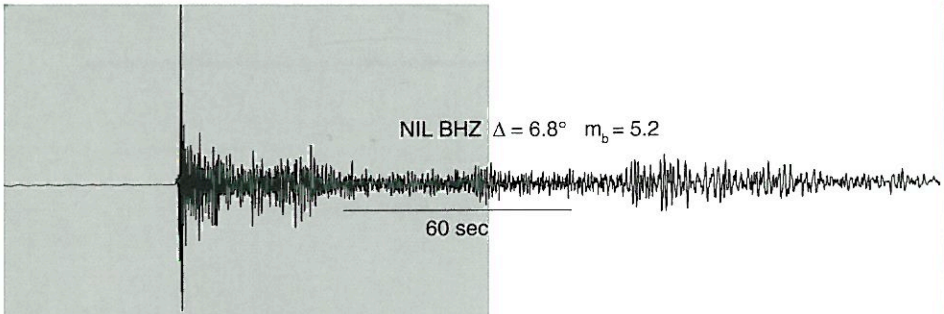

The Indian Nuclear Test on May 11, 1998 as recorded by IRIS station NIL near Nilore, Pakistan. (page 22)

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FALL/WINTER 1998

IRIS NEWSLETTER

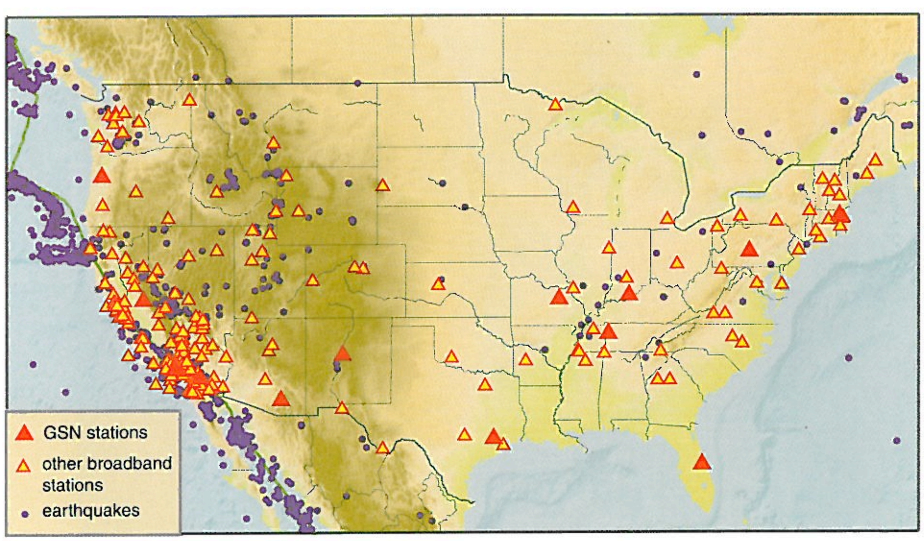
VOLUME XVI ▪ NUMBER 2

New Opportunities, New Directions

The upcoming Millennium Year has motivated many organizations to review their mission. The United States Congress, National Science Foundation, and the US Geological Survey have all issued long-range science plans; and almost all of us have become involved in reviews, reassessments, and reorganizations.

Against this national backdrop of reports and review panels, we must now begin to develop IRIS's next 5-year proposal and program plan, which will be submitted to the National Science Foundation in mid-2000. Although we are unanimous in our first priority of maintaining a strong commitment towards the facilities that we have already developed, we also recognize that the needs and interests of the seismological community have evolved. It is therefore the time to discuss new opportunities and new directions.

This Newsletter is intended to advance our discussions by beginning with two initiatives that are emerging from the seismological community: the USArray and the Plate Boundary Observatory. We present these projects as a sampling of the types of experiments that the Earth science community should consider for support over the next decade. As we explore new directions, we urge all of you to participate in the proposal development process, and to provide us with your ideas and suggestions. ▪



Future experiments that seek to use seismology to explore the structure and formation of the North American continent will require significant enhancements to the current coverage and instrumentation depicted above.

USArray - Probing the Continent

Göran Ekström, Harvard University; Gene Humphreys, University of Oregon; Alan Levander, Rice University

USArray is the working name for an envisioned facility for the seismological probing of the North American continent. The facility is currently conceived to consist of two main parts: (1) a densified network of permanent broad band stations providing uniform coverage across the contiguous US, and (2) a collection of more than one hundred seismometers configured in a transportable telemetered array. This tool is needed for a new style of systematic mapping of the continental lithosphere and upper mantle, with the goal of revealing structures which tell us about the evolution of the continent from the Precambrian to the present.

The scientific and technical design of USArray evolves from the successes of the IRIS PASSCAL program and a growing understanding of the value of combining local and regional, and short- and long-term observations in seismological imaging. A project of systematic seismological mapping of the

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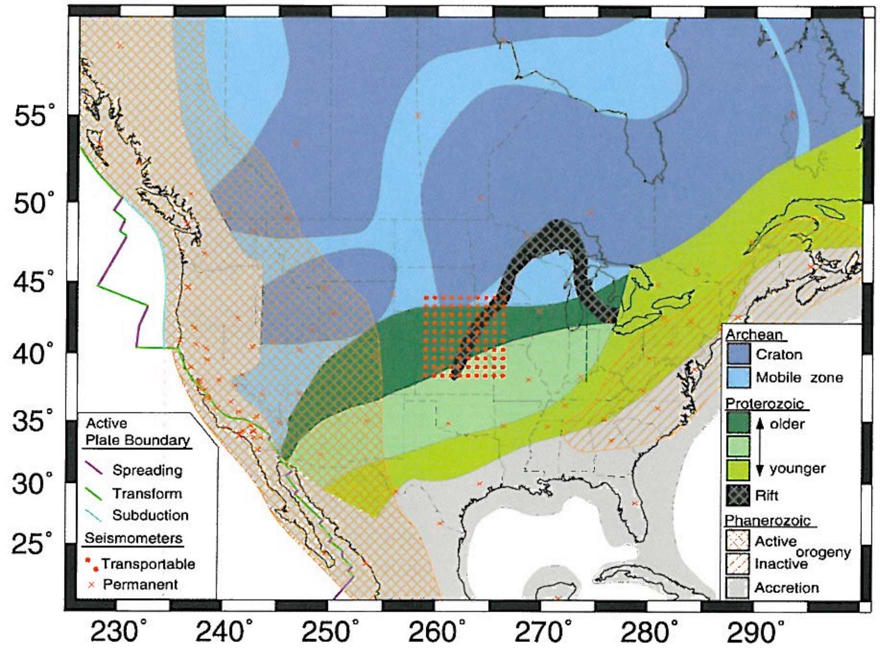

Figure 1. Idealized tectonic map of North America. Many structure boundaries are gradational and poorly understood. The permanent station locations are the existing sites of the Canadian, Mexican and US national broadband networks, the California broadband networks and the IRIS/USGS GSN.

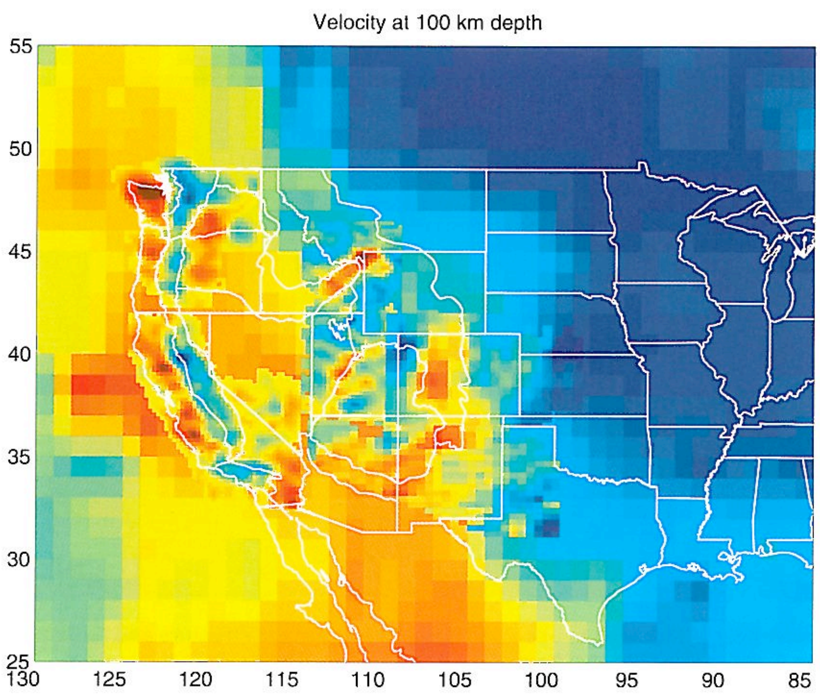

Figure 2. Composite image of upper mantle seismic structure at 100 km depth beneath North America. Blue is high velocity mantle and red is low velocity mantle. The continental scale image is from the multi-bounce S-wave modeling of Grand (1997). Overprinting Grand's image are five regional array inversions by different authors. The scale and baseline of the different inversions have been adjusted and the total range in P-wave velocity is about 8%. Using standard scaling relations, red regions are partially molten and blue regions are subsolidus. (Figure courtesy of Ken Dueker.)

A Plate Boundary Observatory

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[1] Carnegie Institution of Washington, DTM; [2] IGPP, Scripps Institution of Oceanography; [3] University of Southern California/ Southern California Earthquake Center; [4] University of California, Berkeley; [5] University of Utah; [6] Northwestern University/ UNAVCO

A basic tenet of plate tectonics is that plates are rigid and that deformation is concentrated in narrow zones at their boundaries. We now know that plate boundary deformation zones can actually be quite broad, often extending thousands of kilometers into continental interiors, as illustrated by the Alpine-Himalayan chain and the western cordilleras of North and South America. They account for fully 15% of the Earth's surface (Gordon and Stein, 1992). Nearly all present-day tectonic activity and most non-meteorological natural hazards, particularly earthquakes and volcanic eruptions, are concentrated within these zones, making the plate boundary zone a critical area of study both from scientific and societal points of view. The segment of the Pacific-North American plate boundary zone found in the western United States shares these characteristics. It covers a third of the North American continent and includes such diverse features as the Rocky Mountains, the Basin and Range, the Coast Ranges and the Sierras. It also contains the seismogenic San Andreas fault system along its western edge.

The diverse tectonic processes found in these zones are ultimately due to the inexorable and quasi-steady relative motion of tectonic plates. An important constraint provided by modern geodesy is that spatially averaged decadal geodetic estimates of plate motion are, to first order, indistinguishable from geologic estimates based on million-year time scales. This "steadiness" provides a valuable framework for studying plate boundary deformation; it is also in marked contrast to the extremely variable tectonic response to this motion. This deformation spans at least 14 temporal and 3 to 5 spatial orders of magnitude, and includes processes that range from mountain building to earthquake occurrence.

The study of plate boundary deformation is a rich research area that deserves increased attention from a broad spectrum of Earth scientists. There are several first-order unanswered questions that are nevertheless critical to understanding any tectonic process.

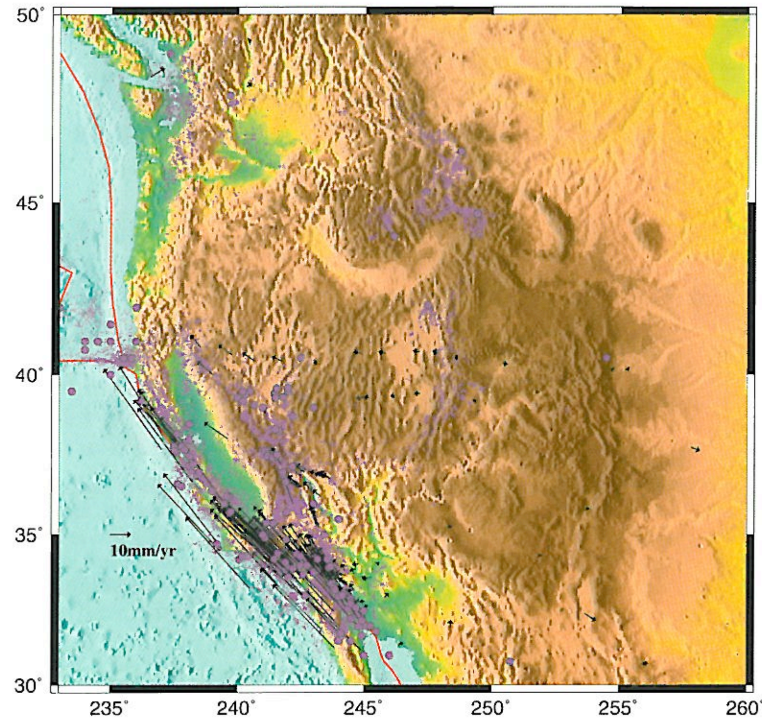

Figure 1. A topographic map of the western U.S., where the Pacific/North American plate boundary zone reaches its greatest width. Also shown are the locations of earthquakes above magnitude 6 that have occurred over the last 200 years (violet circles), and background seismicity over the last 10 years (violet dots). This particular plate boundary is very broad, containing about a third of the width of North America, although the seismic activity is concentrated towards the western edge of the boundary zone. Black arrows give GPS displacement vectors with respect to stable North America for most available GPS data (Bennett et al., 1998). Note large displacements along the San Andreas fault system and smaller, more diffuse deformation in the Basin and Range. Red lines denote plate boundaries.

- How is deformation accommodated three-dimensionally within a plate boundary zone? On which time scales is it homogeneous and on which is it highly heterogeneous?
- What physically controls the spatial characteristics of plate boundary deformation: the structural properties of the deformation zone, the characteristics of the stress field, or an interaction of these factors?
- Are temporal variations in deformation controlled primarily by the slip-rate on faults or the viscoelastic relaxation of the medium as a whole?
- Are there deformation transients, and do they propagate within the plate boundary zone?
- What is the relation between vertical and horizontal tectonics? Is deformation controlled primarily by direct interaction between the two plates, or does the underlying mantle play a critical role?
- Of fundamental importance to seismology, how does plate motion ultimately produce an earthquake?

