GLOBAL DIGITAL SEISMOGRAPHIC NETWORK: RESEARCH OPPORTUNITIES AND RECENT INITIATIVES

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In his book *Inside the Earth* Bruce Bolt (1982) writes about the beginnings of modern seismology some one hundred years ago. In 1883 John Milne, an English seismologist working in Japan, said: "It is not unlikely that every large earthquake might with proper appliances be recorded at any point of the globe". Six years later E. von Rebeur Paschwitz inferred that the waves recorded by horizontal pendulums at Potsdam and Wilhelmshaven were caused by a distant event: "The disturbances noticed in Germany were really due to the earthquake in Tokyo" (April 18, 1889). The era of global seismology had begun. Since then, several generations of seismographic stations have populated our planet, leading to major discoveries both on the earth's internal structure and on the earthquakes themselves. It is only by comparison of observations of the same earthquake at many points on the earth's surface that Oldham was able to infer in 1906 the existence and the size of a fluid core. Similarly, by observing differences in the sign of first motions at many locations around the world, Japanese seismologists initiated the study of source mechanisms.

The need for global coverage of the earth's surface by seismographic stations has been recognized as early as the beginning of this century when the first, very sparse, networks were established. One of the first global networks was supported by the British Association for the Advancement of Science. Seismological research was very much facilitated by the establishment of the International Association of Seismology in 1905 and the publication of the International Seismological Summary with the first issue covering the year 1918; systematic determination of epicenters of the world's large earthquakes can be traced back to 1899.

While the reporting of parameters derived from seismograms – principally the arrival times of body waves – developed early, the research requiring examination of waveforms observed at many stations was difficult. Seismograms had to be requested from individual stations, which often lacked copying facilities and were reluctant to lend the original records.

It was not until the 1960's, however, that the first organized effort to provide seismologists with a complete collection of seismograms from a global network of standardized instruments led to the deployment of the Worldwide Standard Seismograph Network (WWSSN). The data provided by the 125 stations of this network have had a profound effect on modern seismology.

With the advent of digital recording and the simultaneous development of computer technology, new perspectives were opened for global seismology in the 1970's by the possibility of fast processing of large quantities of data. Two digital networks developed by U. S. institutions, IDA and GDSN, have now been providing data for nearly 10 years from stations widely distributed around the world (Figure 1), a hundred years after Milne's prediction.

Today, another leap in technological progress has occurred, with the design of broadband, high sensitivity, high dynamic range seismometers and of high capacity recording systems. Advances both in theory and observation have demonstrated the need for higher quality data. Therefore, there is much excitment again about the prospect of deploying a new generation of globally distributed stations. Efforts towards this goal have now been initiated both in Europe and in North America.

Such state-of-the-art stations would have the dynamic range of about 140 db: sufficient to resolve the ground noise at quiet sites and to record on scale the largest events at teleseismic distances. Their broad-band response would cover a range of frequencies from a fraction of millihertz to $5-20$Hz. The data could be transmitted in nearly real time via satellites.

In what follows, we shall briefly review the existing global seismographic networks, illustrate through several examples the range of the outstanding scientific problems and describe schematically the technical aspects of the new network. We shall also address the issue of data exchange, which is an integral part of the plan, as the objectives of this effort can be realized only by making the data available to the community. This will lead to a discussion of some aspects of international cooperation concerning both network operation and data exchanges.

