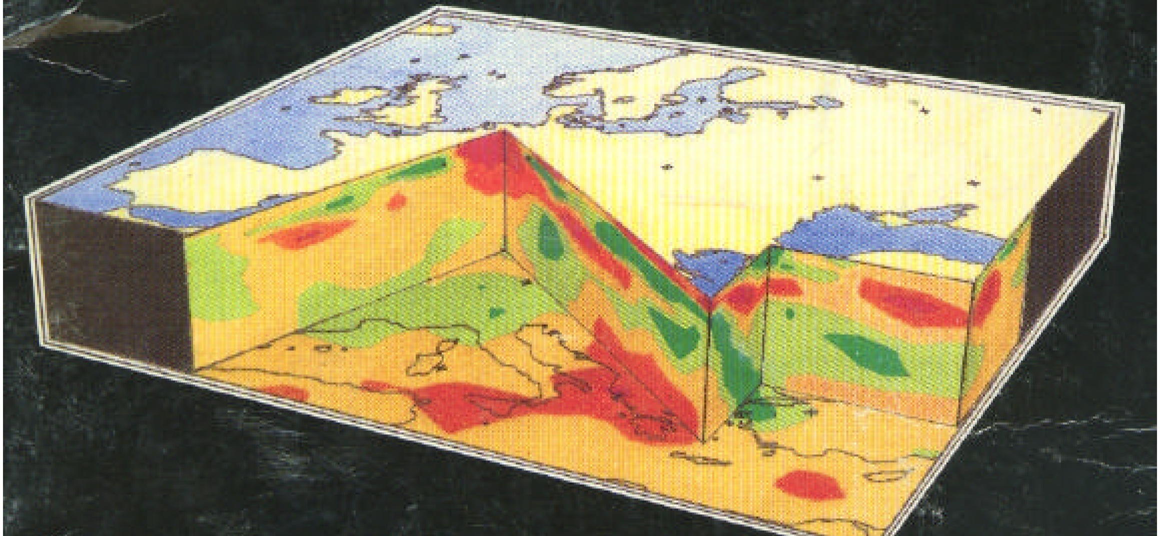
ORFEUS SCIENCE PLAN



OBSERVATORIES
AND
RESEARCH FACILITIES
FOR
EUROPEAN SEISMOLOGY

ORFEUS SCIENCE PLAN

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ORFEUS
SCIENCE PLAN

Observatories and Research Facilities
for European Seismology

January 1986

Orpheus was probably a Thracian king, who was famous for his musical talent. He was married to the nymph Eurydice. Orpheus' wanderings in the underworld began when Eurydice was mortally bitten by a snake that lay hidden in the grass. Heartbroken, Orpheus decided to try to reclaim her from the infernal deities.

With the power of his music, he persuaded Hades and Persephone to give him for once access to the underworld, and take Eurydice from there to the surface of the Earth. There was only one condition: during the journey he should not look back to see if she was following him. At the end of the journey, near the gates of Hades, Orpheus imprudently looked over his shoulder, only to see Eurydice vanish, this time forever, into the inaccessible depths of the underworld.

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TABLE OF CONTENTS

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Summary. This science plan for Observatories and Research Facilities for European Seismology (ORFEUS) is a joint statement of some 25 seismologists, cooperating in the ORFEUS working group of the European Geophysical Society, and representing 13 European countries listed in appendix A. It is composed as a guideline for national efforts, and as support for the financing of national and European projects that are proposed in its context.

As a start, this science plan proposes:

(a) To provide facilities for the exchange of digital seismograms ("ORFEUS data center")
(b) To coordinate placement of permanent, broad band instrumentation
(c) To promote dense deployment of compatible, portable broad-band instrumentation

Its aim is briefly to allow European seismologists to maintain their lead in broad-band seismometry, in view of the efforts of the Incorporated Research Institutions for Seismology (IRIS) in the U.S. to deploy two seismograph networks involving several hundred million dollars in the next ten years.

Europe has the start of broad-band seismometry mainly because of several recent national projects. The German small-aperture Grafenberg array was the first major digital broad band installation. It also initiated the commercial production of a new type of broad band seismometer. The Dutch NARS project showed the feasibility and usefulness of wide-band digital instrumentation in a large aperture, portable array. The French GEOSCOPE network, finally, operates broadband instrumentation on a global scale. All three projects are financed by science foundations on a national scale. The UK department of defence is also operating a small broad band network.

Whereas financing of projects on a national scale is probably the best one can do in the present European situation, there is a growing need to obtain some consensus on the direction that evolutions in instrumentation should take. From a large number of early experiences with broad-band instrumentation, listed in chapter 3 of this plan, it becomes clear that the new technology can indeed lead to significant gains in our knowledge of the Earth's interior, on the condition that the density of seismographs on the surface will be greatly increased. Although digital technology makes it possible to operate many stations with little manpower, the management and exchange of large quantities of data forms a technological challenge by itself, especially when done in "real-time".

The aim should be that, by the year 1996, digital broad band stations are separated not more than 200 km apart, especially in regions of tectonic interest, and that a pool of at least 200 mobile broad band stations is available for temporary increase of the local station density.

In order to obtain the mentioned goals, and to update them in the future, a legal structure for ORFEUS is proposed that enables it to handle financial matters and establish contacts with the major European sponsoring institutions.

1. Introduction

In the past 30 years spacecraft have been sent out by man to orbit terrestrial planets, fly past the outer fringe of the solar system, and sample rocks from Moon, Mars and Venus. Compared to this grand scientific, technological and financial operation, investments in the one Earth science - seismology - that is able to penetrate into the deep inner domains of our *own* planet must be called modest at best. And even though other branches of the Earth sciences did benefit to a larger degree, funding in geophysics cannot be compared to that in space physics.

Yet the scientific results have not been less spectacular: the theory of plate tectonics was developed and provided a framework for the understanding of many phenomena at the surface of the solid Earth, most of which are not only of scientific but also of public interest. Our knowledge of stresses in the Earth and earthquake mechanisms, of the evolution of oceans, continents and continental margins and last but not least the genesis of ores, oil and gas in this process has been steadily growing in the past decades. Industrial and academic research into seismic exploration methods has so far done more to secure our energy needs in the near future than the combined national and international efforts in the nuclear energy sector.

Seismic waves enable us to "look" into the Earth's interior. The picture is blurred because we have a limited resolution, depending on available data and computing capabilities.

In this Science Plan we hope to show that future progress in Earth sciences hangs on our ability to increase the resolution of seismic observations by at least one order of magnitude. This resolution can be improved by modernizing the often obsolete instrumentation of seismic stations, and by significantly increasing the number of broad-band digital seismographs. International cooperation is needed for funding, deployment and data management of such a dense seismic network.

1.1. MAJOR THEMES IN SOLID EARTH PHYSICS

Knowledge of stress fields in theEarth, of sometimes very detailed behaviour of the earthquake source, and steadily improving earthquake statistics, have by now given us the possibility to predict the seismic risk quite accurately in many areas. However, although we can quite well estimate *where* large and damaging earthquakes may occur, we have not yet arrived at reliable methods to predict *when* these earthquakes will happen.

In geodynamics, we are facing many questions and even paradoxes that become more fundamental as they relate to deeper regions of the solid Earth (figure 1.1): how can deep continental roots under the oldest cratons translate with plate movements and what is the basic mechanism of continental rifting? What is the fate of the subducting slab? How can isotope variations survive for billions of years in a convective, hence strongly mixing, environment in the mantle? What is the 650-km discontinuity, and is it a barrier for vertical mantle flows? Are there significant lateral heterogeneities in the lower mantle and on the core-mantle boundary? Is the inner core growing, thus providing the energy for the Earth's magnetic field? Or is this field fuelled by large quantities of potassium in the core - so much that the Earth may even still be warming up? And, most importantly: with what kind of convective pattern does the Earth get rid of all the energy generated in its interior?

Monitoring small changes in seismic velocities precursory to an earthquake in the crust requires a very high spatial resolution, sometimes less than one kilometer. Delineating the convective pattern in the mantle by detecting velocity differences or anisotropy does require a resolution of a few tens of kilometers in the upper mantle to less than a few hundred kilometer in the lower mantle. Measuring the reflection coefficients at the outer and inner core boundary does require very narrow beam-forming to increase the signal/noise ratio. None of these resolutions are available with conventional seismological instrumentation and the present density of seismic stations.

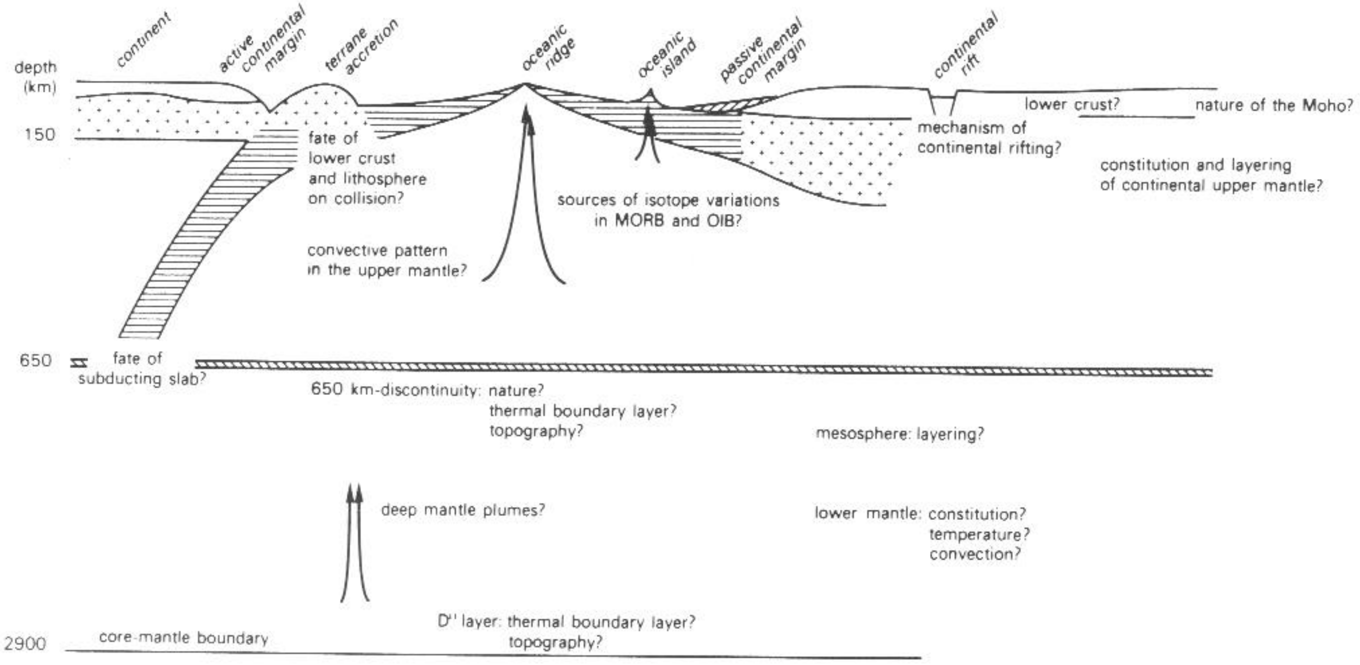

Figure 1.1 A schematic overview of some of the currently most pressing problems in the geosciences that are open to attack by seismological methods. Emphasis in this figure is on the mantle. However, it is likely that new seismic instrumentation will bring in new data with relevance for the structure and dynamics of the core as well (Nolet, with permission).

1.2. SEISMIC INSTRUMENTATION

The problems outlined in the previous section can only be resolved with a significant advance in seismic instrumentation. What form should this improvement have?

Very roughly, the performance of a seismic network can be evaluated by two criteria:

- How wide is the band of frequencies that is recorded with a sufficiently high signal/noise ratio?
- What is the characteristic distance between two stations?

The bandwidth of a seismograph is limited at the low-frequency end by the sensitivity of the seismic sensor. Since the stability of the sensor decreases with increasing sensitivity at low frequencies, low frequency networks require special housing or even boreholes for the instrumentation. The NARS network[1] which operates seismometers with an eigenperiod of 12 seconds and has good sensitivity down to 5 mHz, represents the limit that can be reached with conventional sensors for "portable" seismic stations.

The sensor does not impose serious limitations to the high frequency response of the seismograph. Here it is the digital recording that limits the number of samples per second that can still be handled in a convenient way. Since recording capacities of different devices are still growing quite fast, it is the low-frequency end that needs most of the attention if we wish to deploy networks with broad-band instrumentation. With the term "broad-band" instrument we shall designate in this science plan any instrument that provides useful recordings at least in the band from high (2 Hz) to low (10 mHz) frequencies in a single channel. In order to enable filtering afterwards, recording in digital form is a prerequisite.

Although there is now an adequate sensor available for use in broad-band seismic stations of a more permanent nature (the leaf-spring STS seismometers designed by Wielandt and Streckeisen), development of a stable, low-cost seismometer that combines low-frequency sensitivity with true portability is still highly desirable.

The second criterion mentioned concerns the station density of a network. Locally, very dense seismic networks are available, such as the networks monitoring earthquake activity along the San Andreas fault in California, volcanic activity on Hawaii or the NORSAR array in Norway which is used to detect nuclear test explosions. "Tomographic" studies with data from such networks have shown that a very high resolution is locally available. However, these local networks are in general not large enough, or lack the wide frequency band response needed for their use in more fundamental (deeper) seismological research. Very narrow beamforming, or detailed studies with higher mode surface waves, require a dense network to be spread out over more than 1000 km, a scale of continental dimensions.

1.3. INTERNATIONAL COOPERATION

The existence of political boundaries that do not coincide with geological or geophysical boundaries is - and has been in the past - an unnecessary hindrance to the construction of seismological networks. This problem is even more acute for European seismologists, who cannot carry their instruments over distances of more than a few hundred kilometers without encountering a discouraging amount of paperwork at a local customs office.

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[1] Network of Autonomously Registrating Stations

However, seismological data in digital form can easily be exchanged and this opens up the possibility to deploy a seismological network by combination of well-coordinated national efforts. *Our aim should be to coordinate placement of permanent broad band stations, to provide facilities for the exchange of digital seismograms and to promote dense deployment of compatible, portable instrumentation for observing the seismic wavefield at intermediate wavelengths.*

This is essentially the task that the ORFEUS working group wishes to accomplish. Since several digital, broad-band seismological networks are already in operation or being planned by European seismologists right now, the task is an urgent one. At short notice, the task may be accomplished by three means:

- To establish a European data center for exchange of digital, broad-band seismograms
- To cooperate in matters concerning station design and location selection
- To stimulate the development of portable, broad-band instrumentation

In a later stage ORFEUS can play a major role in coordinating the deployment of matched, portable instrumentation belonging to seismological institutions of different nations. This could be done by means of a second facility for data exchange, and more directly by the initiation of joint projects between members of the group.

1.4. ORFEUS AND EUROPEAN SCIENCE POLICY

This science plan is composed as a guideline for national efforts, and as support for financing of national and European projects that are proposed in its context. These efforts to increase international cooperation coincide with recent developments at a more political level. The European Science Foundation (ESF) is actively exploring-ways of setting up networks for scientific cooperation in Europe, in accordance with a mandate given to it by the conference of science Ministers of the European countries in september 1984. This conference has singled out several themes for such networks, among which seismology.

The technological and theoretical challenge to develop detailed imaging techniques of the deep Earth interior, using digital waveform data from a very large array of stations does seem to fit the objectives of the EUREKA project as well.