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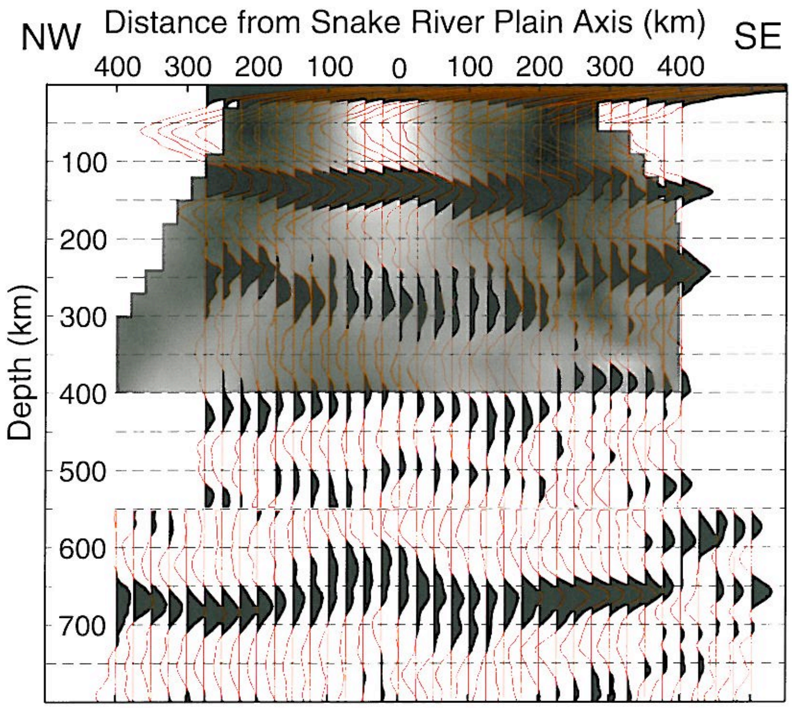

Figure 3. Common-sample-point stacks of receiver functions across the Snake River Plain (Dueker and Sheehan, 1997). Discontinuities are seen at depths of about 250, 410, and 670 km. The feature at 150 km depth is the first reverberation from the Moho. Shown in the background is the S-wave velocity structure, with light areas being about 8% slower than dark areas. (Figure courtesy of Ken Dueker and Anne Sheehan.)

[continued from page 2]

US is likely to stimulate a broad Earth science investigation of the continent, and encourage the collection and (re) examination of geological, geochemical and geophysical observations and data sets. The new facility will also allow a significant improvement in the uniform detection and quantification of earthquakes in the US, providing additional constraints on active stresses and tectonics. The structure of the project would be designed to support broader objectives expressed by the seismological and geological communities, such as multidisciplinary cooperation and educational outreach.

SCIENTIFIC MOTIVATION

The central goal of the project is to understand the structure and evolution of the North American continent. North America exhibits nearly every type of geologic setting. As shown in Figure 1, it includes one of the Earth's great orogenic plateaus and one of the great continental cratons, active plate margins bounded by major strike-slip, subduction, and rift fault systems, an active hot spot, modern passive margins, and the remnants of a Paleozoic mountain belt of Himalayan proportions. Its seismic structure has been explored on many scales using data from North American stations of the Global Seismographic Network and affiliated stations, a number of regional arrays, a growing number of PASSCAL experiments, and numerous reflection and refraction profiles. However, many important questions remain, in particular concerning the relationships between the smaller geological-province and crustal scale structures and the larger continental and lithospheric scale structures. Viewed slightly differently, a principal objective of the USArray project is to tie together the seemingly disparate tectonic provinces into a coherent model of the origin and

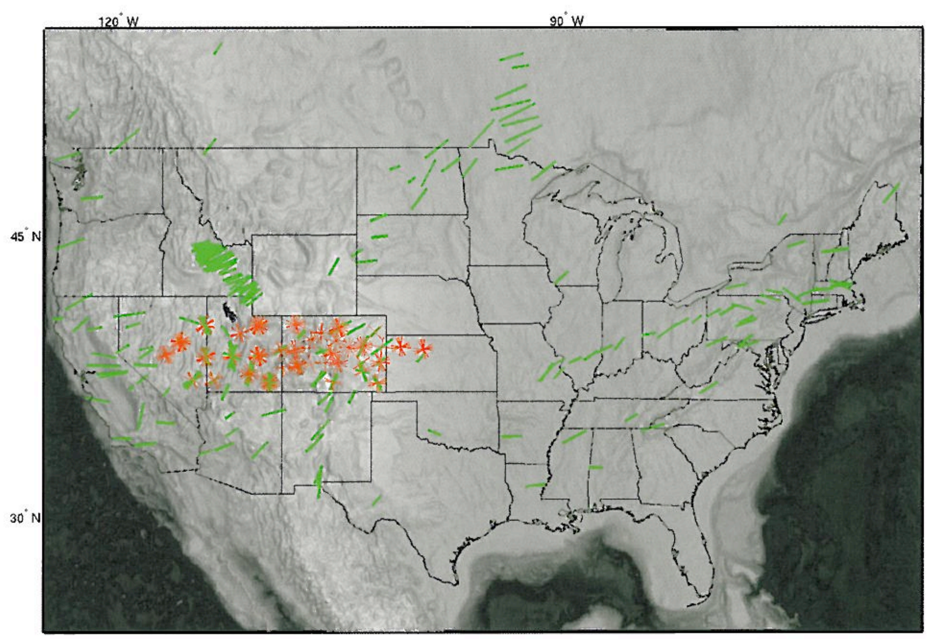

Figure 4. S-wave splits from the U.S. and southern Canada compiled from several different studies and publications. Green lines indicate the fast direction and split time of split SKS arrivals. The greatest reported split time (in southern Canada) is about 2.5 s. Red lines indicate the backazimuths of null arrivals in areas where null arrivals are common.

evolution of continental lithosphere.

THE TRANSPORTABLE ARRAY

The experiment envisioned for the mobile portion of USArray is a 10-year-long roving deployment across the contiguous US with potential land extensions into Canada and Mexico, as well as seafloor extension onto the continental shelf. The target area of ten million square kilometers could be uniformly covered by, for example, 20 deployments of 100 seismometers, each of six months' duration and with the geometry depicted in Figure 1. The result of the experiment would be a uniform, internally consistent data set with well understood spatial sampling and aliasing properties, which would be used to image the entire continent in the same detail and resolution. Many natural opportunities would exist to encourage and coordinate add-on PASSCAL experiments with the deployment of USArray.

Results from recent regional PASSCAL experiments provide examples of the type of seismological mapping of the continent that could be achieved with the new array. Figure 2 shows results from P and S wave tomography of the western US using teleseismic arrival time data. A clear separation is seen between the fast cratonic core and the heterogeneous but largely slow orogenic belt. In the orogenic belt, low velocities correlate with areas of young volcanism, and near the plate margin, high velocities correspond with tectonic domains, indicating a surprisingly complex upper mantle structural geology. Isostatic calculations show that in the high western US interior thermal effects alone cannot explain the high velocities and low densities of the mantle, and that some compositional modification of the mantle, such as basalt depletion, may have occurred as well. Figure 3 shows results from receiver function studies across the Snake River Plain, revealing both significant velocity heterogeneity and topography on the 410 and 660 km discontinuities. These variations indicate lateral variations in temperature or composition that occur in the upper mantle beneath an active portion of North America.

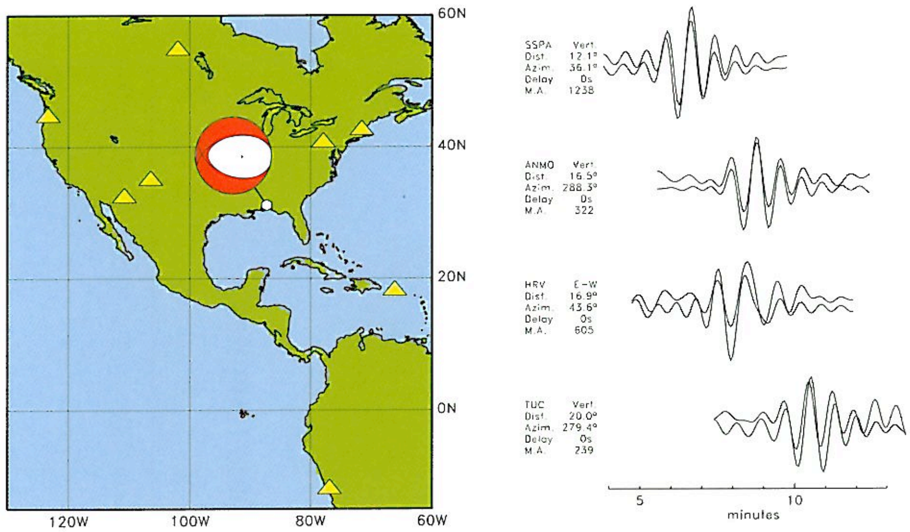

Figure 5. The October 24, 1997 Alabama earthquake. The map on the left shows the location and focal mechanism of the earthquake, with triangles indicating the locations of stations used in the CMT analysis. The record section on the right shows comparisons of observed (top) and model (bottom) seismograms for the four closest stations. The seismograms are dominated by fundamental mode Love and Rayleigh waves.

In addition to a mapping of the isotropic velocity structure of the deep portion of the continent, constraining its temperature and composition, mapping of the anisotropic properties would provide us with a history of the deformation of the continental mantle. Figure 4 shows a compilation of S-wave splitting results across North America. Anisotropy beneath the tectonically inactive portion of North America, and beneath the Yellowstone swell, is aligned in a direction that is generally consistent with shearing of the continental lithosphere (or, for Yellowstone, the asthenosphere) in the direction of absolute plate motion. Results from much of the elevated western US, however, are complex and must represent small-scale, poorly understood deformation processes beneath this currently active area. The transportable array would allow us to map anisotropy uniformly across the continent.

THE PERMANENT NETWORK

The densification of the permanent network of broadband stations would involve cooperation among groups which operate high-quality observatories in the US, such as the USGS, the regional networks, DOD, and IRIS. The USGS National Seismic Network (NSN) already constitutes such a network, cooperating with all the parties mentioned above, and the permanent component of USArray would build on the existing NSN. The emphasis would be on high-quality data and efficient data distribution.

A denser network of high-quality stations will be valuable as a set of fixed reference points for the portable USArray deployments: current efforts to combine tomographic images from a variety of portable experiments have been hampered by the lack of a common baseline between studies. In addition, some tomography experiments benefit from the accumulation of many observations at a single site, since this allows for a better separation of local and distant wave propagation effects. These considerations suggest that an initial goal for the permanent component of USArray should be uniform coverage. To achieve a density of one high-quality station every 350 km within the conterminous US, approximately 30 stations would have to be added to the existing inventory of sites (see Figure 1); several existing stations would need to be upgraded.

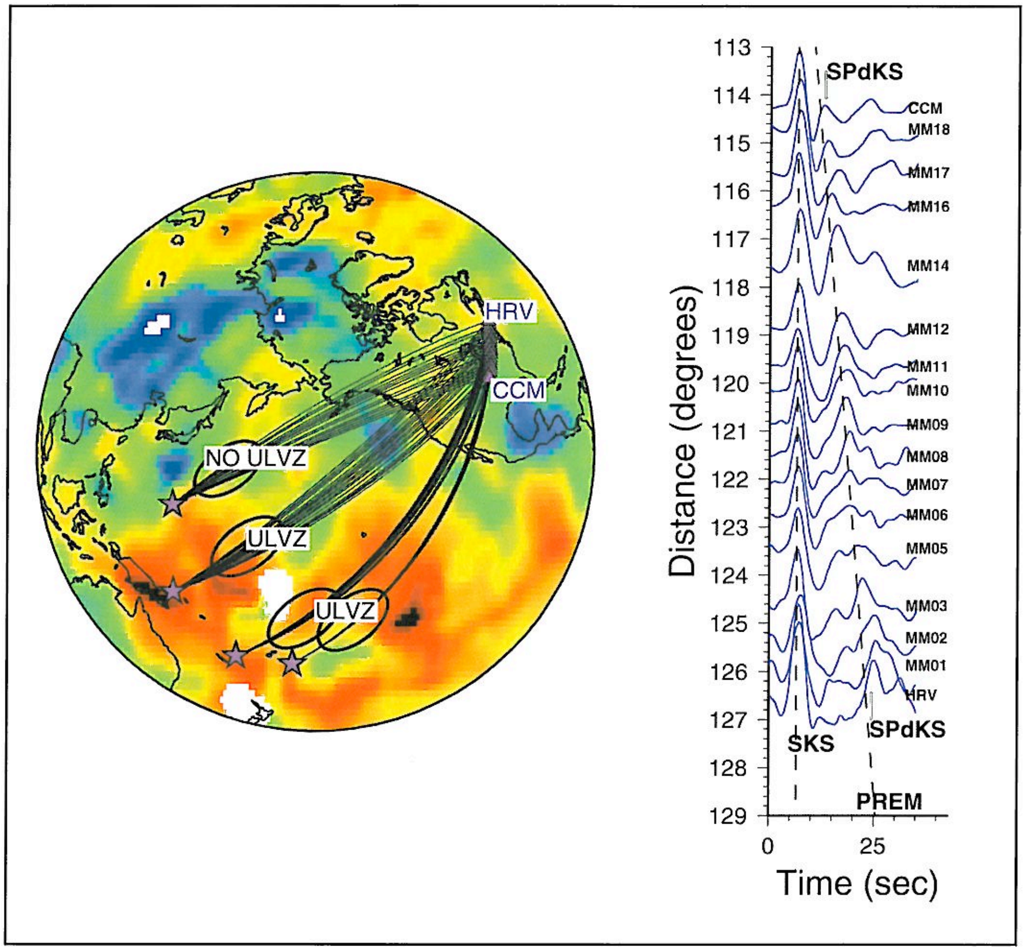

Figure 6. Left: Paths to the stations of the MOMA array from earthquakes in the western Pacific. The regions sampled by possible SPdKS phases on the source side of the path are shown by the four ellipses. Background shows the lowermost layer of the Grand et al. (1997) S-wave model. Paths from Tonga and New Britain require ultra-low velocity zones at the CMB, but paths from the Marianas do not. Right: Record section of SKS/SPdKS phases for the New Britain earthquake. SPdKS is clearly observed moving out from SKS, but its peak arrives up to 5 seconds late with respect to the times predicted from PREM (dashed line). These observations are consistent with the existence of a thin, ultra-low velocity zone, and possibly partially molten mantle. (Figure courtesy of Karen Fischer.)