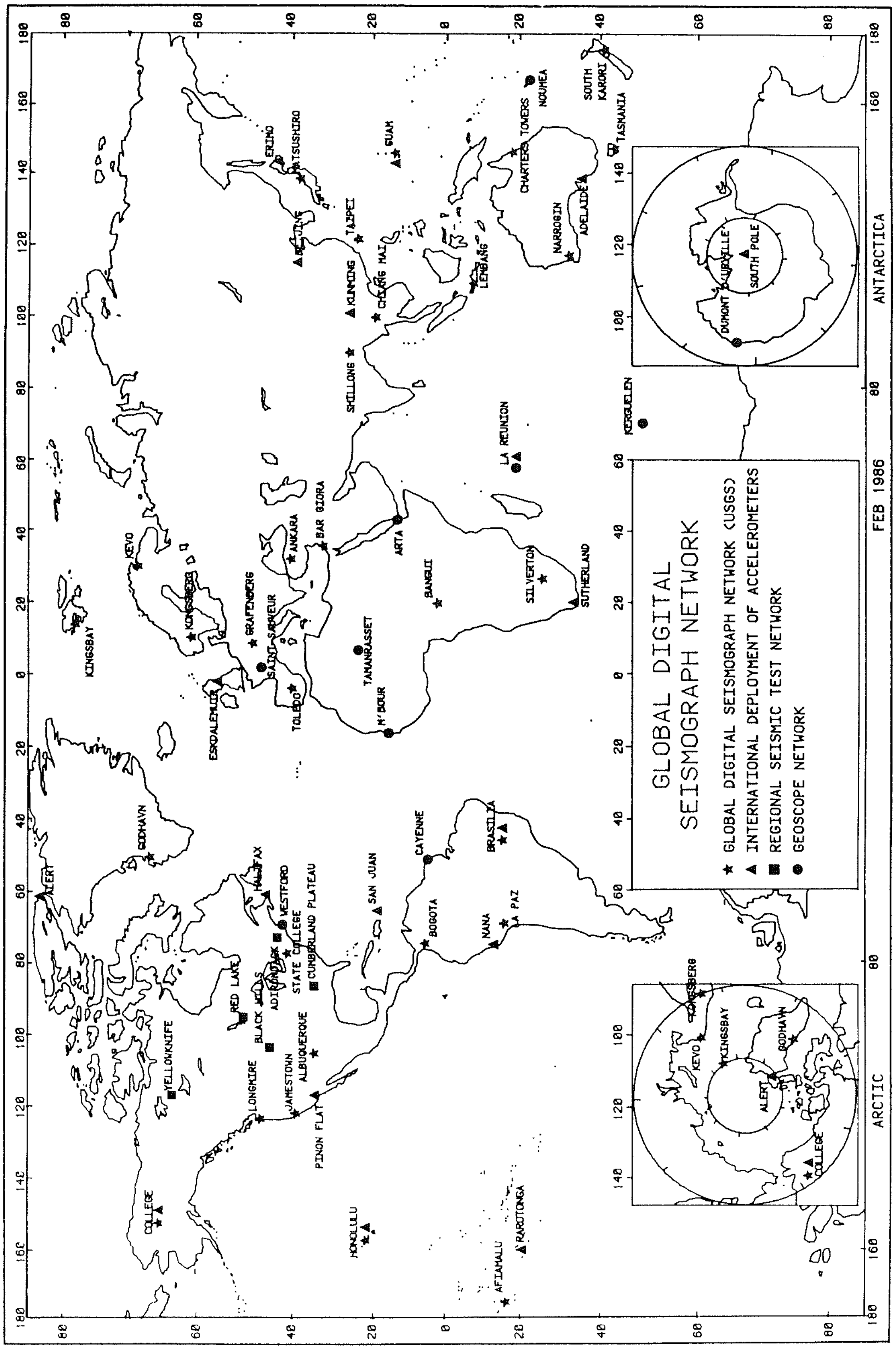

Fig. 1. Distribution of operational worldwide digital stations. (Courtesy of Jon Peterson, USGS.)

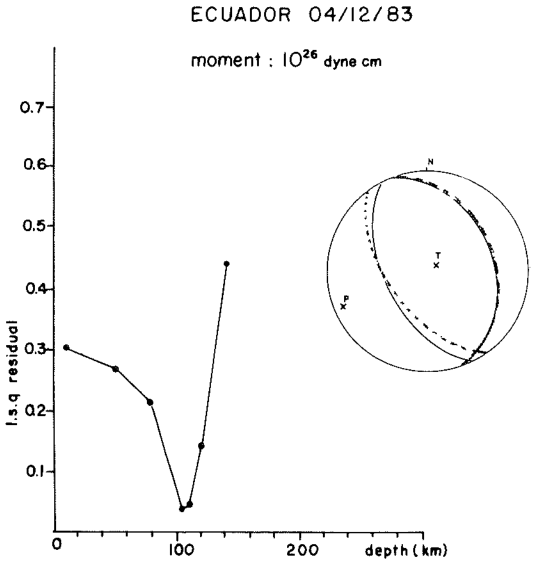

Fig. 2. Example of determination of depth and source mechanism using a moment tensor inversion technique for mantle waves (Romanowicz and Guillemant, *Bull. Seism. Soc. Am.*, *74*, 417-437, 1984). The mechanism obtained (broken lines) is compared with the result of the waveform modelling (solid lines; Dziewonski, Franzen and Woodhouse, *Phys. Earth Planet. Int.*, *33*, 243-249, 1983). The depth of the centroid obtained by the latter method is 111 km.

Being optimistic about the prospects for international cooperation, the authors choose to treat in this report the global digital seismographic network of the future as a single entity.

The format of this report prevents us from acknowledging the work of the multitude of seismologists who contributed to our current state of knowledge. We shall attempt to discuss ideas in general terms and specific references will be limited to the attribution of figures used in the report.

The Present Networks

The existence of WWSSN was a key factor in studies of global seismicity and radiation patterns of earthquakes, which formed the cornerstone of the plate tectonic theory. Also, hand-digitized analog WWSSN recordings were used in quantitative analyses of seismic waveforms. These have led to the determination of improved average models of the earth, provided early evidence for deep seated lateral heterogeneity and revealed the intricacies of seismic sources. These results provided a strong stimulus for the development of digital recording stations. The first of the current generation of globally distributed digital stations was installed in 1975. There are presently nearly 60 operational stations, which are shown in Figure 1.

The Global Digital Seismographic Network (GDSN) is operated by the United States Geological Survey and comprises three different types of instruments from very sensitive borehole seismographs to quarter of a century old WWSSN sensors equipped with digital recording. The International Deployment of Accelerometers (IDA), operated by the University of California, San Diego, is an ultra-long period network of 18 LaCoste-Romberg gravimeters. It was specifically designed to record free oscillations of the earth excited by major earthquakes. The Regional Seismic Test Network (RSTN) consists of 5 installations in the U. S. and Canada and is operated by the Department of Energy. These stations transmit data via satellites in real-time and the entire data stream can be received by anyone within the range of the satellite. In this sense, the RSTN network could be considered the prototype of the new global network. Also, the RSTN stations were designed for unmanned operation – a solution that may have to be adopted in the deployment of seismographs in inaccessible areas such as oceanic islands or uninhabited interiors of continents. The scientific potential of broad-band seismography has been clearly demonstrated through the results obtained from recordings collected over the past ten years by the Grafenberg array in West Germany.

The experience of the last decade proved the importance of digital seismography to the basic research in earth sciences. At the same time, the inadequacies of the limited geographical coverage, narrow-band recording, insufficient dynamic range and resolution became very clear. A movement to instrument the globe with a state-of-the-art network of over 100 evenly distributed stations is gaining wide support. An illustration of this trend is the GEOSCOPE network now being developed in France. This project will be discussed later together with other current initiatives.

