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# GLOBAL DIGITAL NETWORKS—CURRENT STATUS AND FUTURE DIRECTIONS

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ABSTRACT

**The Global Digital Seismograph Network (GDSN), which consists of the Seismic Research Observatories, the Abbreviated Seismic Research Observatories, and the Digital World-Wide Standardized Seismograph Network stations, and the International Deployment Accelerometers (IDA) network, which is operated by the University of California, produce digital seismic data in overlapping bands from short to tidal periods. GDSN and IDA data are available through national and regional data centers, the GDSN data on network-day tapes and the IDA data on bimonthly network tapes. The digital waveforms are being used in research applications that benefit from the high resolution and wide dynamic range of the data, and the ease and speed with which large volumes of digital data can be processed. The usefulness of the data is being enhanced by special processing techniques that overcome some of the constraints of band-limited recording. GDSN improvements under study include an increase in short-period bandwidth, addition of horizontal short-period recording, and the recording of very long-period signals at SRO stations. Several additional stations with borehole seismometers are planned, possibly with satellite data telemetry to the United States. However, in the future, the most likely source of new GDSN data is through the acquisition of digital data from independently operated national and regional networks that are being installed or contemplated in several countries, including the United States.**

## INTRODUCTION

The development of a comprehensive and accessible data base for research is an essential prerequisite to scientific advancement. The accelerated progress in our understanding of earthquakes and global tectonics during the past two decades is due largely to the deployment in the 1960s of a global seismograph network that has generated a seismic data base unprecedented in quality and scope. As in all observational sciences, continued progress in seismology depends most of all upon continuing improvements and modernization of the data base available for research. One of the most important innovations in seismic observations during the past decade has been the advent of digital data recording. Digital recording provides much greater resolution and recording range, and the data are available in a format that is suitable for computer processing and analysis. Digital recording not only provides important new data, it can significantly increase research productivity.

There have been many independent digital stations and several digital networks (Figure 1) installed in recent years. From the standpoint of the general data user, the most important of these are likely to be the Global Digital Seismograph Network (GDSN) and the International Deployment of Accelerometers (IDA) network, principally because the digital data from these networks are readily accessible to the research community through established procedures. Major expansion of existing networks is not likely in the near future. However, there will be opportunities to augment the global digital data base through data-exchange agreements. Independent stations and arrays are producing digital data having significant potential value for general research applications, and several countries, including the United States,

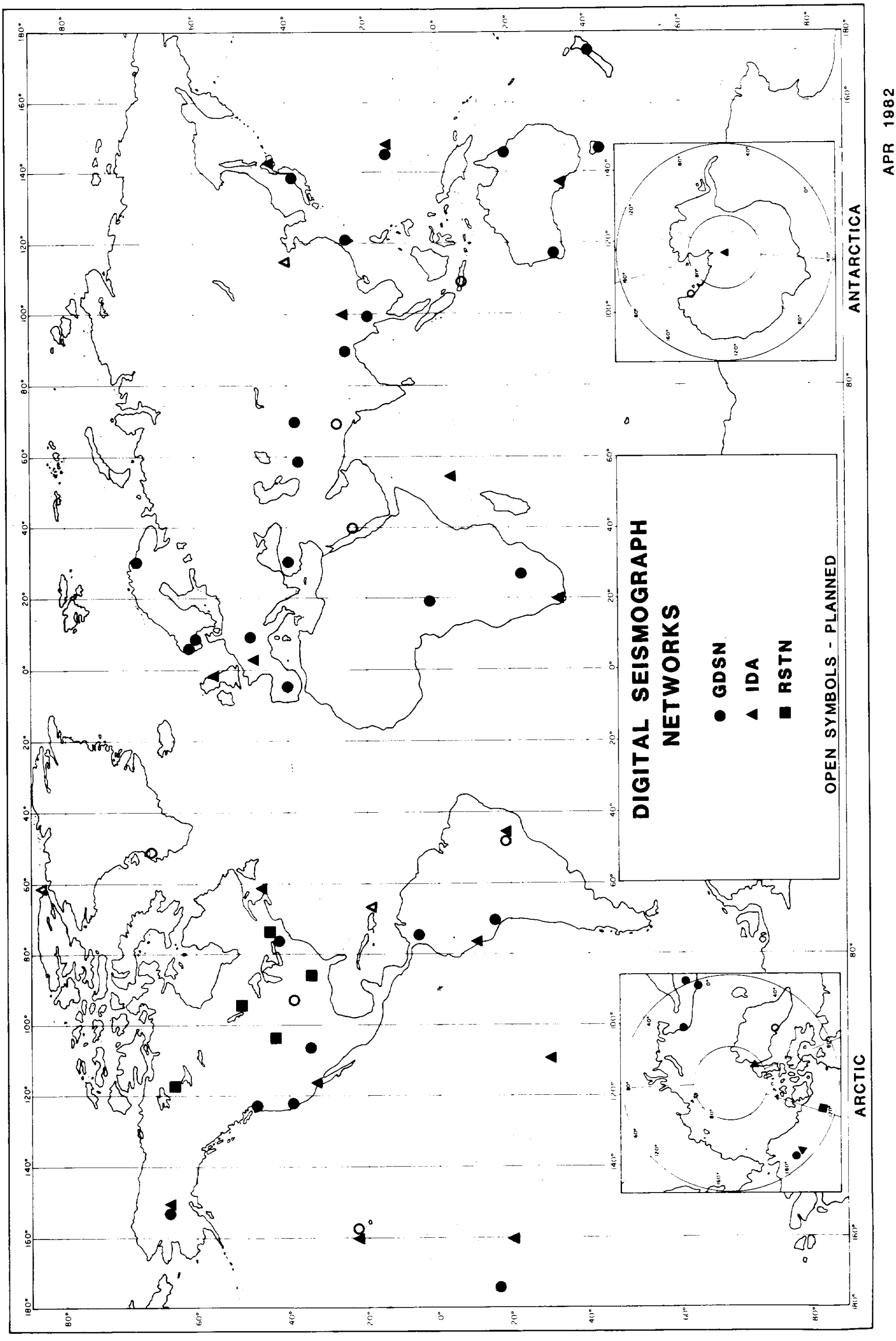


FIG. 1. Global distribution of digitally recording seismograph networks.

are planning national digital seismograph networks. One of the challenging problems of the future will be the qualification and integration of digital data from diverse sources.