An expanded network of stations, contributing data in near real time to the USGS NSN, would improve the detection, location, and source characterization capabilities of the NEIS for earthquakes and other seismic events in the US and surrounding areas. With this expanded network, moment tensor estimation of earthquake parameters from regional waveforms could include earthquakes to smaller magnitudes (approximately magnitude 3.5) anywhere in the continental US. Moment tensors of smaller earthquakes would provide information on current stresses and modes of deformation within the continent. For example, Figure 5 shows the normal faulting mechanism of the 1997 M=4.9 Alabama earthquake, which was large enough to be studied using data from IRIS GSN stations at far-regional distances. A dense national network would allow this type of characterization for much smaller earthquakes.

The permanent component of USArray could also be used to probe deep Earth structure on a global scale. Figure 6, for example, shows a record section across the MOMA array; the emergence of the diffracted phase SPdKS is indicative of an ultra-low velocity region above the core-mantle boundary in the central Pacific.

CONCLUSION

By itself, USArray is a facility and an experiment in seismology and geophysics. Its success would require the active participation of the broader IRIS community. It would provide a natural venue for pursuing IRIS education and outreach goals in seismology. In concept, USArray is also envisioned to be a key element of a coordinated program of broad, interdisciplinary Earth science study of the North American continent. Each of the USArray temporary deployments, moving across the rich variety of geologic provinces of North America, could be the observational core of an integrated field laboratory involving the full spectrum of geoscience investigations, and could also provide a prominent center for an exciting public education program.

ACKNOWLEDGMENT

This article summarizes presentations by the authors at the 1997 IRIS instrumentation workshop in Santa Fe and the 1998 IRIS annual workshop in Santa Cruz. Our attempt at formulating the USArray concept is based on earlier ideas and proposals of various groups and individuals. In particular, we acknowledge the contributions and assistance of Ray Buland, Ken Dueker, Karen Fischer, Bob Hutt, Art Lerner-Lam, Anne Meltzer, Tom Owens, Jeffrey Park, Peter Shearer, Anne Sheehan, Rob van der Hilst, Bob Woodward, Michael Wysession, and George Zandt. ■

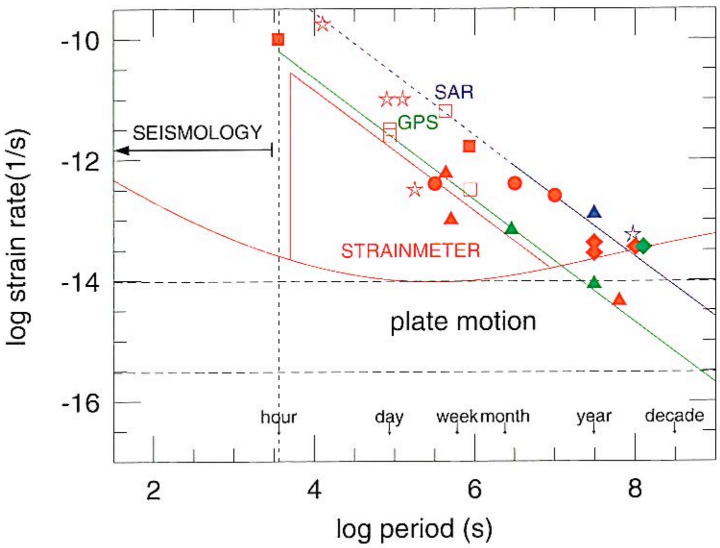

Figure 2. The necessary components of an integrated plate boundary deformation network, and observed transients. Thresholds of strain-rate sensitivity (schematic) are shown for strainmeters, GPS, and INSAR as functions of period. The diagonal lines give GPS (green) and INSAR (blue) detection thresholds for 10-km baselines, assuming 2-mm and 2-cm displacement resolution for GPS and INSAR, respectively (horizontal only). GPS and INSAR strain-rate sensitivity is better at increasing periods, allowing, for example, the detection of plate motion (dashed lines) and long-term transients (periods greater than a month). Strainmeter detection threshold (red) reaches a minimum at a period of a week and then increases at longer period due to an increase in hydrologic influences. This is a conservative estimate which has been bettered in some situations. At long periods (months to a decade), GPS has greater sensitivity than strainmeters by one to two orders of magnitude. At intermediate periods (weeks to months), sensitivities are comparable, and at short periods (seconds to a month), strainmeter sensitivity is one to three orders of magnitude greater than for GPS. Combined use of both data sets provides enhanced sensitivity for detection of transients from earthquakes to plate motion. Also shown are several types of transients observed by strainmeters (red), GPS and equivalent (green), and INSAR (blue): Post-seismic deformation (triangles), slow earthquakes (squares), long-term aseismic deformation (diamonds), preseismic transients (circles), and volcanic strain transients (stars).

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> How do faults interact? How do earthquakes interact? What fraction of fault slip is aseismic? What kinds of earthquake-related transients are there? Do pre-event transients exist that may be utilized for forecasting?

The central observational requirement for the study of plate boundary deformation is the characterization of the three-dimensional deformation field over the maximum ranges of spatial and temporal scales. The surface field can be measured geodetically; instrumentation must provide: (i) sufficient coverage of the plate boundary zone so as to capture an integral tectonic system, (ii) sufficient station density for detecting localized (e. g., fault-specific) phenomena, and (iii) the necessary bandwidth to detect plausible transient phenomena from fast and slow earthquakes to strain buildup and viscoelastic relaxation. For studying long-term, large scale tectonic processes, it is probably sufficient to examine spatial variations in steady-state strain rate, which may then be compared to geologically inferred deformation rates over the last few million years (Figure 1).

For short-term processes and their related deformation, such as earthquakes and volcanic eruptions, temporal and spatial resolution becomes much more important. Good sensitivity is needed across the sub-second-to-decade period band. The sub-second to hour range is readily covered by seismological observations. At longer periods, geodetic techniques are needed, but presently, there is no one geodetic technique that spans this broad temporal range (5 orders of magnitude) with roughly uniform strain-rate sensitivity. It will thus be necessary to utilize several techniques, including strainmeters, GPS, and interferometric synthetic aperture radar (INSAR) —the first being most useful from an hour to a month and the latter two (including non-continuous campaign measurements) for periods longer than a month (Figure 2). The published observations of transient phenomena reveal a variety of temporal scales that span this entire range (Figure 2). The post-seismic deformation of the 1992 Landers earthquake provides an excellent example (Figure 3a). Transients with three distinct time constants have been detected by these three instrumentation types: 5 days by strainmeters (Wyatt et al., 1994), 48 days by GPS (Shen et al., 1994) and 3 years by INSAR (Massonnet et al., 1996). In addition, remotely triggered seismicity from the Landers event at Long Valley was accompanied by a 6-day deformation pulse observed clearly on two strainmeters (Figure 3b, see Linde et al., 1994). These diverse post-seismic transients are suggestive of multiple deformation mechanisms. Two other examples illustrate the potentially broad range of transient behavior. The first is a slow earthquake (duration ~10 days) on the San Andreas fault near San Juan Bautista that was detected on two strainmeters, and was accompanied by increased seismic activity (Figure 3c, Linde et al., 1996). The other is a long-term (multi-year) aseismic transient in San Andreas fault slip that was observed on 2-color geodimeters, strainmeters, and creepmeters, and was coincident with an increase in seismicity (Figure 3d, Gao et al., 1998). Clearly, a crucial task in utilizing a multicomponent system is the integration of these geodetic techniques. There are ongoing efforts by investigators to incorporate at least two of these techniques into an internally consistent measure of the surface strain field: GPS and INSAR (Bock and Williams, 1997), and GPS and strainmeters (Gao et al., 1998).

Determining strain at depth is a less straightforward but crucial task. Deformation within the seismogenic zone, for example, may provide vital information on the triggering of seismic events. Strain indicators rather than calibrated strainmeters, must be used, however. For example, microearthquake activity can be interpreted as the radiated component of deformation in the seismogenic zone. Recent results of cluster analysis of microearthquakes at Parkfield have

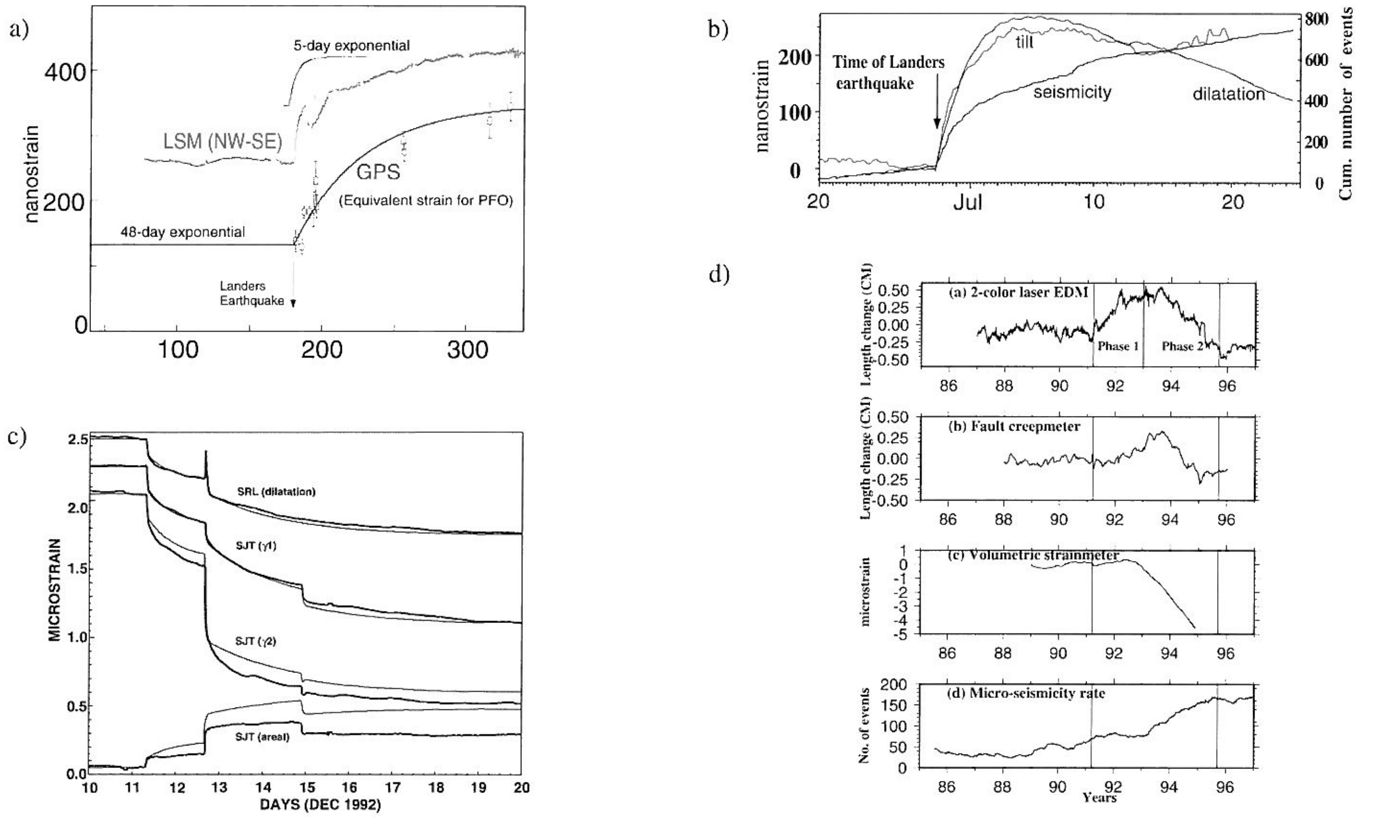

Figure 3: Examples of transients: a) Post-seismic deformation for the 1992 Landers earthquake from a laser strainmeter (LSM) and GPS, illustrating 5-day and 48-day time constants, respectively (after Wyatt et al., 1994). (b) Landers-triggered strain transient produced at Long Valley. Produced increase in seismicity (blue) and observed by a dilatometer (green) and tiltmeter(green) 20km apart (After Linde et al, 1994). (c) Slow (10-day) earthquake detected along the San Andreas fault at San Juan Bautista (south of Bay Area) and accompanied by elevated seismicity (Linde et al., 1996). (d) Multiyear aseismic transient in San Andreas fault slip at Parkfield, observed on 2-color geodimeters (stack of fault-crossing lines, GPS equivalent), dilatometers and tensor strain (not shown), creepmeters, and accompanying increased seismicity. The increase and decrease in line length (top panel) between 1991-1993 and 1993-1996 corresponds to a decrease and increase in fault slip rate, respectively (Gao et al.,1998).

demonstrated the power of this type of technique for furthering our understanding of fault zone processes (Nadeau et al., 1995). Another important approach is imaging spatial and temporal variability in crustal structure. Images of faults can be obtained by the use of fault-zone guided waves (e.g., Li et al., 1997). The seismological detection of strain-induced opening and closing of fluid-filled cracks can be achieved through characterizing temporal variations in crustal structure. Mantle deformation is also accessible by seismic imaging, through constraints on the thermal (tomography) and strain (anisotropy) fields.

