GEOSCOPE: A French Initiative in Long-Period Three-Component Global Seismic Networks

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Introduction

Progress in long-period seismology has been considerable in the past few years, owing to the availability of digital data from well-calibrated worldwide instruments. The very long period International Deployment of Accelerometers (IDA) network [*Agnew et al.*, 1976] has provided many new measurements concerning both earth structure and seismic source studies and demonstrated the usefulness of sparse global digital networks. The broadband Global Digital Seismographic Network (GDSN) network has given access to a large quantity of data whose exploitation can be readily automatized.

Both networks have their shortcomings, however, now expressed in the desire of many U.S. scientists to develop a new global digital network better adapted to present requirements of geophysical research. In the very long period domain (periods from about 100 s to 1 hour), the IDA network only records the vertical component of ground motion, making information from horizontally excited modes of the earth unavailable. It also saturates the first Rayleigh wave trains from the largest earthquakes, causing a loss of data on direct source station paths, regrettable both for source and structure studies. The GDSN network suffers from some nonlinearity problems and, above all, the inadequacy of instrument responses for present needs of seismologists: The Seismic Research Observatories (SRO) network [*Peterson and Orsini*, 1976], which is the main constituent of GDSN, was designed mainly for discrimination between earthquakes and nuclear explosions.

In the past few years, improvements in technology, in Europe in particular, have led to the design of easy to handle, robust, well-calibrated, three-component broadband seismometers, with built-in flexibility and multiplicity of instrumental responses and a large dynamic range [*Wielandt and Streckeisen*, 1982]. Progress has also been made in the design of digital recording systems with the advent of microprocessor technology and the increased capacity of magnetic recorders of low power consumption. It thus became possible to embark on the design of a new global long-period digital network that would complement the existing ones with improved capabilities and original station locations.

At the Institut de Physique du Globe (IPG) in Paris, we felt well prepared for this enterprise, given our long-term experience in long-period seismology [*Jobert and Roult*, 1976; *Jobert et al.*, 1977], instrumentation, digital recording, and data processing [*Blum and Jobert*, 1959; *Blum and Gaulon*, 1971] as well as our access to original sites through the numerous scientific cooperation programs that France maintains worldwide.

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Editorial

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A Change for Reviews

AGU's review journal, *Reviews of Geophysics and Space Physics*, began 20 years ago with the title *Reviews of Geophysics*. In 1970 the title was changed to *Reviews of Geophysics and Space Physics* (RGSP). By AGU Council action in December 1983, the title will revert to *Reviews of Geophysics*, effective 1985.

With the growing number of geophysics articles published each year, review journals have an ever more important role to play, and they must be continually reevaluated to see if they meet their responsibility. In a comparison of the types of papers published in this journal for the years 1979–1982, and in a comparison of AGU membership according to section, one sees the results given in the table.

This suggests that we have an imbalance in the types of papers published. More papers are needed from members of the Hydrology, Ocean Sciences, Tectonophysics, and some other sections while the good flow of papers is kept up from the Atmospheric Sciences, Planetology, SPR, and other sections.

By allowing the name of the journal to revert to *Reviews of Geophysics*, in agreement with the name of our Union, we remove any shadow of a doubt that all types of articles are welcomed and needed by this review journal. We hope that members in those sections of AGU which were underrepresented will be further encouraged to submit reviews.

It takes more than a name change to change the nature of a journal, and we hope the readership will appreciate the effort that the editorial staff is now making to promote timely and comprehensive reviews across the full range of our interests.

J. R. Heirtzler
Editor, Reviews of Geophysics and Space Physics

Section	Papers in RGSP, %	AGU Membership, %
Geomagnetism and Paleomagnetism	4.9	4.8
Geodesy	8.3	3.7
Seismology	6.9	10.0
Atmospheric Sciences	17.4	6.8
Ocean Sciences	9.7	13.4
Volcanology, Geochemistry, and Petrology	8.3	10.2
Hydrology	0.7	17.0
Tectonophysics	0.7	9.5
Planetology	14.6	4.7
Solar-Planetary Relationships	26.4	11.5

Cover. Artist's stylized representation of some highlights of San Francisco, host to AGU's 1984 Fall Meeting. Timeless and pleasing—with fine restaurants, temperate December climate, and the charms of Chinatown, Ghirardelli Square, Fisherman's Wharf, Nob Hill, and North Beach—San Francisco is an elegant city and an ideal backdrop for AGU's scientific sessions. This year's meeting will be held December 3–7 at the Civic Auditorium. Housing reservation deadline is October 31. Meeting preregistration deadline is November 9. See Session Summary and Housing and Registration forms in this issue. (Cover designed and drawn by Dae Sung Kim.)