Despite the limitations of the existing stations, the digital data recorded during the last 8 - 9 years led to many important results and there is no question that they represent a valuable asset for seismology. The value of digital seismometry is reflected by the fact that most of the research topics discussed in the next section have already benefited from it.

Scientific Perspectives

The collection of data from global networks is crucial for both seismic source and earth structure studies. These two fields are indeed closely related since any seismic record is a convolution of source and propagation effects, which need to be accounted for simultaneously or separated from one another by various techniques. Progress in one area is therefore dependent on progress in the other and this can be viewed as a sort of iterative process over the years. Let us first address the problem of seismic source determination.

Structure was not of primary concern during the era when seismologists were mainly studying source mechanisms using first motion data. P-waveform modelling, which has been shown to improve the resolution of depth, a key factor in plate tectonics applications, is still well adapted to the analog WWSSN data, since only several minutes of long period records need to be digitized. The

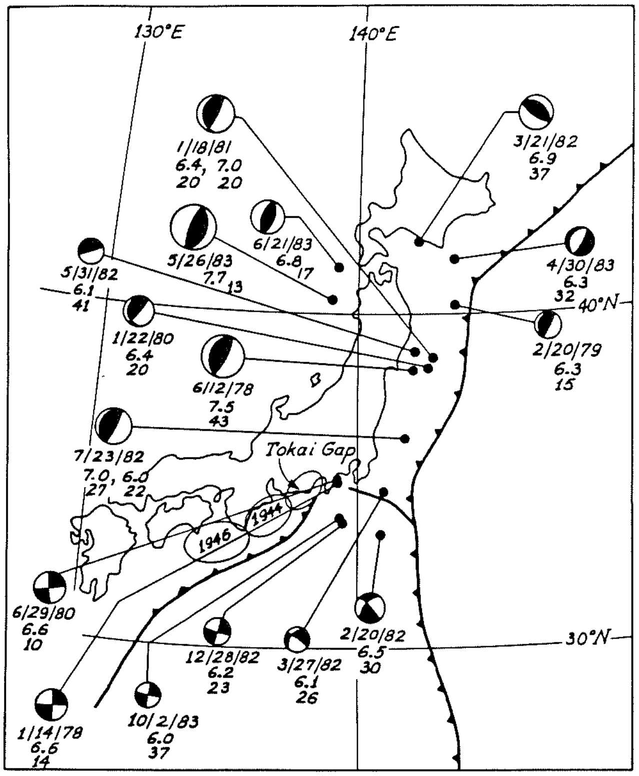

Fig. 3. Best double couple solutions obtained through the analysis of digital data for the years 1977-1983 in the vicinity of the Tokai Gap, Japan (Kanamori and Dziewonski, *EOS Trans. A.G.U.*, *54*, 235, 1984).

advent of digital seismometry has, in turn, stimulated the development of sophisticated methods of analysis of large portions of seismograms, encompassing entire (fundamental mode) surface wave trains or the whole set of body waveforms in front of them.

Seismic Source Mechanism Studies

The availability of the very long period mantle wave data from the IDA network has led to the design of techniques for fast moment tensor inversion in the frequency domain. Data from the GDSN, whose short period cut off permits higher frequency studies, have been the basis for the development of body waveform modelling techniques. The main parameters of seismic sources: mechanism, depth, seismic moment and source duration can now be determined with good accuracy for a wide range of source sizes. Figure 2 shows a comparison of depth and source mechanism obtained, for the Ecuador event of April 12, 1983, by a moment tensor inversion method for mantle waves in the frequency domain on the one hand and a body waveform modelling technique on the other. The latter makes use of the information contained in the first tens of minutes of the seismogram. This procedure has now been automated and solutions are routinely reported in the PDE catalogues, together with moment tensor inversions of P waveforms. A large number of events can be processed in a short time, with seismic moments as low as 5×10^{23} dyne-cm, permitting detailed, regional scale, studies of stress distribution and relaxation in the lithosphere.

Figure 3 shows an example of the best double couple solutions obtained through analysis of digital data for the years 1977-1983. The Tokai seismic gap along the southwestern coast of Japan is extensively monitored by Japanese seismologists. In this gap a magnitude 8+ earthquake occurred in 1854. Since the average repeat time of large earthquakes in this area is about 120 years, some Japanese seismologists believe that another great earthquake is imminent in this gap. Monitoring of earthquake activity is important to assess the pattern of stress accumulation in the gap area.

During February 1982 to October 1983, three moderate earthquakes (2/20/82, M_w = 6.5; 12/28/82, M_w = 6.2; 10/2/83, M_w = 6.0) occurred in the Philippine Sea plate just offshore the Tokai gap. The compression axes of these events are almost horizontal and sub-parallel to the convergence vector of the Philippine plate at the trench.

Such inversions can, with time, improve our picture of the instantaneous stress release around the world, by increasing both the quantity of well determined earthquakes and the quality of these determinations. Real-time monitoring of seismicity in areas or particular interest would allow timely assessment of the significance of individual earthquakes. The addition of digital stations in new locations will improve the azimuthal coverage of the source for many seismic regions. Both mantle wave moment tensor inversions and bodywave modelling techniques could readily be implemented on a nearly real-time basis, when teletransmission of data from network stations to central processing centers is implemented. This is one of the technical goals of the new global seismic network. It will have a major impact on the rapid determination of post seismic risk, including tsunami warning as well as on the efficiency of on-site field studies of aftershocks of large earthquakes.

As we improve our knowledge of the basic parameters of seismic sources, it becomes possible to go into increasingly more detailed studies of source processes. Mapping the source rupture in space and time along the fault break brings insight into the physical processes which govern it. Efficient methods of bodywave modelling for that purpose have already been developed and applied to available data from the WWSSN and GDSN. An example is given in Figure 4.