With these issues in mind, we recommend that the scientific community consider establishing a strain observatory along the Pacific/North American plate boundary (hereafter referred to as the Plate Boundary Observatory or PBO). The PBO should measure deformation over a broad spectrum of spatial and temporal scales and provide sufficient spatio-temporal resolution to constrain any transients associated with short-wavelength phenomena such as earthquakes. We propose that, where such phenomena are most prevalent, namely the most seismogenic areas of the boundary, 10-km spacing of instruments be achieved (Figure 4). This portion of the plate boundary is also where the greatest temporal resolution is needed. A close integration of seismometers, strainmeters, GPS, and INSAR is necessary to provide uniform strain-rate sensitivity, at plate-motion strain rates, across the temporal band from several Hertz to a decade. On the order of 1000 observing sites would be required. For the broader plate boundary, it would be possible to use coarser spacing, and to utilize GPS and INSAR exclusively, since these techniques are most successful for detecting long-period or steady-state strain. Constraints on the subsurface deformation field would be supplied by studies of strain indicators: microeathquake activity and crustal and mantle structure (including possible temporal variations). The seismological component would require both an augmentation of permanent seismic instrumentation in the plate boundary zone and transportable array deployments to map out particular regions in detail.

It would not be necessary to start from scratch in this effort, since some pieces of the PBO are already, or will soon be, in place (Figure 4). The most advanced component consists of geodetic-quality arrays of continuous GPS stations in southern (SCIGN) and northern (BARD) California, northern (NBAR) and eastern (EBAR) Basin and Range, and the Pacific Northwest (PANGA) (Figure 4). There are presently about 200 GPS receivers deployed in the proposed area, and 250 more should be installed within the next 1 to 2 years. The strainmeter component is much less advanced, since there are only about 20 strainmeter sites along the entire San Andreas fault system. Regarding INSAR, images are being acquired by non-U.S. satellites over western North America and are available to U.S. investigators, although issues of data access remain.

The establishment of a fully capable plate boundary observatory will require progress in four areas: (i) A more effective integration of strainmeters and GPS for a truly broadband plate boundary observatory. This integration concept should first be tested on a smaller scale, limited to a region of the plate boundary, where there are GPS receivers and strainmeters in roughly equal numbers. (ii) The densification of geodetic and seismic instrumentation along the northern San Andreas fault system for increased spatial resolution. (iii) The linking of the northern and southern San Andreas zones, to cover the seismogenic part of the plate boundary. (iv) Improving access to INSAR data for more effective integration. Present efforts involve operating a downlink facility in cooperation with the European Space Agency, and/or launching a SAR satellite that would collect data over western North America on a regular basis.

While the main focus of the PBO would be to gain a basic understanding of plate boundary processes, the PBO would also provide information of immense practical value. In particular, we would be in a position to detect precursory strain transients that may prove practical for the forecasting of earthquakes and volcanic eruptions. Such precursors exist for volcanic eruptions and have already been used to make predictions. Whether such precursors exist for earthquakes as well is something we still have to find out. The answer to this question would be crucial knowledge for society.

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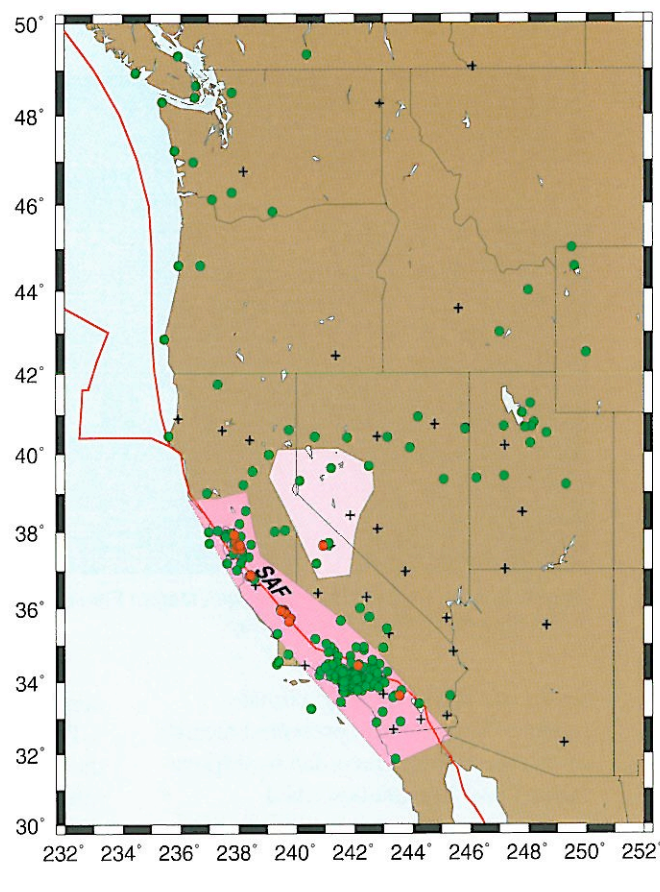


Figure 4. Existing and planned GPS (green circles), strainmeter installations (red circles), and three-component broadband seismographs (crosses). Pink zones denote most seismogenic part of the plate boundary (see Figure 1). These zones, shaded dark and light pink, correspond to areas of high and low population density, respectively. The PBO would be concentrated in these areas, factoring in population density in deployment priorities. The rest of the plate boundary (brown) would have more sparsely distributed instrumentation.

Tenth Annual IRIS Workshop

Peter Shearer, University of California, San Diego

(photo: M. Hasting)

Participants at the Tenth Annual IRIS Workshop

Over 230 seismologists recently wandered among the redwoods of the U.C. Santa Cruz campus to attend the 1998 IRIS workshop. This year's workshop was the first to be held on a college campus, as guests doubled up in student apartments and enjoyed cafeteria food with unlimited free ice cream.

Talks began early on Thursday, July 9, focusing on the San Andreas Fault (SAF) as an example of a continental transform boundary. Rick Sibson compared the SAF to the Alpine fault in New Zealand. Tanya Atwater presented a computer animated history of the North American-Pacific plate boundary and described the constraints on relative plate motion. Paul Segall and Ken Hudnut described strain measurements and inversion methods in northern and southern California, respectively. Tim Henstock discussed crustal structure near continental strike-slip boundaries; while Kevin Furlong related strain localization to plate boundary evolution. In the final afternoon talk, Ross Stein reviewed recent progress in understanding how the stress changes caused by earthquakes can trigger future earthquakes.

Late Thursday afternoon, the W. M. Keck Seismology Laboratory hosted a reception in their new building. Following dinner, Tom Jordan described the status of the National Research Council's Science of Earthquakes report.

Friday morning focused on applications of high-resolution seismic imaging for shallow structures. Following an introduction by Anne Meltzer, archeologist Payson Sheets described geophysical exploration at the Ceren site in El Salvador; climate modeler Tom Johnson presented records of climate changes recorded by African lakes; Dave Roelant described government programs for environmental monitoring; and Roelof Versteeg presented time varying images of shallow structures. Field trips that afternoon included hiking, sailing on Monterey Bay, and sampling products of nearby wineries.

(photo: M. Hasting)

Harold Bolton, Keith Richards-Dinger, Megan Flanagan, and Peter Shearer at the IRIS Workshop.

Saturday morning talks reviewed the heat flow paradox, and how faults can slip at low apparent levels of shear stress. Wayne Thatcher began by describing how ductile shearing below the brittle crust should generate heat flow anomalies. Next Mike Blanpied reviewed laboratory results for rock friction; and Peter Mora described numerical simulations of faulting. Finally, Greg Beroza reviewed constraints on rupture provided by seismic observations.

Talks on Saturday afternoon covered the future of regional seismic networks and outlined possible major new initiatives in seismology. Ian MacGregor presented the National Science Foundation's perspective on long-range planning in the Geosciences. Harley Benz and Steve Malone described research results and coordination among the regional seismic networks. Ralph Stephen reported encouraging results from the Ocean Seismic Network Pilot Experiment. Paul Silver presented the case for the proposed Plate Boundary Observatory (see article on page 3). Gene Humphreys and Göran Ekström described the types of instruments and experiments proposed for the USARRAY concept (see article on page 2).

Poster sessions were held throughout the workshop and provided a focus for informal discussions. The workshop concluded with a barbecue dinner on Saturday evening. ■

Seismology on Kola: Monitoring earthquakes and explosions in the Barents region

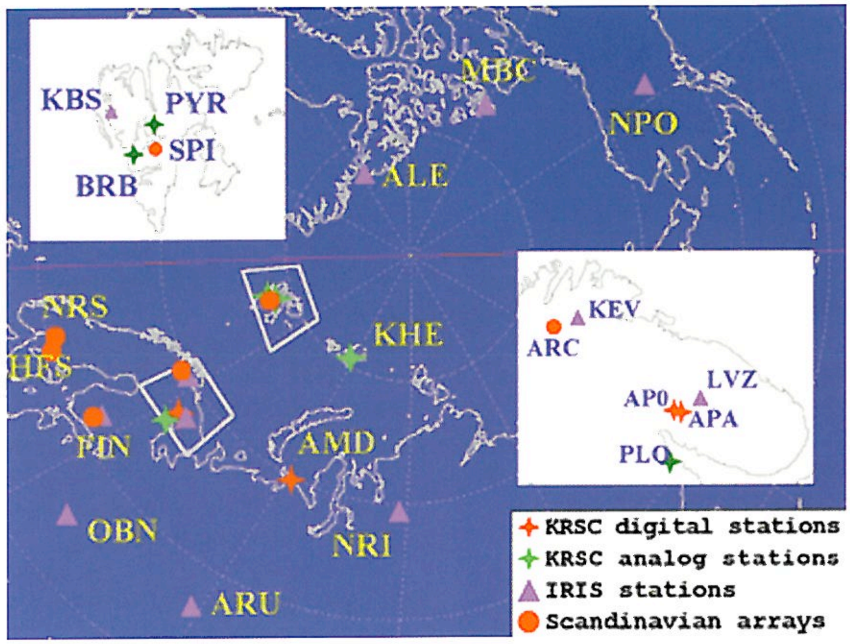
Elena Kremenetskaya, Vladimir E. Asming
Kola Regional Seismological Centre, Apatity, Russia

The Kola Regional Seismological Centre of the Russian Academy of Sciences (KRSC) is a small organization in the town of Apatity on the Kola Peninsula, North-West Russia. Since 1982 we have been continuously monitoring seismic events in North-West Russia and the adjacent seas.

In the past, we have primarily used our own set of seismological stations (see Table 1), but in recent years we have also been using data from IRIS stations (KBS, LVZ, KEV, ARU, ALE, NRI, etc.) and the Scandinavian seismic arrays (ARCESS, SPITS, FINESA, HFS, NORESS) for analysis of complicated events.

As a result, a large amount of information has been collected, including seismic bulletins and catalogues, digital wave forms data, digitized seismograms for selected events, results of spectral processing, etc.

Because of the mining activity in our region, a lot of artificial seismic signals have been registered here including open-pit, underground and underwater explosions. These events give us a good basis for developing some criteria to discriminate explosions and earthquakes.



KOLA REGIONAL SEISMIC NETWORK

Before 1992, KRSC used only analog seismic stations. All of our stations were equipped with SKM-3 short-period seismometers with the same amplitude-frequency response (amplification 50000 in frequency range 1.25-2 Hz). In addition, the Apatity station included long-period sensors SKD (Ts=25 sec). Seismograms from all the stations (excluding KHE) are stored in Apatity. Data from KHE were transferred by daily telex into KRSC.

In 1991, a cooperative program between KRSC and NORSAR (Norway) began. As the result, three digital seismological stations have been installed.

1) A seismic array (aperture 1 km) comprising 11 short-period sensors (Geotech S-500) is located about 17 km to the west of Apatity.
2) In the town of Apatity there is a 3-component broad band digital station (Guralp GMG-3T).
3) A micro-array, with aperture about 150m, was installed in Amderma in 1993. The array is situated in an underground fluorite mine and comprises 3 vertical sensors and a 3-component station in the center. The sampling rate is 40 samples per second.

EVENTS LOCATION

Because the IASPEI-91 model is not suitable for the Barents region [1], we use local travel-time curves developed from a set of strong explosions with known locations. In addition, a 350 ton underground calibration explosion was carried out in the Khibiny Massif on September 29, 1996 [2]. Our velocity

TABLE 1. KOLA SEISMIC NETWORK

Name	Latitude (N)	Longitude (E)	Type	Worked since	Till
APA	67.558	33.442	Analog	1956	now
PLQ	66.410	32.750	Analog	1985	now
BRB	78.073	14.197	Analog	1982	1990
PYR	78.659	16.216	Analog	1983	1987
AMD	69.744	61.648	Analog	1983	1995
KHE	80.600	58.200	Analog	?	1990
APA	67.558	33.442	Digital 3-C	1991	now
APO	67.603	32.994	Array	1992	now
AMD	69.744	61.648	Micro-array	1993	now

model is a combination of the NORSAR model for shallow depths (above 200 km) and the IASPEI-91 model for below 200 km.

To confirm it we relocated several previous seismic events. As seen in Table 2, a comparison of our locations with the known locations indicates the model's capability. In addition, we have sufficient data to locate the small nuclear explosion [3] on the Novaya Zemlya test site on August 26, 1984. The result is shown in Figure 1.

TABLE 2

Date	Our location	JHD	Remark
18.08.83	73.289 N, 54.893 E	73.358 N, 54.943 E	
01.08.86	72.945 N, 56.549 E	73 N, 56.7 E	Located by Marshall
02.08.87	73.298 N, 54.398 E	73.324 N, 54.597 E	
07.05.88	73.275 N, 54.436 E	73.314 N, 54.557 E	
24.10.90	73.304 N, 54.634 E	73.317 N, 54.803 E	

DATA ANALYSIS

The KRSC detection and location software is based on our algorithm which is close to the generalized beamforming approach [4]. It operates well when data from several seismic stations are available. The Amderma station, however, is far from other seismic stations so we frequently have to locate weak near events using only its data. The small aperture makes it impossible to use beamforming or other procedures to determine array-style back azimuths. Moreover, high noise levels (probably due to construction work) are commonly present. Under such circumstances, the totally automatic processing often results in wrong phase association (true phases may be associated with a noise, etc). To avoid this error, we use a semi-automatic routine. An analyst marks approximately the phases and the automatic procedure is executed for the filtration, STA/LTA detection, and joint polarization analysis both for P and S phases. Although accuracy of this method is not high, it is often suitable for preliminary locations (see examples below).