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GEOSCOPE Project: Specifications

After a period of experimentation with the Wielandt seismometers in our Saint-Sauveur Observatory in the center of France [*Roult*, 1982], this project came to life in 1981 as a joint effort of the IPG in Paris and Strasbourg, sponsored by INAG (Institut National d'Astronomie et de Géophysique). It was first meant to be a three-component very long period (VLP) network to fill gaps in the geographical distribution and remedy the lack of horizontals of the IDA network. For purpose of comparison, an IDA instrument was run in parallel with the Wielandt vertical seismometer at Saint-Sauveur for a period of 1 year starting in October 1981. The comparative study of performances and especially of noise had shown that similar noise levels are to be expected from both instruments with the advantage of wider dynamic range for the Wielandt seismometer [*Romanowicz and Agnew*, 1984].

It soon appeared, under the pressure of new developments in the field of digital seismology, that the potential of the instruments was not being used at its best, and that with little additional effort the broadband (BRB) output inherent to the seismometers could also be recorded to satisfy the needs of research in the period range 1–100 s. If three-component VLP channels provide basic data for large earthquake investigations and for the study of large-scale processes in earth physics, the BRB outputs are of fundamental importance in obtaining finer details both in source and in structure studies. They open the field of body wave and surface wave seismology, allowing us to apply most of waveform modeling techniques to the records to be provided by the network. Furthermore, the recording of the BRB channels will be important for participation in the collection of regional data in connection with more local networks.

The Wielandt-Streckeisen seismometers can provide signals up to 5 Hz. The BRB output is, for example, recorded at 20 samples per second in the Graefenberg array [*Harjes and Seidl*, 1978]. There is, however, a stringent constraint for the GEOSCOPE project: Most remote stations should have recording facilities with an autonomy of at least 1 week. Our philosophy is to use well-tested technology that has proved high performance in remote sites. Owing to the storage capacity of low power consuming recorders presently available, this forces us to (1) use event detection for the BRB output and (2) limit the sampling rate to five samples per second. If the magnitude threshold is fixed to about six, worldwide, allowing for additional triggering by possible small magnitude events and if the recording length per event is fixed to 2 hours, five samples per second appears to be the upper limit.

Thus the specifications of the network presently retained are as follows: About 20–25 stations worldwide, each equipped with a three-component set of Wielandt seismometers, and a digital recording system of low power consumption, providing data simultaneously in two-frequency bands: (1) VLP (very long period), with continuous recording at a sampling rate of 10 s; (2) BRB (broadband), recording on event detection for 2 hours, with a sampling rate of five points per second in the present experimental stage.

The instrument response curves of both channels are shown in Figure 1. When the more powerful technology presently under development has proved its performance in the field, it will be possible to update the system to fully use the capabilities of the seismometer. The seismometers have been described in detail by *Wielandt and Streckeisen* [1982]. The vertical is a leaf spring feedback seismometer of 20-s natural period; the horizontals are simple pendulums with 10-cm boom length. All have a very small size and are well shielded from pressure and temperature variations by void glass jars and several layers of insulating materials. Their dynamic range is about 140 dB at the output of the analog units.

Two recording systems are presently being tested. The first one has been designed by G. Streckeisen. It records on digital magnetic cartridges with a capacity of 1–2 million samples and has gain ranging dynamic range of about 114 dB. A second system has been developed independently at IPG in Strasbourg. It is derived from a low power consuming PCM acquisition system which has been developed for a mobile network of portable short-period stations; 400,000 samples can be easily stored on a 1-hour regular audio tape (305 m)in the system currently being tested in the GEOSCOPE station in Kerguelen. The dynamic range of the recording system is presently 114 dB. Both systems are designed to be well adapted to installation in remote, uncomfortable sites.

While these systems are being tested, most stations are temporarily equipped with a simple DATEL cassette recorder. This restricts us for the time being to recording only the VLP channel on all three components. The station at SSB has just been equipped with the new Streckeisen recording system, and the station at Kerguelen Islands (PAF), benefiting from nine-track tape recording facilities, also records a very long period channel with a broadened response to higher frequencies, called HGLP, as well as the vertical BRB channel at a rate of one sample per second.