The GDSN, which is a major topic of this paper, was established with the support of the Defense Advanced Research Projects Agency. It was established with two objectives: one was to develop and demonstrate new technology, and the other was to produce high-quality digital data for unrestricted use by the research community. The latter purpose has, of course, become the most important reason for the continued operation of the network by the U.S. Geological Survey (USGS). In a very real sense, the GDSN belongs to the scientific community; its continued operation and further evolution depend upon the interest and support of the scientists that use the data. The USGS, for its part, places a high priority on making the network data available and useful for a wide range of research objectives. Judged by the number and importance of research activities that are now utilizing the digital data, the value of the GDSN has surpassed early expectations.

## Major Data Sources

The GDSN, the IDA network, and the recently installed Regional Seismic Test Network (RSTN) are the principal sources of digital data supplied through established data centers. The GDSN consists of several types of digital data systems (Figure 2). The Seismic Research Observatories (SRO) were developed for the specific purpose of producing high-resolution data in the 20- to 40-sec period band. This was accomplished by combining the Teledyne-Geotech KS 36000-01 borehole seismometer with an advanced digital-recording system. Operated at a depth of about 100 m, the seismometer is isolated from most wind-generated surface noise in the period band of interest. The sensors used in the seismometer are broadband, force-balance accelerometers that provide a fundamental signal with a bandwidth from 0 to 1 Hz. These signals are filtered and amplified in the seismometer to produce the data-output signals that are brought uphole, one for each axis. The data-output signals are flat to acceleration from 0.02 to 1 Hz, and these are filtered in turn to produce long-period signals and, for the vertical component, a short-period signal. The four data channels are digitized using a 16-bit, gain-ranging analog-to-digital converter that produces a data word with 11 bits of resolution, 1 sign bit, and 4 bits specifying gain. The digitized long-period signals and events detected in the short-period signal are recorded on magnetic tape. All four channels are also recorded on analog recorders. Twelve SRO systems have been installed, and there is one remaining system that may be installed in the future. For a more detailed description of the SRO system, see Peterson *et al.* (1976) and Peterson *et al.* (1980).

The Abbreviated Seismic Research Observatories (ASRO) data systems are modified versions of the high-gain long-period seismographs described by Savino *et al.* (1972). Vertical-component short-period seismometers have been added, and the original data loggers were replaced by SRO-type recording systems. The channels of data recorded and the data format at the five ASRO stations now operating are the same as at the SRO stations. The major difference between the ASRO and SRO systems is that, in the case of the ASRO system, the seismic signals are acquired from conventional short- and long-period seismometers rather than a borehole seismometer. The long-period seismometers are installed in airtight tanks to provide isolation from barometric disturbances.

In order to extend the geographical coverage of the global network, a digital

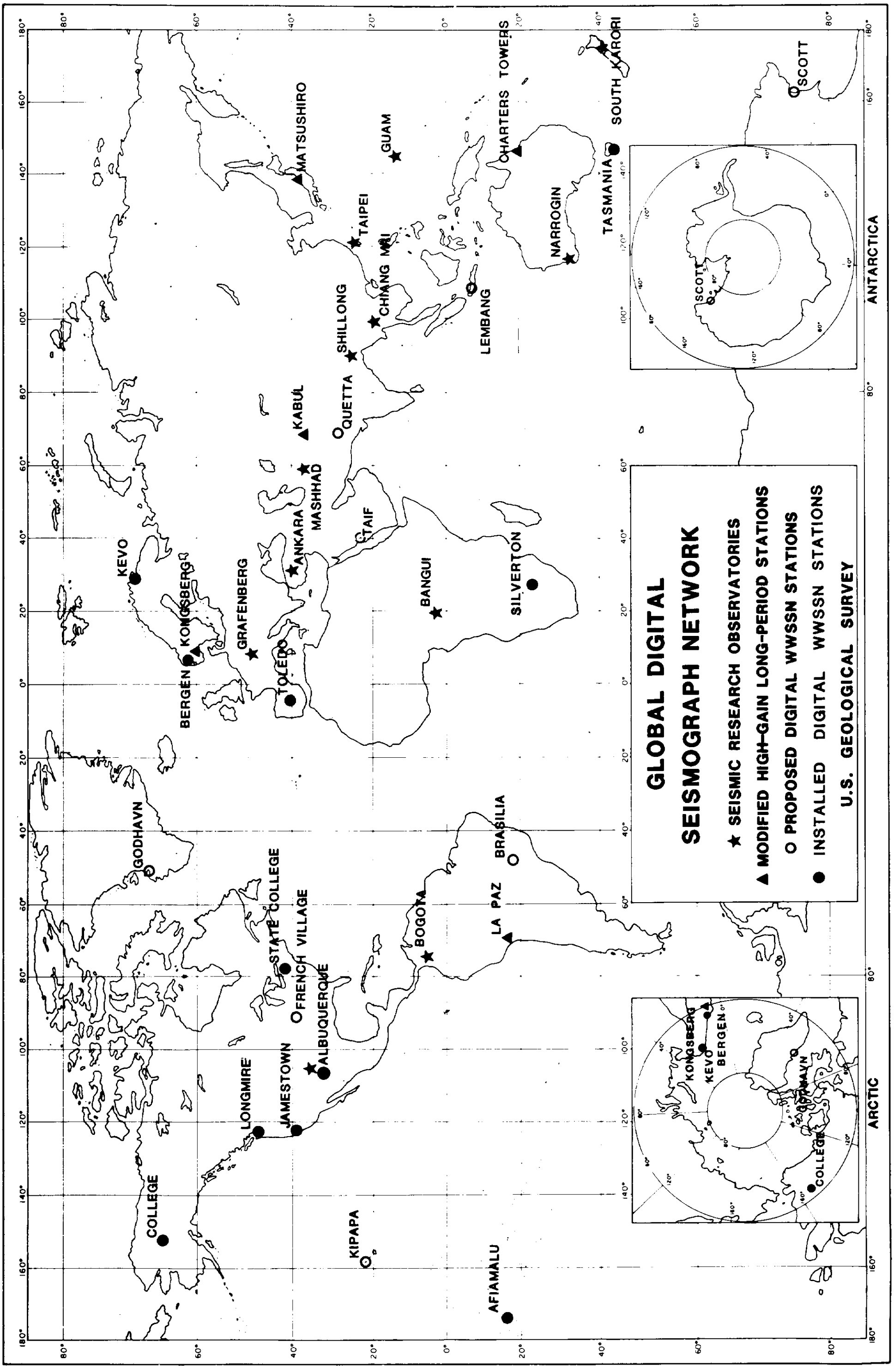


FIG. 2. The GDSN. Comprised of SRO, modified high-gain, long-period ASRO, and DWWSSN data systems.