To use this method an analyst has to look through large data volumes. To assist the analyst , we developed a variant of site-specific monitoring (SSM) [5]. It scans for pairs of detected phases and for each pair assumes as a hypothesis that the first phase is P-wave and the second one is the S-wave from an event inside a given region. The hypothesis is evaluated by joint polarization analysis for P and S phases as well as several additional criteria such as frequency and amplitude compatibility. Those pairs with estimations greater than some threshold correspond to real seismic events. Of course false alarms do exist, but their number is within reasonable limits.

AUGUST 16, 1997 EVENTS

On August 16, 1997, five seismic events occurred near Amderma station. Two of the events were very similar events and occurred in the same location of the Kara sea (distance from Amderma is about 320 km). The wave forms are shown in Figure 2.

The other two events were explosions near Vorkuta (about the same distance but to South-West from Amderma) and one event was too weak to locate.

The result of the site-specific monitoring for this day is shown in Figure 3. The SSM procedure detected and located the two Kara events and the two Vorkuta explosions. False alarms are also shown. The results of semi-automatic location for the Kara event (6.20 GMT) and the Vorkuta explosion (7.02 GMT) are given in the insertions.

EVENT DISCRIMINATION

As mentioned, we often record seismic events which can not be identified by traditional criteria like P/S ratio. For instance, an event on February 9, 1998 near Murmansk (69.18 N, 32.63 E, 16.51:07) was recorded by seismic

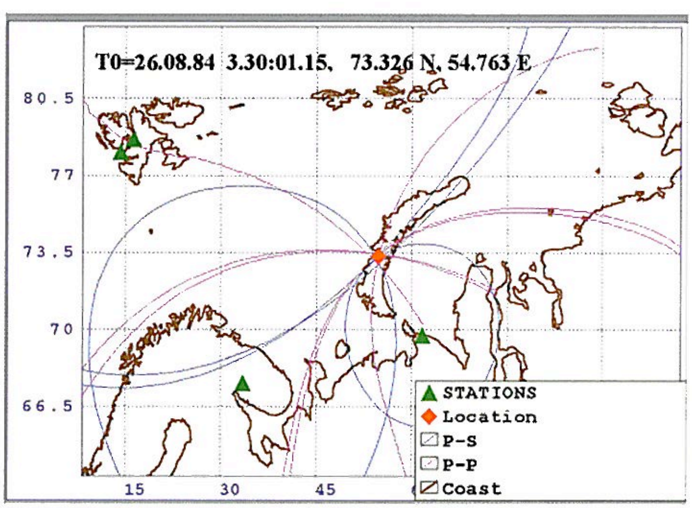


Figure 1. Location of the smallest Soviet nuclear explosion using data by stations PYR, BRB, APA and AMD.

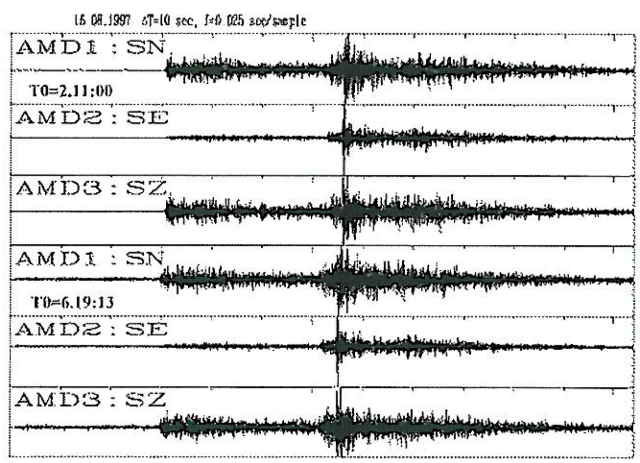


Figure 2. Wave forms for two events on August 16, 1997, in the Kara Sea (Amderma stations). Low frequencies filtered below 2 Hz.

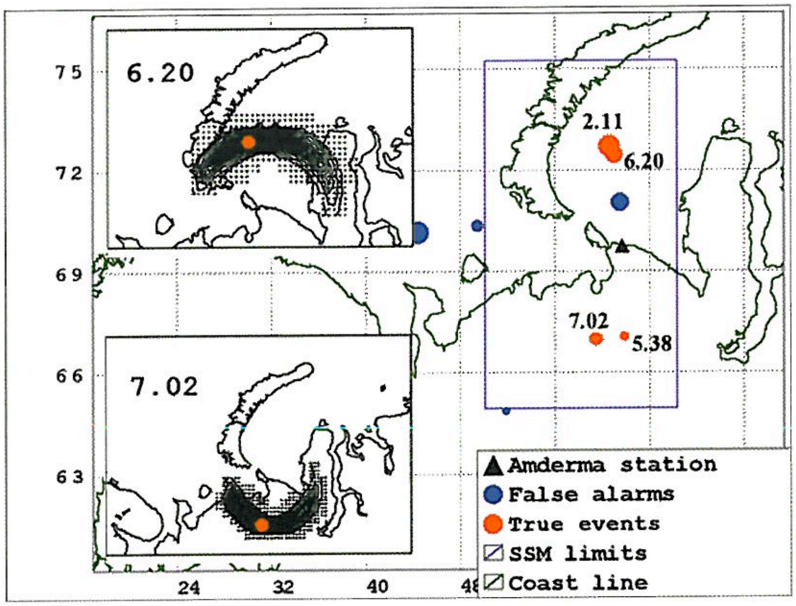


Figure 3. Results of site-specific monitoring using Amderma station for August 16,1997. Examples of semi-automatic location (isolines of rating functions and their maxima corresponding to epicenters) are shown in the insertions.

arrays ARCESS and SPITS very differently. The S-wave amplitudes for SPITS were much less than the P-wave amplitudes independent of the bandpass filter used. ARCESS recordings, on the other hand, include strong S-wave and even Lg and Rg phases.

A striking event occurred on April 18, 1998 in the Norwegian Sea near Bear Island. Its wave forms (recorded at APA, ARCESS and SPITS), together with our location are shown in Figure 4.

The nearest station is SPITS (about 470 km) and it's recording contains no noticeable S wave in any frequency band. ARCESS (670km) recorded strong S, whereas APA (1020 km) registered the P-wave only in the band 8-12 Hz.

Note that the calculated epicenter of this event is the same (within the limits of location errors) as the position where the nuclear submarine "Komsomolets" found its rest in 1989 [6]. Could the nuclear submarine be the source of this mysterious event ?

ACKNOWLEDGMENT

The authors greatly appreciate the support and scientific advice of Dr. Frode Ringdal. We thank Dr. Ralph W. Alewine for his consistent support of KRSC's developments. Finally, we appreciate the encouragement by Dr. Gregory van der Vink to write this article.

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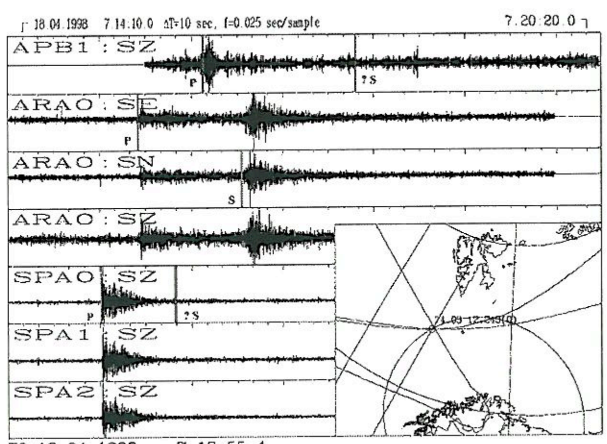


Figure 4. Wave forms together with our location of the strange event on April 18,1998. Signs "? S" mark places where S-onsets could be.

Deep Sea Fishing For BBOBS

Barbara Romanowicz, University of California, Berkeley,
Adam Dziewonski, Harvard University

The June 1998 OSN1 recovery cruise was proceeding smoothly under Chief Scientist Ralph Stephen's watchful eye. Three broadband packages had been built as a joint project of Scripps and WHOI and successfully deployed in February 1998: one downhole broadband package and two Broadband Ocean Bottom Seismometer (BBOBS), one of which was destined to be completely buried in the sediments. The downhole package and the buried BBOBS had been recovered on previous days and secured aboard the oceanographic research vessel "Melville". Now it was the second BBOBS's turn to be hoisted from the seafloor, 4400 m below the ship, attached by a cord to its recording package. The recording frame was dangling on a grapple hanging 30m below the control vehicle (CV), a crucial element in the system, equipped with lights, cameras and thrusters, and lowered to the seafloor on a sturdy cable.

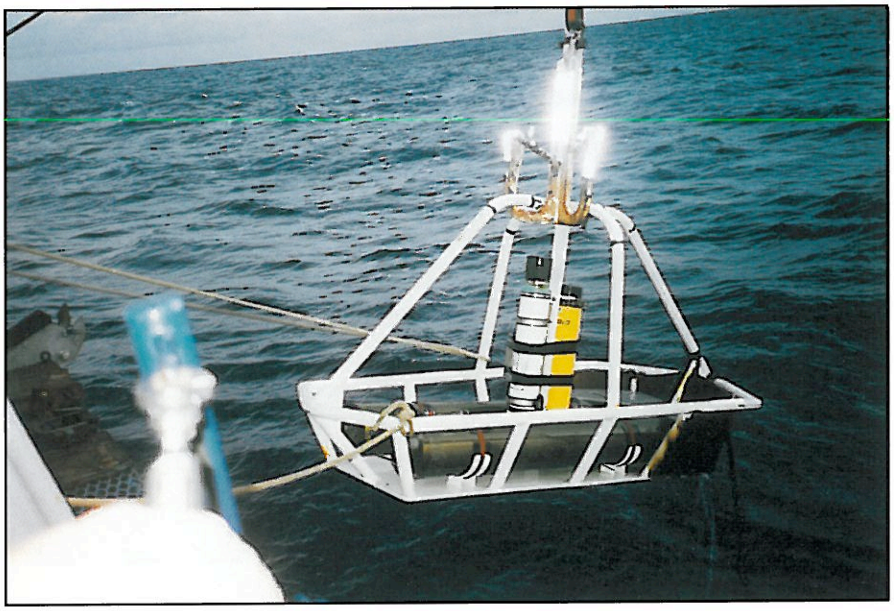
At 30 meters/minute, it would take close to 3 hours to bring the last packages back to the surface, so most of us dispersed to resume other activities. We had plenty of time left before going back to watch the delicate final stage during which the heavy packages are brought onto the ship. The last stage involves a complex system of pulleys and ropes operated with skill by a joint Scripps/ WHOI crew led by Gary Austin and Matt Gould, to break down the weights and prevent them from swinging wildly over the shark infested water.

We were sitting in the computer room, when suddenly Frank Vernon burst in and shouted: "we lost it". At 1000m above the seafloor, jerked by a sudden surge, the frame slipped out of the grapple's grasp and went tumbling back down. Then followed several hours of tense search for the lost packages as Gary maneuvered the CV's thrusters to let the camera explore their possible location and bring back images on monitors aboard the Melville. For a long time, there was hopelessly nothing in sight. A radius of 50 meters around the presumed location had been scanned, straight down from where the package should have dropped. We were settling for a lengthy wake...

Lowering down the control vehicle for BBOBS OSN1 experiment.

There must be a better way to do this, thought Cris Hollinshead, who had been in charge of recalling the automatic-release Scripps standard OBS's, using acoustic signals. How about trying to take advantage of the acoustic transponder on the BBOBS recording package to locate it with respect to the CV, and guide the positioning of the ship? An acoustic signal was then promptly sent several times down the cable to the CV, from there to the BBOBS recording package and back to the ship. The decreasing times it took for the pulse to come back gave an indication of the direction in which the ship should move. The package responded, and soon it was clear that it had fallen well outside of the circle of search. Owing to this ingenious triangulation method, guided carefully by John Hildebrand, the package was soon found and this time brought safely back up. It was already past midnight, when the last piece of equipment, the BBOBS's seismometer, came out of the water.

The OSN1 pilot experiment dates back over 10 years. Following the COSOD II conference in Strasbourg in 1987, a workshop was held at Woods Hole in the spring of 1988. During this workshop and in the following report, the scientific needs to deploy long term seismic observatories on the sea floor were spelled out, and related technical issues were reviewed. The principal motivation for sea floor broadband observatories is to complement the land-based networks and provide better global coverage for studies of the deep Earth's structure and tectonics. The Woods Hole workshop led to the formation of an Ocean Seismic Network (OSN) steering committee, chaired first by Mike Purdy and Adam Dziewonski, and later by John Orcutt, to prepare general plans for the deployment of a 25 station sea floor observatory network. The Ocean Drilling Program (ODP) responded positively by agreeing to drill a borehole specifically for the seismological experiment. The chosen site was conveniently located 250km south-east of Oahu (Hawaii), in deep water, not too far from land, offering the



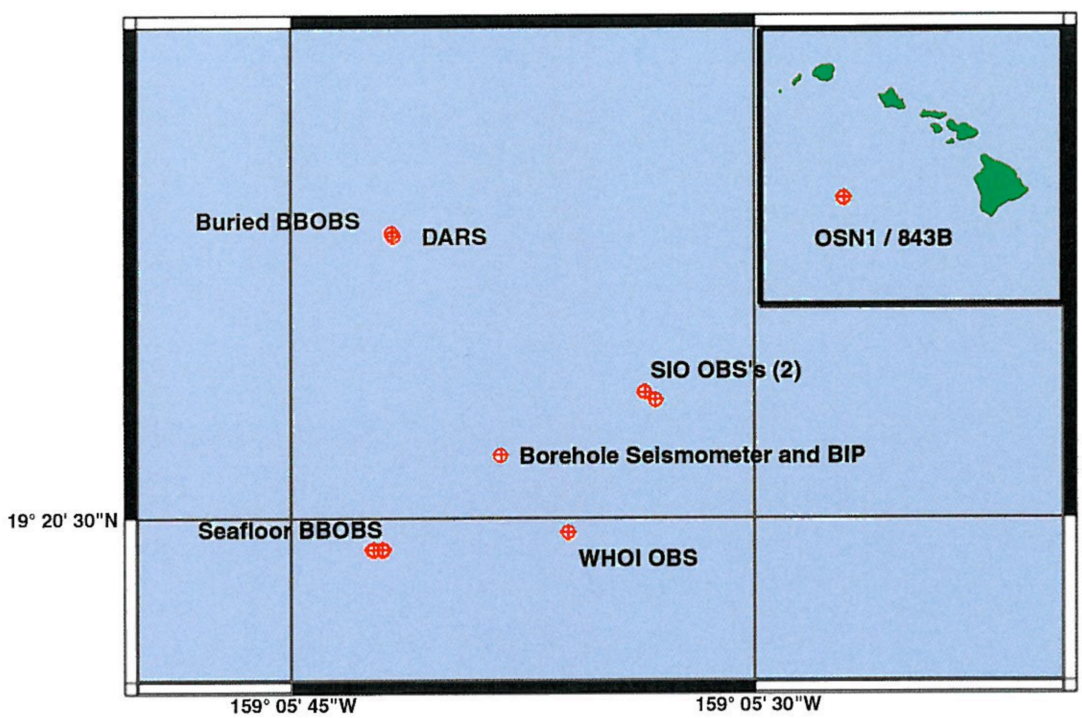
Ocean floor recording package being recovered.

possibility of signal comparison with the Kipapa island site (KIP: a joint Geoscope/IRIS broadband station) (Figure 1) . The OSN-1 hole was drilled in March 1991 and the pilot experiment was designed by an *ad hoc* group under the chairmanship of Don Forsyth, in the summer of 1991.