Progress in this field is dependent on the azimuthal distribution and on the frequency band available in the seismic records, periods between 1 and 5 sec are particularly interesting. Unfortunately, for data from the WWSSN and GDSN, this implies deconvolution of the long and short period instrument responses at frequencies close to the cut-off limit, a process which can be

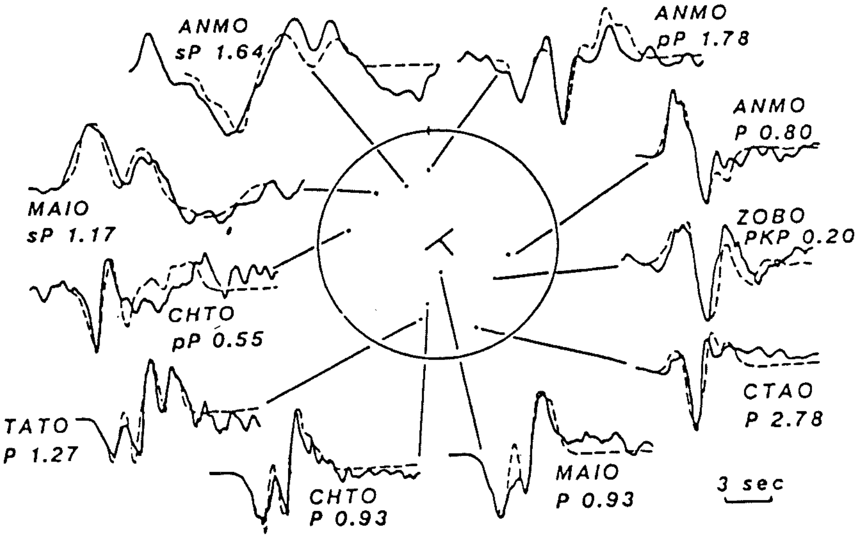

Fig. 4. Velocity pulse shapes deconvolved from digital data (solid lines) for the Kuriles event of 06/21/78 compared with synthetics (dashed lines). The focal sphere is oriented so that the fault plane coincides with the plane of the stereonet. The relative amplitude of the data to synthetic pulse shapes is given next to each record. (From Choy and Boatwright, *Bull. Seism. Soc. Am.*, *71*, 691-712, 1981.)

very unstable. Therefore, much improvement is expected from a global distribution of truly broadband stations.

Earth Structure Studies

As already mentioned, resolution of source parameters and the rupture process implies some knowledge of the structure through which the observed waves have passed, and therefore is tributary to the improvement of our earth models. This is one of the motivations for the detailed study of the earth's structure. The main one, however, is that seismology provides the most accurate tool to gain insight into the dynamic process of the earth's interior, and, in particular, to constrain the patterns of convective flow in the mantle, and the mechanisms of interaction between the lithospheric plates and the underlying asthenosphere.

Different parts of the seismic spectrum are relevant to different aspects of lateral heterogeneity within the earth. Long period free oscillation and mantle wave data are well adapted to map global variations in shear velocity, anisotropy and anelasticity in the upper mantle. Intermediate period surface waves are better suited for regional studies of the same parameters, to constrain lithospheric thickness and detailed structure of the asthenosphere. Shorter period body waves yield complementary information on the fine structure of transition zones and, in particular, that of upper mantle discontinuities and of the core mantle boundary.

In all these respects, a global distribution of broadband, high dynamic range, three component stations complemented by regional networks using the same type of instrumentation can greatly improve the present state of knowledge. We shall illustrate this in the light of recent progress made possible by the available digital datasets, and specifically bear in mind questions relating to the lithosphere - asthenosphere system.

The collection of hundreds of long period records from the digital IDA and GDSN networks over the past ten years has allowed remarkable progress in 3D mapping of large scale upper mantle heterogeneities.

Great circle average measurements of phase velocities of mantle waves, which do not require knowledge of the seismic sources, have led several authors to observe an order two pattern of global heterogeneity whose origin is now thought to be in the upper mantle transition zone. Great circle measurements give us information only about the even part of global heterogeneity of structure. In order to retrieve the odd part and thus localize this heterogeneity, it is necessary to add measurements on arcs of great circle linking sources and stations, which implies corrections for source effects. With the progress in source retrieval, this is now possible and several inversion techniques, in the time or in the frequency domain, have been developed, to produce maps of lateral S wave velocity variations in the whole upper mantle. These maps have been expressed in spherical harmonic expansions up to degree 6 and 8. They agree, in general, in their outstanding features. In particular, the correlation of seismic velocity distribution with surface features down to depths of at least 200 km comes out clearly: most ridges show up as slow regions whereas shields and platforms are fast. Some deeper anomalies, unknown until now, have been displayed. For example, the South