recorder was developed that could be attached to the seismometers used in the World-Wide Standardized Seismograph Network (WWSSN). Digital data are recorded using a 16-bit, fixed-point data word that provides 15 bits of resolution. Three-component long-period and vertical-component short-period signals are recorded on magnetic tape, the latter in an event-only mode. In addition, three-axis intermediate-period event-detected signals are recorded. The intermediate-period signals are derived from the long-period seismometers and have a response roughly flat to velocity from a 1- to 15-sec period. The sensitivities of these signals are set low so that body waves from large earthquakes ($M_S$ ~8 at 20°) can be recorded without overdriving the system (Figure 3). The USGS is installing 17 of the digital recorders. In addition, the University of Bergen has purchased and installed one of these recorders at Bergen, Norway, and a similar type of recorder will be installed as part of a new geophysical observatory to be located near Taif, Saudi Arabia. A description of the operating characteristics of the digital WWSSN (DWWSSN) is provided by Peterson and Hutt (1982).

The IDA network, which has been installed and is being operated by the University of California at San Diego (UCSD), is an important complement to the GDSN because it provides very long-period (1 min or more) digital data that are not now available from other sources. The IDA data system, described by Agnew *et al.* (1976) and Farrell and Berger (1979), uses a modified LaCoste-Romberg gravimeter with electrostatic feedback to sense vertical ground motion. The output of this system is amplified and filtered to acquire two channels of data, one of seismological interest which is flat to acceleration for periods of 1 min to 1 hr, and another, less sensitive and flat to acceleration down to 0 Hz, to record earth tides. Originally intended only for the study of normal modes, the former data channel has also provided much useful information on the early body-wave phases. Because the sampling rates are low, the data can be recorded on cassette tapes. The tapes are collected from the stations by UCSD for processing and further distribution. Eighteen IDA systems have been installed. Future plans include the addition of three stations, relocation of some stations, and improvements in the instrumentation.

The RSTN is a five-station telemetered network recently installed by Sandia National Laboratories. The stations, which are unmanned, acquire signals from a three-axis Teledyne-Geotech KS 36000-04 borehole seismometer and a single-axis Teledyne Geotech Model S-750 seismometer that is also mounted in the borehole package. Three data bands are transmitted: short period, mid-period, and long period. The signals are normally acquired from the broadband KS 36000 seismometers, the S-750 being an alternate source for short-period vertical-component data. Geosynchronous satellites provide two-way communication between the network control station in Albuquerque, New Mexico, and each RSTN station. Seismic data and station state-of-health information are transmitted from the RSTN station to the control station. Short-period seismometer selection commands, calibration commands, and network time synchronization data are transmitted from the control center to the individual stations. The nine channels of data are transmitted continuously. Current plans are to merge RSTN data (events, in the case of the short- and mid-period signals) with GDSN data on the USGS network-day tapes for general distribution. A detailed description of the RSTN data system is in preparation (H. B. Durham, Sandia National Laboratories, personal communication).

The types of seismic data being obtained from the GDSN, IDA, and RSTN networks are summarized in Table 1. Relative amplitude response characteristics of the data channels are shown in Figure 4.

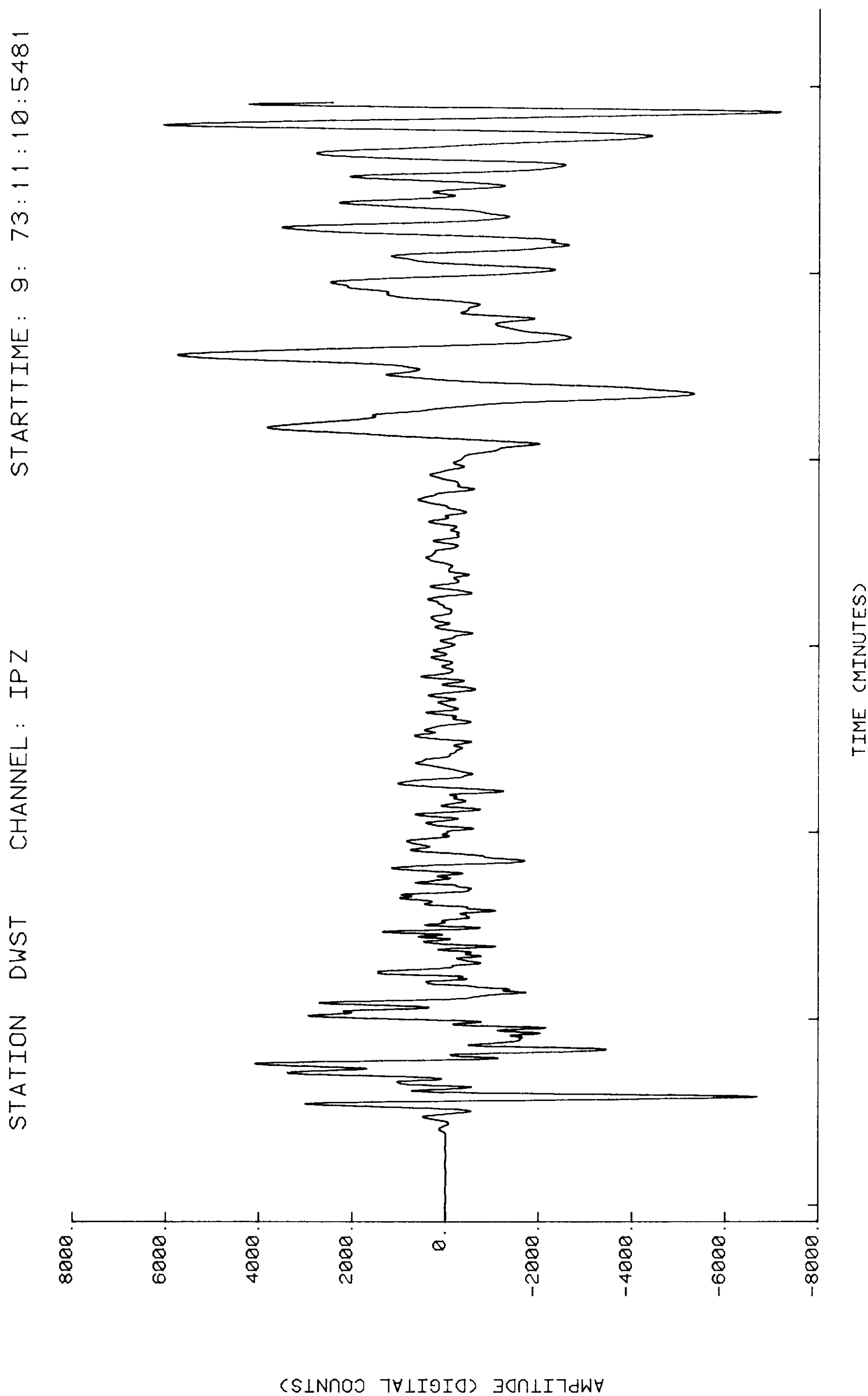


FIG. 3. Example of large-amplitude body waves recorded on the intermediate-period channel of the digital WWSSN at ALQ from $M_S$ 7.6 earthquake at a distance of about 18°. Signal overdrove all other seismographs (WWSSN and SRO) at ALQ.