Many technical challenges needed to be overcome. A crucial question, partly addressed by an earlier, unfortunately too short, French experiment in the mid-Atlantic (OFM), was to determine the optimal mode of installation of broadband seismic systems on the ocean floor: would the background noise level be lower deep down boreholes versus on the sea-floor, and, for the latter, whether significant improvements could be achieved by burying the sea-floor instruments in the sediments. The development of the instrumentation as well as the deployment and recovery cruises were funded by the National Science Foundation.

The deployment cruise took place in February 1998, nearly 7 years after the OSN1 hole was drilled. Three separate broadband packages were then deployed successfully, two on the seafloor (one buried, the other one not) and one 300m down the OSN1 hole. Four months of continuous data were acquired and retrieved, providing invaluable information on background noise. About 60 teleseisms, ranging in moment magnitude from 5.5 to 8.1 were also recorded with good signal to noise ratio. Preliminary comparisons indicate that the downhole recordings are less noisy in a period band from 15-100 sec than at KIP. In the same band, the buried BBOBS's teleseismic records track the downhole recordings wiggle by wiggle (Figure 2). At the lowest frequencies, the buried BBOBS perform much better than the borehole system, whereas it is the opposite at high frequencies. As expected, background noise is generally

Figure 1. Site of the OSN1 experiment, 250 km east of Hawaii. The ocean floor instrumentation included a borehole broadband package and its recording system, the BIP (PI's John Orcutt, Frank Vernon, Ralph Stephen and Ken Peal), two BBOBS (PI's John Collins, John Orcutt and Frank Vernon), one buried in the sediment and the other not. Each of the BBOBS had its own recording system (DARS). The control vehicle (CV) used to deploy and retrieve the broadband packages was built at Scripps by Fred Spiess, John Hildebrand and his group. Three standard short-period OBS's (1 WHOI, 2 Scripps) were also deployed, and later retrieved using an acoustic release system which makes them "pop-up" to the ocean surface, a technique widely used in ocean seismology campaigns.



much higher on the surface BBOBS. Near the microseismic peak, the difference between borehole and seafloor or shallow buried sensors is dominated by shear wave multiples in the sediments. These cause the microseismic peak on the seafloor sensors to shift to 0.4 Hz, and they add a resonance to impulsive body wave arrivals. These shear modes are greatly attenuated for a borehole sensor, emplaced even just a few meters into the basement. On the other hand, understanding the source of the very low frequency noise in the borehole and high frequency noise on the buried BBOBS, is one of the issues that need to be addressed in the future. The technical and scientific results of the OSN1 project will be described in forthcoming publications. The data will soon be available to the community from the IRIS-Data Management Center.

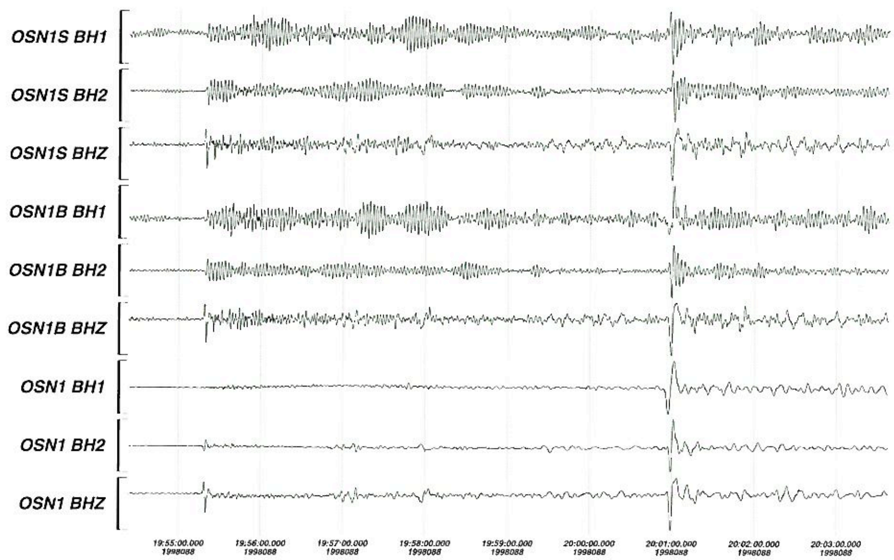


Figure 2. Example of data recorded by the borehole instrument (OSN!: BHZ: vertical component; BH1, BH2: horizontal components), buried BBOBS (OSN1B) and seafloor BBOBS (OSN1S), for the magnitude 7.1 (Mw) deep (554 km) Fiji earthquake of March 29, 1988. The horizontal components in each system are orthogonal to each other, but have no preferred orientation with respect to North. Note that the short period background noise is lower on the borehole data than on the seafloor data which are affected by sediment resonances.

Even before all the data have been processed, it is clear that the successful OSN-1 experiment has confirmed that high quality seismic broadband data can be acquired on the seafloor over extended periods of time. These results justify proceeding with developing rapidly national and international plans for a global network of long-term sea-floor observatories. Many technological lessons will have been learned towards optimal deployment procedures, which can be applied to such projects in the future. Before deploying such systems permanently or semi-permanently (for durations of 1 to 2 years), future efforts will need to address the issue of power supply and data retrieval in places where ocean bottom cables are not available. ■

Principal Investigators on the OSN1 experiment

R.A. Stephen	Dept. of Geology and Geophysics	Woods Hole Oceanographic Institution (WHOI)
J.A. Collins	Dept. of Geology and Geophysics	Woods Hole Oceanographic Institution
J.A. Hildebrand	Marine Physical Laboratory (MPL)	Scripps Institution of Oceanography (SIO)
J.A. Orcutt	Institute of Geophysics and Planetary Physics (IGPP)	Scripps Institution of Oceanography
K.R. Peal	Dept. of Applied Ocean Physics and Engineering	Woods Hole Oceanographic Institution
F.N. Spiess	Marine Physical Laboratory	Scripps Institution of Oceanography
F.L. Vernon	Institute of Geophysics and Planetary Physics	Scripps Institution of Oceanography

Scientific team on the OSN1 recovery cruise

Chief Scientist: Ralph Stephen, WHOI
SIO/MPL: John Hildebrand ,Gary Austin, Dave Jabson, Patrick Jonke, Dave Price, Aaron Sweeney
WHOI: John Collins, Ken Peal, Matt Gould, Tom Bolmer
SIO/IGPP: Frank Vernon (co-PI), Cris Hollinshead, Jeff Babcock, Chris Say, Marc Silver

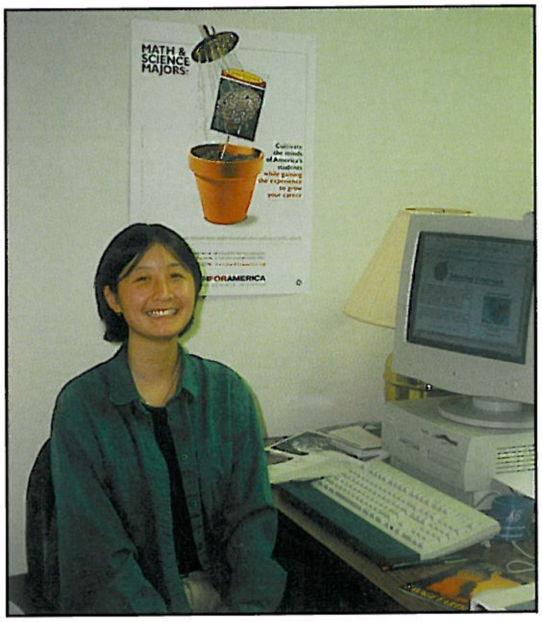
Other participants:
Adam Dziewonski, Harvard University and IRIS;
Joris Gieskes, SIO/GRD;
Masanori Kyo, JAMSTEC;
Barbara Romanowicz, University of California, Berkeley

Teach For America Intern at IRIS

Abigail Paske, Teach For America

Summer has come to a close and I am heading back to San Jose, California. During the school year, I teach high school as part of Teach for America, an Ameri Corps sponsored program that addresses the current teacher shortage by placing recent college graduates in under resourced public schools across the country. Teach for America is a two year commitment to the students and community. As part of our commitment to life-long learning, Teach for America encourages math and science majors to participate in science-oriented internships during the summer between the first and second year. At the end of August I will begin my second year of teaching chemistry, physics, and perhaps most importantly, Introduction to Science, which is a mandatory year-long course to give high school freshman an overview of scientific processes. One of the major components of this course is a unit on Earth Science.

This summer, as an IRIS intern, I have been working on a hands-on thematic unit for my freshmen. With the help of Greg van der Vink and Christel Hennet, I put together about 14 lesson plans in a unit designed to motivate and teach seismology to high school students. From my brief experience teaching, I have noticed that students are morbidly fascinated by anything that explodes or is dangerous to their personal well-being. To this end, the unit we designed is loosely based on Greg, Christel, and Danny Harvey's analysis for the US Senate, of the Japanese terrorist cult, Aum Shinrikyo. After the cult released Sarin nerve gas into the Tokyo subway system, there was some question of whether they performed an underground nuclear test on a sheep ranch in Western Australia a couple of years earlier. In the lesson, students use various scientific techniques to figure out if the terror-cult really did have nuclear capability or if the incident was simply an aberrant earthquake. It is my belief that students will be motivated to learn seismology when presented with such a relevant and engaging scenario — even if the initial interest is simply in hearing about big explosions.



Also this summer, Catherine Johnson advised me on research for an educational poster to highlight our changing view of the interior of the Earth. Investigating the history of seismology gave me valuable insight into the science and how best to teach it. The research lead me on a wild goose chase through the far nether-regions of the Internet and then lead me to the Still Picture Gallery of the National Archives where I donned white gloves and sorted through boxes of images to use on the poster. If you ever have a chance (or a good excuse) to visit the National Archives I highly recommend it. The poster is still in the construction stages but will be finished over the next few months.

Exciting upcoming events include implementing the Aum Shinrikyo lessons in my classroom and the classrooms of other Teach for America Corps members. Additionally, I will be writing numerous grant proposals to have a high quality seismometer installed at the school where I teach in San Jose. If you happen to have a spare seismometer kicking around your basement, let me know!

It has been a productive and fruitful summer of collaboration. I hope that future Teach for America Corps members will have a chance to participate in expanding the excellent Education and Outreach program at IRIS and to have a brush with seismology on the front lines. ■

TEACHFORAMERICA

Teach For America is the national teacher corps of outstanding recent college graduates of all academic majors and cultural backgrounds who commit two years to teach in under-resourced urban and rural public schools. Since 1989, Teach For America has inspired more than 20,000 individuals to apply and has placed about 4,000 of them in 13 geographic regions where each year about 1,000 corps members reach more than 100,000 students. Corps members were leaders on their college campuses, are leaders in their classrooms, schools and communities, and will be lifelong leaders in the pursuit of educational excellence for all children.

For more information about Teach For America and how to apply, call 1-800-832-1230 or visit their web site - www.teachforamerica.org ■

Kyrgyz Seismic Network Becomes Cornerstone for New International Geodynamics Research Center

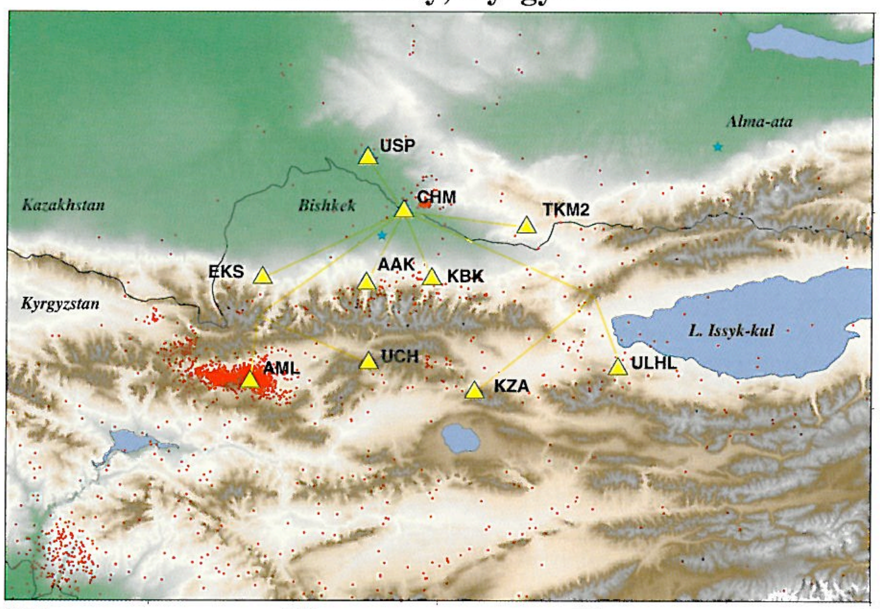
Frank Vernon, University of California, San Diego

The Kyrgyz Seismic Network (KNET) will become the scientific cornerstone of a new International Geodynamics Research Center. The ten-station broadband telemetered network was installed following the 1988 earthquake in Armenia when the Soviet Union requested IRIS to help evaluate areas of high earthquake hazard. The network was jointly developed under IRIS's Joint Seismic Program by the University of California, San Diego, the Kyrgyz Institute of Seismology, and the Russian Institute of High Temperature Physics.