This science plan does not cover all of European seismology, but limits itself to stimulate the deployment of digital broad-band seismographs of which the data are exchangeable. Cooperation with seismologists engaged in studying local seismicity is highly desirable, although the very large amounts of very high frequency waveform data produced by local networks will require additional investments in a data center that bear little relation to the limited global use these data will have. The task of storing and distributing non-waveform data is a different problem that has to be addressed in the framework of existing data centers (EMSC[2] for Europe)

2. Ongoing efforts

A number of digital broad band networks are already in operation by European seismologists. In fact, European seismology has the lead with respect to similar

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[2] European Mediterranean Seismological Centre (Strasbourg)

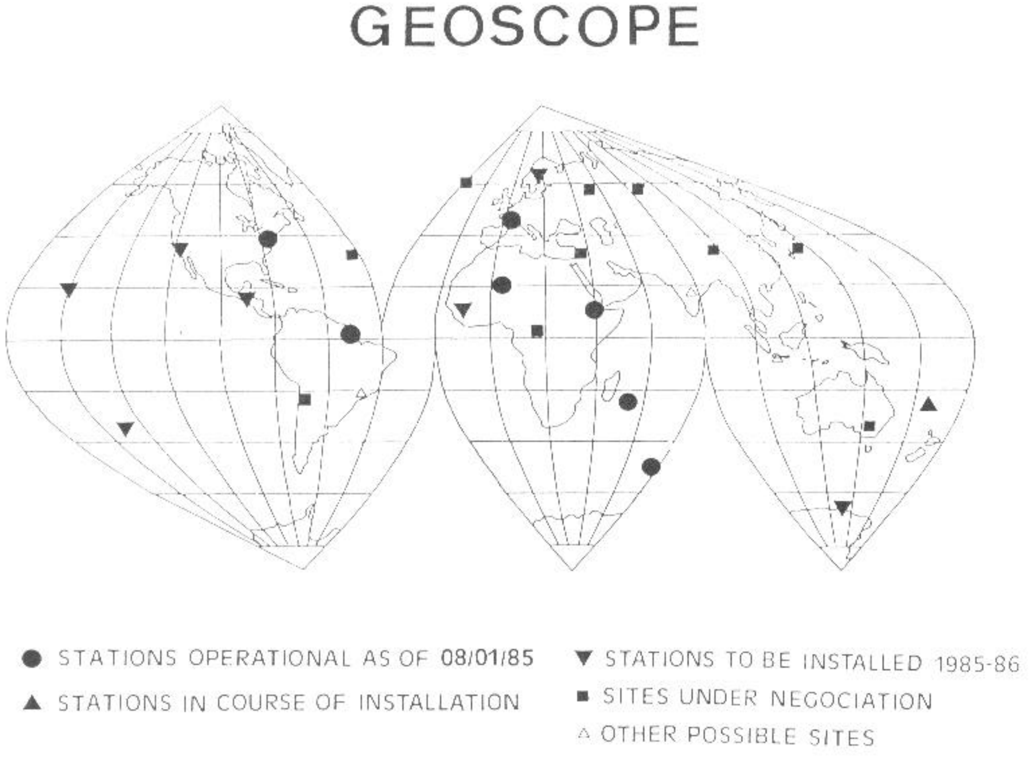

Figure 2.1 Map of existing and planned stations of the GEOSCOPE network (Romanowicz, with permission)

developments in the U.S., that are still in a planning stage. However, any facilities for data exchange, or for densification of networks by international cooperation are lacking.

In this section we give a brief description of the three broad-band networks in operation, and draw up an inventory of existing plans. More detailed information is listed in appendix B.

2.1. Graefenberg array (FRG)

The GRF array is part of Bundesanstalt fuer Geowissenschaften und Rohrstoffe (BGR) at Hannover. It covers an area of about 100x50 km in northern Bavaria, containing 13 recording sites (see Figure 2.2), three of which have three component stations. The instruments are the Wielandt-Streckeisen STS seismometers. The first instruments were installed in 1976, the array was completed in 1980. The data are recorded at 20 samples/sec on magnetic tapes in a data center at Erlangen, which distributes the data on request and also issues a monthly bulletin. The German Research Association (DFG) finances the hardware requirments of the observatory.

2.2. NARS project (The Netherlands)

The NARS array is operated by the department of theoretical geophysics at the University of Utrecht. It is a portable network of 14 digital, broad band seismographs

Figure 2.2 Map of permanent seismic stations (existing and planned) with broad-band response in Europe.

(three components). It is presently (1982-1987) set up along the great-circle between Gothenborg (Sweden) and Granada (Spain). The sensors are Teledyne-Geotech long-period seismometers. Broad-band data are initially recorded on cassette tapes at 8 samples/sec and processed and archived in a data center in Utrecht. The USGS at Boulder distributes some of the NARS data to outside users. Operational and hardware costs of NARS are financed by the Dutch Science Foundation (AWON/ZWO). In its current phase, NARS is the Dutch contribution to the ESF's Geotraverse project.

2.3. GEOSCOPE (FRANCE)

This is a worldwide network operated by groups at the Institut de Physique du Globe (IPG) in Paris and Strasbourg. The project started in 1981, has currently 7 stations operational and aims at a network of some 20-30 three component, broadband digital seismological stations (figure 2.1). Recording of the broad-band channel is on magnetic cartridges covering 1-2 weeks of data at 5 samples/sec, but quasi-real time acquisition by international teletransmission networks will be realized soon. A data center has been set up at IPG Paris to collect, archive and distribute network tapes. GEOSCOPE is sponsored by INSU of CNRS[3] since 1981, but other French and foreign institutions are beginning to participate financially in the project, or are joining the project by contributing data.

2.4. Planned broad-band stations

Several countries (Germany, Holland, Belgium, Italy, Norway, Sweden and Finland) plan to install one or more broad-band seismic stations with sensors of the Wielandt-Streckeisen type and digital recording. For as far as decisions on the location of these instruments have already been announced, these stations are summarized in figure 2.2. See also appendix B.

2.5. Upgrading of refraction equipment

Within the French LITHOSCOPE project, 50 field instruments will become available shortly to record digitally. A similar conversion is planned for the German instruments. The ORFEUS working group strongly recommends that the new equipment will be designed such that it is suitable for recording of broad-band seismograms. Development of a suitable sensor with broad-band sensitivity that can be used under field conditions has high priority. It is hoped that this refraction equipment will also become available for temporary service in "passive" portable array studies.

2.6. Developments outside Europe

The Chinese Digital Stations Network (CDSN) is a broad-band network that comes close to what we want in Europe. Nowhere else outside Europe have networks with true broad-band sensitivity been realized yet, but the plans by IRIS for a new Global Seismograph Network (GSN) and the program for Array Seismic Studies of the Continental Lithosphere (PASSCAL) promise to become a major step forward in observational seismology.

The GSN is a proposal for a network of 100 permanent broad-band stations, PASSCAL involves a pool of some 1000 portable digital instruments, of which 400 will have broad-band sensitivity once a suitable field sensor becomes available. IRIS is to provide a Data Management Center for sorting, archiving and distribution of the very large amounts (500 Gbyte/year) of data expected from this project. Figure 2.3 compares bandwidth and station density of several existing and planned networks.

2.7. ORFEUS and other seismological projects

ORFEUS is not the only seismological project in Europe. Recently, many efforts have been succesful to study the lower crust, and even the upper mantle below it, with conventional reflection seismic techniques such as in use in the oil industry. Projects

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[3] Institut National des Sciences de l'Univers (formerly INAG) and Centre National de la Recherche Scientifique

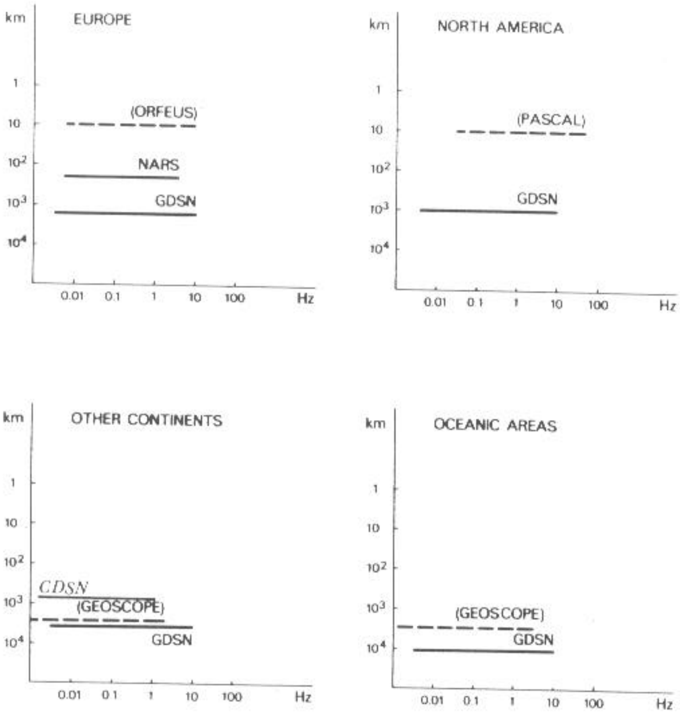

Figure 2.3 Schematic representation of existing (solid line) and planned (dashed line) digital networks, showing frequency band and station separation in km. Station separation of the PASSCAL and ORFEUS portable networks has been calculated for deployment of these networks in a linear array of continental dimension, for comparison with NARS (Nolet, with permission)

BIRPS, ECORS and DEKORP are greatly advancing our knowledge of structural features at depth between 10 and 50 or more kilometers.

There are important differences between these studies and the network plans advanced by the ORFEUS working group. Crustal reflection profiles offer a resolving power which is unsurpassed by any other technique. However, their applicability is restricted to fairly local studies, their depth penetration unlikely to reach much deeper than about 100 km in the near future. Unlike refracted waves, which are very sensitive to velocity gradients, reflected waves will only image sharp discontinuities.

A dense portable array may provide a resolution of the order of only 10 km, but throughout the whole upper mantle, at much reduced cost. The cost of even one deep crustal reflection profile exceeds the estimated running cost of the ORFEUS data center for a whole year.

The difference between crustal refraction profiles, such as now being conducted in the European Geotraverse, and the plans for densification of the network of broadband stations is less sharp, and it may very well be possible that recordings of artificial sources from such a network will provide important supporting evidence in refraction surveys. Especially if the next generation of refraction instruments becomes broad-band, the distinction between this equipment and that of a portable array for passive studies may dissappear.

A broad-band network could be used for the study of strong local events, but it will not be specifically oriented for the investigations of local microseismicity. Because of the ease of data handling, we expect that conventional analogue field recorders will continue to play a role for a long time in the future, possibly supported by intelligent satellite beacons such as now being proposed within the LITHOSCOPE project. Satellite beacons are able to provide very large amounts of very precise arrival times, which are complementary to the full waveform information provided by digital broadband stations.

3. Broad-band seismology: ongoing research in Europe

Much of the need for a dense network of broad band digital stations comes from recent advances in the possibilities to analyze and synthesize large amounts of seismic data on digital computers. Wherever broad band data are already available, new paths of research open up. This chapter lists a few recent contributions from European seismologists that illustrate how well seismology could benefit from the ORFEUS proposals. It is not intended to be a complete survey of present-day seismological research in Europe, nor can it ever pretend to be a fundamental program for research with the new instrumentation: most good scientific projects raise more questions than are answered. In addition to the scientific results described in this chapter, the IRIS proposals[4] also contain a number of good arguments for the deployment of broad band digital networks.

3.1. SEISMIC SOURCES

3.1.1. Centroid Solutions at Long Periods

Most studies of earthquake source processes have concentrated on the study of large earthquakes at plate boundaries. For such events, which have corner frequencies lower than a few tens of milliHz, the data from the existing WWSSN network permit to determine the large scale features of the energy release at the source. The main difficulty with such studies has been the limited dynamic range of WWSSN records, many interesting records being saturated.

Some aspects of source complexity do already show up in conventional low frequency records. Here waveform fitting techniques allow us to estimate the centroid time shift[5] which is by itself related to the finite size of the source. Recent results obtained by Doornbos with this method show a clear increase of centroid time shift with seismic moment (figure 3.1). For lower frequencies (3-50 mHz) surface wave data may be used to obtain estimates of centroid depth, source duration and moment tensor, providing information on the rupture process which is complementary to the shorter body wave analysis (figure 3.2).

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[4] These are described in two documents issued by IRIS: "Science plan for a new Global Seismographic Network" (April 1984) and "PASSCAL: Program for Array Seismic Studies of the Continental Lithosphere" (December 1984)

[5] "Centroid" solutions average in time and space over the whole rupture process, contrary to the conventional first motion solution which represents the onset of rupture as seen by high frequency waves

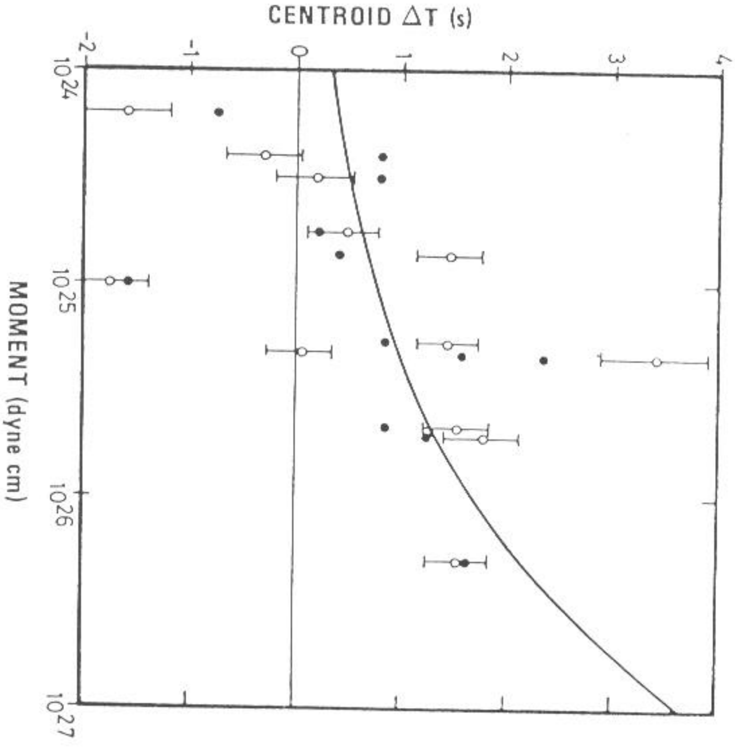

Figure 3.1 Centroid time shift as a function of seismic moment (Doornbos, with permission)

3.1.2. Source Complexity

For smaller events, digital recording networks provide an opportunity to solve the dynamic range problem and at the same time to broaden the pass band of the instrument towards higher frequencies. This is extremely interesting for the study of seismic release from medium size ($5 < M < 6.5$) earthquakes for which the present day instruments are poorly adapted since their corner frequencies are situated in the "blind spot" of the band passes of short and long period instruments, i.e. between 80 and 500 mHz.

The study of these events is particularly important in Europe since many damaging Mediterranean earthquakes have magnitudes in this range. Careful modelling would provide a unique set of data on the development of rupture on the fault. Problems like the distribution and role of asperities in the rupture process could be adressed by the study of Mediterranean events. Another important problem that could be studied is that of the generation of high frequencies by the source. This problem, of great importance in seismic engineering, has been the subject of much debate in recent years. Broad band recording would permit us to observe seismic radiation in the crucial transition zone around the corner frequency. Is this transition sharp, are there subfaults of a specific size as proposed by Papageorgiu and Aki, what is the dynamic stress drop? These are some of the many questions that could be adressed with these data.

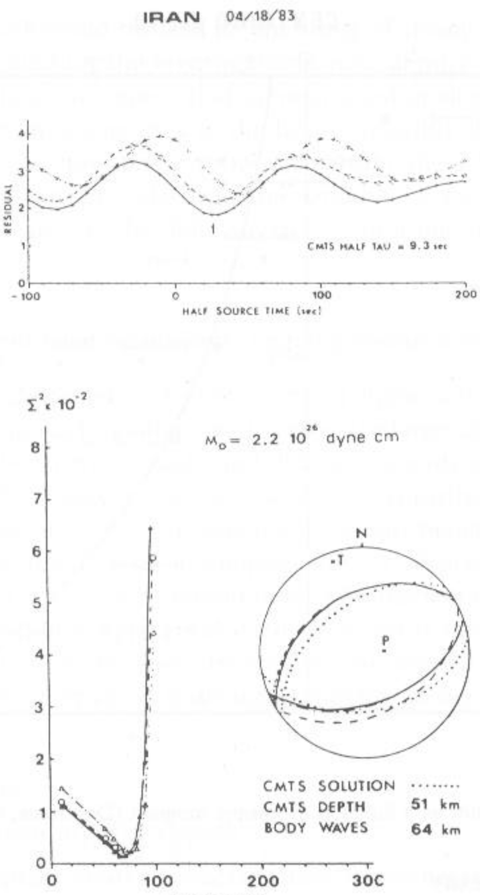

Figure 3.2 Estimating centroid source time, depth and source solution with broad band data from GEOSCOPE and from the IDA network (Romanowicz and Monfret, Ann. Geophysicae 1986)

Finally, we could elucidate the true role of asperities and barriers in the rupture process. While their role in controlling the progression of rupture is not in question any more, the degree of heterogeneity is a major problem. Are all earthquakes in fact multiple events, or is there a characteristic size of heterogeneity for a fault zone? Large events are clearly multiple, yet medium size earthquakes frequently have smooth ruptures. This is a major problem for earthquake prediction because it appears that the difference between a large event and a smaller one depends crucially on the breakage of certain asperities which are maintained at stress levels close to the fracture strength.