The data are sent back via airmail to the IPG in Paris (through Strasbourg in the case of station PAF), where a data center is being equipped, to unpack, verify, and transfer the data to nine-track tapes for distribution to potential users worldwide. The format for the final nine-track tapes is a hybrid between the IDA and GDSN formats, which should make retrieval of data as simple as possible. Real-time transmission of data is currently under study, in cooperation with INAG. An experimental system is currently being installed at Saint-Sauveur (SSB).

Present Status of the Network

The three stations now running for over a year are SSB (Saint-Sauveur, France), PCR (La Reunion, Indian Ocean), and PAF (Kerguelen Islands). The network counts five operational stations as of May 15, 1984: One has been installed in October 1983 in Tamanrasset (Algeria), in cooperation with the ONRS, and another one has been installed in Wallace Observatory (Cambridge, Mass.) in cooperation with the Massachusetts Institute of Technology. Figure 2 shows the geographical distribution of the existing and planned stations. By the end of 1984, eight stations should be in operation. In addition to the stations installed by France, stations equipped with Wielandt seismometers by Eidgenössiche Technische Hochschule (ETH) (Zurich) will be upgraded to join the GEOSCOPE network (Azores, Iceland, and possibly western Canada), when the digital recording system, now in an experimental stage, will have reached its final version.

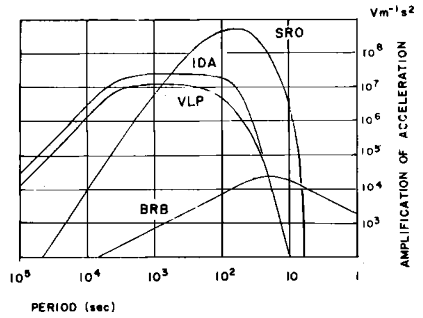

Fig. 1. Instrument response curves of Wielandt VLP and BRB channels as compared to IDA and long-period SRO responses.

For the years 1985–1986 we plan to install more stations in sites easily accessible for France (Tahiti, Dumont d'Urville in Antarctica) or in cooperation with other countries, as is presently the case for Algeria and the United States.

So far, the sites installed have benefitted from pre-existing facilities, mostly seismic observatories, which have not required the building of vaults and the design of data transmission systems to removed recording sites. In the stations planned for 1984, Djibouti, French Guyana, and Noumea, this is necessary. A seismic vault has already been built in Djibouti. Sites are carefully chosen to be shielded from winds and other atmospheric perturbations, but for the time being we do not intend to bury the instruments in depth.

Scientific Potential of the Network

Recent observations of eigen periods and attenuation of spheroidal modes from the IDA network have led to the improvement of average earth models but also to the discovery of specific patterns of *S* velocity heterogeneity in the upper mantle and transition zone [*Silver and Jordan*, 1981; *Masters et al.*, 1982]. Regionalized models of the earth have been improved in the past few years by using data from the IDA network [*Dziewonski and Steim*, 1982] and from other digital stations, in particular stations installed in the past in France and the Pacific Ocean by IPG [*Blum and Gaulon*, 1971; *Jobert et al.*, 1979; *Lévêque*, 1980]. Recently, maps of lateral heterogeneity in the mantle have been obtained from low-order spherical harmonic expansion of phase velocity data from the IDA, GDSN, and Worldwide Standard Seismograph (WWSSN) networks [*Nataf et al.*, 1984*a*; *Souriau and Souriau*, 1983; *Dziewonski and Woodhouse*, 1984]. On the other hand, attempts at resolving the question of anisotropy in the upper mantle as raised by the PREM model [*Dziewonski and Anderson,* 1981] and many regional surface wave studies, including overtones [*Lévêque and Cara,* 1983], have been promising [*Journet and Jobert,* 1983].

S velocity and its anisotropy are two parameters whose heterogeneity plays a key role in geodynamics. *S* velocity can be related to density, which governs mantle dynamics, while anisotropy can be related to lines of convective flow; in other words, to mantle kinetics.

While many more interesting results are to be expected from the existing digital networks, some of their limitations make the project GEOSCOPE attractive and necessary.

To attain a better resolution of lateral heterogeneity, a better distribution of stations is necessary. This means more stations but also a more homogeneous distribution around the earth. From this point of view, GEOSCOPE stations in the Indian Ocean and South Pacific are bound to play a decisive role.