In 1997 the Department of State and the Agency for International Development asked the US Civilian Research and Development Foundation (CRDF) to administer an assistance package for Kyrgyzstan that includes support for the Kyrgyz Seismic Network. Plans for the Center include annual cost-shares by the Kyrgyz and Russian governments. The shared facility will also be available to visiting researchers from other countries.

Over the past six years KNET has recorded over 20,000 local, regional and teleseismic events. The data have been used by researchers at many IRIS and non-IRIS members who have produced a reference list of 25 publications and 11 currently in the review process. KNET data have been used for detailed studies of the 1992 Suusamyr Mw 7.2 earthquake, local and regional studies of tomography and attenuation, as well as receiver functions and shear wave splitting studies. In the future, KNET will provide essential information for local and regional studies such as for the NSF Continental Dynamics project of the Tien Shan region and for global studies of Earth's deep interior. All KNET data are delivered to the IRIS DMC and are immediately available. ■

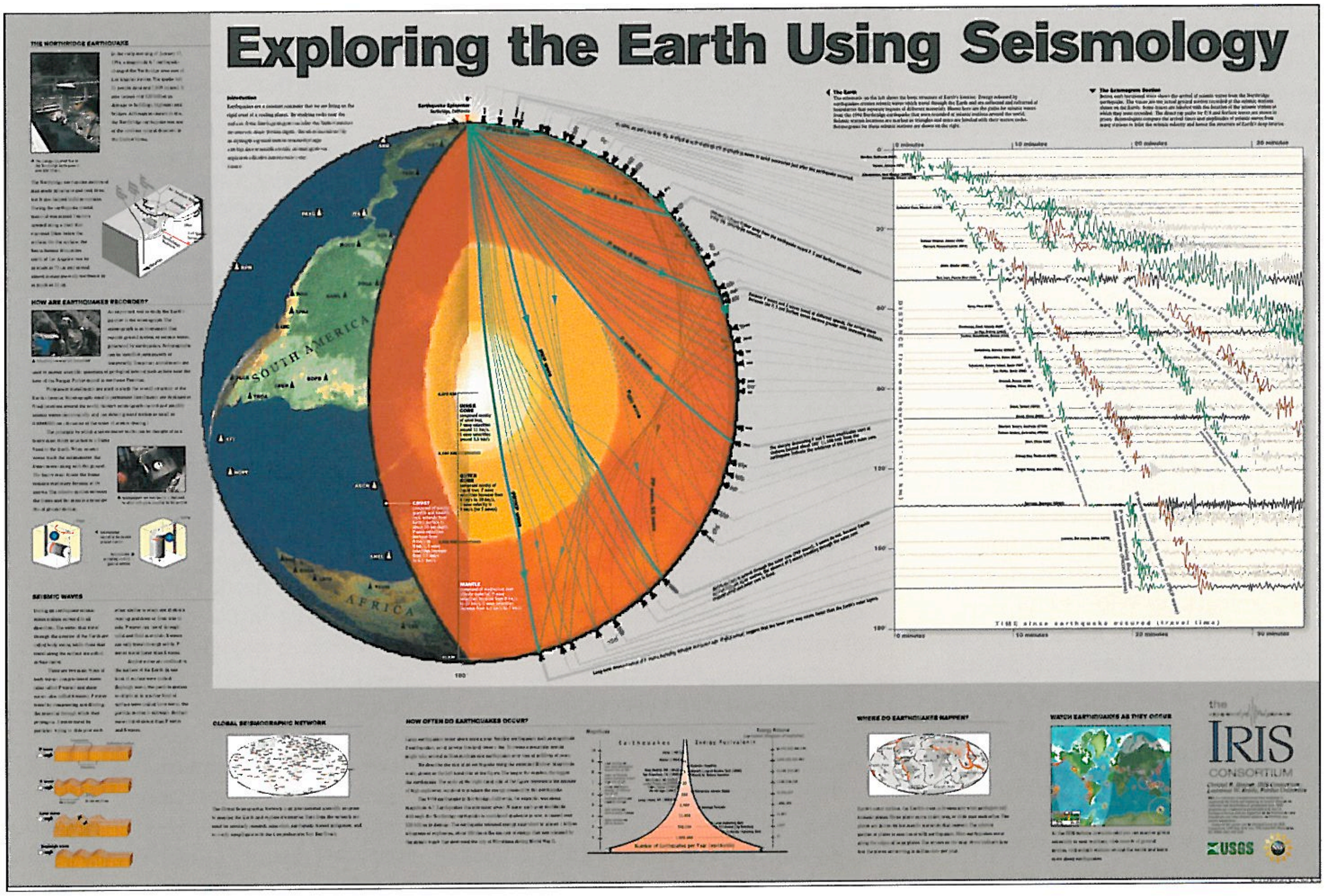
KNET array, Kyrgyzstan



Ten-stationed broadband telemetered network installed under the JSP program around Bishkek, the earthquake prone capitol of Kyrgyzstan.

Yuri Trapeznikov, Institute for High Temperature Physics; Asker Turdukulovich, Kyrgyz Institute of Seismology; Tynymbek Ormonbekov, Kyrgyz Government Committee for Science and Technologies; Angus Simmons, U.S. Embassy, Bishkek; Gerson Sher, US Civilian Research and Development Foundation. (Photo: US Civilian Research and Development Foundation)

IRIS Releases New Poster on Seismology



As part of our education and outreach efforts, the IRIS Consortium has developed a poster to illustrate how seismology is used to explore the deep interior of our planet.

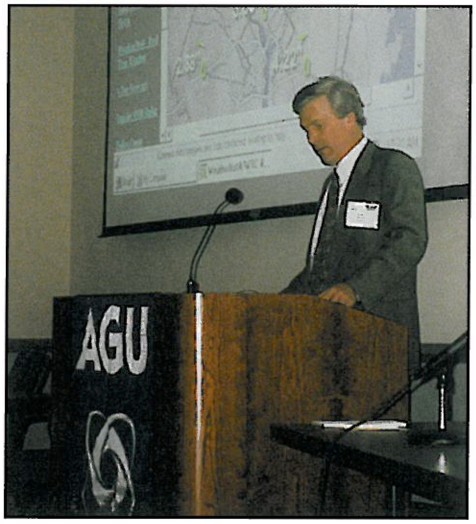
The poster consists of a high resolution schematic Earth cut open to reveal its basic structure, a seismogram section, and explanations of how we use seismology to infer the structure of the Earth's interior. The seismogram section shows traces of actual ground motion recorded during the 1994 Northridge earthquake. All major phases, such as P, S, PP, SS, PKP, PKIKP, and surface waves, are identified and highlighted. The schematic Earth shows the paths for all the rays identified on the seismogram section. Seismographic stations are marked at their angular distances from the epicenter, labelled, and visually linked to enhance the relationship between the individual ray paths, the locations at which the seismograms are recorded, and the composite seismogram section. The border of the poster includes descriptions of the Northridge earthquake, seismicity patterns, types of seismic waves, functions of a seismometer, and the Global Seismographic Network. Much of the information in the border of the poster is available as individual one-page handouts from IRIS. A one-pager of the main section of the poster is also available.

The IRIS E&O program is currently developing a teachers' guide for grades K-12 to accompany the poster. The poster is used in teacher workshops run by the E&O program at meetings such as the National Science Teachers Association convention and at teacher workshops run at individual IRIS member institutions. Copies have also been distributed to schools participating in the Princeton Earth Physics Project (PEPP). The poster and other materials developed by the E&O program are available from IRIS Headquarters. Contact Catherine Johnson, E&O Program Manager (catherine@iris.edu)

We would like to acknowledge Tracy Keaton Drew, designer and illustrator.

IRIS Co-Sponsors Forum on Natural Hazards

On June 7, IRIS joined the American Geophysical Union and the American Geological Institute in sponsoring a symposium on "Real-time Monitoring and Warning for Natural Hazards". The meeting was part of the series Public Private Partnerships 2000 (PPP-2000): Forums on Public Policy Issues in Natural Disaster Reduction developed by the National Science and Technology Council's Subcommittee on Natural Hazards Reduction and the Institute for Business and Home Safety.



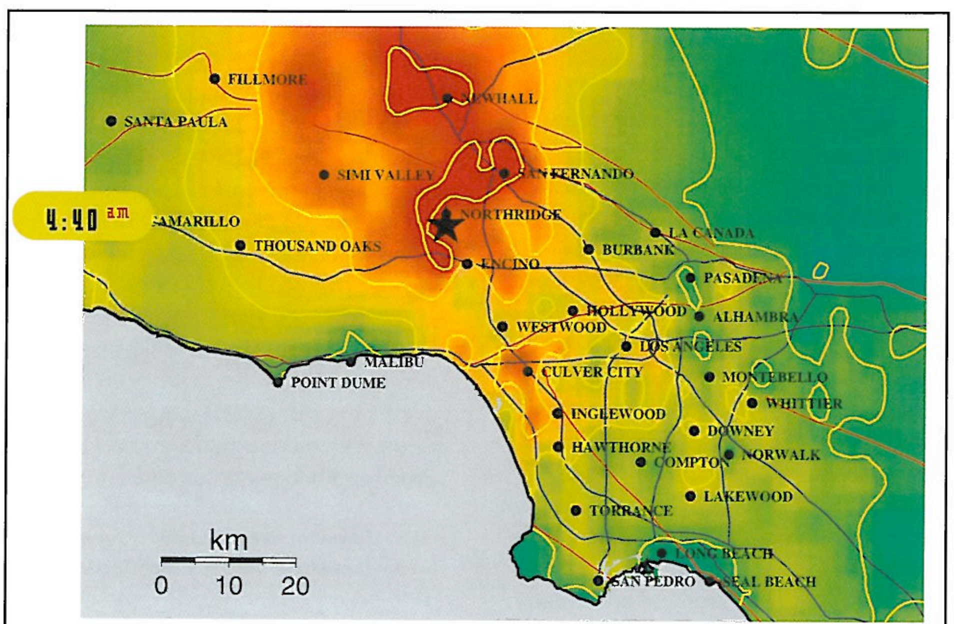
Bob Ryan, chief meteorologist for WRC-TV in Washington, DC and former President of the American Meteorological Society, gave a keynote presentation on how technologies such as satellite systems and Doppler radar have improved our forecasting capabilities

Seismologists, volcanologists, hydrologists, and atmospheric scientists, joined emergency managers, engineers, insurers, and legislators for a full day of discussions about opportunities to mitigate hazards through real-time warning systems. Bob Ryan, chief meteorologist for WRC-TV in Washington, DC and former President of the American Meteorological Society, gave a keynote presentation on how technologies such as satellite systems and Doppler radar have improved our forecasting capabilities. Representatives from the scientific community assessed emerging technologies. Emergency managers discussed how new warning systems were being implemented to save lives and prevent property loss.

Although emerging sensor systems and new communication networks hold great promise for informing the public of natural hazards, information by itself is not adequate. Furthermore, just because people are informed and know the risk does not mean that they will always act rationally.

The combination of scientists and policy makers was reflected in the discussions that followed such questions as not only "Are there technologies we have not implemented?, but also "How do we produce information so that the end-user will take action?" Strong incentives are needed to encourage mitigation against low probability, high-cost events, especially in market places where time frames are measured in quarters of a year. Accordingly, much of the focus of the PPP-2000 forums is designed to instill hazards mitigation as a national value. More information about the Forums on Public Policy Issues in Natural Disaster Reduction can be found at the web site:

www.usgs.gov/ppp2000/



The TriNet system being installed throughout southern California by California Institute of Technology and the USGS was presented as an example of real-time application in earthquake hazards. This map of ground-shaking intensity for the Northridge earthquake took several weeks to generate. TriNet will provide ground-shaking maps for emergency response within minutes of an earthquake to direct emergency response and to provide rapid regional damage assessments. *(Figure courtesy of TriNet)*

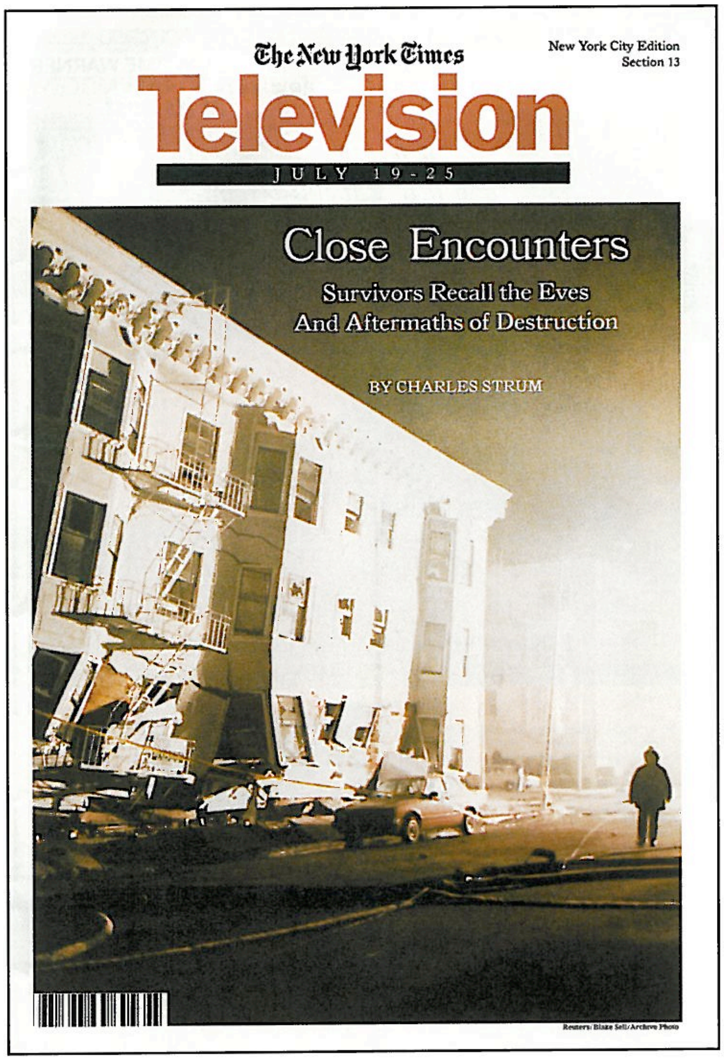
IRIS Contributes to Savage Earth Television Series

IRIS has assisted Thirteen/WNET in New York and Granada Television in the production of a four hour PBS series "Savage Earth" about volcanoes, earthquakes and tsunamis. The series premiered in July 1998 and is accompanied by educational web sites that can be found at these locations:

www.wnet/savageearth
www.pbs.org/savageearth

Members of the IRIS Education and Outreach Committee served as scientific advisors for the script, helped develop material for the web site, and responded to public questions about earthquakes in the "ask the expert" web site forum. The IRIS web site and the Seismic Monitor are included as direct links from the WNET and PBS web sites.