Bezzeghoud, Deschamps and Madariaga studied the short period GDSN records of the three earthquakes of February 24, 25 and March 4, 1981 in the Gulf of Corinth. Their results show clearly how source complexity is masked in long period records. A precursive rupture of an asperity clearly appears on the shorter period records (figure 3.3).

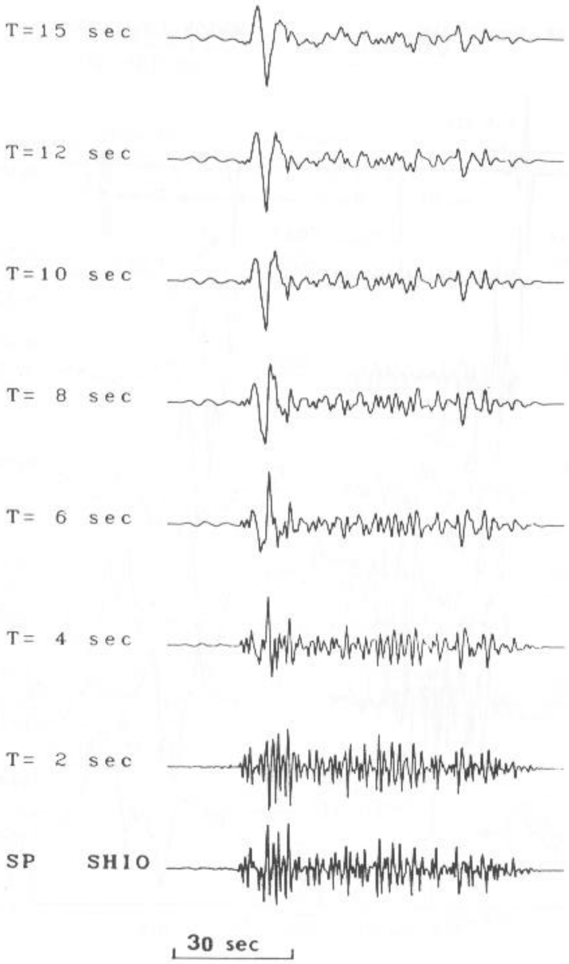

Figure 3.3 Low pass filtered records from a short period recording at SHIO of the Febr 25, 1981 earthquake in the Gulf of Corinth. T indicates the filter cut-off period (Bezzeghoud, Deschamps and Madariaga, Ann. Geophysicae 1986)

Recent work by Bruestle with broad band recordings from the GRF array further illustrates the power of broad band instrumentation to resolve source complexity (figure 3.4). Such studies may lead to profound insight into the kinematics of the rupture process (figure 3.5).

3.1.3. Depth Phases

The most accurate depths of earthquake sources are obtained from interpretations of depth phases. This method is routinely used for teleseismic events. It is much less used for local and regional earthquakes, because it is very difficult to identify depth phases in very oscillatory short-period records. If the earthquakes are strong enough to produce sufficient signal-to-noise ratio in the broad band, then these records can be very useful for source depth determinations of local or regional events.

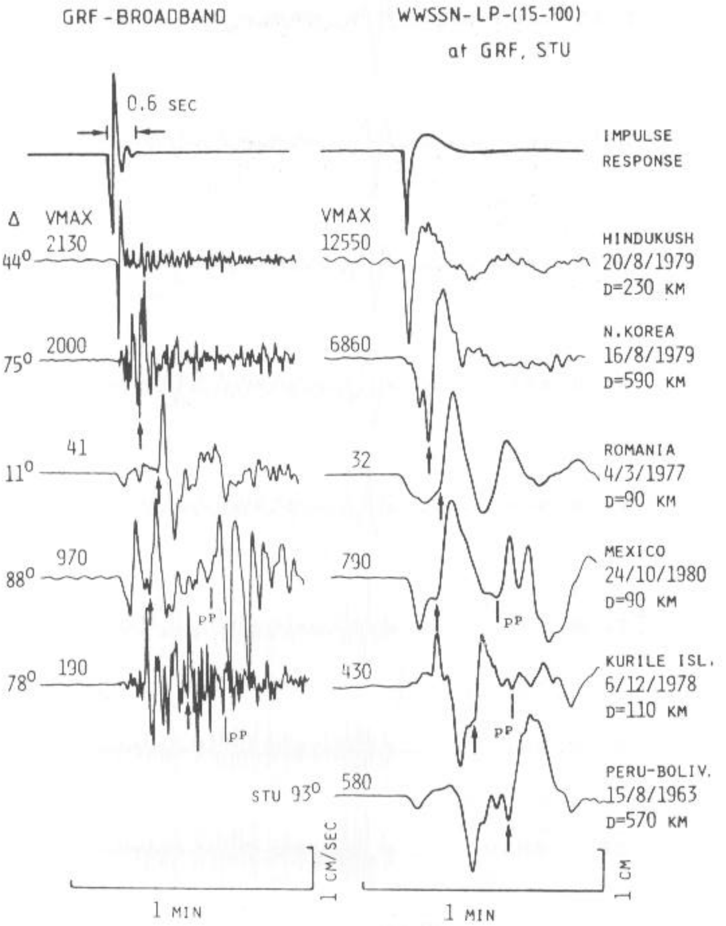

Figure 3.4 Source complexity in broad band seismograms (left) and simulations of conventional long-period registration (right), shown for the P phase of several earthquakes. The arrow marks stopping phases (Bruestle, with permission)

Kind found depth phases of the Swabian Jura event of Sept 3, 1978 (ml = 6.0), recorded in Graefenberg at 200 km distance. The first phase is the Pn phase and the depth phase was sPn, which is very clearly seen in the displacement record (figure 3.6). It is much less clearly seen if simulations of other recording systems are used. This depth phase was observed in aftershocks as well.

Figure 3.7 shows displacement records of the largest Friuli events from 1976-1979 recorded in Graefenberg (epicentral distance 400 km). All these records have clear phases between Pn and Pg. With help of synthetic seismograms, this phase was again identified as sPn. These Friuli events range between 5 and 8.5 km depth. Especially the relative source depths of different events can be determined very precisely.

Faber and Bonjer used similar depth phases in the GRF records from the recent Liege event (Nov 8, 1983) to decide between two possible fault plane solutions, which are both in agreement with first motion data from conventional instrumentation (figure

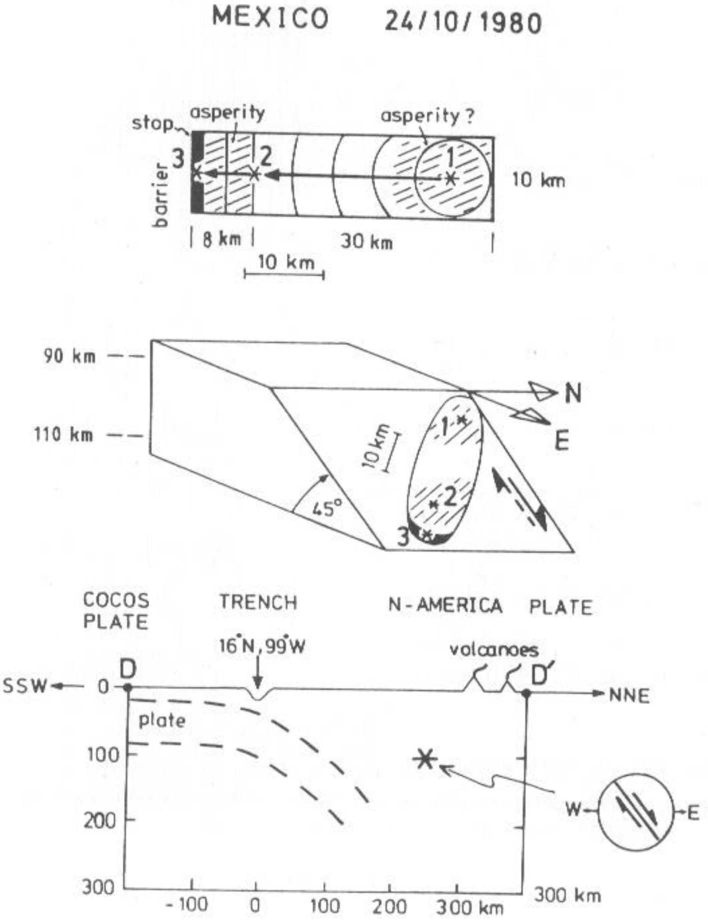

Figure 3.5 Rupture process of the Mexico earthquake of October 24, 1980. The cross section through the upper mantle (bottom) shows the hypocenter. In the center and at the top the rupture surface is sketched with the hypocenter (1), a region with acceleration of rupture (2) and termination of rupture (3). (Bruestle, with permission)

3.8). All these examples show how succesful broad band records are in interpreting regional earthquakes. The search for secondary phases is much easier in such records because of the less oscillatory nature of the broad band data. The interpretation of signal forms is for the same reason also easier. The examples indicate that data from more broad band stations could also improve the interpretation of regional earthquakes considerably, and contribute much to the study of source processes of such events.

3.2. EARTH STRUCTURE

A more detailed determination of the structure of the Earth's interior is vital to a better understanding of many aspects of the evolution of the Earth in general; of particular interest today is the relationship between continental upper mantle and continental

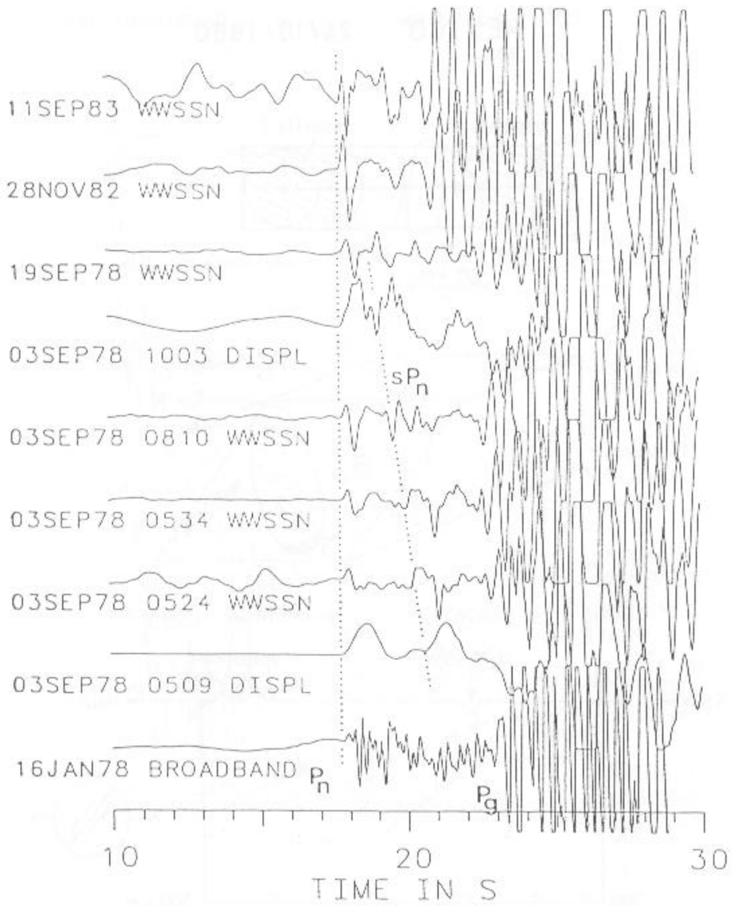

Figure 3.6 Summation traces of Swabian Jura events recorded at the Graefenberg array. sPn is the depth phase of Pn. The time delay of this phase is clearly decreasing for the aftershocks of the main shock (Sept 3, 1978). The hypocenters moved from a depth of 6.5 km to about 2-3 km depth within 5 hours of the main shock. (Kind, J.Geophys. 1985)

evolution. Earth scientists still do not agree on the composition, nor on the physical properties of the upper mantle under continents. A search through the recent literature of upper mantle models resulted in figure 3.9. The very large number of discontinuities at different depths does probably not only reflect the limited precision of present day seismological methods, but expresses true lateral variability as well. Partial confirmation of this is shown in a recent tomographic study by Spakman for the region in SE Europe, where station density and seismicity is high enough to apply seismic tomography with wave arrival times routinely reported to the ISC (figure 3.10).

In the following we summarize some recent studies that illustrate the usefulness of broad band digital data for structural investigations. It should be mentioned that the field of seismic tomography is relatively new. Significant theoretical advances are to be expected in the near future, that will make these data even more powerful.

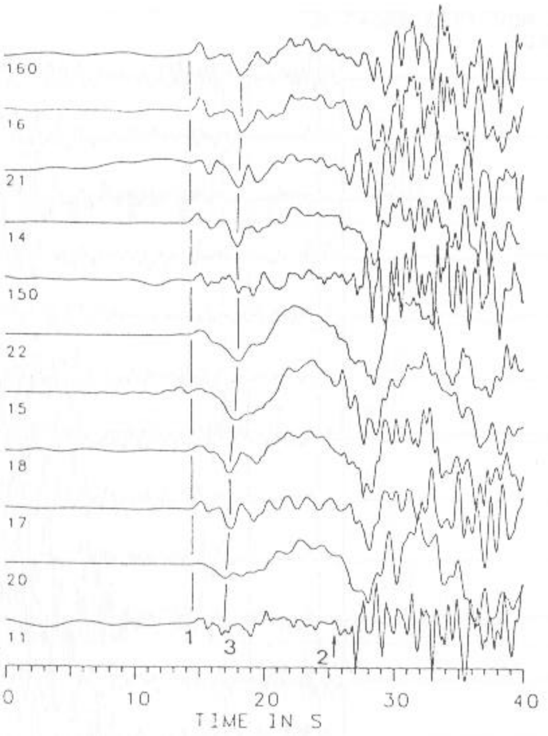

Figure 3.7 Friuli events recorded at Graefenberg station A1. Phase 1 is Pn, phase 2 is sPn and phase 3 is Pg. Note the different amplitude ratios of Pn and sPn for the different earthquakes. This observation permits an improved determination of fault plane dip (Barbano, Kind and Zonno, J.Geophys. 1985)

3.2.1. Surface Wave Studies

In most regions of the Earth the local seismicity and the station density is not high enough to provide enough depth resolution in the lithosphere or upper part of the mantle with methods of body-wave tomography. Anomalies in the propagation of surface waves from distant earthquakes can reveal at least the gross features of regional lithospheric and upper mantle structure.

Fundamental modes: measurements of surface wave dispersion, although small in number as compared to measurements of body wave travel times, have contributed significantly to our knowledge of the seismic structure of the uppermost mantle. Regional phase velocities in Europe are strongly correlated with the tectonic classification. Figure 3.11 shows a typical profile density, whereas figures 3.12 and 3.13 show some results.

There are still large areas in Europe where we have insufficient data, and in other places a check of previous results might be desirable. These reasons alone would make data from a regional network of modern broad-band stations highly welcome. More important, such data will permit the application of new, more powerful methods of interpretation.