To reduce the uncertainty in the odd order terms of spherical harmonic expansions of *S* velocity, it is necessary to be able to use surface and mantle Rayleigh wave trains in direct source station paths. With a large dynamic range, the GEOSCOPE instruments are well suited to this purpose. To study anisotropy, one must analyze simultaneously Love and Rayleigh wave trains. The three-component configuration of GEOSCOPE stations is again appropriate. It is also the case for depth resolution of *S* velocity heterogeneities. Figure 3 shows examples, on the longitudinal components, of phases rich in long-period Rayleigh wave overtones (X phases) at two different GEOSCOPE stations and for two different events. Regionalization of such overtones will notably increase spatial and depth resolution of heterogeneities [*Okal and Jo,* 1983], whose study was until now practically limited to the analysis of the fundamental mode alone, for example, in oceanic areas [*Montagner and Jobert,* 1981, 1983]. With this perspective the hope is raised that it will soon be possible to obtain information of primary importance on the convective regime within the mantle of the earth.

Owing to the broadening of the frequency band up to 1 Hz, the GEOSCOPE records will permit the study of smaller-scale structures. Long-period body wave modeling is particularly well suited to investigate mantle transition zones, and body wave correlation techniques, as used by *Stark and Forsyth* [1983], will permit the investigation of deep lateral variation of velocity. Figure 4 shows an example of long-period body waves recorded in the Kerguelen station. The structure of the lithosphere and, in particular, the question of possible coupling between seismic thickness of it and anisotropic parameters, as raised by *Anderson and Regan* [1983], could be properly addressed by making full use of Love and Rayleigh wave data provided by the three-component broadband output of the GEOSCOPE network.

Progress has also been considerable in the past few years in the domain of long-period source studies, owing to the rapid analysis made possible with the availability of digital data.

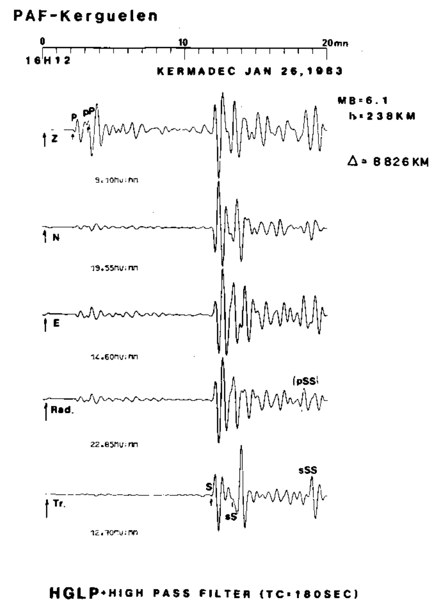

Fig. 4. Example of long-period body waves recorded in the GEOSCOPE Kerguelen station (PAF).

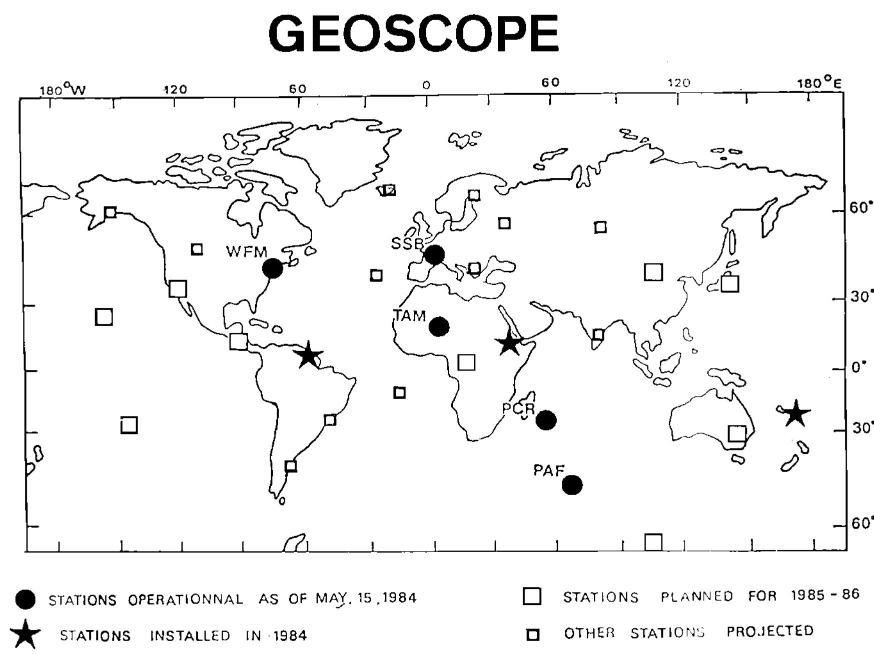

Fig. 2. Geographical distribution of GEOSCOPE stations in operation and planned. Sites for stations planned beyond 1984 are hypothetical.