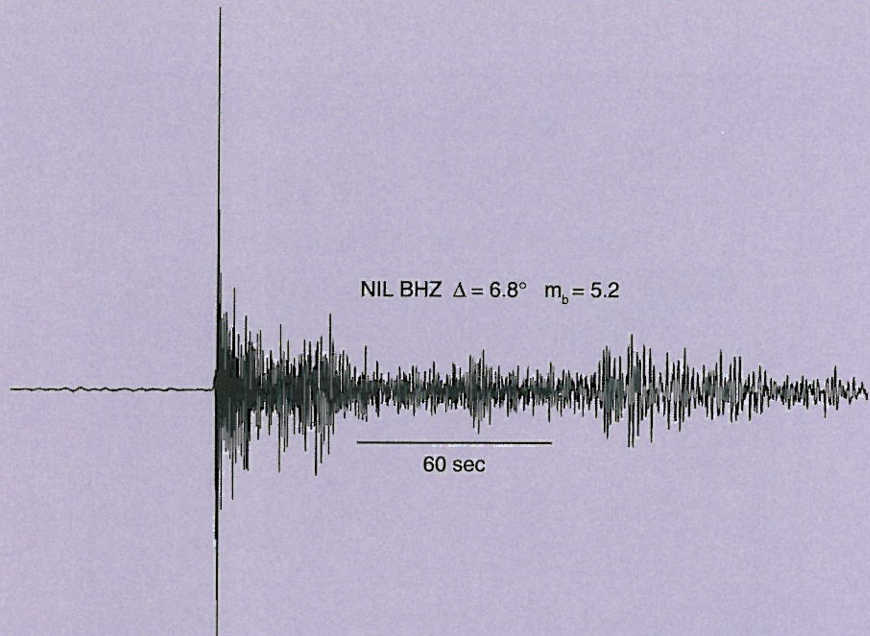
The series featured footage from notable earthquakes, volcanic eruptions and tsunamis around the world. Concepts such as liquefaction and site response were presented using examples from Mexico City and Loma Prieta. Viewers were cautioned at the end with reminders that two of the most devastating earthquakes in recent history - Northridge and Kobe - occurred on faults that were previously unknown; and that historical records indicate that great earthquakes have hit North America in the past. ■



IRIS Education and Outreach Program Plan

The IRIS Education and Outreach (E&O) program held a workshop in April 1998, bringing together individuals from the seismological and science education research communities, K-16 educators, and representatives of other Earth science organizations with education and outreach programs. The discussions and outcomes of that workshop form the basis for a medium- to long-range planning document for the E&O program. The Education and Outreach Program Plan not only describes the mission, goals and objectives of the E&O program but sets these in the context of current needs in K-12, higher and informal education and in the context of existing Earth science education and outreach programs. It is hoped that this document will be a useful resource for a broad audience, including the IRIS community and those involved in education and outreach activities in Earth Science. A draft of the program plan is currently being finalized. The draft will be reviewed by workshop attendees and by additional reviewers not associated with the planning process. The program plan is expected to be published in June 1999. ■

This Issue's Bannergram



Broadband, vertical component seismogram recorded at the IRIS Global Seismographic Network station Nilore (NIL) in Pakistan. The signal is from the magnitude 5.2 Indian nuclear test on May 11, 1998. Although this station is not part of the official International Monitoring System for the Comprehensive Test Ban Treaty, it is the closest open seismic station to the Indian test site 750 km to the south.

According to Indian announcements, the test consisted of a 43-kiloton thermonuclear explosion, a 12-kiloton fission explosion and a 0.2-kiloton fission explosion. Reportedly, the nuclear devices were detonated simultaneously in two deep holes, drilled roughly 1,100 yards apart.

In addition to confirming that a nuclear explosion had occurred at the Indian test site, the seismic data has allowed independent evaluation of the validity of India's claims. In contrast to India's announcement of a cumulative yield of 55 kilotons, a magnitude 5.2 seismic event at the Indian test site corresponds to an underground nuclear explosion with an equivalent yield of approximately 5-25 kilotons.

For further discussion see:

"False Accusations, Undetected Tests and Implications for the CTB Treaty" by Gregory van der Vink, Jeffrey Park, Richard Allen, Terry Wallace and Christel Hennet, **Arms Control Today**, May 1998, p.7-13.

"The May 1998 India and Pakistan Nuclear Tests" by Terry C. Wallace, **Seismological Research Letters**, September/October 1998, p.386-393.

"Monitoring Nuclear Tests" by Brian Barker, Michael Clark, Peter Davis, Mark Fisk, Michael Hedlin, Hans Israelsson, Vitaly Khalturin, Won-Young Kim, Keith McLaughlin, Charles Meade, John Murphy, Robert North, John Orcutt, Chris Powell, Paul G. Richards, Richard Stead, Jeffrey Stevens, Frank Vernon, Terry Wallace, **Science**, 25 September 1998, p.1967-8. ■

Staff News

Gregory van der Vink presented the talk "Verifying the Ban on Nuclear Weapons Testing" at the National Research Council. Greg has been reappointed to the AGU Committee on Public Affairs and has been elected by the membership of the Federation of American Scientists to their National Council.

The Data Management Center said a fond farewell to Raoul Titus and welcomed Stacy Fournier, their new Data Control Technician. She is a graduate of the University of Washington, with a degree in Geographic Information Systems. ■

IRIS Newsletter

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the IRIS CONSORTIUM

The Incorporated Research Institutions for Seismology (IRIS) is a university consortium of over 90 research institutions dedicated to monitoring the Earth and exploring its interior through the collection and distribution of geophysical data. IRIS programs contribute to scholarly research, education, earthquake hazard mitigation, and the verification of the Comprehensive Test Ban Treaty. IRIS operates through a Cooperative Agreement with the National Science Foundation under the Division of Earth Science's Instrumentation and Facilities Program. Funding is provided by the National Science Foundation, the Department of Energy, the National Imagery and Mapping Agency, other federal agencies, universities, and private foundations. All IRIS programs are carried out in close coordination with the US Geological Survey and many international partners.

The IRIS Newsletter welcomes contributed articles. Please contact one of the editors or send your submission to the address above.

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On the issue of rapid and free data distribution

Barbara Romanowicz, University of California, Berkeley

Should seismological data collected by individual investigators or research groups be made freely and immediately available to the general scientific community?

As recording and archival of data have entered the digital world on a routine basis, widespread means now exist to organize efficient on-line archives that are readily accessible from anywhere over the Internet. Gone are the days when you had to travel across the world to consult a valuable and unique dataset, set a few weeks or months aside to analyze the data on-site and engage in a collaborative project with the scientific team that originally collected the data. Now, you can sit at your computer terminal and, with a minimum effort "ftp" Gigabytes of wiggles from remote sites without ever needing to move a toe. Meanwhile, it still takes years to design a data collection program, obtain the funding, deploy the instruments and verify the quality of the data produced, and only at the end of this crusade can you finally sit down and glean the fruits of your labor. No wonder there is some resistance to those vultures waiting around ready to grab your data as soon as they are available, and scoop you and your students before you have time to even realize it.

How do we reconcile the need for widespread use of data that, in one form or another, have been collected owing to community fund-raising efforts, and at the same time protect the rights of those scientific teams whose specific efforts have produced them?

This clearly is not a problem for such programs as the IRIS GSN, where the data generation, collection and archival is clearly separated from their usage, inasmuch as the Consortium members participate collectively in the design of the system, but its actual implementation is in the hands of specially funded groups, the DCC and DMC. However, it is the subject of debate regarding PASSCAL datasets, and also, to some extent, data produced by individual University-funded groups such as the one I am currently in charge of, at UC Berkeley.

I believe in making data available freely and rapidly. There are many advantages for all of us, collectively. First, no one research group can squeeze *everything* out of a good dataset, and there is enough creativity around to find ever new applications for it. This way you get more research results for the buck, and consequently reinforced support for continued funding. Second, the aggregate dataset available at any time to the global research community becomes much richer, since different datasets often complement each other and, by combining them, you can take your research farther than if you are restricted to the data collected in your own backyard. However, I do get frustrated too, each time I find out that some outside group has been using our data for the same purpose as we are, without even referencing any of our work.

> ***"All that may be needed is to develop the appropriate ethics in the community"***

How do we deal with such issues and make everybody happy?

One solution, currently adopted by the PASSCAL program, is to restrict access to such special datasets for a limited period of time after completion of the project (i.e. 1-2 years), in order to give the "owners" time to advance the research project which motivated the data collection. This works well, to some extent, but has some anachronistic resonances in our era of rapid access capabilities. And it does not readily apply to longer term deployments or permanent networks. There are many instances when you might wish to utilize someone's dataset to complement other data, for a current research project unrelated to the PI's motivations, and if you have to wait that long, your interest and perhaps your funding will have waned.

I would like to suggest a potentially more viable solution. All that may be needed is to develop the appropriate ethics in the community, supported by well organized information made available through the appropriate data centers.

A simple rule can be established whereby active research topics and related publications (on-going Ph.D. theses, funded research) by data "owners" would be described and posted on the relevant data center web page. Those outside researchers who wish to access the data should take care to educate themselves about the existence of these topics and either stay away from them, or negotiate cooperative arrangements with the data "owners", and make sure to reference the latter in their publications.

How do we enforce this? There's no completely iron-clad way, of course. But there are helpful measures. For example, access to a given dataset can be conditional on having familiarized yourself with the work of the "owners", and having filled out a web questionnaire describing your intentions. In addition, reviewers of major journals could be routinely asked whether a given paper submitted for publication properly acknowledges the source of the data used. Proposals could also be reviewed with that in mind.

Much of this is already happening. In fact, the seismological community has a long tradition of no-big-deal widespread data exchange, much longer than in many other fields. In particular, the role and organization of the IRIS data archival and distribution is now often cited as a model in other communities. All it might take to make most seismologists happy is to spell out the rules somewhat better. I'd suggest that the discussion of these rules also be extended to other types of geophysical data that are increasingly facing the same issues, such as GPS data. ■

Calendar

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March 15-17
USArray Workshop
Albuquerque, NM

June 9-12
IRIS Workshop
Tenaya Lodge, Yosemite, CA

July 5-9
An International Workshop on Tomographic Imaging of 3-D Velocity Structures and Accurate Earthquake Location
Pafos, Cyprus

July 18-30
The 22nd General Assembly of the International Union of Geodesy and Geophysics
The University of Birmingham, UK

IRIS Welcomes the Following New Members

IRIS welcomes as a new member institutions, Montana Tech of the University of Montana, Michael Stickney, Representative; University of Arkansas, Little Rock, Haydar J. Al-Shukri, Representative. IRIS also welcomes as a Foreign Affiliate, ETH, Zürich, Switzerland. ■

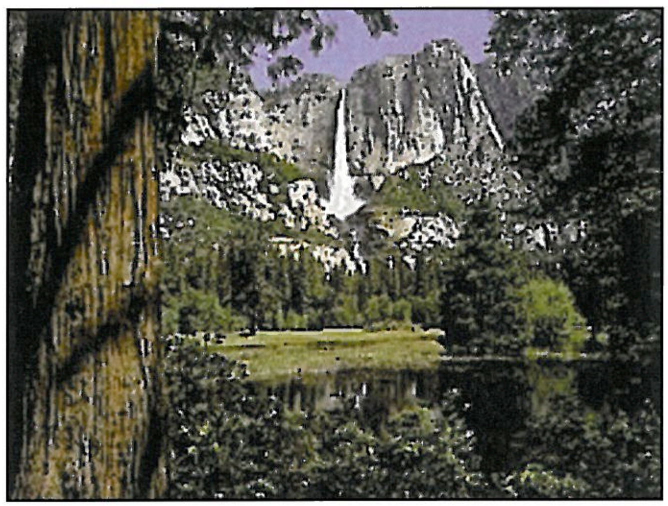
11th Annual IRIS Workshop

June 9-12, 1999
Tenaya Lodge at Yosemite
Fishcamp, California

The 11th Annual IRIS Workshop will be held June 9-12 at the Tenaya Lodge just outside Yosemite National Park in Fishcamp, California. Science themes for the workshop entail Mountain Building, Circulation in the Lowermost Mantle, and Earthquakes. This workshop will also be a significant step in the development of the next IRIS proposal. There will be pre-workshops sponsored by the Education and Outreach Committee and the Data Management Center. Registration for the pre-workshops is limited. Please watch for registration information in the mail and on our website in the coming month.

The Sierras create a stunning site for the workshop along with such activities such as hiking, fishing, horseback riding and mountain biking. The closest airports are the Fresno and the San Francisco airports. Tenaya Lodge is 55 miles north of Fresno, and a 3.5 hour drive from San Francisco.

For more information on Tenaya, see their website:
http://www.tenayalodge.com/ ■



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