## Data Management

GDSN data flow from the stations to the users, initiated in January 1980, is shown in Figure 5. The station tapes generally contain from 1 to 2 weeks of data. They are mailed together with the analog seismograms to the USGS Albuquerque Seismological Laboratory (ASL), usually with a transmit time of 1 to 4 weeks. At ASL they are reviewed and edited, usually within 24 hr after receipt. Automated review procedures include the reduction of calibration data, detection and correction of errors in timing, parity, and format, listing of dropouts and outages, and other quality-control operations. During the review, segments of the data are checked visually using graphics terminal. Following the review and editing, station data are placed in a large disk file. When data from all of the GDSN stations are in the disk for overlapping periods of time, the data for successive days are read from the disk and organized onto network-day tapes. The length of time between data recording and compilation of the day tape is about 8 weeks.

TABLE 1

Types of Seismic Data Obtained from the GDSN, IDA, and RSTN Networks

| Data Type | Recorded Components | Recording Mode | Sampling Rate (samples/sec) | Data Word |
|---|---|---|---|---|
| ASRO SP | *Z* | Triggered | 20 | 16-bit gain ranged |
| ASRO LP | *Z, N, E* | Continuous | 1 | 16-bit gain ranged |
| DWWSSN SP | *Z* | Triggered | 20 | 16-bit integer |
| DWWSSN IP | *Z, N, E* | Triggered | 10 | 16-bit integer |
| DWWSSN LP | *Z, N, E* | Continuous | 1 | 16-bit integer |
| IDA mode | *Z* | Continuous | 0.1 | 16-bit integer |
| RSTN SP | *Z, N, E* | Continuous* | 40 | 16-bit gain ranged |
| RSTN MP | *Z, N, E* | Continuous* | 4 | 16-bit gain ranged |
| RSTN LP | *Z, N, E* | Continuous | 1 | 16-bit gain ranged |
| SRO SP | *Z* | Triggered | 20 | 16-bit gain ranged |
| SRO LP | *Z, N, E* | Continuous | 1 | 16-bit gain ranged |

* Events only will be placed on the network-day tape.

The network-day tape is the principal product of the GDSN. The format has been designed to provide a 1-day block of network digital data complete with all essential information required by an analyst to use and process the data. This information, which includes station parameters and complete calibration data including transfer functions, timing corrections, periods of outages, and other useful data, is contained in special logs which are inserted at appropriate locations in the tape. Hoffman (1980) provided a complete description of the format used in compiling the network-day tape. Station tapes that are late or are from remote stations are processed and distributed as station-month tapes in network-day tape format. Station tapes are returned to the originating stations, if requested.

Copies of network-day tapes are sent to the USGS Digital Data Analysis Center in Golden, Colorado, to four regional data centers, and to the National Geophysical and Solar-Terrestrial Data Center (NGSDC) in Boulder, Colorado, and one copy is archived at ASL.

The USGS Digital Data Analysis Center was established to provide facilities and service to assist the general scientific community in research studies that utilize