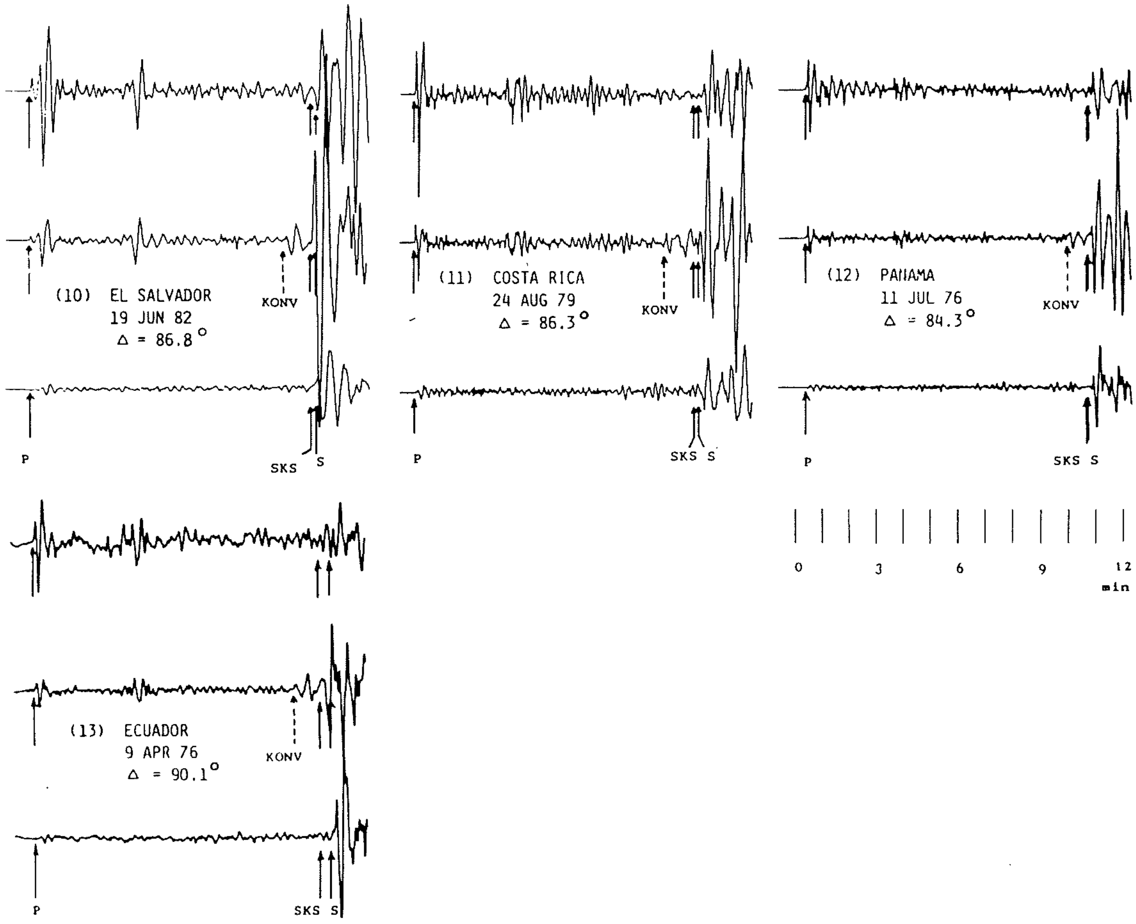

Fig. 8. Long period WWSSN simulations of the broadband Grafenberg data with strong converted phases on the radial component for earthquakes in Central America. From top to bottom: vertical, radial and transverse components for each event (From Faber and Muller, *J. Geophys.*, *84*, 183-194, 1984.)

The study of the variation of attenuation with frequency within the earth's interior is a typical example where broadband worldwide observations are necessary. In order to understand the mechanisms of anelastic relaxation, the whole width of the seismic spectrum must be covered. In particular, the decrease in attenuation around 1 Hz, observed in bodywave studies, must be further documented. Again, this falls right in the domain where available long or short period instrument responses are inadequate.

While long period waves are suited to the study of large scale global patterns, shorter period body waves have much more resolution for problems such as detailed structure of regions of high velocity gradient. Determining whether the upper mantle discontinuities are sharp, and mapping their regional variations are crucial to our understanding of the thermal structure of the mantle and thereby of the convection patterns. The usefulness of broadband instruments in this field has been recently demonstrated with data from the Grafenberg array in West Germany, where reflected and converted phases from the mantle transition zone have been well observed and interpreted in terms of lateral variations in the sharpness of the 400 and 650 km discontinuities. Figure 8 shows an example of such data.

Studies of this type need to be conducted at many stations widely covering the earth's surface and equipped with proper instrumentation. Other body wave converted and reflected phase observations can, in a similar manner, lead to better resolution of the seismic structure of the lower mantle.

The role of the new generation global network in elucidating the seismic structure of both upper mantle and lower mantle is thus clear. As demonstrated by recent comparisons of available seismic models and the observed geoid, stringent constraints will ultimately be imposed on whole mantle dynamics and in particular on the dynamics of the lithosphere - asthenosphere system. More detailed investigations of the structure of the lithosphere on a regional scale, also using broadband surface wave

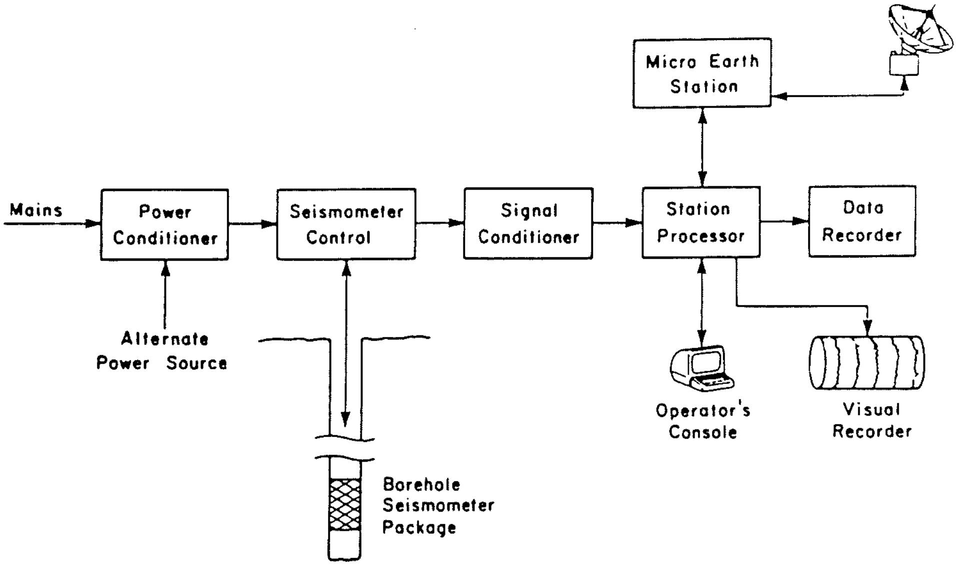

Fig. 9. Block diagram of the remote seismic station of the new generation. Seismometers may be installed on the surface or in boreholes and telemetered where possible to central recording facilities (*Science Plan for a New Global Seismic Network*, I.R.I.S., 1984).