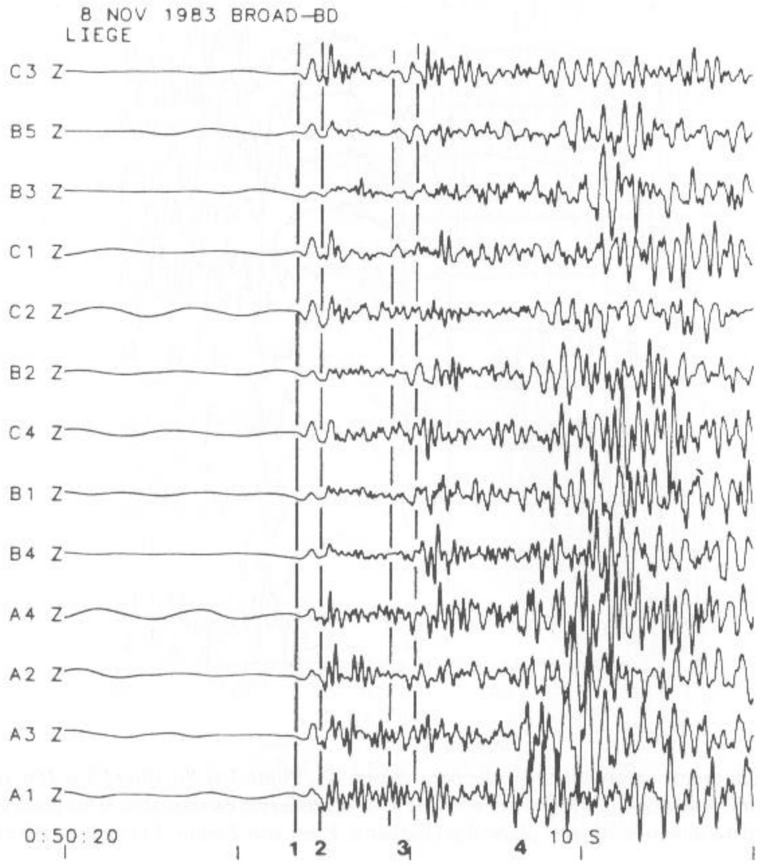

Figure 3.8 GRF broad-band records of the Liege event (Nov 8, 1983) at a distance of 450 km. Phase 1 is Pn, phase 2 is sPn, phases 3 are crustal multiples of Pn and sPn, and phase 4 is Pg. The fault plane solution from first-motion data was not unique. From the observation of strong sPn phases it was concluded that the source orientation was dip-slip, and not strike-slip (Faber and Bonjer, with permission)

Conventional work with surface waves has been severely limited in two respects: it only resolves the structure at shallow depths and it is founded on the doubtful theoretical basis of the ray approximation.

Higher modes: fundamental mode surface waves do not provide a good depth resolution beneath, say, a depth of 200 km, and do not permit an independent determination of the seismic velocities and density. Higher mode surface waves reach much deeper, but require a dense array with station separations less than a few hundred km to be measurable. They also provide information on the density distribution with depth as is shown from low-frequency higher mode data from the Pacific Ocean (figure 3.14) and some first interpretations of data from the NARS array (figure 3.15) Using higher mode surface waves, Leveque and Cara where recently able to show that the upper mantle under the Pacific may be anisotropic down to 300 km depth (figure 3.16). Figure 3.17 shows the sensitivity with depth of the fundamental and higher modes up to order 3. It is clear that with 5 or 6 overtones and periods to 50

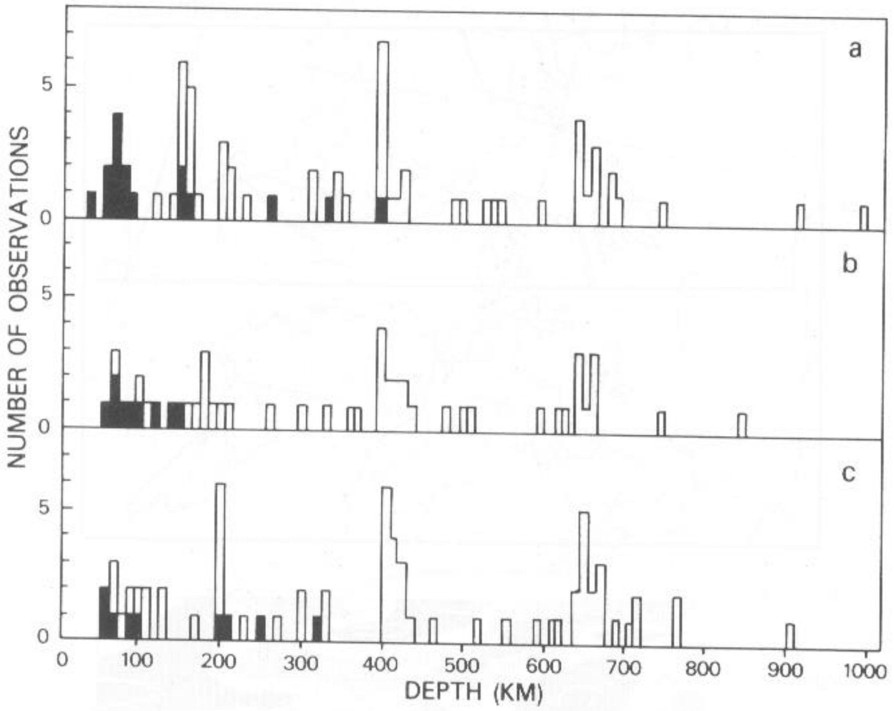

Figure 3.9 A histogram of observed discontinuities or gradients in the upper mantle in (a) Phanerozoic orogeneous zones, (b) Phanerozoic platforms and (c) Precambrian shields. Black indicates the top of a low velocity layer (Paulssen, with permission)

sec, we can explore the whole upper mantle. To do this data from horizontal components are of primary importance if only since many overtones of Rayleigh waves show a better excitation for the horizontal displacements (figure 3.18).

In order to analyze higher mode data with tomographic methods, new techniques for waveform fitting of the surface wavetrain have been developed, which allow for the introduction of smooth lateral heterogeneity along the wavepaths. Figure 3.19 shows the result of an application of this new method to recordings of the fundamental Rayleigh mode from a recent W Africa event (Dec 22, 1983) with the NARS instruments. In this case, lithospheric velocity differences of 1-3% between W Africa, Iberia and the W European platform had to be invoked to obtain a good waveform fit.

Very fast mode summation algorithms, such as now under development by Panza, may soon provide the possibility to apply nonlinear waveformfitting to large parts of the seismogram (figure 3.20).

Limitations of the ray approximation: present methods of interpretation are based on a ray approximation to the propagation of surface waves; the observed phase travel times are assumed to depend on local structure only along the profile. This is a short wavelength approximation that becomes questionable when the wavelength of the seismic signal is larger than the structures investigated. In practice the method is largely justified by its consistent results.

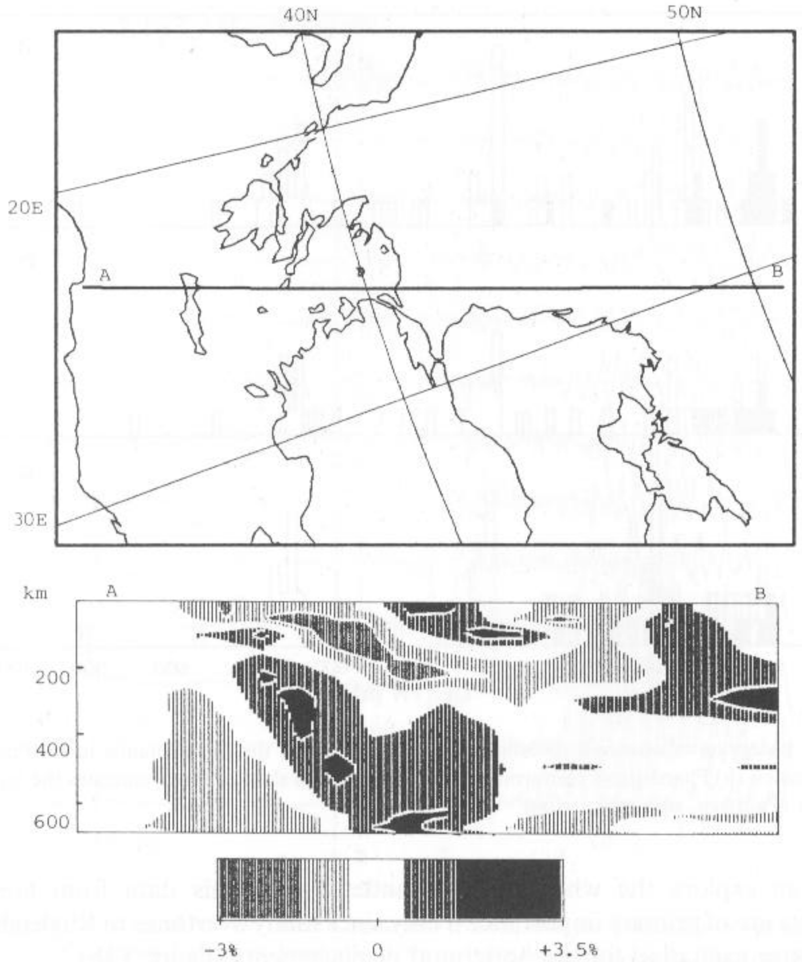

Figure 3.10 In regions of high seismicity and high station density, seismic tomography is able to image the Earth's velocity structure in three dimensions. This figure shows the deviations in P-velocity from a standard model in a depth section (A-B) which delineates a deep descending slab structure in the Eastern Meditterranean. (Spakman, with permission)

However, the length scale of the structures needed to satisfy the dispersion data is often smaller than a wavelength. Here we are certainly beyond the limits of the ray theory. Obviously we cannot increase the spatial resolution unless we develop a better theory that remains valid at the scale of the heterogeneity considered.

Numerical experiments by Wielandt using acoustic full wave theory show how different regions may influence the local phase velocity measured with the classical phase difference method between two stations. The phase delay of a surface wave between two stations depends not only on the structure between them, but on the whole surrounding area, and on the geometry of the incoming wavefront. In order to apply the ray approximation typical effects of wave propagation - such as diffraction, interference, the dependence of phase velocity on the geometry of the wavefront - have

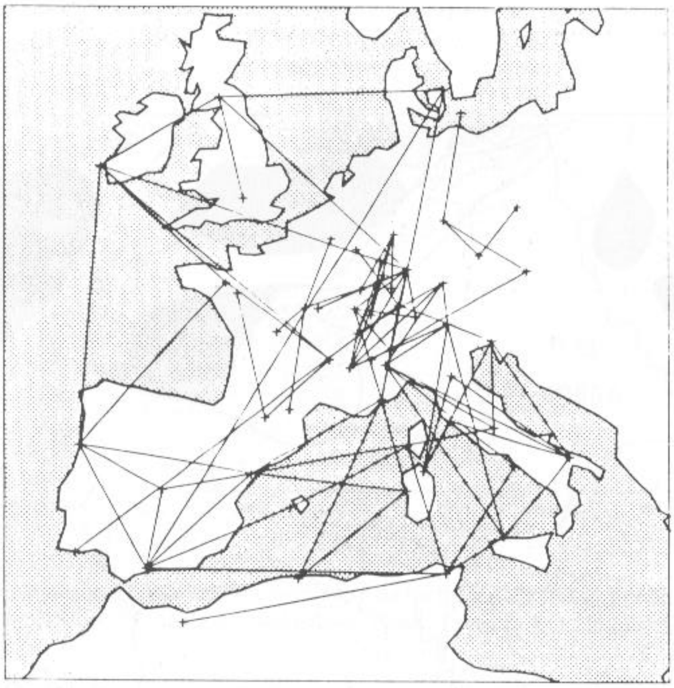

Figure 3.11 Rayleigh wave profiles in W Europe measured up to 1985 (Wielandt and Mueller, with permission)

Figure 3.12 Regional phase velocities of Rayleigh waves at a period of 50 sec. Vertically hatched areas are faster than average (3.95 km/sec), horizontal hatched areas are slower. (Wielandt and Mueller, with permission)

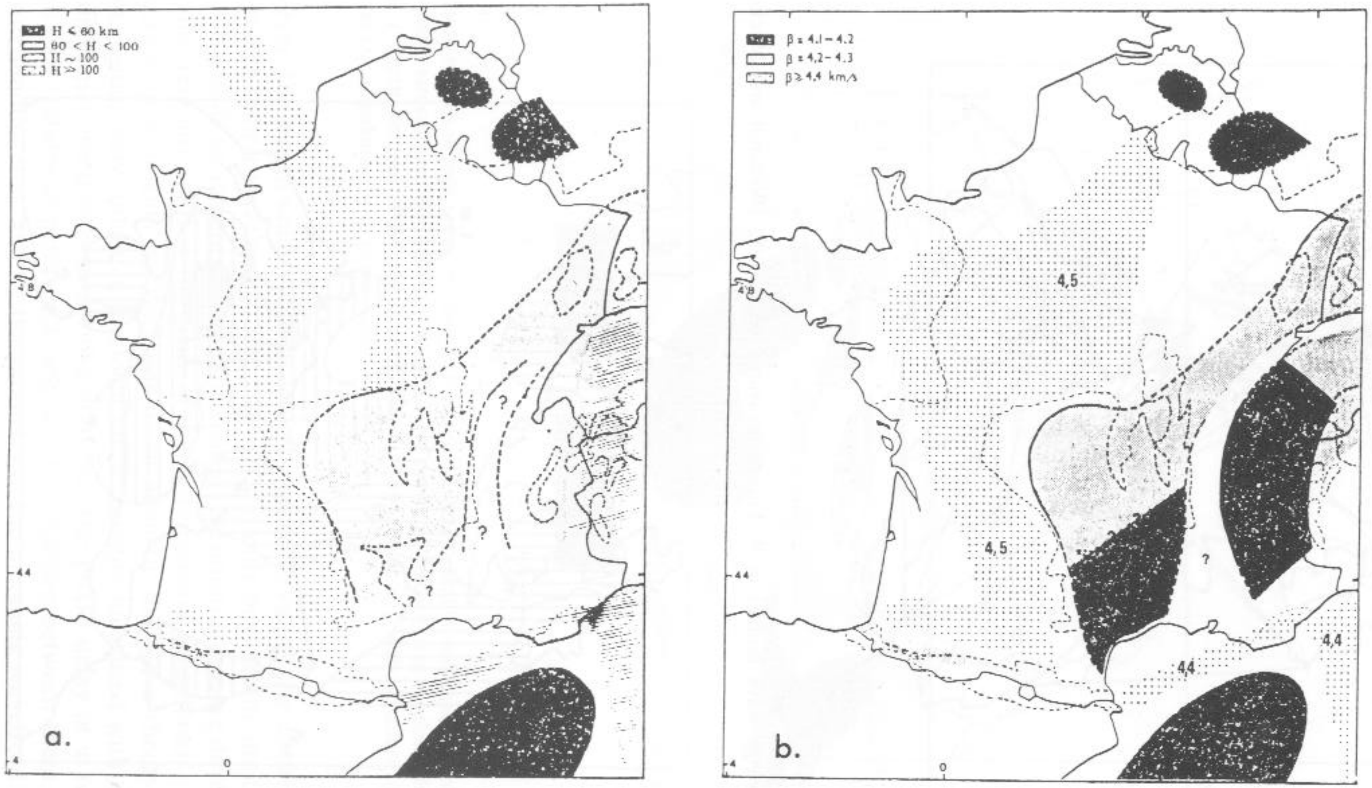

Figure 3.13 The upper mantle beneath France, from surface waves an P-wave residuals: (a) lithospheric thickness, (b) shear wave velocity in the LVZ (Souriau, Bull.Soc.Geol.Fr. 1981)

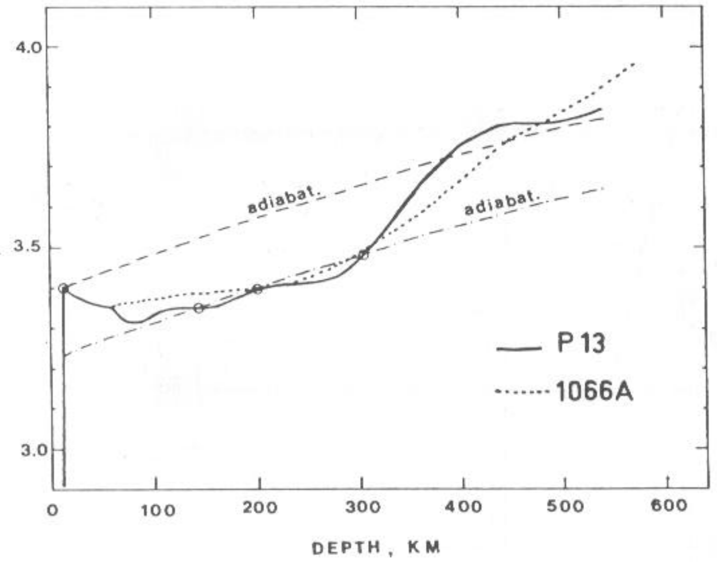

Figure 3.14 Density-depth model deduced from overtone data for the Pacific Ocean. The adiabat for a mantle of homogeneous composition is shown for comparison (Cara, Leveque and Maupin, Geophys.Res.Lett. 1984)