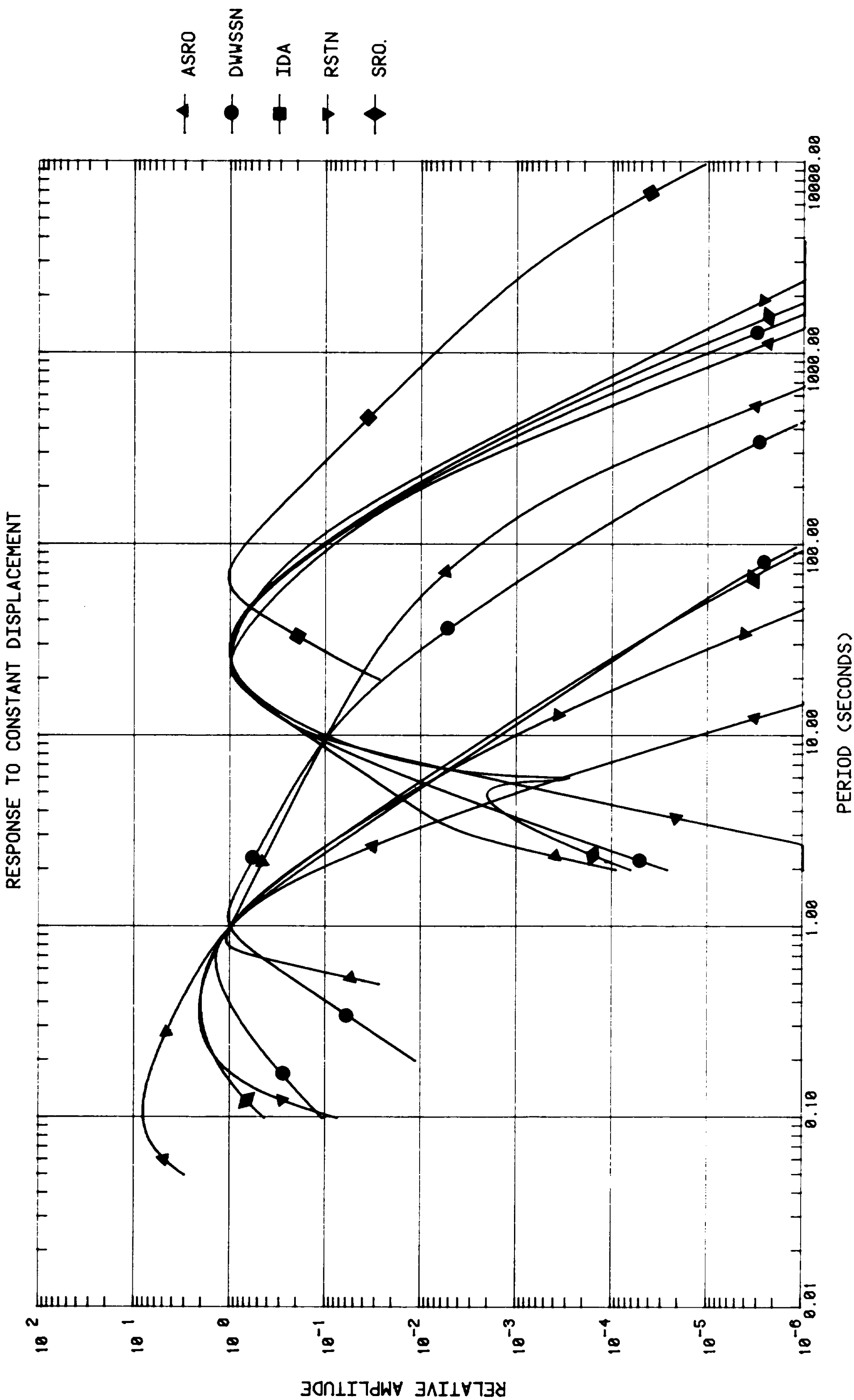


FIG. 4. Relative amplitude response characteristics of the data channels obtained from GDSN, IDA, and RSTN systems. Short- and intermediate-period systems are normalized at 1 sec, long-period systems at 25 sec, and the IDA mode channel at 60 sec. The curves do not reflect the relative sensitivities of the different systems.

digital seismic data, and to develop new techniques and computer analyses for the routine determination of generalized source parameters as part of a general upgrading of seismological services provided by the National Earthquake Information Service. The center has a library of digital seismic data, dedicated computer facilities, a variety of software for the manipulation, display, and processing of the digital data, and a staff which includes programmers, analysts, and research seismologists. One important development at the center has been a software package for reading GDSN network-day tapes. It consists of an easily portable set of programs written in FORTRAN that can search for and decode desired data, as well as produce summaries of the data on a tape. This package is intended to provide access to GDSN data in as machine-independent a manner as possible, but

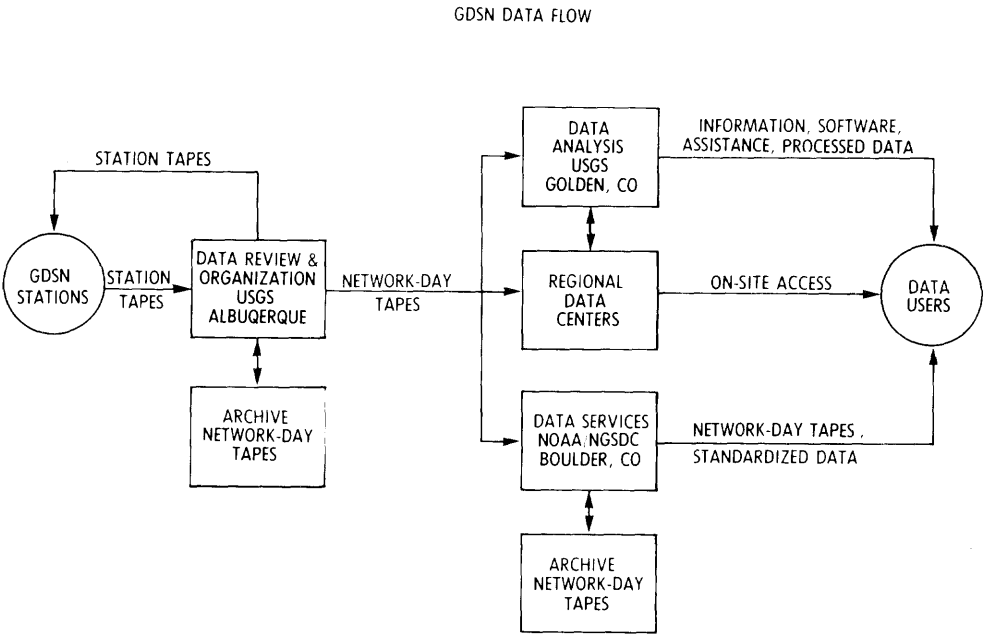


FIG. 5. GDSN digital data flow from the stations to users.

some modifications are usually nécessary to accommodate individual computer facilities. This software has been extensively distributed to the scientific community along with documentation (Zirbes and Buland, 1981) that includes notes on installation. A new release of this software will also permit recovery of data from the original station tapes and pre-1980 network-day tapes.

Regional data centers provide blank magnetic tapes to ASL and receive, at no cost, copies of the network-day tapes. Four data centers have been established: two on the east coast (the Seismic Data Analysis Center in Alexandria, Virginia, and Harvard University); one in the central United States (Saint Louis University); and one on the west coast (California Institute of Technology). The role of the regional data centers is to permit local and regional users access to a computer facility on a not-to-interfere basis for utilization of network-day tape archives and general-purpose software provided by the USGS. At a minimum, the centers will provide for on-site copying of network-day tapes and software transfer. Local users may prefer to borrow data tapes from the centers and copy them or extract the desired data on their own computer facilities. With prior approval from a center, users with more extensive on-site processing requirements can be accommodated.

The NGSDC is the designated national archive for GDSN data. It can provide copies of network-day tapes or pre-1980 digital data on nine-track tapes at either 800 or 1600 bits per inch. It can also provide microfiche copies of analog GDSN recordings. Additional services, such as furnishing edited data, may be provided on request. Visitors are welcome at the NGSDC and, with prior arrangement, may use the tapes and facilities without charge. The network-day tape is provided to NGSDC by ASL at no cost. However, NGSDC is required to recover costs and thus to charge users $100 per tape copy. This is a standard for all tape copies at NGSDC. NGSDC will make available a network-day tape on request at no cost for the purpose of testing programs and determining suitability of the data. NGSDC may quote special reduced prices for large orders provided in a single shipment.

IDA data are distributed directly from UCSD to cooperating institutions and from NGSDC at a nominal charge. The data are distributed in the form of network tapes, with 2 months of data per tape. For the years through 1979, both tide- and normal-mode data are available. Beginning with 1980, only the normal-mode data are distributed through NGSDC.