and bodywave data, can be achieved by supplementing the stations participating in the global network through the deployment of denser portable or fixed arrays, specifically designed for this purpose. The models inferred, however, will always have some degree of indeterminacy. The global network will then serve to unify results, by making them compatible with the large scale upper mantle models and this can best be achieved if the regional arrays are deployed around one or several of the fixed, 'global', stations.

Technical Aspects of the New Global Seismographic Network

The goal of a new generation global seismographic network is to produce broad band, wide dynamic range digital data from at least 100 well distributed stations and provide for the timely collection and distribution of these data to a wide variety of users worldwide. The technical requirements of the new stations dictated by the scientific goals are: bandwidth from hours to approximately 10 Hz; dynamic range of 140 db – sufficient to resolve ground noise and to record signals from the largest earthquakes at 30°; low noise instrumentation and environment; linearity of at least 0.01%; real time or nearly real time telemetry, whenever possible.

Figure 9 shows a block diagram of a seismic station. The novel concept is modularization of the system. Any of the modules can be replaced, with the other ones remaining intact. This is the key element of the new network, because it can be gradually upgraded as new technology develops. In this way, we hope, the network will never become obsolete.

While modular standardization is highly desirable, the network must maintain the flexibility to encourage participation of stations with differing characteristics as long as they meet certain standards. Addition of digital stations in unique locations will be of great value to science even if they do not cover the full frequency band or if the real time telemetry were not feasible. A truly global network of standardized broad band instruments, as well as real time data broadcast by satellites throughout the world, represent evolutionary goals.

Let us now briefly discuss the technical developments related to the principal modules.

Seismometer Design

The advantages of feedback systems have been conclusively demonstrated and there is little question that an instrument based on this principle will be used in the network. The feedback systems provide both better linearity and higher dynamic range than the traditional velocity sensors, for example. This has been clearly demonstrated during the ten years of operation of an array of broadband feedback seismographs in Grafenberg, Germany.

A new development, still under tests, is a very broadband system with a response flat to ground velocity from about 3 milliHertz to 5 Hertz. Thus, data from a single channel can be used to study the gravest modes of free oscillations of the earth and short period body waves.

The experience of the SRO stations showed that by placing a sensor some 100 meters below the ground it is possible to achieve significant reduction (up to 20 - 30 db) of wind generated noise. There are thus important advantages of borehole deployment. The disadvan-