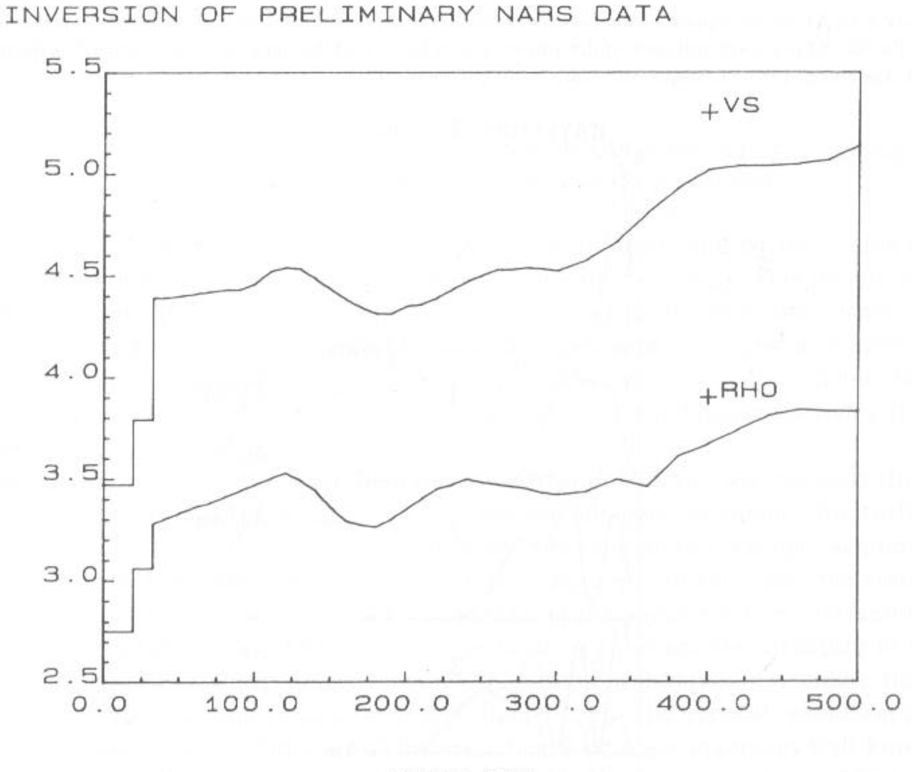

Figure 3.15 S-velocity and density averaged over the W European platform, from a preliminary inversion of higher mode dispersion data from the NARS array (Dost, with permission)

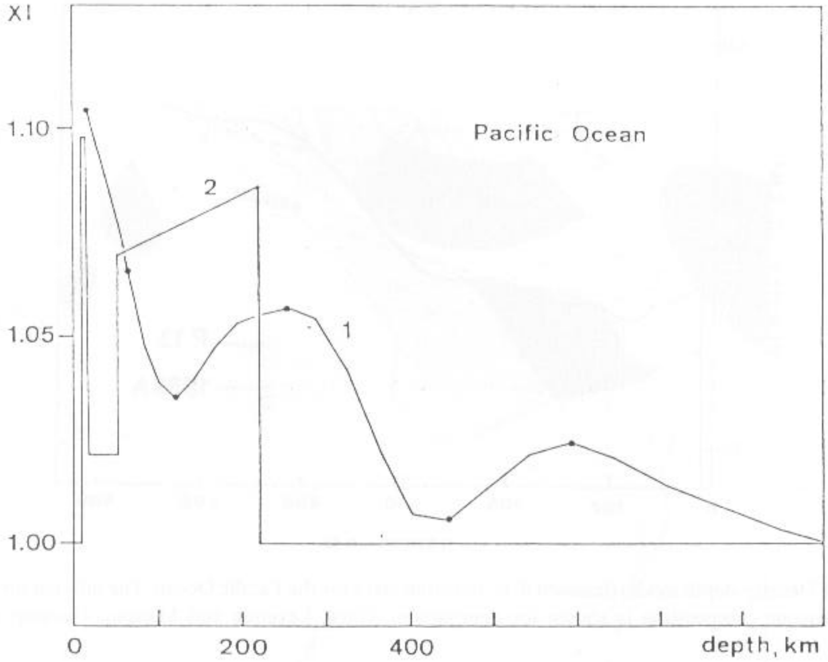

Figure 3.16 XI, or the square of the ratio between SH and SV velocity, as deduced from overtone data in the Pacific. XI is a good indicator of the anisotropic behaviour of the upper mantle. Curve (2) is from Regan and Anderson, 1983. (Leveque and Cara, with permission)

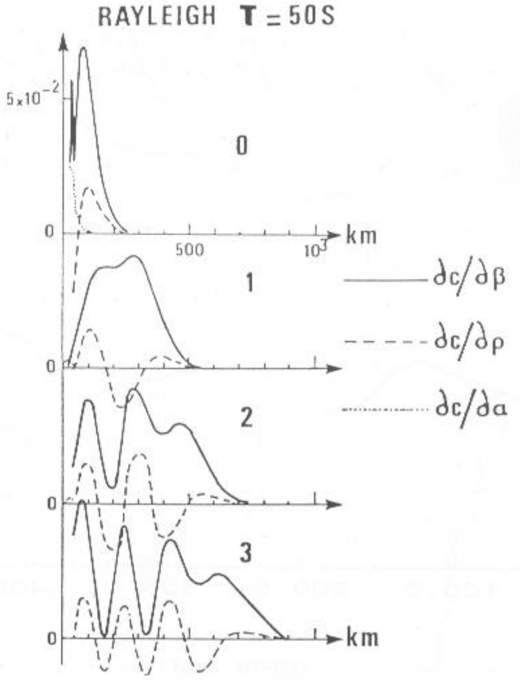

Figure 3.17 Partial derivatives of phase velocity of the first 4 Rayleigh modes with respect to S velocity, density and P-velocity. Density is in gr/ccm , velocity in km/sec (Cara, with permission)

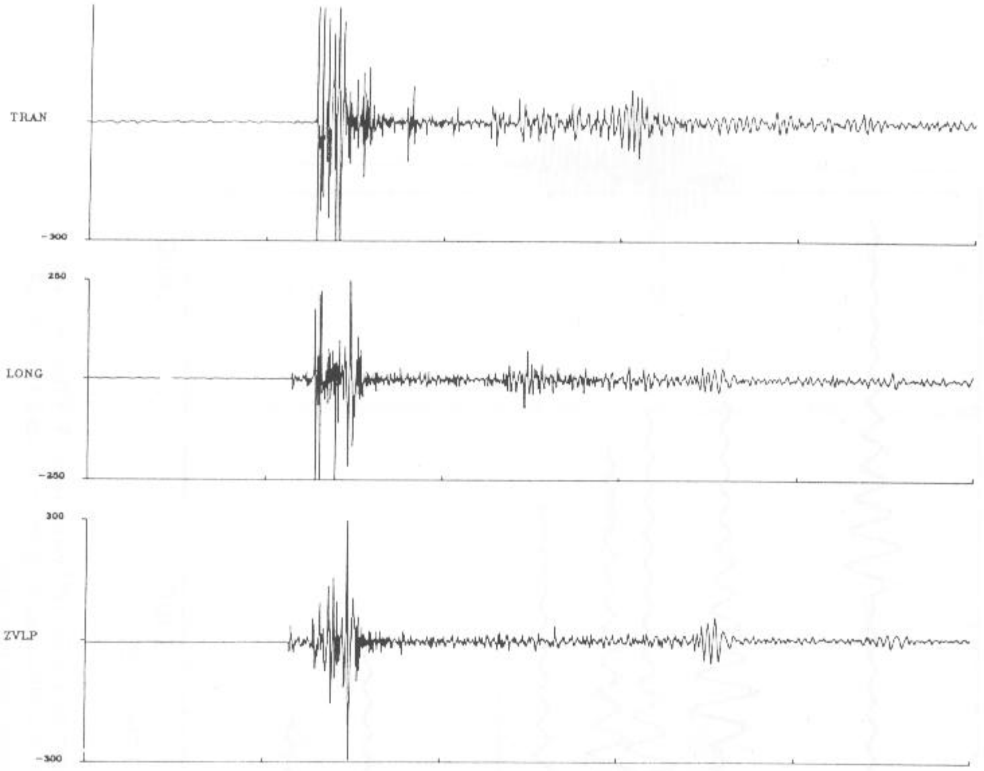

Figure 3.18 An example of three component records from the GEOSCOPE station in Tamanrasset (Algeria) displaying X-phases rich in overtones on the longitudinal component (Roult, with permission)

to be removed from the data by averaging over several events and by smoothing the phase velocity curve. Substantial information is thus thrown away. This means that we can no longer determine an average structure for one profile from one dispersion curve, but have to determine the seismic structure in a large area, and also some of the focal parameters of the earthquake used, simultaneously from all available data. This will require data from many stations for a number of earthquakes arriving from different directions.

Born scattering: for an improved theoretical treatment of lateral heterogeneity, Born scattering methods may be invoked, and at present imaging techniques for surface wave modes are being developed that will allow the mapping of strongly scattering structures in the lithosphere with a dense array of stations. In this case, the station separation should be of the order of a wavelength of the surface waves involved (40 km). A dense array of, say, 100 stations may be used to image the structure in the horizontal plane. For sharp heterogeneities, Kirchhoff techniques not unlike those used in exploration seismics could be tested (figure 3.22). The vertical resolution can then be obtained using techniques of linearized surface wave inversion well known from 1-D studies. We propose to use all European broad band seismic stations for such investigations. A nucleus for this array does already exist in the presently one-dimensional NARS array. The temporary use of digital seismic field equipment for

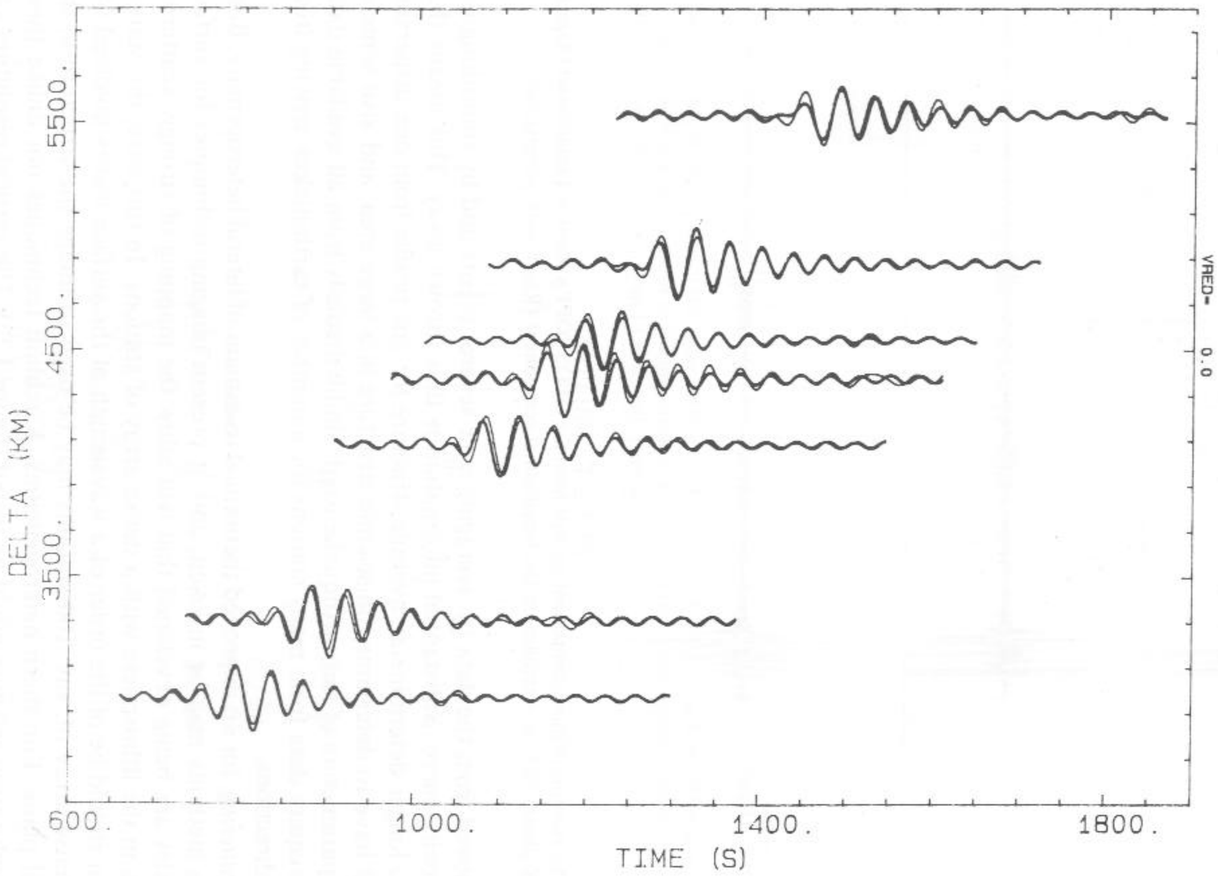

Figure 3.19 Fundamental Rayleigh mode wavetrains from the Dec 22, 1983 eartquake in W Africa, recorded by NARS (low passed at 30 sec), and waveform fit of synthetic seismograms calculated for a laterally heterogeneous structure (Nolet, van Trier and Huismans, with permission)

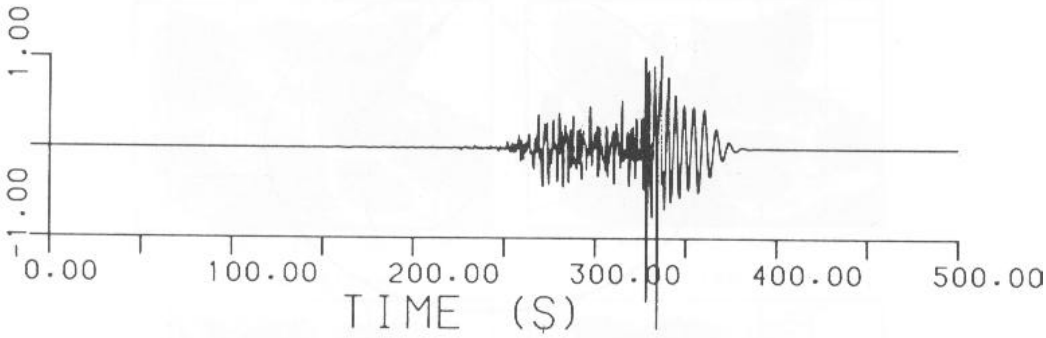

Figure 3.20 A synthetic broad band seismogram, constructed by mode summation (Panza and Suhadolc, with permission)

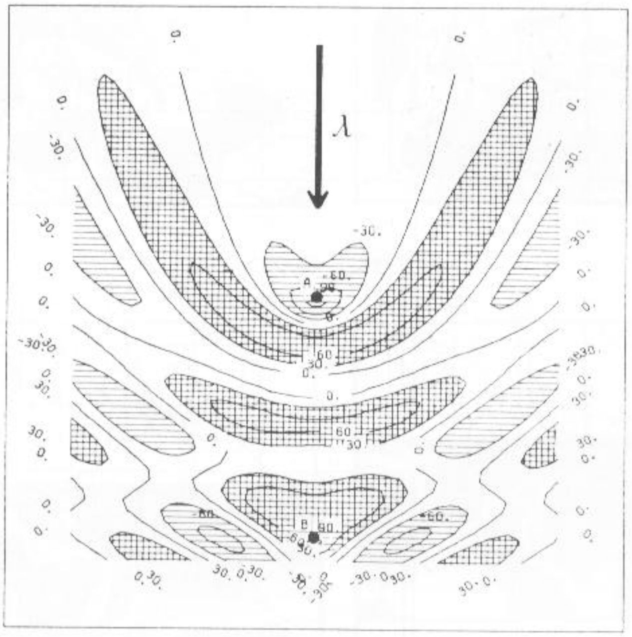

Figure 3.21 A plane acoustic wave is incident from the top of the figure; its phase velocity is measured between the stations A and B (dots). In a homogeneous medium the observed phasevelocity equals the constant velocity of sound. When small deviations from homogeneity are present, the observed phase velocity is a weighted average over the local sound velocity in the vicinity of the stations. This figure shows the weight function for the case that the distance between the stations is 1.5 wavelengths. Areas with a relative weight over 30% are shaded. Some areas have a negative weight exceeding -60%. (Wielandt, with permission)