## Digital Data Utilization

Research applications of the digital data base have expanded steadily as academic and government organizations have developed the capability to process and analyze digital data. The principal advantages of GDSN data are the wide dynamic range, high-recording precision, and the ease and speed with which large volumes of the data can be processed. With modern computer processing, many of the recent advances in theoretical seismology can now be quickly tested and verified by comparing synthetic waveforms and spectra against large volumes of high-quality digital data. In addition, the routine use of many digital processing techniques, until recently impeded by the lack of resolution in analog recordings, is now possible with digital-recorded data.

Recent advances in source theory and the theory of wave propagation have shown that the ability to resolve earth structure and to study the earthquake source mechanism, which are strongly coupled problems, can be greatly enhanced if all the amplitude and phase information present in pulse shapes and wave trains is used. The description of the seismic source, for instance, has become increasingly sophisticated, and with the availability of digital data, many new parameters can now be routinely estimated (Engdahl and Kanamori, 1980). Whereas our primary concern in the past has been with hypocenter location, magnitude, and fault-plane solutions, current interest now includes computing the moment (both scalar and tensor) and dynamic and static descriptions of the source (such as associated stresses, source complexity, and the time history of the source function). The seismic moment tensor, as an example of the new technology, is an effective and general representation of the seismic source that can be determined from normal modes, long-period body waves, or surface waves, and the representation has the theoretical advantage of being linearly related to the observed seismograms. The discussion that follows will briefly describe examples of what can be done with digital data, but is not intended to be a comprehensive survey of digital research.

An immediate application of digital data, where dynamic range and resolution are important, is in determining the anelastic properties of the earth. Choy and Boatwright (1981) and Choy and Cormier (1982) have shown that $Q$ models derived from free oscillations and from long-period body- and surface-wave data cannot be extrapolated in a frequency-independent fashion to high frequencies. Important applications of digital data to measurement of $Q$ from $ScS$ waves have been demonstrated by Jordan and Sipkin (1977) and Sipkin and Jordan (1980a). At very low frequencies, IDA records of the August 1977 Sumbawa earthquake gave measurements of the single frequencies of the low-order modes ${}_0S_2$ and ${}_0S_3$ (Buland *et al.*, 1979), and extremely precise estimates for the frequency and $Q$ of the fundamental radial mode ${}_0S_0$ (Riedesel *et al.*, 1980), which provides the best estimate of bulk attenuation in the earth. The records from this and later events have been used by many workers to estimate the $Q$'s of fundamental spheroidal and overtone modes. Masters and Gilbert (1981) were able to detect overtone modes sensitive to rigidity of the inner core, and inferred from measurements of them that the inner core has a high $Q$ at long periods.

Digital data have important application in the study of lateral heterogeneities. North (1979) measured dispersion of mantle Love waves from several hundred paths using SRO data. Dziewonski and Steim (1981), using a traveling wave approach, confirmed different dispersive properties for various tectonic regions and inferred that major differences in shear velocities (about 4 per cent) exist in a depth range from 400 to 700 km between "old" and "young" oceanic structures. Sipkin and Jordan (1980b) have used digitally recorded multiple $ScS$ waves to determine differences in upper mantle structure between continents and oceans. Further refinement of our understanding of the global pattern of lateral heterogeneities should be possible through application of digital data to the study of overtones and through the location of fundamental mode multiplets in the 200- to 700-sec period range.

Digital data have been recently applied in the determination of earthquake size and earthquake source mechanism. Silver and Jordan (1981) have reported on a technique for estimating the scalar moment of earthquakes from normal-mode data, allowing for the effects of errors. Kanamori and Given (1981) have developed a rapid method of source mechanism determination using long-period mantle waves and have applied this method to all large earthquakes in 1980 (Kanamori and Given, 1982). Dziewonski *et al.* (1981) and Sipkin (1982) described methods that have made the estimation of the moment tensor of the "the best source" for moderate-sized earthquakes essentially a routine process. Figure 6 is an example of the fit to observed data obtained by the method of Dziewonski *et al.* (1981). The range of seismic moments (now about three and one half orders of magnitude) could be increased still further by using data for the fundamental Rayleigh mode (cf. Aki and Patton, 1978; Romanowicz, 1982). Considering the usual level of global seismicity, these types of analyses could eventually be applied to as many as several hundred events per year, rapidly increasing our level of understanding of the process of stress accumulation and release. Furthermore, on the basis of these advances, it now appears feasible—provided that digital data from a sufficient number of well-distributed stations are transmitted in real time—to estimate the moment tensor and rupture parameters for a large magnitude earthquake anywhere in the world, very rapidly. This capability is obviously of great value in the case of potentially tsunamigenic earthquakes.

It has been demonstrated that spectral information in the period range from 0.2 sec to hundreds of seconds can be recovered from GDSN data by digital processing. This includes an intermediate-period band that has not been directly available from analog short- and long-period recordings of the WWSSN (Harvey and Choy, 1982). This extended bandwidth of spectral information (Figure 7) is particularly useful for quantifying directivity effects associated with finite seismic sources and for studies of frequency-dependent attenuation. In an analysis recently presented by Choy and Boatwright (1981), the complete rupture history for two deep earthquakes was determined, including constraints on the dynamic and static stress drops, the rupture velocity, and the rupture complexity (Figure 8).

Although seismic moment probably best expresses the overall size of earthquakes, there remains a need to calculate magnitude more reliably and meaningfully. The body- and surface-wave magnitudes $m_b$ and $M_S$ are still very important in many