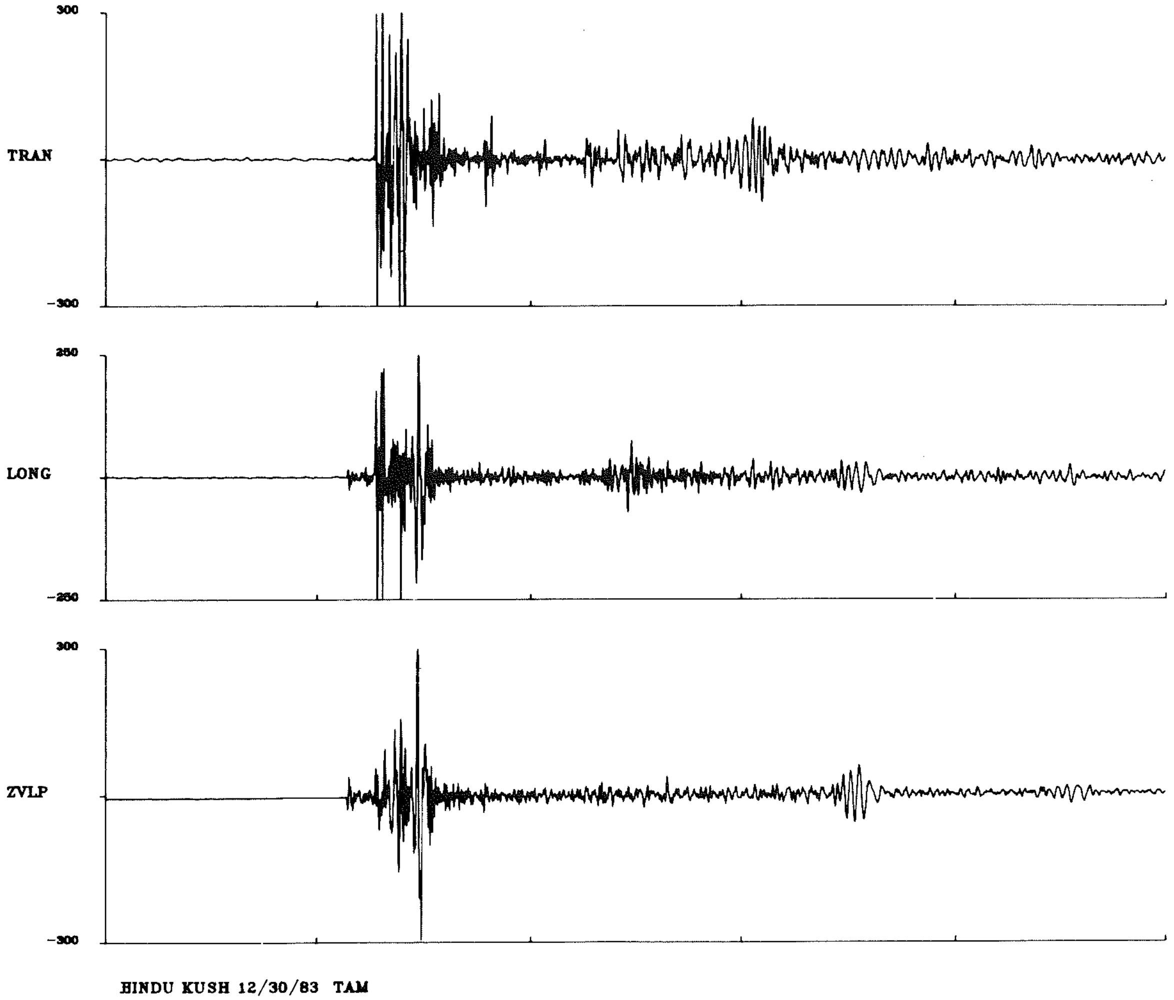

Fig. 10. Example of three component very long period records from the GEOSCOPE station at Tamanrasset (Algeria), for the Hindu Kush event of December 30, 1983. The horizontal components have been rotated and high pass filtered at 500 sec. Tick marks indicate time intervals of 1 hour.

tages are the higher cost and technical difficulties – particularly severe in less developed countries. On small oceanic islands, where the noise level is generally high, little would be gained by borehole installation at short periods.

Analog-to-digital conversion. The essential part of the 'Signal Conditioner' stage is the analog-to-digital (A/D) conversion. The most commonly used 12-bit gain ranged converters are inadequate for very broad band stations. The large differences in spectral power at different frequencies may obliterate the weaker signal at short periods through the insufficient resolution of the mantissa. Recently developed 24-bit A/D converters would eliminate the need for gain ranging. While the initial tests are highly encouraging, the cost of these devices may be considerable. It seems that a 16-bit gain ranged system might be adequate for most purposes; the linearity of the currently available seismograph systems is estimated not to exceed 90 db. However, the high resolution A/D converters clearly point the future direction and their availability might stimulate improvements in the seismograph system.

Station processor. This is the 'brain' of the system. It is based on a micro-computer, which is programmed to control the data flow and operation of the remaining elements. Recent developments in micro-computer technology have brought about a very significant increase in the power of these devices. It is quite feasible to accomplish multi-channel real-time filtration involving FIR (finite impulse response) filters with several hundred coefficients. At the same time, the computer can compress the data, arrange them in buffers, send the buffers to the data recorder and satellite link and take corrective action in the presence of errors. In stations using triggered recording, it can also operate the triggering algorithm. It might respond to remote requests for transmission of specific blocks of data or change the operational parameters such as sampling rate or filter coefficients. Standardization in the choice of the micro-computer would increase the flexibility in evolution of the system by the easy exchange of improved software.

The additional advantage of a very broadband system is that digital filtration of a signal digitized at high data rate leads to an increased resolution at low frequencies. Assuming that the noise in the A/D system is random, 16-bit resolution at a sampling frequency of 20 samples/second allows 20-bit resolution of waves with a period of 25 seconds. This, by the way, is the principle on which the design of 24-bit digitizers, described above, is based.

On site recording. Recent developments in storage technology allow recording with very high density. This makes practical continuous recording of data sampled at a fairly high frequency. For example, a 67 Mb cassette – only slightly larger than the common audio cassette – can contain nearly 10 days worth of data for a 3-component station using a sampling rate of 20 samples/second. This, in part, is aided by compression of the data (first differences), such that only slightly more than 1 byte per sample is required on average. Both station processors and recording systems need to be chosen so that the power consumption is low enough to permit their installation in remote sites located far from a stable power supply.

Satellite link. While the real time seismic data transmission via satellites has been implemented some time ago (RSTN stations, for example), these solutions involved the standard communications technology, which requires expensive equipment and carries high transmission charges. It appears that the spread spectrum technique would make real time data transmission for as many as 100 globally distributed stations economically viable. This subject is treated in some detail in the Science Plan for New Global Seismographic Network (1984).

The real time transmission has important advantages both from scientific and operational viewpoints. In particular, it makes the process of data collection much simpler, such that in about 10 years it may be more cost effective than collating the mailed on-site recorded data. However, for various reasons, it is expected that the real time data transmission will be implemented only gradually.

Data centers. Several countries and institutions are now involved or will be in the near future in the deployment of parts of the new global network. It is only natural that each of these institutions has the responsibility of collecting and handling their own data. In order for seismologists worldwide to have easy access to the dataset from the whole network, it is desirable that two or three regional data centers be deployed in the world to distribute the whole network data collection to interested users. The individual 'sub-networks' could then have their data center linked to only these few data centers, reducing the load of individual requests for data as well as helping to unify the global network operation.

Organizational Developments

It does not really matter to a seismologist using data from the global network under what organizational arrangements the data were recorded. Clearly, the preference would be for receiving all of them from the same data center, written under a uniform format, with stations covering the widest possible band of frequencies and having compatible characteristics. Yet, establishing and running a network of globally distributed stations presents many complex issues. Only one aspect is that of the trade-off between meeting all political preferences and providing good geographical coverage as early as possible.