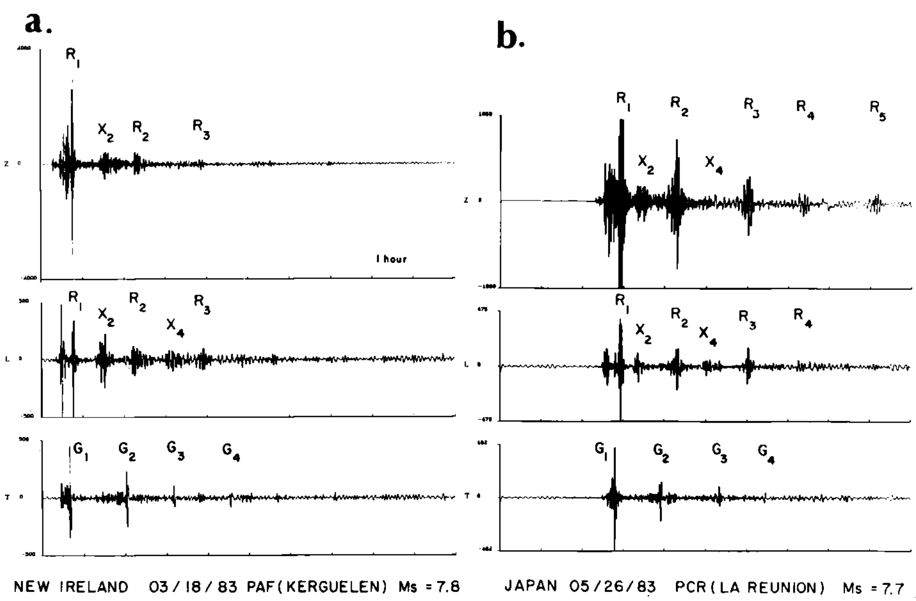

Fig. 3. Records at two stations of two large events in 1983, on the VLP channel. Horizontals have been band pass filtered (100–500 s) and rotated to yield longitudinal and transverse components

Source parameters for the larger earthquakes that have occurred in the past 5 years have been retrieved from the IDA network [*Kanamori and Given,* 1981; *Silver and Jordan,* 1983], yielding information on the long-period behavior of the sources. It appears that in many cases an estimate of depth of source can also be obtained from very long period data alone [*Romanowicz and Guillemant,* 1984]. Waveform modeling of the first tens of minutes of the long-period GDSN records has also permitted to complement the automatic compilation of first-arrival data by information on source parameters and depth of relatively small earthquakes [*Dziewonski et al.,* 1981].

The new data that GEOSCOPE can provide will increase the resolution in long-period source studies by complementing azimuthal station distribution and, again, providing three-component data on the first Rayleigh and Love wave trains. Source studies using body waves will also benefit from the availability of broadband data. For example, *Choy and Boatwright* [1981] have shown how increasing the frequency band of the signal toward shorter periods is important for the study of variation with frequency of attenuation and details of seismic sources, such as directivity and rupture process. To achieve this, scientists have to combine long- and short-period records, a disputable process which can be avoided with the broadband data provided by GEOSCOPE.

Conclusion

The GEOSCOPE network represents a new experiment in global networks that incorporates to date technological achievements and is geared toward satisfying the requests of present-day geophysical research. As such, it is bound to become a basic tool of seismologists in the next 10–20 years.

Out of 20–25 stations planned in the next 5 years, five are operational, and three more will be installed by the end of 1984. With its present setup of international cooperation (e.g., that planned with ETH in Zurich), we hope that GEOSCOPE will become the core of a denser future international network, with Contributions from several other countries.

Acknowledgments

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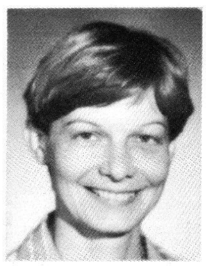

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