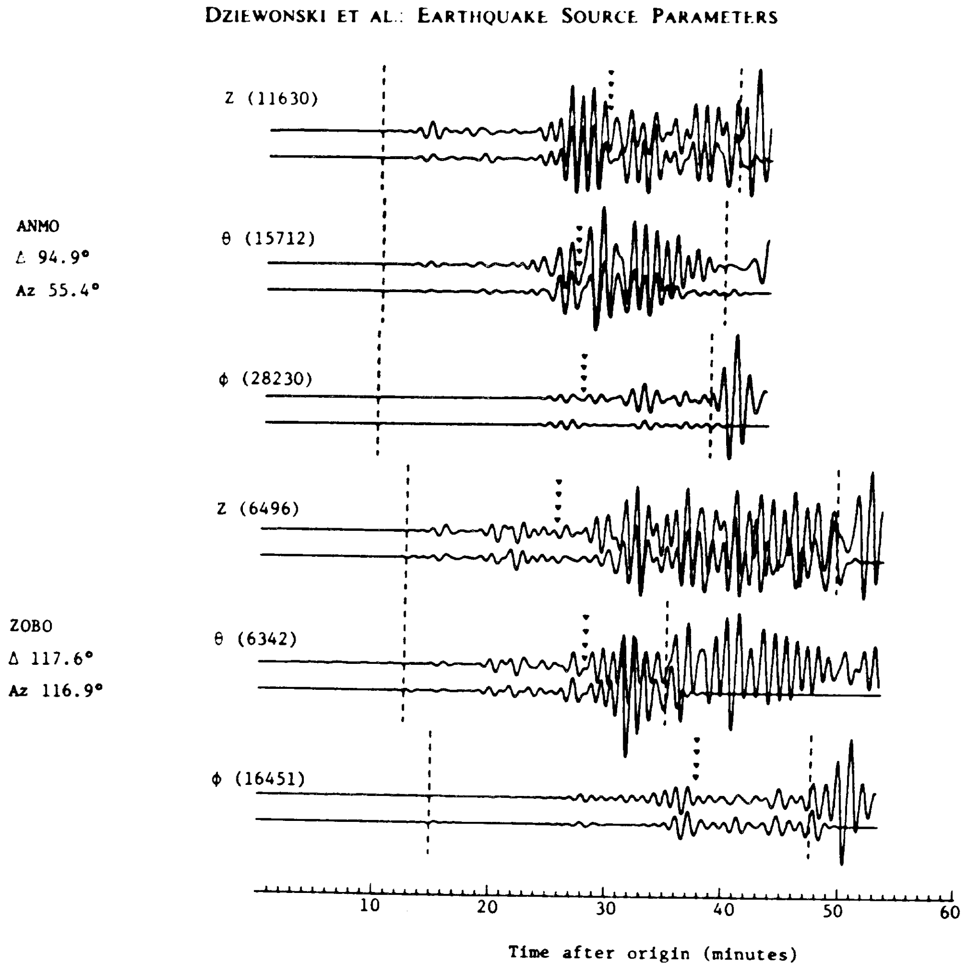


FIG. 6. Comparisons of the observed (*top*) and synthetic (*bottom*) seismograms from the SRO station ANMO and the ASRO station ZOBO for the $m_b$ 6.3 intermediate-depth (200 km) earthquake of 23 September 1978, in the New Hebrides region (from Dziewonski *et al.*, 1981).

applications, such as in discriminating between nuclear explosions and earthquakes, and more effort should go into developing regional calibration functions for estimating $m_b$ and $M_S$ values that are consistent from region to region. Digital data permit seismic phases to be picked automatically from short-period data. In one method (Blandford *et al.*, 1981), a digital seismogram is passed through a set of narrow bandpass filters and, in each case, the maximum in the envelope of the filtered trace picked out. Body-wave phases are then isolated by looking for coinci-

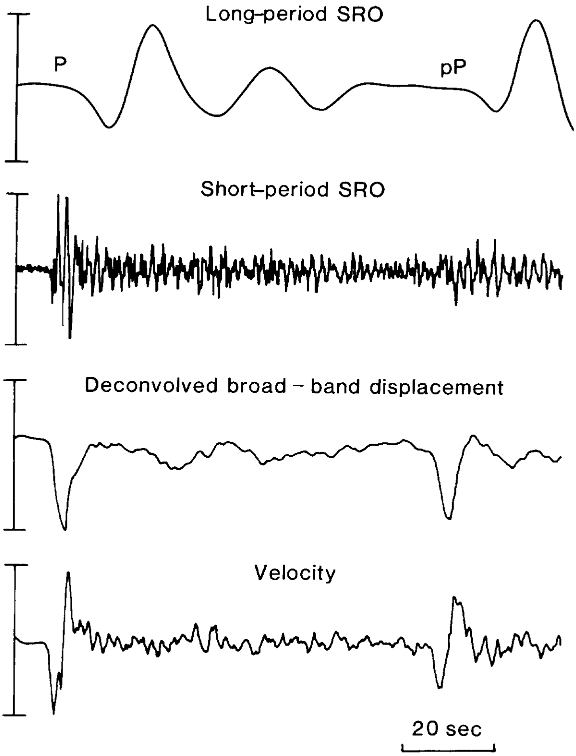


FIG. 7. Long- and short-period vertical seismograms as recorded by the SRO station MAIO from a deep earthquake. The broadband displacement and velocity records were constructed from the long- and short-period vertical channels after instrument deconvolution (from Choy and Boatwright, 1981).

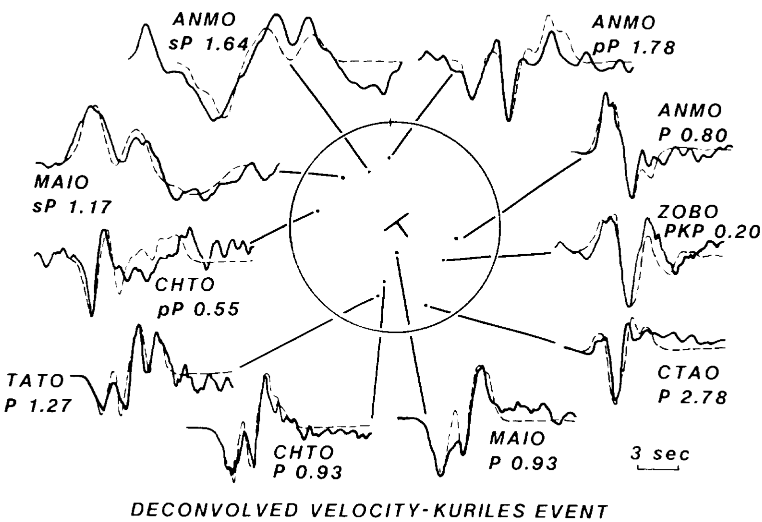


FIG. 8. Deconvolved velocity pulse shapes (solid lines) and synthetic waveforms (dashed lines) are plotted around the focal sphere of a deep earthquake. The fault plane coincides with the plane of the stereonet. Note the directivity of the $P$ wave for stations between 30° to 85° azimuth. Going clockwise from ANMO to TATO, $P$-wave splitting is manifested by the gradual development of a doublet in the first trough and the following peak (from Choy and Boatwright, 1981).

dences in time of high-amplitude envelope points (i.e., a nondispersive arrival). The method seems to be very successful at identifying phases in noisy data (or in coda) and in defining a characteristic behavior when two phases are interfering. As amplitudes of seismic phases are preserved as a function of time, this technique provides a means of representing short- or long-period source complexities, and it may help to sort out multiple events. Broadband digital data should also be useful in improving the estimates of hypocentral depth (cf. Fitch *et al.*, 1980, 1981).