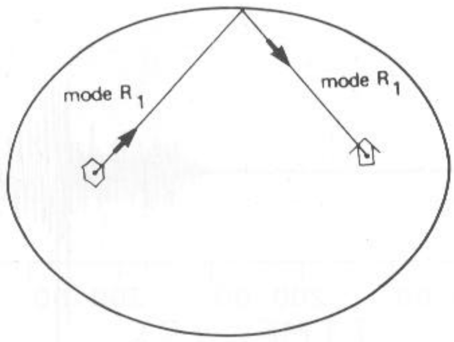

Figure 3.22 Time delays of surface waves scattered from a sharp discontinuity observed in one station may be used to locate the scatterer on a geometrical curve. Dense arrays can be used to image the scatterers in a focal point (Snieder, Geophys.J.Roy.astr.Soc. 1986)

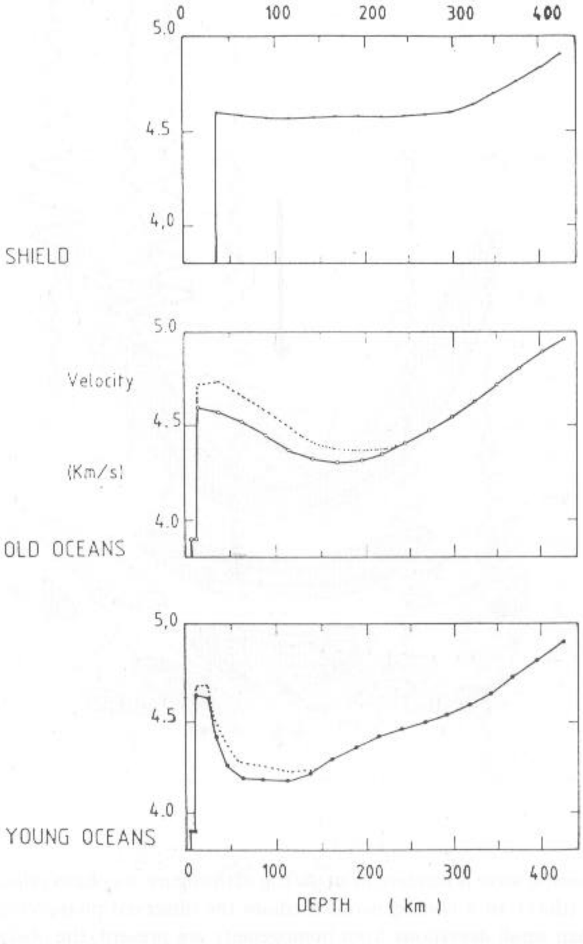

Figure 3.23 Results of global regionalisation of low-frequency surface wave data show variation of anisotropy with lithospheric age under oceans and absence of anisotropy for shields. The continuous line gives the SV, the broken line the SH velocity (Journet and Jobert, Geophys.Res.Lett. 1983)

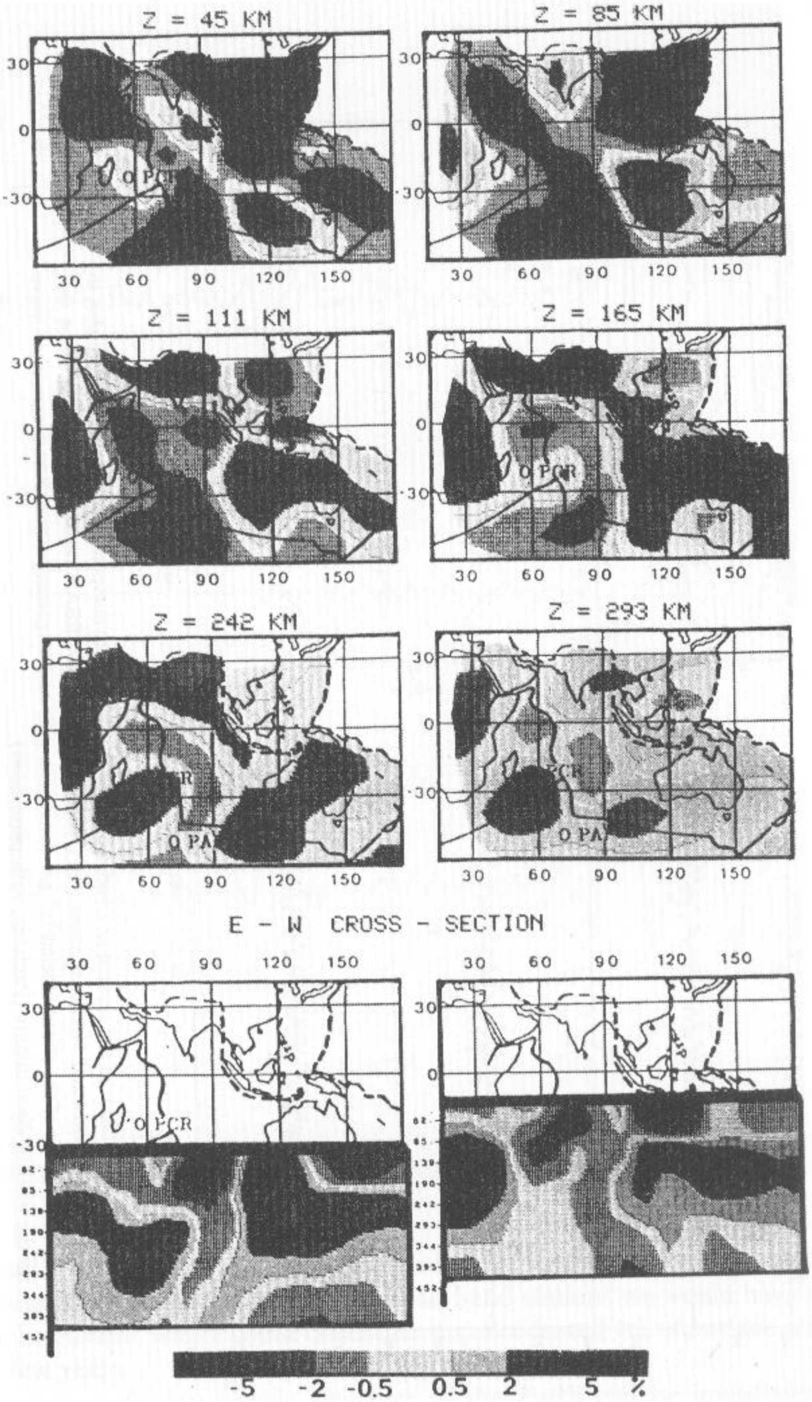

Figure 3.24 Shear wave velocity distribution in the Indian Ocean. Top: horizontal maps at different depths; bottom: East-West vertical cross-sections at latitudes 30S and 10S. This is a black and white version of an original color figure. The shading near the 90 East Ridge indicates low velocities at all depths, the shading of Australia at 111 km is for positive velocity deviations. (Montagner, Ann.Geophysicae 1986)

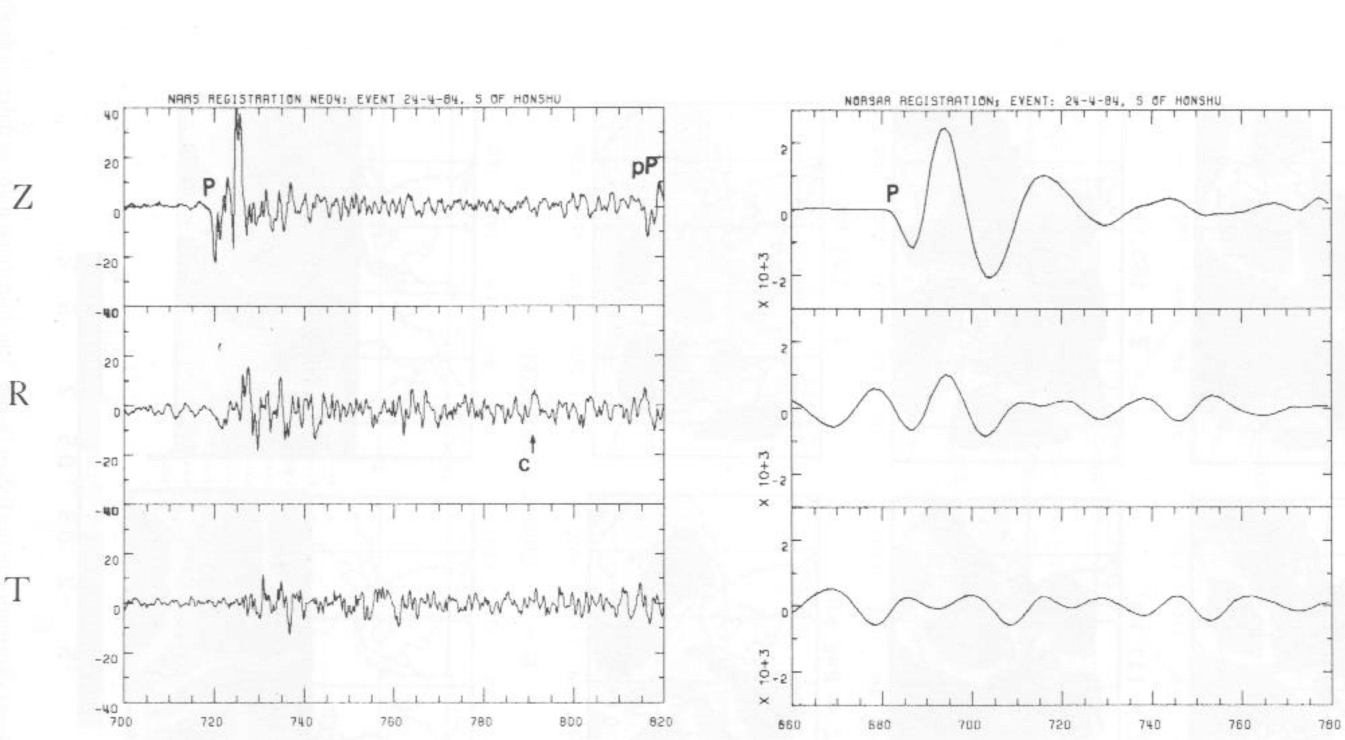

Figure 3.25 Records of the vertical (Z), radial (R) and transverse (T) component of an event in Honshu, in one of the broad band NARS stations (left), compared to LP NORSAR registrations. Arrival time and particle motion of the phase labeled "c" are consistent with its interpretation as a P-to-S converted wave at the 670 km discontinuity (Paulssen, with permission)

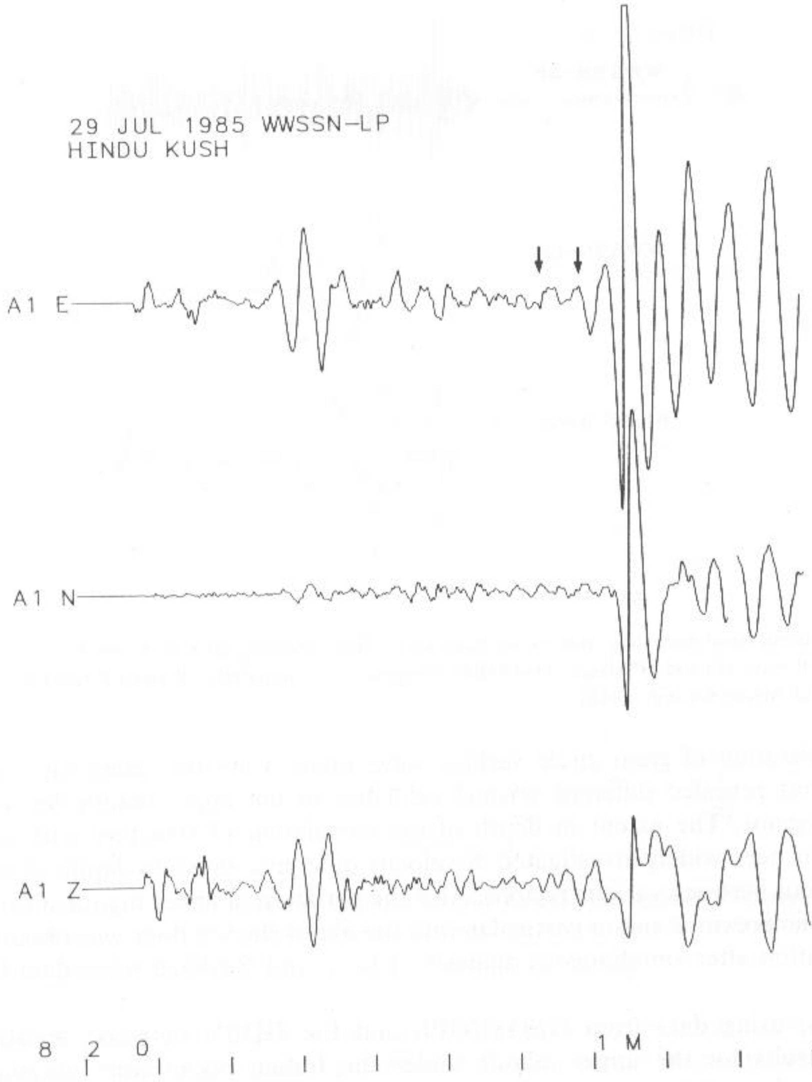

Figure 3.26 Low-passed GRF seismograms from the Hindu-Kush event of July 29, 1985. S precursors are marked with CONV (Faber and Mueller, with permission).

broad-band recording would greatly enhance its potential and with the addition of one or two dozens of suitably located other broad-band stations we would have a unique research instrument which could collect an unprecedented set of surface wave data within a few years.

Global studies: the large scale structure of the Earth can be investigated using measurements of the dispersion and attenuation of very low frequency surface waves. The distribution of seismic velocities and their anisotropy obtained by inversion of such data will ultimately put severe constraints on the geometry and nature of the large scale mantle flow.

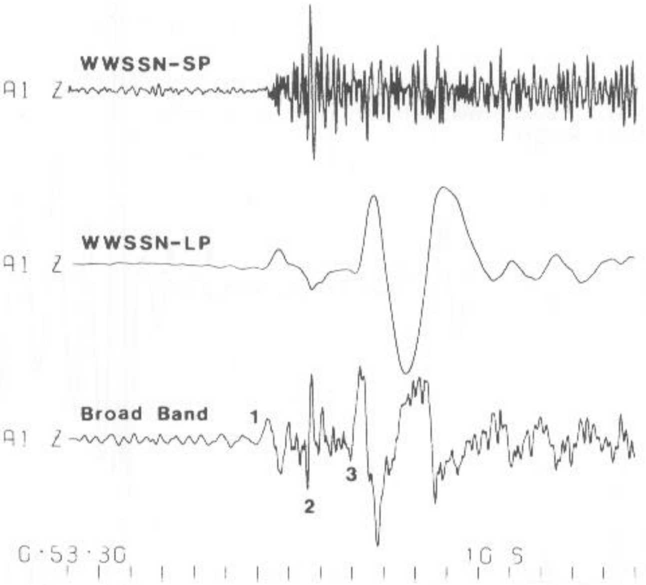

Figure 3.27 Broad band recording from an earthquake in Chile, showing an S to P converted wave (2) in between the P wave (1) and pP phase (3) at GRF, compared to (simulated) SP and LP recordings. (Kind and Seidl, Bull.Seism.Soc.Am. 1982)

Regionalization of great circle surface wave phase velocities using ray approximations, has revealed different seismic velocities in the upper mantle for various tectonic regions. The extent in depth of the correlation of structure with surface features has been widely investigated. S-velocity difference down to depths of at least 250 km occur between various regions. Also the variation of upper mantle anisotropy with tectonic province and in particular with the age of the sea floor was obtained by regionalization after simultaneous analysis of Love and Rayleigh wave data (figure 3.23).

