to the entire world; they mapped areas in which the plates of lithosphere were judged to be continuous or discontinuous on the basis of the efficiency of propagation of certain types of waves through those areas. With few exceptions the results supported the simple model of plate tectonics. Although at least as early as the work of Gutenberg and Richter (*18*) there had been occasional indications of anomalous propagation in certain areas, before the WWNSS there was no possibility of a global study and, hence, of a comprehension of the global pattern. The studies cited above are only a few examples; numerous other studies based on amplitudes or wave character have come from WWNSS data [see (*19*) for additional examples], and many more will follow. Readers should remember that predictions of seismic-wave amplitudes at a given location from a given earthquake are not uncommonly in error by a factor of 10. Knowledge of seismic-wave amplitudes is far less advanced than that of wave travel times, and this will be an area of emphasis in the future.

The Future

What of the WWNSS of the future? Surely our modern technological society must maintain as a minimum a facility like the present network to provide a modest written record of modern seismic activity. Maintaining such a record will improve our chances of diminishing the earthquake hazard and will provide our descendants with a basic history of seismicity. Such information is vital now, and it is growing rapidly in importance as the life-support systems of civilization become larger, more complex, and more vulnerable. We must develop a climatic record of earthquakes. We need it now; that need will increase with time.

We must also strive to improve the WWNSS so that we do not fail to acquire important knowledge of the earth that is potentially available to us in earthquake records. Many seismologists would like to see WWNSS data recorded in a form suitable for immediate introduction into a computer. Such recordings are expensive, but they are valuable for many studies. It would be foolish, however, to abandon completely the present visual system of recording, which provides important evidence without the elaborate analysis necessary for a system that provides data suitable solely for computers. A possible compromise for the near future might be the addition of auxiliary digital equipment at a limited number of WWNSS stations. Increased dynamic range is needed at some of the WWNSS stations for, with the present configuration, the largest shocks (in many ways the most important) saturate the system and are not well recorded.

Certainly there are many desirable locations for seismograph stations throughout the world that are not currently occupied by instruments of the WWNSS or by other instruments. Better coverage of many areas, including the ocean floors, would be advantageous. Installations on the deep-sea floor are feasible; a station now operates in deep water off the California coast. But the cost per station is high, and the cost of a large, worldwide, deep-sea network is currently out of reach. The near future may, however, see additional installations on the ocean bottom in selected locations.

A very effective and economical way of adding to the value of the WWNSS would be to include a substantial number, say 100, of existing non-WWNSS stations in the data copying and distribution system. Such a procedure would make much more information widely available throughout the international seismological community, and the information would be of great value even though all the stations would not have instruments directly comparable to those of the WWNSS. The cost of the added operation would not be high; the value to society would be large.

Each devastating earthquake triggers a widespread "let's do something about earthquakes" reaction that is nearly always short-lived. But the never-ending series of such shocks calls for a level of effort that is persistent and that does not fluctuate with public concern. The WWNSS with modest improvements, or something comparable, is an essential component of the effort required to keep society informed about earthquakes and to develop protection against their dangers.

References and Notes

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Deep-Water Archeology

Ancient ships that may exist virtually intact on the deep-sea floor can be found, studied, and recovered.

Willard Bascom

The greatest remaining treasure-house of information about the ancient world—the bottom of the Mediterranean—is about to become accessible. In this article I explain why I believe that there may be many ancient wooden ships in reasonably good condition on the deep-sea floor, how these ships can be located and recovered, why they sank, and why their cargoes are clearly worth a substantial search and recovery effort. In addition, I present the rationale for deciding where to search in order to optimize the chances of finding long-lost ships.

A new form of underwater archeology will begin when a new kind of scientific ship and new techniques are used to explore the deep-sea floor for sunken ancient ships. The *Alcoa Seaprobe* (*1*) is such a ship—capable of reaching down with its sensors, which are in a pod at the tip of a pipe, and making a detailed examination of the bottom in water several thousand meters deep (Fig. 1). It is equipped with sonar to systematically search the sea floor at a rate of about 1 square nautical mile every 6 hours (1 square nautical mile = 3.4 square kilometers). Men at the surface will be able to inspect objects on the bottom with television, dusting away sediment by means of jets and propellers. Photographs can be taken and objects of interest identified (and perhaps recovered) by means of grasping devices. Because *Alcoa Seaprobe* will be capable of lifting from deep water loads weighing 200 metric tons, it may be possible, under some circumstances, to recover entire small ships in one piece. The overall capability of this new ship will be substantially greater than that of any previous device for search and recovery in deep water.

I deal here only with ships that sailed the Mediterranean Sea during the pre-Christian era, but it is evident that there are many other, more recent (but still very old) ships in that sea, and else-

The author is chairman of the board, Ocean Science and Engineering, Inc., Long Beach, California.