There are two extreme modes under which a global network can be operated. In the first mode, the operations are centralized under a single organization, which has the responsibility for the design, installation, maintenance, provision of supplies, quality control and collection of data from individual stations. In the other mode, each station (or all stations in a particular country) is operated independently, but contributes the data to the common collection or archival center.

For technological, economic and political reasons, neither of these two modes is likely to succeed in its pure form. It is unlikely that a network operated by a single national agency could achieve the desirable global coverage. The same is true in the other case, as the research priorities, the level of technological development and economic realities might leave many countries, or even large portions of continents, outside such a program. In theory, the first mode could be acceptable, if there existed a truly international agency capable of undertaking this assignment. The establishment of such an organization should be an evolutionary goal and a challenge to the seismological community of the world. At this time, it seems most effective to pursue both ways of development. It is highly encouraging that, indeed, this is what is taking place.

The decision to initiate the GEOSCOPE program was made in France in 1981. There are now 14 operational stations (Figure 1, prepared in February 1986, is not up to date), and the goal is to bring the total to 20 or 30 stations. GEOSCOPE is a global three component network which includes many sites previously unoccupied by high quality instrumentation. It uses as sensors the STS-1 instruments manufactured by Streckeisen and Co. in Switzerland. These broadband feedback instruments are known for their high sensitivity, good linearity and large dynamic range. The data are recorded digitally on site and collected in Paris and will be made available to the seismological community as soon as the initial processing is complete. Real time telemetry to the processing center in Paris is being experimented with. Figure

10 shows an example of very long period records from GEOSCOPE stations.

Incorporated Research Institutions for Seismology (IRIS), a private not-for-profit corporation, was established in the United States in 1984 and it has now 49 member universities. For legal reasons, the membership is limited to U. S. institutions. The establishment of a new global seismographic network (GSN) that would meet the needs of basic science, within a very broad range of frequencies and magnitudes of earthquakes, was one of the principal reasons for the formation of IRIS. The other objectives are the development of a 1000-element portable array for seismic studies of the continental lithosphere (PASSCAL) and establishment of a data center which would distribute to the users both the GSN and PASSCAL data. IRIS has recently submitted a proposal to the National Science Foundation which requests $280 million over a ten year period.

The GSN program of IRIS will be executed in close cooperation with the United States Geological Survey (USGS), which currently manages 97 analog WWSSN stations and 28 digital GDSN stations. While the long range objective of IRIS is to assure the global coverage with approximately 100 broadband, high dynamic range, three component stations with the real time satellite data transmission, the improvement of the selected existing facilities is the most likely early development.

The efforts in France and the United States are directly aimed at providing the global coverage. An equally important contribution to this program can be made by upgrading the national networks. A broadband digital network of nine stations is about to become operational in the People's Republic of China and it was recently announced that 14 stations of the Canadian Network will be upgraded. Both networks will deploy the STS-1 instruments, the same as those used in GEOSCOPE.

In all cases discussed above, at least informal, agreements on data exchange have been reached, so the seismological community shall fully benefit from the operation of these networks.

It is, perhaps, the developments in Europe that potentially may point the way for the future organizational structure of the global seismographic network. In the summer of 1984 the European Geophysical Society created a Working Group for the Global Seismographic Network. Representatives of nine west European countries were present at the initial meeting and 13 countries participated in the subsequent one. It led to the formation of a multi-national consortium under the name of Observatories and Research Facilities for European Seismology (ORFEUS). ORFEUS published its Science Plan in 1986. It is hoped that its activities would be supported by the European Science Foundation through contributions from individual countries. The consortium would sponsor new efforts on the regional (European) as well as global scales. It is planned that a European Seismic Data Center would be developed for the management of the collection and distribution of the data.

The authors believe that the development of regional multi-national consortia may be the most promising way to assure the stable environment for the global network. Such groups of countries, united by the need to study the regional seismicity, could share the maintenance facilities as well as the data collection and distribution centers. Through agreements on the station characteristics and data exchange with the other regional consortia of the world it should be possible to assure the required level of uniformity and meet the needs of science to a greater extent than it is feasible now.

At the same time, it is necessary that full cooperation be extended to the current efforts, as their success will provide the experience needed to stimulate the world program in seismology on an unprecedented scale. The network of the future cannot be global only in its coverage but must also involve active participation of all seismologists.

Note added in proof: New developments have taken place since this report was prepared nearly two years ago. In particular, a Federation of Digital Broad-Band Seismographic Networks was formed in August 1986. The statement of purpose of the Federation reads as follows:

"The international seismological community recognizes new opportunities within its field for improved understanding ot the internal structure and dynamical properties of the Earth provided by recent developments in seismograph network technology.

It also recognizes that rapid access to seismic data from arrays of modern broad-band digital instruments, wherever they might be, is now possible.

The developments include greatly improved broadband seismographic systems that capture the entire seismic wave field with high fidelity, efficient and economical data communications and storage, and widely available, powerful computing facilities.

In view of the above, and to take advantage of existing developing global and regional networks, it is considered that the Federation be formed to provide a forum for:

–developing common minimum standards in seismographs (e.g. bandwidth) and recording characteristics (e.g. resolution and dynamic range);

–developing standards for quality control and procedures for archiving and exchange of data among component networks;

–coordinating the siting of additional stations in locations that will provide optimum global coverage.

The Federation welcomes the participation of all institutions committed to the deployment of broad-band seismographs and willing to contribute to the establishment of an optimum global system with timely data exchange."

The initial members of the Federation are: Australia, Canada, China, France, Germany, Japan, ORFEUS and the United States (represented by IRIS and the USGS). The Federation is affiliated with the International Association of Physics of the Earth's Interior (IASPEI) and the Inter-Union Commission on the Lithosphere (ICL).