Recently, using data from GEOSCOPE and the GDSN network, spectacular imaging results for the upper mantle under the Indian ocean were obtained by Montagner (figure 3.24).

Three dimensional models of the upper mantle heterogeneities are an important element for modelling the low degrees of the geoid. Seismic heterogeneities can reflect thermal effects related to convection or chemical heterogeneities. This is reflected in the value of the Vp/Vs ratio, which is not the same everywhere. In the same way, the relation between seismic velocities and density is probably not constant, so that density heterogeneities cannot be deduced directly from the seismic velocities.

3.2.2. *Body Wave Studies*

For structural investigations using teleseismic body waves, there is a growing need for recording capabilities in the intermediate frequency band (0.1 to several Hz). One striking example of this is shown in figure 3.25, which shows a clear record of a P-S conversion in one of the NARS instruments, which is invisible on long period records from NORSAR.

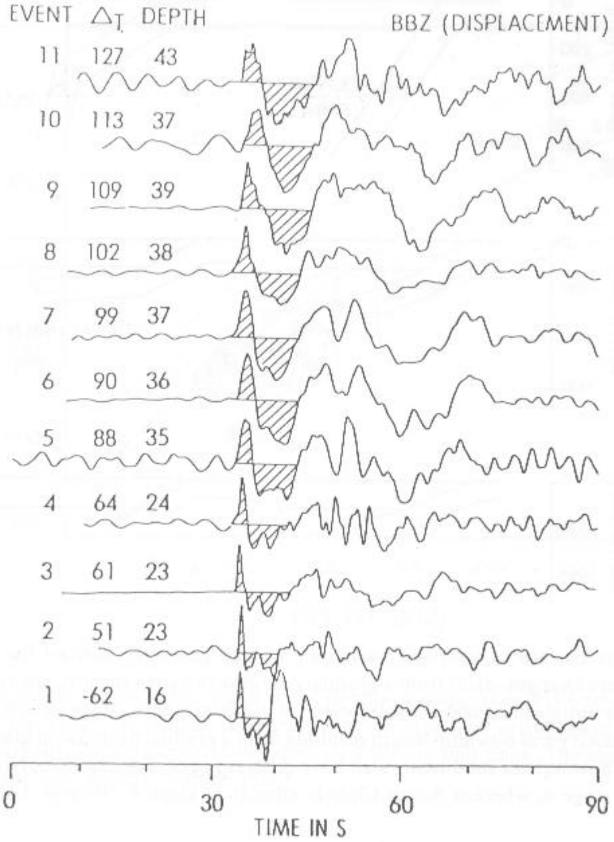

Figure 3.28 Displacement-proportional recordings of central Aleutian earthquakes. The deeper events show greater complexity, and longer duration, leading to very accurate source depth determinations (Engdahl and Kind, Ann. Geophysicae 1986)

Faber and Mueller studied S precursors at Graefenberg at epicentral distances from 70-90 degrees. these precursors were identified as converted phases from the mantle transition zone. A recent example of precursors, from the Hindu Kush earthquake of July 29, 1985 (epicentral distance 44 degrees), is shown in figure 3.26. Since the waves of this event arrive at GRF almost exactly from East, conversions are expected only on the E and Z component, not on the N component; this is so indeed. Then, if the conversion hypothesis is correct, at what depth were the conversions generated? Conversions from the 400 km or 670 km discontinuity are strong enough only beyond about 70 degrees, according to calculations of theoretical seismograms. A conversion depth less than 400 km would be a highly interesting result.

Even more striking is the observation of some converted phases from regions with subducting slabs. Figure 3.27 shows a phase in the P-wave group found at the GRF records of South American events, which cannot be explained by a laterally homogeneous Earth model. This phase was found in a number of records from South American events. It was identified as an S-to-P conversion at the subduction zone. Comparison with conventional SP and LP records clearly shows the advantages of the broad band recording.

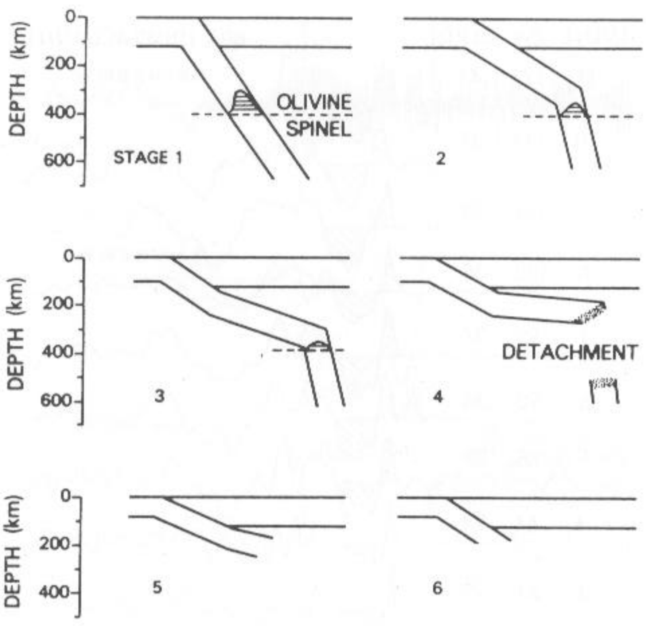

Figure 3.29 Schematic pattern of temporal variations in slab geometry derived for the South American subduction zone. These changes result from a gradual decrease in age of the lithosphere entering the trench. Stage 1 represents the initial configuration: subduction of old lithosphere. Stages 2 to 6 show the consecutive changes in vertical velocity and downdip length resulting from a gradual decrease in lithospheric age. Various segments of the South American subducting slab have different ages. For example, North-Central Peru and Central Chile are in stage 4, whereas South Chile is already in stage 6. (Wortel, J.Geol.Soc.Lond. 1984)

A compilation of P arrivals from Aleutian events clearly shows a significant trend in the complexity of the P wave as a function of depth or distance to the trench, in the intermediate frequency band (figure 3.28). A global broad band network will provide precise information on earthquake depths that is also of considerable importance to geodynamic studies. Accurate determination of the position of the seismic activity in subduction zones, for instance, yields insight into the stress conditions and kinematic behaviour of the subducting plate. As an example, figure 3.29 shows an evolutionary pattern of the South-American subduction zone derived from seismicity data and seafloor spreading data.

Accurate depth determinations such as can be provided by broad band data also have an important bearing on our understanding of the role of the 670 km discontinuity in the convective process. Recent work shows that the absence of seismic energy release at depths greater than the level of this discontinuity can be explained as the effect of temperature on the mechanical properties of the rock, and need not necessarily invoke this discontinuity as a barrier against mantle penetration (figure 3.30). Experience from GRF shows that one can considerably improve on the standard NEIS depth determinations.

Not only converted phases, also refracted and reflected phases from teleseismic events can be observed much better on broad-band records, as is evident from figure 3.31 , showing P-wave groups of GRF records from Greek earthquakes. These records

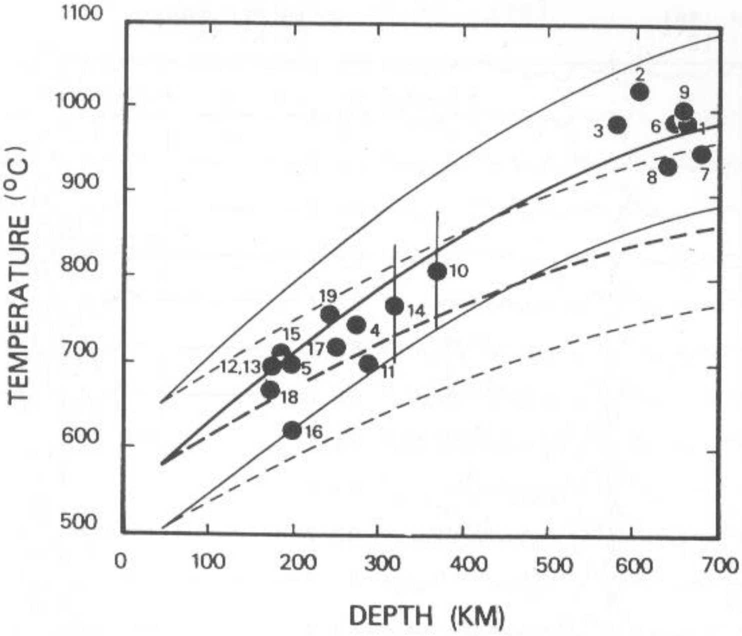

Figure 3.30 Minimum temperatures at the depth of the deepest earthquakes in 19 major subduction zones. The thick solid curve represents the critical temperature above which no earthquakes are generated, based on Stacey's mantle solidus, with its uncertainty indicated by the thin lines. The dashes lines are for an alternative, extreme solidus (Wortel, Nature 1982)

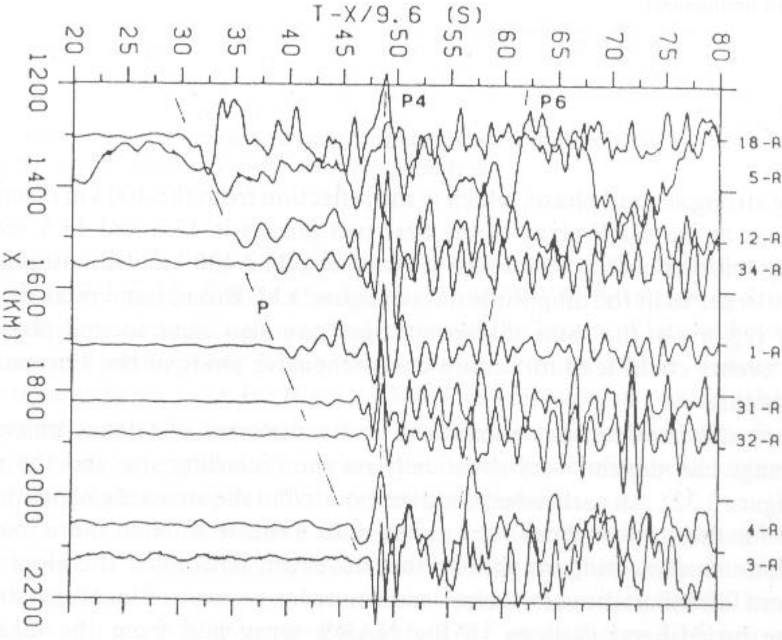

Figure 3.31 A section of several Greek earthquakes recorded at the GRF array. Phase P4 is a reflection from the 400 km discontinuity. (Rademacher, Odom and Kind, with permission)

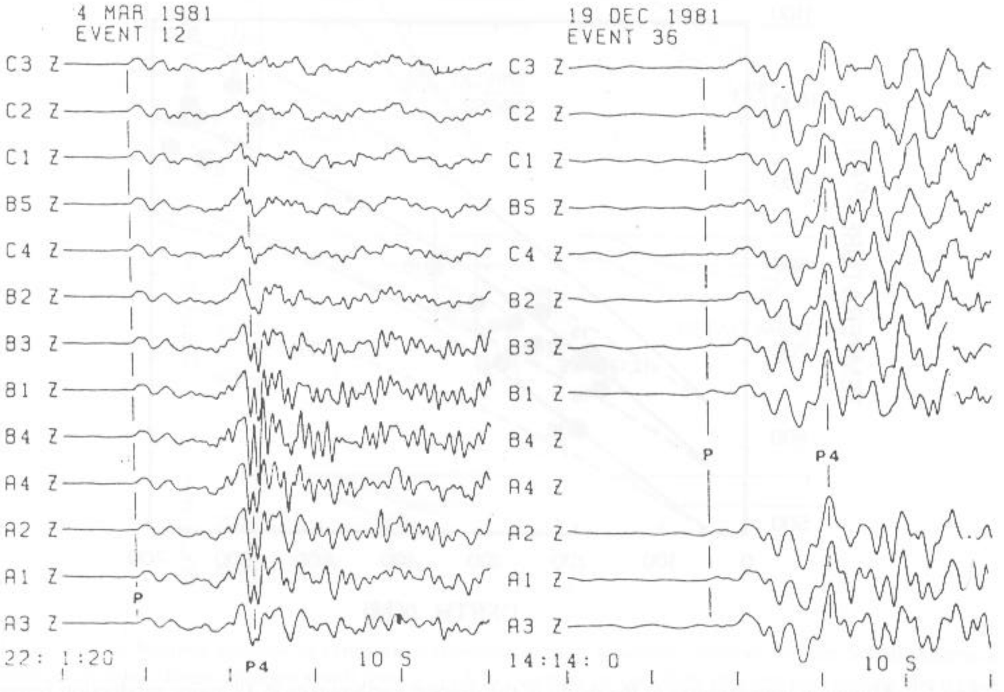

Figure 3.32 GRF data from an event in the Hellenic arc (left) and the Agean Sea (right). The phase P4 in the left record, but not P, is strongly distorted across the array, although these phases have similar angles of incidence. This is probably due to a peculiar structure in the proximity of the stations (Rademacher, Odom and Kind, with permission)

have a very strong second phase, which is the reflection from the 400 km discontinuity. The slowness at the GRF array of the first two phases is 13.6 and 11.5 sec/degree, respectively (corresponding to 8.1 and 9.6 km/sec). The 400 km discontinuity can be modelled in order to fit the amplitude data in figure 3.31. Broad band records of events from other regions in the same distance range have also clear second phases. Data from such events could lead to a more comprehensive study of the European upper mantle structure.

GRF data also indicate that amplitudes and waveforms of seismic phases in this distance range can depend very drastically on the recording site and the epicenter location (figure 3.32). An early interpretation pointed to the structure beneath the Alps as a cause for these instabilities, but newer data indicate a much more local cause. Upper mantle studies using amplitude and waveform data must therefore use data from stations distributed over a larger area in order to control local instabilities.

Both the broad-band stations of the NARS array and from the Graefenberg observatory yield observations of shear-wave splitting, possibly by upper mantle anisotropy, although contaminating effects from lateral heterogeneity may not be ruled

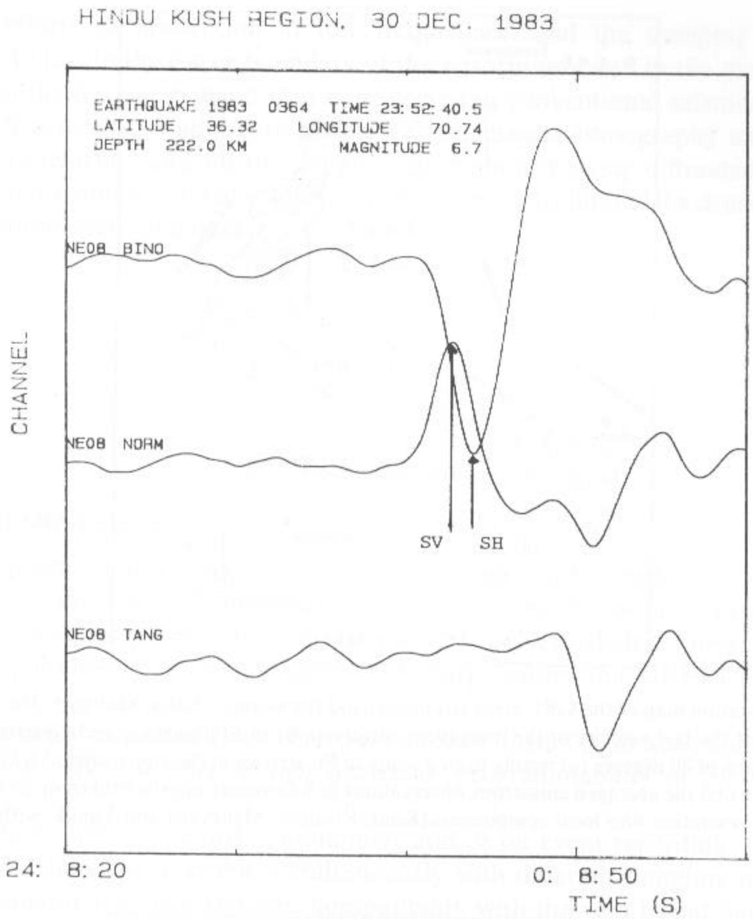

Figure 3.33 Time differences between vertically and horizontally polarized shear waves, such as here shown for one of the NARS stations (Van Rijssen, with permission)

out completely (figure 3.33). Comparison of the direction of the fast velocity axis under GRF with earlier measurements by Vinnik in the WWSSN station in Stuttgart show a difference of 50 degrees, again an indication of the extent of lateral heterogeneity in the continental lithosphere which necessitates a much higher density of seismic stations than hitherto available (figure 3.34). This will allow us to study the anisotropy in more detail using besides body waves the dispersion properties of surface waves on paths criss-crossing the area. The azimuthal dependence of wave velocities as well as the Love-Rayleigh incompatibility can then be studied.