Even with these important current applications, we believe that the potential of the digital seismic data has yet to be fully realized. The digital networks are just now on the threshold of giving adequate geographic coverage for most events—hence, usage has not been widespread. Researchers are waiting until there is enough data per event to apply the digital data to their problems. And, for the most part, current applications represent an extension of techniques used in the processing of manually digitized analog data. Nevertheless, the availability of digital data permits investigations that are simply not possible using analog data. Ultimately, the impact of digital data on seismological research is certain to be as great as the impact of the WWSSN more than a decade ago.

## Future Directions

It is recognized that there are limitations to the scope and applicability of the global digital data base and that there must be a sustained effort to modernize the existing networks and seek new sources of digital data. The three major factors that limit the usefulness of the current digital data base are bandwidth, dynamic range, and geographic coverage. Improvements in these areas depend more on the availability of funds than on the need for any technological breakthroughs. Again, our comments focus on the GDSN because it is a nonproprietary network that can be modified to meet the needs of the scientific community. Although it is unlikely that the GDSN can ever become a truly general-purpose digital network satisfying the data needs of every research objective, there are improvements that can be made to increase the versatility of the data.

One suggested improvement is to record horizontal-component short-period data. This recording can be done simply by adding more hardware, principally filters (and horizontal seismometers in the case of ASRO stations), because all of the GDSN data systems were designed to accommodate three short-period channels. Recording horizontal-component short-period signals will also improve the bandwidth in a sense because the short-period signals contain useful spectral information to periods beyond 10 sec. Harvey and Choy (1982), in an extension of a procedure developed by Burdick (1977), have shown how broadband signals can be recovered through the simultaneous deconvolution of short- and long-period signals. However, at present, this technique is limited to the available vertical-component channels. At the SRO stations, the short-period bandwidth can be extended to somewhat longer periods by recording the unfiltered data-output signals in place of the short-period signals, and this modification is being studied.

In a further effort to exploit the available bandwidth of the SRO borehole seismometer, an evaluation is in progress of a modified KS 36000 seismometer that produces signals that are flat to acceleration from 0.001 to 4 Hz, as opposed to the data output signals now used that have a flat response from 0.02 to 1 Hz. With this modification, it should be possible to record very long-period data, either in a separate normal-mode channel or by broadening the passband of the long-period filters now in use. The modification should also improve the dynamic range of the

SRO signals as well. Unfortunately, the modification is expensive, especially on a network-wide basis.

Although digital recording is a vast improvement over analog recording with respect to dynamic range, serious deficiencies remain in our ability to recover useful data through the entire amplitude range of interest. The GDSN was never intended as a strong-motion network, yet it is reasonable for data users to expect that signals from the largest earthquakes could be linearly recorded at teleseismic distances. The requirement is an amplitude range of about 160 dB, assuming that the data systems continue to be operated at a high enough sensitivity to resolve earth noise in the band from 0.01 to 10 Hz. The SRO and ASRO systems have a recording range of 126 dB, but the useful operating range is somewhat less for the long-period channels and considerably less for the short-period channels. Because of the low clipping threshold in the SRO systems, impulsive body-wave signals from the large deep earthquakes sometimes cause nonlinear transient pulses to appear in the recorded waveform (Peterson, 1982). The DWWSSN systems have an operating range and resolution of 90 dB, however, in the long-period band the useful operating range is currently limited by noise in the long-period amplifiers.

Several manufacturers are developing high-resolution digital encoders that could become a factor in the design of new seismic data systems. At least one of these encoders has evolved to the testing stage (J. Woodward, Gould Inc., personal communication, 1981). The new encoders are expected to provide a resolution of 21 bits (126 dB), with the data formated into 24-bit words. Further testing is needed to determine if the sensors available today can produce linear, noise-free signals over this range and if the new encoders are stable at long periods. If so, one potential advantage in the high resolution is the possibility of recording single broadband signals in lieu of the multiple bands now recorded. The resolution would permit the detection of small signals buried in the microseismic noise.

The SRO and ASRO stations are not sited in an optimal configuration for uniform coverage of major earthquake zones. The addition of the DWWSSN systems is improving the coverage, but there remains a need for more digital stations in some regions. A plan has been developed by the USGS (Peterson and Orsini, 1982) for a Global Telemetered Seismograph Network. If the plan is implemented, there will be eight to ten SRO-type data systems with borehole seismometers installed. The data will be telemetered via satellite in real time from the stations to the ASL. The real-time data will be furnished to the National Earthquake Information Service and other users to supplement other telemetered data and used for rapid location of earthquakes. Event-detected short- and intermediate-period signals and continuous long-period signals will be stored and merged with other GDSN data on the network-day tapes.

Several countries, including the United States and the People's Republic of China, are preparing plans for national or regional international networks of digital seismographs. If these plans are implemented and if data exchange agreements can be negotiated, the global digital data base will be significantly enhanced. Not only will the volume of data be much greater, the quality and applicability of the data base will be improved as well. In the United States, the National Academy of Sciences has called for the establishment of a National Digital Seismograph Network to provide uniform, continuous, and standardized earthquake records over the entire country (Bolt, 1980). Preliminary design studies (Peterson and Hutt, 1981) have emphasized the need for broadband recording and the capability to accommodate the entire amplitude range of interest. A National Digital Seismograph Network station will also sample short-period signals at a higher rate than the GDSN stations in order to produce useful data for local and regional earthquake studies.

There are many other potential sources of digital seismic data. Ganse and Hutt (1982) have identified more than one hundred digital stations, local networks, and arrays. Many of these organizations may be willing to share their data, perhaps on a continuous basis. However, there are technical problems to be overcome because of the different recording formats. There have been efforts to standardize the format used in the exchange of digital data (S. S. Alexander, Pennsylvania State University, personal communication, 1981). As yet, however, individual data users must obtain the data and write their own program for reading the tapes. This represents a significant amount of work if the data are requested from a number of different sources. Also, procedures must be established for qualifying digital data with respect to transfer functions, calibration procedures, and other information that is essential for proper utilization of the data. Clearly, there is a need for systematic procedures in digital data exchange and perhaps a clearinghouse to assist data users in the acquisition and reformating of data from nonstandard sources.

One cannot close a discussion on the global digital networks without commenting on the need for ocean-bottom seismographs. With two-thirds of the Earth's surface, including many of its interesting tectonic features, covered by water, it is manifestly evident that the global digital data base will not be fully satisfactory until the technological problems are resolved and ocean-bottom instruments deployed that can produce seismic data reliably and continuously.

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