There are of course many more observations to be drawn from broad band records of body waves. It is generally appreciated that the effect of anelastic absorption on body wave amplitude is most pronounced in the high frequency band. This was shown convincingly in a study of Q-spectra from the GRF array (figure 3.35) using teleseismic body waves. Note however that the detail in this curve is almost completely located in the blind spot of conventional seismographs. Doornbos recently used both the

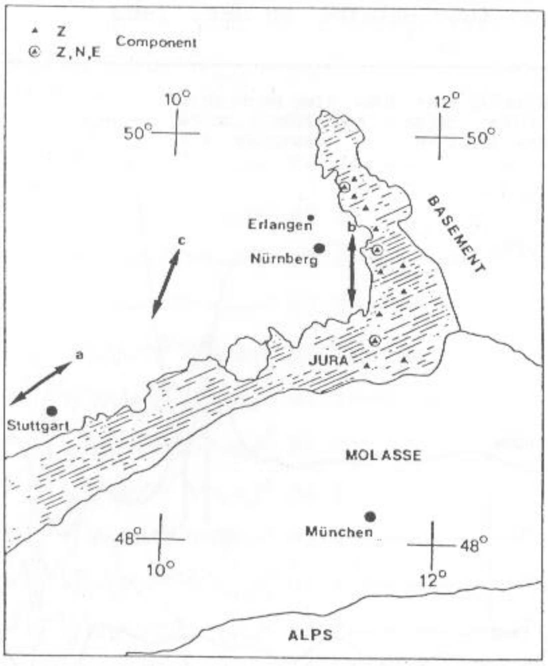

Figure 3.34 Location map of the GRF array (triangles) and the seismic station Stuttgart. The arrows mark the direction of the fast velocity of the anisotropy observations in Stuttgart (a) and Graefenberg (b). An average direction of 20 degrees (c) results from a study of Pn arrivals in the entire area of S Germany. This figure indicates that the averaged anisotropy observations in S Germany may be broken up by methods with higher spatial resolution into local components.(Kind, Kosarev, Makeyeva and Vinnik, with permission)

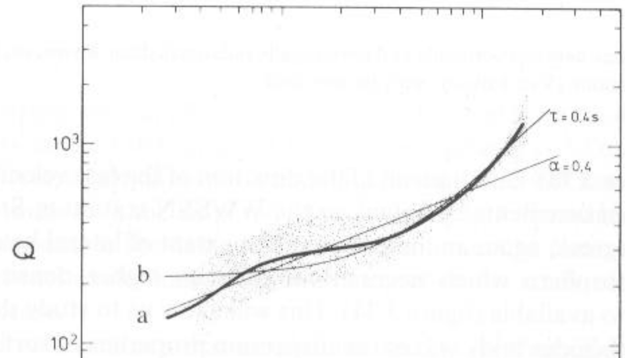

Figure 3.35 Mean (thick line) and range of standard deviations (dotted area) of 15 Q-spectra, scaled at 1 Hz. Line (a) denotes a power law fit, (b) a fit by a absorption band model (Ulug and Berckhemer, J. Geophys 1984)

dispersive effects of absorption at low frequencies, and the damping at higher frequencies to locate the lower boundary of the absorption band in the mantle at 0.5 Hz, again in the frequency band that is neglected in conventional seismometry.

At IPG Strasbourg, studies are under way on mantle tomography using cross-correlated waveforms, and on the core-mantle boundary using diffracted P-waves. These, and many similar kind of studies, would be greatly facilitated if a dense, portable array of stations were available.

4. Technical issues

4.1. INSTRUMENTATION

Digital equipment and processing capabilities leave much freedom to the exact specifications of the field or station instrumentation that will be useful in a cooperative environment such as proposed in this science plan. Nevertheless there are some minimum requirements on which agreement exists within the ORFEUS working group:

- The instruments should in general possess enough flexibility to accomodate future developments. This implies a high degree of programmability of the hardware involved.
- One should be able to record continuously and/or on event recording. Preferably both modes should be possible simultaneously with differing sampling rates.
- For permanently installed stations, compatibility with the very broad band (VBB) range of the instruments currently operated in Zurich and Harvard, and of the planned regional network in Germany is advised. These recorders should preferably have the possibility of access by telephone or data link.
- The broad band instruments of the portable array should be robust and inexpensive. Like the NARS instruments, the sensors should have a good response for frequencies down to 10 mHz at least. The development of a stable, inexpensive seismometer with a broad band response has the highest priority.

4.2. ORFEUS DATA CENTER (ODC)

4.2.1. Purpose

This center is intended both as a collection and distribution center for regional (European) data and will participate in global data exchange.

In a preparatory stage, even an embryonal data copying center could help to avoid the development of unwanted hardware and software incompatibility between the future stations. It could gradually evolve into a data center with research facilities and provide software service.

4.2.2. *Technology of the data center*

An important design parameter for the data center is the desired turn-around time between a seismic event and the availability of a nearly complete event file. One cannot imagine that this time would be less than three months when tapes are used as the primary data carrier. The fact alone that many stations will be operated in event-triggered mode, and tapes will not be changed and mailed before these are nearly full, will account for a delay of the order of one month. Then the tapes will not be mailed to the ODC but to a national data center where they will have to be copied, or at least searched for local events. This kind of delay will make the data unattractive for some applications were broad band data would be most welcome, such as the rapid determination of focal processes of destructive earthquakes, or the identification of nuclear test explosions.

If, on the other hand, a well distributed subset of the stations would store current events on disc or large semiconductor memory, and these data were accessible by telephone, then an active data center could collect very valuable information within one day. From a hardware point of view, this solution is perfectly possible now. The recently formulated design goals for the IRIS global network include this option.

One could even imagine that data telecommunication will become so convenient and inexpensive, that we might completely renounce the idea of using tapes for distribution.

4.2.3. *Data volume*

Depending on the final size of the ODC and future advances in new storage technologies (optical disk), one has to impose limits on the number of events that can reasonably be stored. As a minimum requirement, it seems fair to preserve regional seismic events from magnitude 4 or 4.5 on, and global events from magnitudes somewhat below 6. Depending on how much we include of the Mediterranean seismicity, this would amount to 50-500 regional and about 100 global earthquakes per year.

The special events with rapid data collection would have to be few. We would have to rely on some well-organized seismological institution for the decision on which events are sufficiently important (CSEM Strasbourg would be an obvious candidate).

Regional events would not be recorded at all stations, so their contribution to the volume of data would not be as large as their number suggests. The surface wave train of global events could be stored at a reduced rate of 1 Hz (this data set would comprise the whole seismogram).

For an order-of-magnitude estimate of the data volume, let us assume that some 30 new three-component stations will be operating in the 1990's, and record 150 regional and 70 global events in the average. This would result in about 300 Mbyte of data per year. A comparable amount of data could be contributed by a small portable array. This is not a prohibitive data volume; the event archive would consist of about one computer tape per month, if we do not find better ways of storage.

4.2.4. *Large portable array data*

Requirements to operate and handle data from a large portable array are probably an order of magnitude larger than the needs discussed in the previous section. One might envisage a separate data center, or even separate national centers. Again close cooperation on a European scale is needed.

5. Organisation

5.1. HISTORY OF THE ORFEUS WORKING GROUP

The EGS meeting in 1984 in Belgium saw the start of an informal working group, which held its first formal meeting on November 30, 1984 in Paris. The goal of this meeting was to demonstrate the usefulness of broad-band data to the seismological community and to clarify the integrated European approach to broad-band seismometry.

Although the group was initially formed in response to efforts to deploy a global network by the IRIS group in the US, it was soon recognized that any plans originating from the group should be based on those aspects of seismology in which Europe has the lead: broad-band instrumentation and experience in deployment of digital broad band networks. Most significantly, participants at the Paris meeting agreed that the best approach would be to establish a regional broad band network in Europe. Although some of the stations constituting this network would be operating in a dual role, that is, also be part of GEOSCOPE or IRIS, the European approach would not overlap with the global undertakings of these organisations.

At the same meeting in Paris, representatives to the IRIS committee and data center, and the editorial board of this science plan, were elected. The working group finally acquired the name ORFEUS at the EUG meeting in Strasbourg in April 1985, where the plan for the data center was accepted as a first priority.

5.2. FUTURE STRUCTURE OF ORFEUS

A legal structure for ORFEUS is needed, to handle financial matters and official contacts to European sponsors. Such a structure will be headed by an Executive Committee, whose members have the following fields of responsibility:

- Establishment of an ORFEUS data center
- Coordination of efforts in instrument developments
- International contacts
- Coordination of broad-band station deployment
- Administrative duties and financial affairs

The Executive Committee will be headed by a president.

The first task of the Executive Committee will be to set up an appropriate legal basis for ORFEUS before August 1, 1986.

5.3. TIME SCHEDULE

The need to archive and distribute broad band data other than those from existing networks may already arise in 1987. But we would not be able to install a tape copying center earlier because at this instant it is not yet clear what the exact hardware requirements are going to be. there is much work to be done in the next 3 years (phase I).

As a first step towards the proposed data center we suggest to finance the appointment of a competent scientist who keeps track of technical developments and advises those who are going to install broad band stations. He may experiment with the building of the telecommunication aspect of the future data center, and acquire or write the necessary software. This scientist may be delegated to one of the existing data centers for digital seismograms (GRF/Erlangen, GEOSCOPE/Paris, NARS/Utrecht or NORSAR/Kjeller) or he could serve for some time at each of these centers and use their facilities. Standards for the future exchange of data could be established in this process; the working group alone would probably be unable to arrive at definite recommendations without this direct experience.

Soliciting the necessary funds for starting up this experimental phase, inviting candidates for the ORFEUS data center and select a host institution will be among the first tasks of the Executive Committee.

From 1988 on (phase II), the data center might be able to acquire the hardware for its subsequent routine operation. We anticipate that the data center will be organized within an existing seismological institution that has already adequate computing facilities and part of the necessary know-how. Routine operation in phase II will probably require an extra room, a dedicated minicomputer with large disk and special playback hardware, in addition to an existing mainframe computer. The costs of telecommunication could be substantial. To maintain permanent presence, 3 fulltime positions will be required in phase II.

A tentative list of duties for the ODC in phase II is:

- The ODC will collect broad band data from as many European stations as possible, plus a few other stations. These will be edited into event files, archived and distributed on request.
- For special events defined as being of general interest, the ODC will actively try to collect broad band data as quickly as possible, preferably by telecommunication. These data should be ready for distribution a few days after the event.
- The ODC will exchange waveform data with other regional and global networks.

The ODC will keep data of type (2), as well as a reasonable amount of type (1) data on a mass-storage device for direct access by telecommunication. The protocol should permit the user to specify the sampling rate, the station(s), and the exact section of the seismogram he wants to obtain. The ODC should issue a monthly bulletin on available data that may also contain technical information. The ODC may occasionally assist users in obtaining or transcribing data that are not routinely handled.

The setting up of permanent stations is in principle a matter for initiatives on a national scale, supported and/or advised by the ORFEUS consortium. In view of the variability of the wavefield, even at a very local scale of 10 km (see figure 3.32), there is no lower limit to the useful station distance for scientific reasons, and we are only limited by financial resources. Therefore, our aim should be that by the year 1996, broad band stations are separated not more than 200 km apart, especially in regions of tectonic interest, and that a pool of at least 200 mobile broad band stations is available for temporary increase of the local station density. In figure 2.2 we show that this station distance is already within reach of existing plans for part of Europe by 1990.

5.4. TENTATIVE COST ESTIMATES FOR THE ODC

(in 1000 Swiss Francs)

Design phase (1986/87)	
One full time scientist	90/year
Hardware	100
Initial costs	
Hardware and software	400
External engineering and design studies	60
Furniture	20
Running costs	
Three full time positions	250/year
Supplies and maintainance	100/year
Telecommunication	40/year
Infrastructure, travel	50/year
Unforeseen expenses	100/year

Hardware upgrades may be desirable after a few years of operation. These cost estimates do not include any research facilities. The overhead costs for the ORFEUS Executive Committee can be estimated tentatively at 50/year.

Appendix A

National representatives in the ORFEUS working group

Belgium	M. De Becker, T. Camelbeeck
Denmark	S. Gregersen, J. Hjelme
France	B. Romanowicz (chairman), M. Cara
Finland	H. Korhonen
Germany	R. Kind (secretary), W. Zuern
Italy	R. Console
Netherlands	G. Nolet, H. Haak
Norway	E. Husebeye
Portugal	L. Mendes-Victor
Spain	A. Correig, J. Gallart
Sweden	O. Kulhanek, A. Christoffersson
Switzerland	E. Wielandt, St. Mueller
UK	C. Chapman, C. Browitt

Technical committees

Editorial board:
G. Nolet, B. Romanowicz, R. Kind and E. Wielandt

Field instrumentation and data center:
E. Wielandt (convener)

Network configuration
R. Kind (convener)

Organization matters:
E. Husebye

European representation in IRIS

Standing Committee for global seismic networks:
B.Romanowicz and E. Wielandt

Standing Committee for a Large Portable Array:
G. Nolet

Standing Committee for the Seismic Data Center:
E. Husebye

Appendix B

Inventory of existing plans for broad band seismometry

Belgium 4 permanent stations planned with STS seismometers in Uccle, Dourbes, Membach and Walferdange(Lux). Sampling 20/sec, 16 bit. The superconducting gravimeter will also be exploited in a broad-band mode.

Britain The ministry of Defence operates 9 digital stations. A cheap reliable broad band seismometer has been developed by Dr C.M. Guralp at Reading University, and is under testing at Blacknest.

Finland The University of Helsinki plans to perform broad band recording in stations KEV, KJF and NUR. NUR is a WWSN station and KEV belongs since 1980 to the Global Digital Seismic Network GDSN.

France In addition to the GEOSCOPE network (see chapter 2) there are two broad band stations in the east of France (STR and ECH), and there are plans to use a small portable array of 4 broad band stations for surface wave studies in several regions (Indian Ocean, Peru, Spain).

Germany A project study has been made for a regional network with a radius of about 300 km around GRF Broad band stations with STS seismometers are proposed for the existing observatories near Berlin, Bochum, Clausthal, Muenchen, Schiltach (Black Forest), Frankfurt and Wettzell (Bavarian Forest). Temporary storage of all data on disk should allow for a 14-day period to tap interesting events by telecommunication (Datex-P) and archive at the GRF data center. The system is of modular design and very flexible. In addition to this, Germany supports installation of an STS station in India.

Italy An experimental digital broad band station has recently been installed at l'Aquila (AQU) by the Istituto Nazionale di Geofisica (ING), in cooperation with Harvard University. Five more similar stations are planned to be put in operation either in Italy or in other Mediterranean countries.

The Netherlands Three broad band stations will be installed by the Metereological Institute (KNMI) in the eastern part of the country in the near future. The installation of the first station, equiped with an STS seismometer, is expected near Epen in 1986. The future (1988) location of the broad band portable NARS array has not yet been decided, awaiting plans for international cooperation within ORFEUS.

Norway Has three broad band stations planned, of which one at Spitsbergen.

Switzerland The stations in Iceland, the Azores and the Black Forest will be upgraded to broadband recording as soon as recorders are available, plus 5 vertical component stations in Switzerland.

Sweden Upgrading to broad-band recording is planned for the existing stations UPP, UME and KIR.

Other countries (Portugal, Spain) have expressed general interest in broadband seismology, but have no specific plans for stations as yet.